BIOMECHANICS AND PHYSICAL TRAINING OF THE HORSE

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Preface

Equestrian literature is full of books and information on the arts of riding and education of the horse. The ideas presented in this book come from a specific angle and they cast a new light on the preparation and exercise of the horse. The various attitudes and movements of the horse during classical exercises have been the main objective of our reflections and there are very few studies that have supported analyses of the regional biomechanics of the horse from a precise anatomical basis.

The objective of this book is to provide riders and trainers of competition horses with an anatomical and functional overview. This will allow them to understand and analyse the different exercises to which their horses are subjected during training and competition. Basic knowledge is indispensable in the understanding of movement; it serves to implement, in a rational way, preparatory exercises for the specific movements of each discipline.

The text in this book reflects a combination of objective information derived primarily from anatomical study through dissection, experience in the biomechanical function of the locomotor system, photographic observation and cinematographic evaluations. Analysis of this information has resulted in an improvement in the understanding of locomotion of the horse during different gaits and exercises. The key goals of this information are to identify the attitudes that result in most of the constraints on the osteoarticular and musculotendinous systems and to research the key mechanisms of efficient movement. The aim is to address the daily concerns of trainers, who search to improve the performance of their horses while striving to maximize the integrity of the musculoskeletal apparatus. The study has been deliberately limited to the most frequent movements found in equine sports and to the exercises most frequently used during preparation of horses destined for competition. The analysis is far from exhaustive and many other movements could have been evaluated. This book focuses on the most important aspects of equine locomotion and will provide a foundation for further reading and investigation into the biomechanics of the horse.

This publication should be of interest to all equine professionals and the concepts developed herein will allow them to manage more effectively the sport career of these exceptional athletes, characterized by their physical capacity and their will to perform. With a better understanding of the physical constraints imposed on the horse during riding, the rider should be able to manage the body and mind of their partner in an improved manner.

Professor Jean-Marie Denoix

About the author

Jean-Marie Denoix graduated from the National Veterinary School of Lyon in 1977. He became Professor of Anatomy of Domestic Animals in 1983 and in the same year he created an imaging department for small and large animals at the Veterinary School of Lyon. He remained responsible for the department until 1988. In 1987 Professor Denoix completed a PhD thesis on the Biomechanics of Equine Limbs.

In 1988, Professor Denoix became head of the Anatomy Department for Domestic Animals at the National Veterinary School of Alfort and was also put in charge of the Equine Clinic. During this time he developed a consultancy service for lameness and locomotor pathology of the horse in conjunction with the Equine Veterinary Clinic of Grosbois. From 1990 to 1998, he was the Editor in Chief of the journal *'Pratique Vétérinaire Equine'* (*Equine Veterinary Practice*) as well as vice-president of the European Association of Veterinary Anatomists. In 1991, he was appointed Director of the Joint Research Unit INRA-ENVA on Biomechanics and Locomotor Pathology of the Horse.

Professor Denoix's experience in Normandy started in 1999 when he became Director of CIRALE (Centre for Imaging and Research into Locomotor Problems in Horses). The Centre was constructed in Goustranville, near Dozulé in the Calvados region of Normandy, and the facilities and equipment were funded by the Regional Council of Lower Normandy. CIRALE is the result of a project developed by Professor Denoix, who designed the facility and guided its construction. Attached to the National Veterinary School of Alfort, it is renowned as one of the best facilities in the world for the diagnosis of lameness and poor performance in horses. The Centre has some of the most sophisticated medical imaging equipment in radiology, ultrasonography, thermography, scintigraphy and magnetic resonance imaging.

In 2006, several overseas conferences drove Professor Denoix to develop the International Society on Equine Locomotor Pathology (ISELP) in the USA and Europe. The primary goal of this association is to provide an education programme for veterinarians on the biomechanics, diagnosis and treatment of lameness in sport and racehorses. Currently, over 300 veterinarians around the world are members of this organization. Professor Denoix's success and acknowledgement led him to be in charge of diagnosis of lameness and diagnostic imaging at the World Equine Games in Lexington, Kentucky, in 2010. During these games he performed over 100 examinations and took many photographs, some of which are featured in this book.

In 2013 professor Denoix became a Diplomate of the American College of Veterinary Sports Medicine and Rehabilitation (ACVSMR).

Professor Denoix is the author of several books, has contributed chapters for many international books and has written many articles. He has been requested to present several times at international conferences in Europe, the USA, South America, the Middle East and Australia. His clinical activities, research and teaching have all been directed to the study of the musculoskeletal apparatus of the horse. He is constantly integrating the fundamentals of anatomy and biomechanics into the clinical evaluation of lameness and poor performance. Diagnosis of lesions is made through combining clinical evaluation with a diverse range of imaging techniques.

Despite his professional activities taking up most of his time, Professor Denoix has not stopped writing. He has also illustrated (with drawings and photos) a series of articles published by Eperon I. H. between 1986 and 1989. Jean-Marie Denoix is a horse rider, a qualified driver for trotting and an informed spectator of anything equestrian. He is not only a consummate researcher, but also a keen amateur artist in plastics (design and sculpture) and photography.

This book is a revised and enriched edition of Professor Denoix's initial publications, and it contains many new illustrations.

Acknowledgements

THE author would like to thank the professional riders who have enabled him, through their availability and knowledge, to enrich the illustrations in this book, with particular gratitude to Michel Robert, Dominique d'Esmé and Christian Hermont. He would also like to thank Anne-Laure Emond for her attentive proofing of the text.

Foreword

LIKE many horse riders and trainers, I have endeavoured to make progress in my career through study, work experience and reading texts written by world renowned trainers and riders.

In the past, the majority of the training techniques described have been developed through personal experience and instinct. This was often done in an empirical manner employing common sense rather than scientific data.

Our aim within equine sports activities is to optimize the performance of our horses while at the same time preserving their physical and mental integrity.

The sport itself is evolving at a dramatic rate, with only small differences between the calibre of the best horses on the international circuits. This small divide drives the industry to progress continually, thus improving the quality of the sport and its horses. This progression, as in all sports, is based partly on the investigations and conclusions from researchers in the many fields associated with the sport. The findings from their research and publications can then be adapted and integrated into our everyday work.

Thanks to his many years of experience, Professor Jean-Marie Denoix has provided us once again with a publication that is detailed and precise. It follows on from a special issue in collaboration with the French horse magazine '*l'Eperon*', '*Biomechanics and Physical Training of the Horse*', which I found a fantastic tool to use in training over many years.

This book is easy to read. The drawings, captions and comments are within the scope of all potential readers and I hope that many horse people will take advantage of this without hesitation.

With this in mind, rather than question the works of the 'Grand Masters' of equitation, we should instead combine them all so that our horses may be better prepared for the sport we have chosen for them. After all, we owe them this much.

Happy reading.

Jean-Maurice Bonneau
Former Coach of the French Show Jumping Team
Coach of the Brazilian Show Jumping Team

Introduction

To improve the physical capacity of the horse, a trainer must learn to value its qualities and to compensate for its flaws. Physical training of an athlete, particularly a human athlete, requires a deep understanding of the sporting discipline in question. It is in this same spirit that the chapters in this book describing the biomechanics and physical training of the horse as an athlete have been developed.

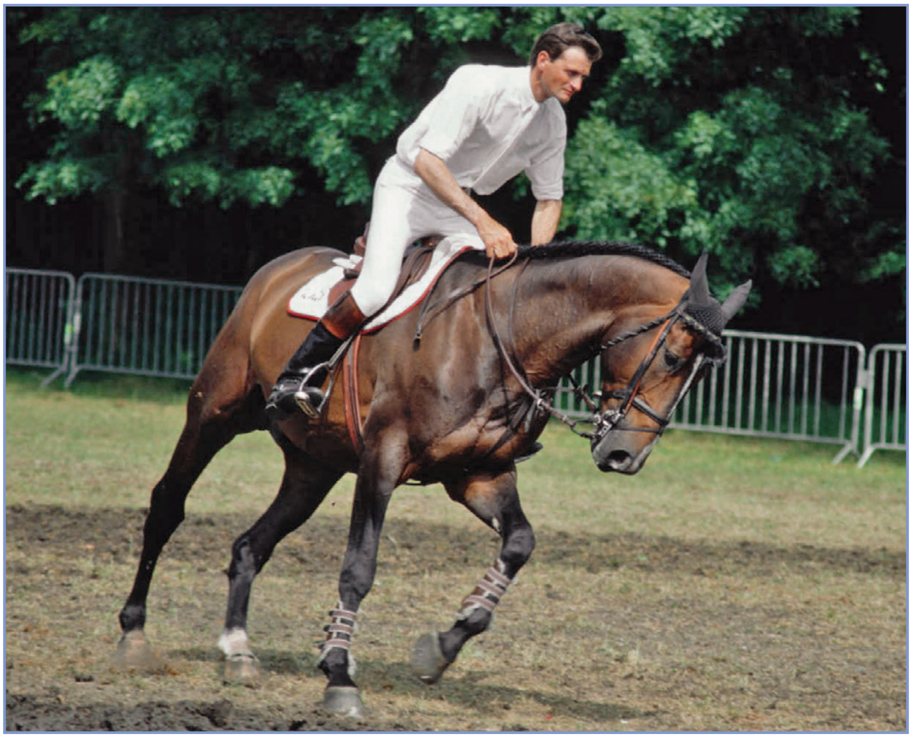
The presentation of these concepts begins with a series of simplified and educational reminders on the biomechanics of the muscles underlying overall movement. The primary body system involved in active physical exercise is the muscular system and the first three chapters focus on the muscular groups and actions of the forelimb, the hindlimb and the neck and trunk, and this leads to a chapter discussing the biomechanics of lowering of the neck. To evaluate the usefulness of an exercise and to understand its mode of action, including its advantages and disadvantages, it is essential to have a basic understanding of musculotendinous functional anatomy. An understanding of these fundamental ideas is directly applicable to the later chapters, which focus on training and the core exercises for a horse.

Training a horse for every discipline brings together two specific but complementary areas, which are often worked on at the same time: conditioning and strengthening.

The aim of conditioning is to develop respiratory capacity and to improve cardiovascular function. This results in a greater ability to perform with prolonged effort, while also improving the recovery time after this effort.

Strengthening of the horse has two main goals: (1) to improve the flexibility of joints secondary to the action of ligaments and muscles (these structures have an intrinsic role in the control and stability of joints) and (2) to develop effective muscular contraction and coordination, making movements more fluid, lighter and confident (**1, 2**).

▲ **1** Purebred Arab in Andulasia freely demonstrating a natural position and equilibrium.



▲ **2** Quito de Baussy and Éric Navet: relaxed and focused.

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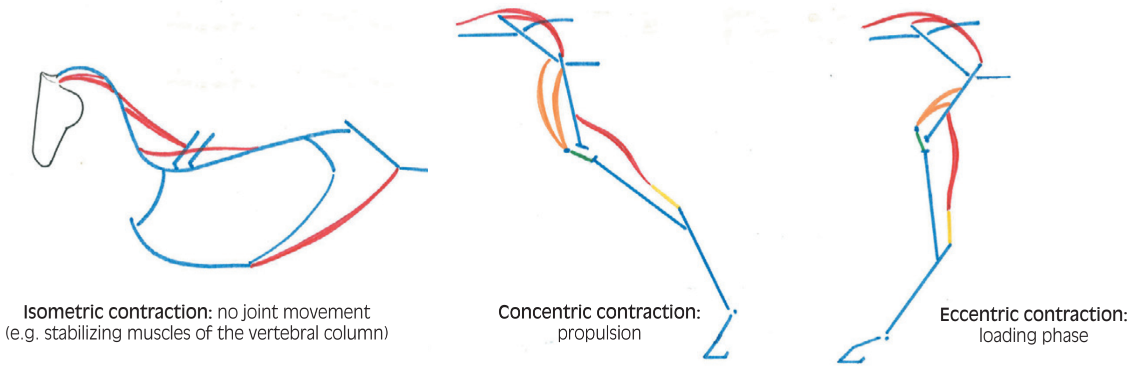
PART 1:
Muscle groups and their actions

CHAPTER

1 The forelimb

To allow for a better understanding of the later chapters in this book, it is sensible first to consider the fundamental concepts of muscle physiology during exercise relative to various types of muscle contractions and levers within the locomotor apparatus.

Types of muscular activity



▲ **1.1** Different types of muscle contractions in the neck, body and limbs of the horse. Isometric contraction: no change in muscle length; concentric contraction: shortening of the muscular body (reduction in distance between insertion sites); eccentric contraction: controlled lengthening of the muscle (increase in distance between insertion sites).

Muscles can work in three different ways depending on the particular movement (**1.1**):

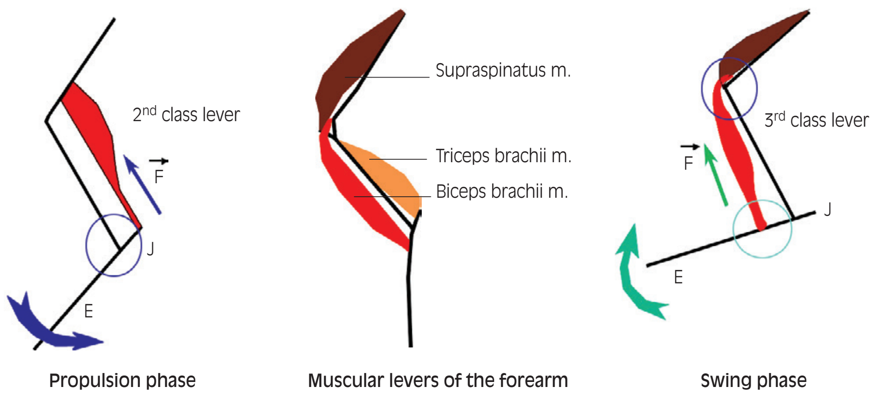
- **Isometric contraction** is the contraction of muscles without joint mobilization and is fairly uncommon in equine disciplines. The muscle body may be shortened or lengthened depending on the actual length of the muscle at the time of contraction. Isometric contractions result in stabilization and control of joints during exercise. This contraction is most often seen in classical training with collection of the head and neck and pelvic flexion.
- **Concentric contraction** is when contraction is accompanied by shortening of the muscle. The result is a reduction in distance between the origin and insertion of the muscle. Concentric contraction of the extensor muscles results in opening of the joint angles, for example during the propulsion phase of the stride.
- **Eccentric contraction** is when muscles contract while undergoing lengthening. The result of this contraction is a distancing between the origin and insertion of the muscle. In terms of biomechanics, it enables the horse to brake and limits closure of the joint angles during the loading phase of the stride.

As in human sports physiology, it is eccentric contractions that provide power to muscles through stored potential energy accumulated during elongation. This results in efficient muscle action. It is for this reason that particular effort has been dedicated in this book to the study of muscular groups and their roles during exercises and the different gaits in the various equine disciplines. By doing this, the exercises that result in eccentric contraction of certain muscles and, therefore, those that are best adapted to particular movements, can be accurately identified.

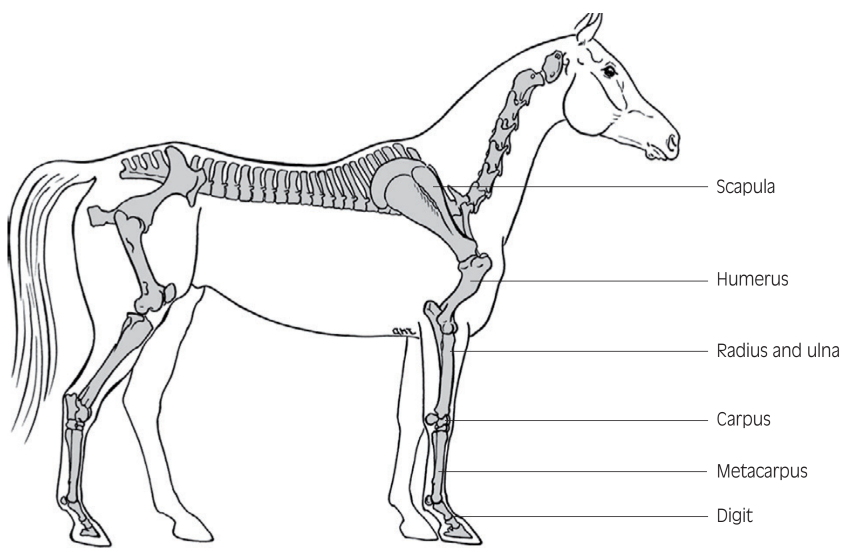
Muscle levers

Movement of living animals is possible due to a unique system of levers (**1.2, 1.3**). In the horse, two main types of powerful levers control all movements:

- The first type of lever (2nd class lever) acts during the **propulsion phase**. The joint (**J**, fulcrum) is situated between the muscular force (**F**, effort) and the moving extremity (**E**), which undergoes a substantial displacement. This type of lever requires powerful muscular action. The pressures placed across the joint are greater than those experienced in the swing phase lever system and the displacement of the extremity is faster and more extensive. The propulsion phase levers have a specific role in muscular loading during eccentric contraction (permitting load absorption) and propulsion, achieved through concentric contraction. In the forelimb there are two particular examples of a propulsion phase lever: first, the combination of the supraspinatus muscle and the humerus that pivots around the shoulder joint; and second, the pair formed by the triceps brachii muscle and the bones of the antebrachium (radius and ulna) where the pivot point is the elbow joint.
- The second type of lever (3rd class lever) acts during the **swing phase**. The muscular force (**F**, effort) exerts itself on the mobilized segment and is located between the joint (**J**, fulcrum) and the displaced extremity (**E**). This type of lever is muscle sparing, imposes mild pressure across the joint and results in a moderate to high speed of displacement of the limb. It is mostly active during the swing (non-weight bearing) phase of the stride for acheiving retraction of the limb. This action is best illustrated by the action of the biceps brachii muscle on the forearm.



1.2 Muscle levers. Note the position of the muscle insertions on the displaced segment relative to the joint.



1.3 The bones of the forelimb. Muscles act on different bony prominences, thus creating lever arms.

The different phases of the stride

A stride can be broken down into two phases: a **stance** (weight-bearing) **phase** during which the limb is in contact with the ground and supports the weight of the horse, and a **swing** (non-weight-bearing) **phase** (**1.4**) during which the limb is undergoing a forward displacement (retraction and protraction) to prepare for the following stride. Using a vertical line as a reference, the sequential positions of the limb can subsequently be considered as cranial (closer to the head), intermediate (closer to the vertical line) or caudal (closer to the tail).

Therefore, the **stance phase** is composed of three parts: the cranial part (load absorption phase), the mid-stance phase with full weight bearing of the limb and the caudal part or propulsion phase pushing the horse's body forward. During the **swing phase**, the limb is displaced forward (cranially) like a pendulum. All the joints flex during the first (caudal) part (retraction phase) of the swing phase and present a maximal flexion during the mid-swing phase. Then the joints extend during the last (cranial) part of the swing phase or protraction of the limb, preparing for landing and initiating the following stride.

▲ **1.4** The forelimbs during the swing phase. Note the involvement of the extensor muscles.

Muscle groups and their actions

The muscles of the forelimb may be divided into four different groups based on their location and role (**1.5, 1.6, 1.7**). The first group results in movement of the entire limb and includes some muscles of the trunk. The three other groups are categorized according to region (shoulder, arm and forearm) and actions (extension and flexion) on distal bone segments.

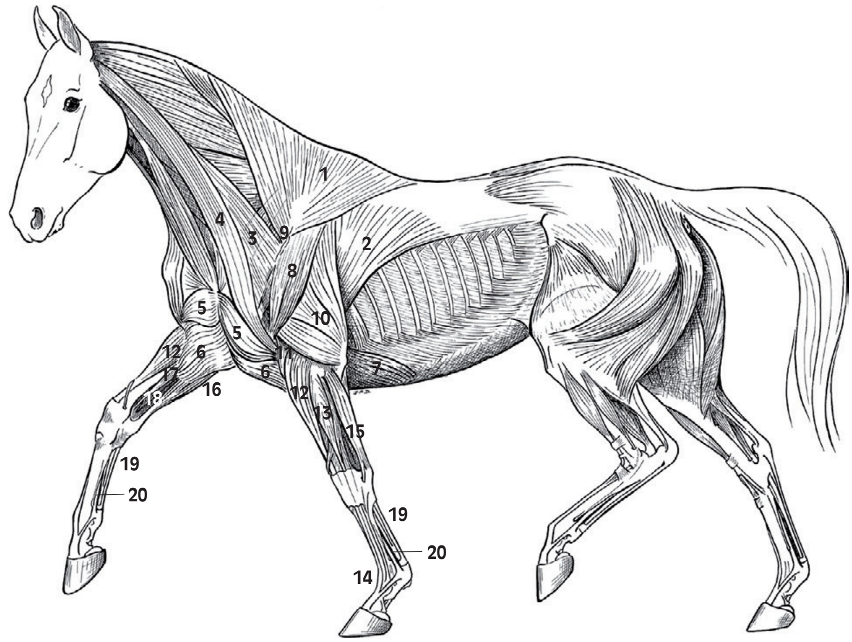
MUSCLES MOBILIZING THE ENTIRE LIMB

Protraction

The muscles of the neck have a major role during the swing phase and protraction, before impact of the limb, and include the brachiocephalicus and omotransversarius muscles. The brachiocephalicus muscle in particular is very long and joins the head and the forelimb through its attachment on the humerus. Contraction of this muscle results in a strong forward pull of the humerus. The omotransversarius muscle extends between the scapula (shoulder blade) and the cervical vertebrae.

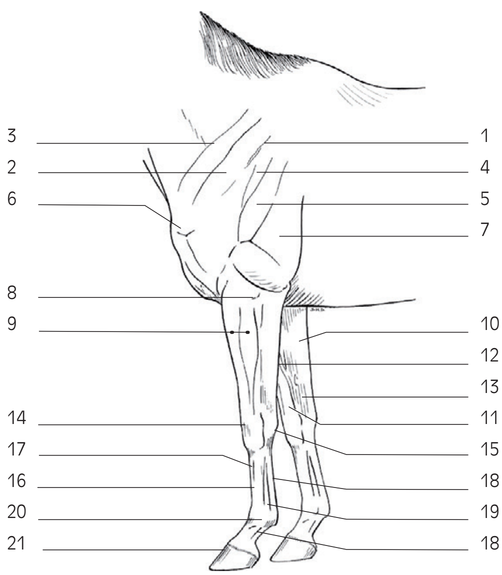
Propulsion

The muscles located over the ribs are extensive and contribute significantly to propulsion. They pull the forelimb powerfully backwards and thrust the body forwards. This is illustrated by the latissimus dorsi muscle, which pulls the humerus back towards the spine, while contraction of the pectoralis ascendens muscle results in traction towards the abdomen.



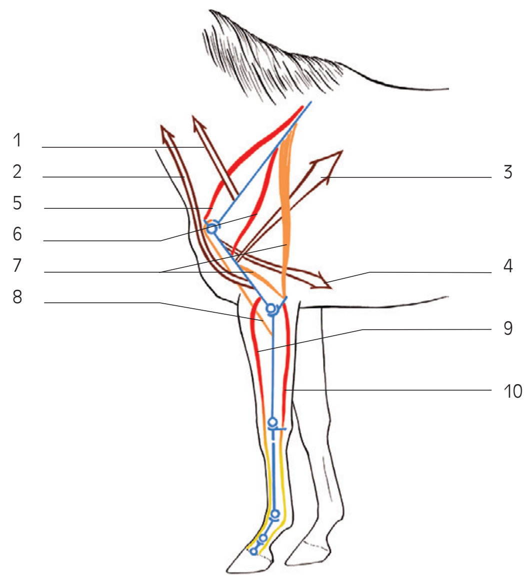
◀ **1.5** Muscles of the forelimb during loading (left forelimb) and protraction (right forelimb).

1 Trapezius muscle
2 Latissimus dorsi muscle
3 Omotransversarius muscle
4 Brachiocephalicus muscle
5 Pectoralis descendens muscle
6 Pectoralis transversus muscle
7 Pectoralis ascendens muscle
8 Deltoideus muscle
9 Supraspinatus muscle
10 Triceps brachii muscle
11 Brachialis muscle
12 Extensor carpi radialis muscle
13 Dorsal digital extensor muscle
14 Dorsal digital extensor tendon
15 Ulnaris lateralis muscle
16 Flexor carpi ulnaris muscle
17 Flexor carpi radialis muscle
18 Digital flexor muscle
19 Digital flexor tendons
20 Suspensory ligament (3rd interosseous muscle).



▲ **1.6** Superficial anatomy of the equine forelimb.

1 Scapula (shoulder blade)
2 Supraspinatus muscle
3 Subclavius muscle
4 Infraspinatus muscle
5 Deltoideus muscle
6 Point of the shoulder (shoulder joint)
7 Triceps brachii muscle
8 Lateral tuberosity of the radius (elbow joint)
9 Cranial antebrachial muscles (extensor carpi radialis and dorsal digital extensor muscles)
10 Caudal antebrachial muscles (flexors of the carpus and digit)
11 Radius
12 Cephalic vein
13 Chestnut
14 Carpus (knee)
15 Accessory carpal bone
16 Metacarpus (cannon)
17 Digital extensor tendons
18 Digital flexor tendons
19 Suspensory ligament (3rd interosseous muscle)
20 Metacarpophalangeal joint (fetlock)
21 Foot



▲ **1.7** Muscle groups mobilizing the forelimb.

Protraction
1 Omotransversarius muscle
2 Brachiocephalicus muscle

Propulsion
3 Latissimus dorsi muscle
4 Pectoralis ascendens muscle

Muscles of the shoulder
5 Supraspinatus muscle
6 Infraspinatus muscle

Muscles of the arm
7 Triceps brachii muscle
8 Brachialis muscle

Muscles of the forearm
9 Cranial antebrachial muscles (extensors of the carpus and digit)
10 Caudal antebrachial muscles (flexors of the carpus and digit)

MUSCLES OF THE SHOULDER (1.8)

This includes all of the muscles around the scapula (shoulder blade), which finish on the humerus. Their actions result in mobilization of the shoulder joint (scapulohumeral joint).

Extensor muscles

The powerful supraspinatus muscle extends the shoulder joint during the last part of the swing phase (protraction of the limb) (concentric contraction) and prevents joint closure during the stance phase (eccentric contraction).

Flexor muscles

The most active flexor muscle is the deltoideus, which flexes the shoulder joint during the first (caudal) part of the swing phase of the stride.

MUSCLES OF THE ARM

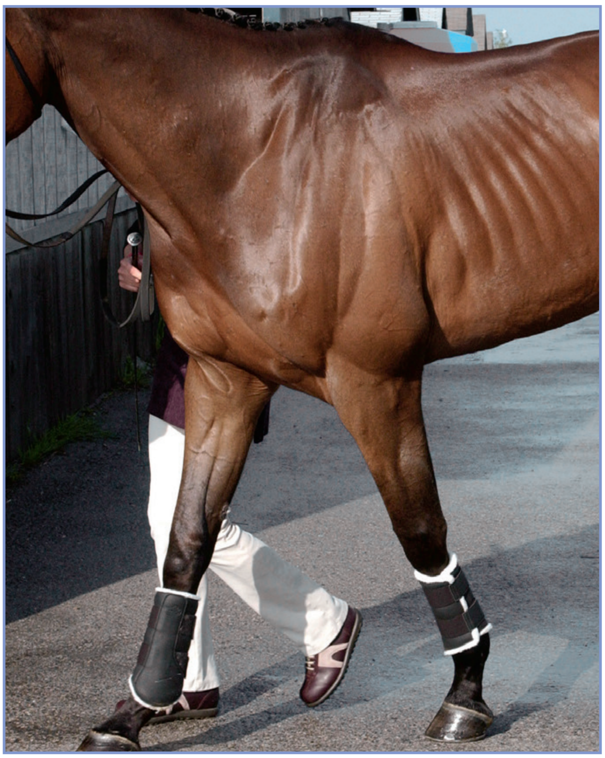
These muscles finish on the radius and ulna and extend or flex the elbow joint.

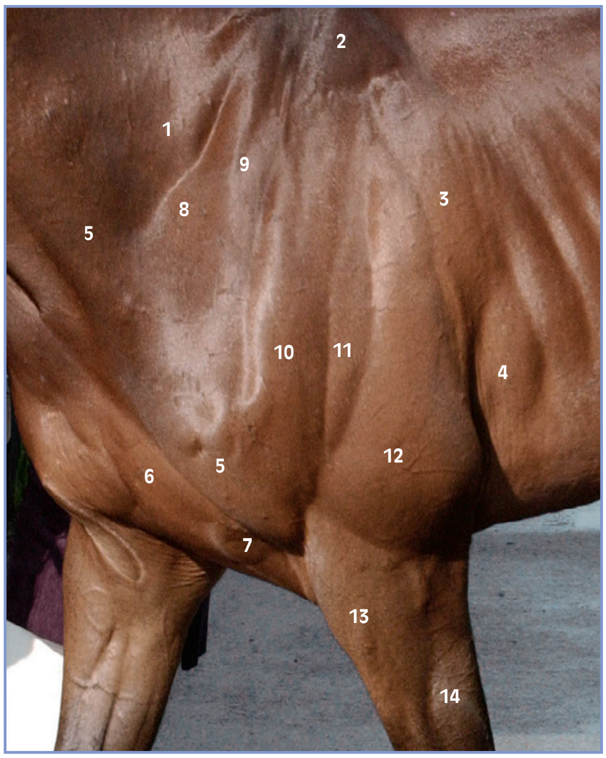
Extensor muscles

The major component of this group is the large triceps brachii muscle, which has a very powerful action not only during propulsion, but also during the last (cranial) part of the swing phase of the stride.

Flexor muscles

The biceps brachii and brachialis muscles close the elbow joint during the swing phase of the stride.





▲ **1.8** The defined muscles of the shoulder in a very fit three-day eventer horse.

Muscles of the neck and thorax
1 Serratus ventralis cervicis muscle
2 Trapezius muscle
3 Latissimus dorsi muscle
4 Serratus thoracis muscle
5 Brachiocephalicus

Pectoral muscles
6 Pectoralis descendens
7 Pectoralis transversus muscle
8 Subclavius muscle

Muscles of the shoulder
9 Supraspinatus muscle
10 Infraspinatus muscle
11 Deltoideus muscle

Muscles of the arm
12 Triceps brachii muscle

Muscles of the forearm
13 Cranial antebrachial muscles (extensors of the carpus and digit)
14 Caudal antebrachial muscles (flexors of the carpus and digit)

◀ **1.9** Extension of the fetlock and carpal joints through concentric muscle contraction of the cranial antebrachial muscles. Extension of the shoulder results from concentric contraction of the supraspinatus muscle. Simultaneous contraction of the brachiocephalicus and trapezius muscles facilitates protraction of the limb.

◀ **1.10** Loading of the left forelimb. Note the hyperextension of the carpal and fetlock joints with concurrent flexion of the shoulder joint.

MUSCLES OF THE FOREARM

These muscles originate around the radius and ulna and finish in long tendons inserting either on the cannon, thus mobilizing the carpus (knee), or on the phalanges, mobilizing the fetlock and the interphalangeal joints.

Extensor muscles

The cranial antebrachial muscles are located in front of the bone axis and extend the carpus and phalanges. Their concentric action occurs primarily during the last (cranial) part of the swing phase of the stride (**1.9**).

Flexor muscles

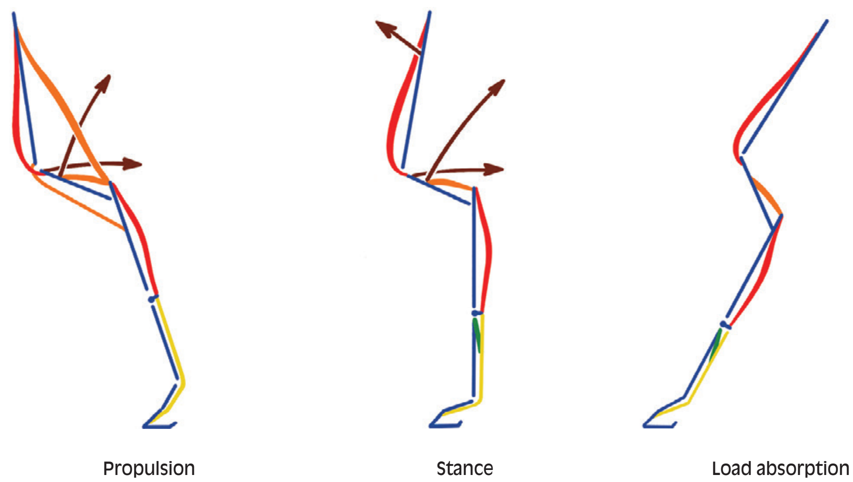
The caudal antebrachial muscles are located behind the bone axis. They flex the carpus and digit and act to flex the limb during the swing phase (assisting protraction of the limb). More significantly, during the stance (weight-bearing) phase of the stride, from landing to propulsion, they function to support the fetlock joint against the weight of the body (**1.10**).

Muscle actions during the stride

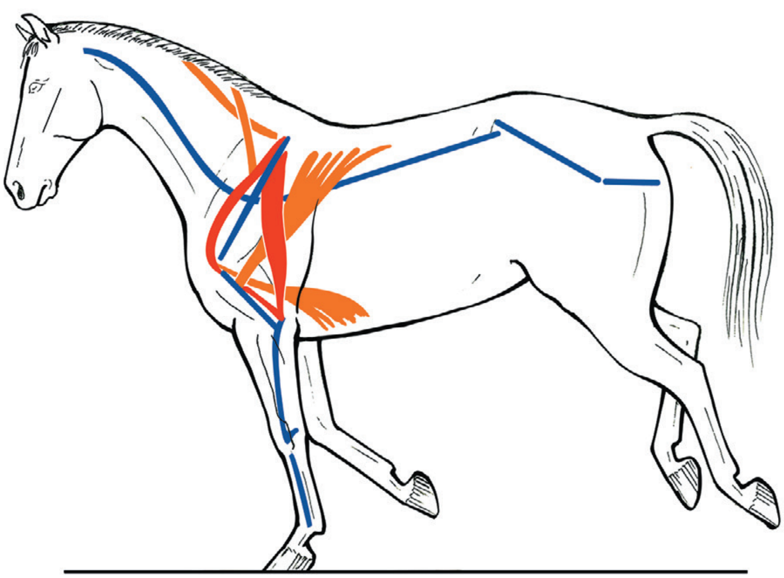
As described above, the two phases of the stride can be further broken down into three components during which muscular actions can be clearly defined.

STANCE (WEIGHT-BEARING) PHASE OF THE STRIDE (1.11–1.13)

During this phase of the stride the limb shifts backwards relative to the body. This phase can be broken down into three components: a cranial part (load absorption phase), which occurs directly after ground contact and during which there is a controlled closure of joint angles, resulting in absorption of forces created at impact between the ground and the kinetic energy of the horse; an intermediate part (mid-stance phase), where the limb supports the mass of the horse, the body moving in a horizontal plane; and a caudal part (propulsion phase), which is characterized by opening of joint angles secondary to dynamic muscular action and is assisted by the elasticity of the tendon system. Overall, this results in forward displacement of the horse's body.



▶ **1.11** The three components of muscle action during the weight-bearing phase of the stride.



▶ **1.12** Muscle actions of the forelimb during the weight-bearing phase of the stride.

▲ **1.13** Stance (weight-bearing) phase of the right forelimb. Right image: cranial part (load absorption); middle image: mid-stance; left image: caudal part (propulsion phase). Swing (non-weight-bearing) phase of the left forelimb. Right image: caudal part (retraction phase); middle and left images: intermediate part (mid-swing phase).

◀ **1.14** Loading of the limbs at landing after a jump illustrating an exaggerated form of the stresses seen in flat work. The fetlock joint is in hyperextension; the degree to which it drops is controlled by the caudal antebrachial muscles. The cranial antebrachial muscles stabilize the carpus during extension. Closure of the shoulder joint is controlled by eccentric contraction of the supraspinatus muscle.

Cranial part (load absorption phase)

During the cranial part of the stance phase, muscles contributing to controlled closure of the joints play a key role in shock absorption. This controlled loading takes place because of the eccentric contraction of the upper limb muscles:

- In the distal limb, flexor muscles have tendinous extensions that are supported by elastic accessory ligaments (superior and distal check ligaments). Contraction of the flexor muscles in combination with support from the tendons and the suspensory ligament limits dropping of the fetlock on weight bearing.
- Contraction of the short heads of the triceps brachii muscle controls closure and prevents collapse of the elbow joint.
- Eccentric contraction of the supraspinatus muscle limits the closure of the shoulder joint.

Intermediate part (mid-stance phase)

All of the muscles previously described continue their action during the intermediate part (mid-stance phase) of the stance phase. This consists of intense contraction while undergoing lengthening (eccentric contraction). This action prevents collapse of the limb once it is loaded with the full weight of the horse. In particular, the flexor muscles of the forearm actively support the fetlock (**1.14**).

The limb then moves backwards following active concentric contraction of the muscles that initiate propulsion (i.e. the ascending pectoral and the latissimus dorsi muscles). Their action is assisted by the trapezius (cervical part) and rhomboideus muscles, which pull the upper extremity of the scapula forward.

Caudal part (propulsion phase)

Activity of the muscles is at its peak during the propulsion phase of the stride. Powerful retraction of the limb is combined with opening of all the joints through concentric muscle contraction (**1.15**). During propulsion the weight of the horse almost bounces off the limb, utilizing the stored energy from the muscles, tendons and ligaments generated during the previous two parts of the stance phase.

The supraspinatus muscle opens the shoulder joint, potentiating the action of the triceps brachii muscle in extending the elbow. In turn, the fetlock is lifted by contraction of the flexor muscles of the forearm and the elasticity of their tendon extensions (superficial and deep digital flexor tendons) and accessory ligaments.

▲ **1.15** End stage of propulsion of the right forelimb. Note the retraction of the limb with maximal opening of the elbow joint; the pastern becomes vertically oriented and the foot starts to rotate forward.

SWING (NON-WEIGHT-BEARING) PHASE (1.13, 1.16, 1.17)

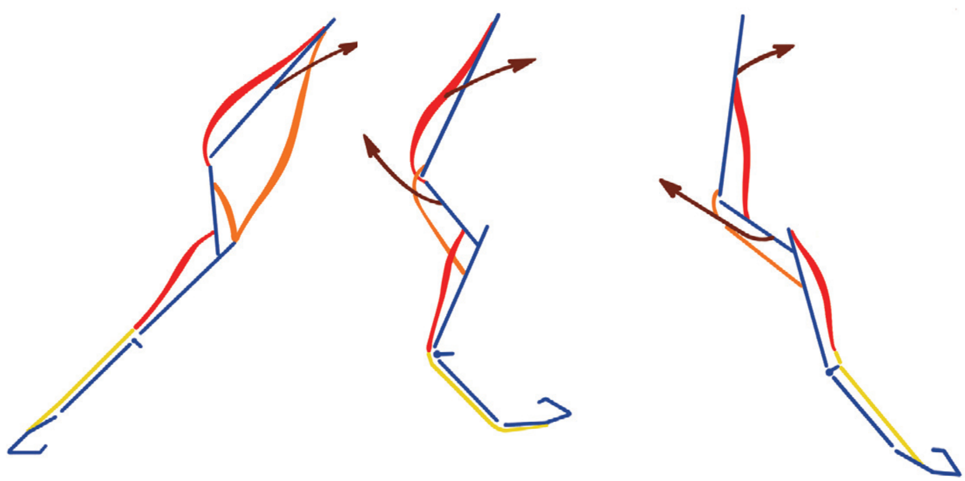
During this phase of the stride there is an overall forward swing of the limb. This may be broken down into three components: the caudal part (retraction phase), which starts as soon as the limb leaves the ground following propulsion; the intermediate part (mid-swing phase); and the cranial part (protraction phase) ending with ground contact or landing. The final movement is the forward placement of the limb.

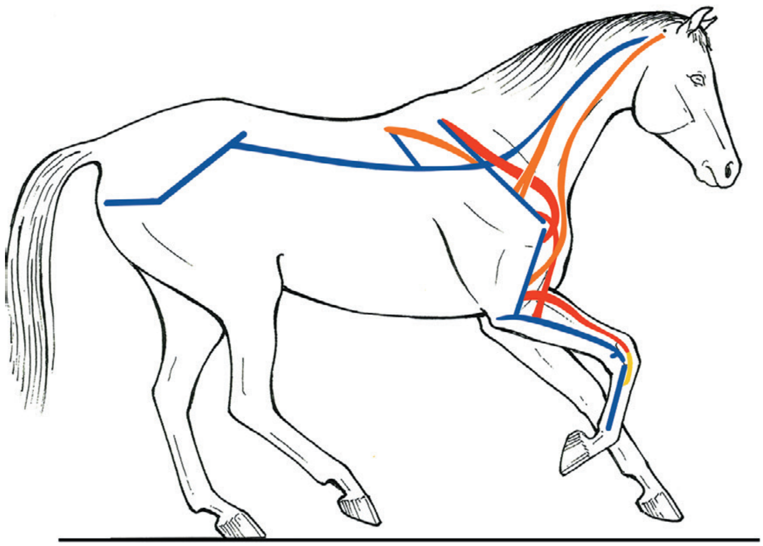
Caudal part (retraction phase)

During this phase of the stride the scapula undergoes a pendulum-like movement such that its lower extremity swings forward. This movement is the result of shortening (concentric contraction) of four muscles. The thoracic portion of the trapezius muscle pulls the upper portion of the scapula backwards, while the brachiocephalicus, omotransversarius and pectoralis descendens muscles pull the lower extremity of the scapula forward, thus guiding the overall movement of the limb.

All the joints of the limb flex through concentric contraction of the flexor muscles described above. The inertia of the foot and the distal limb contributes to further flexion of the distal limb and carpus:

▼ **1.16** The three components of muscle action during the swing phase of the stride.





◀ **1.17** Muscle actions of the forelimb during the swing phase of the stride.

- The deltoideus and teres major muscles flex the shoulder joint. Contraction of the deltoideus muscle can easily be seen in a fit horse.
- The biceps brachii and brachialis muscles close the elbow joint.
- The caudal antebrachial muscles flex the carpal joints and distal limb (fetlock and interphalangeal joints).

Intermediate part (mid-swing phase)

The forward swing of the scapula is facilitated by action of the trapezius muscle, which exerts backward traction on the upper extremity of the scapula, and the brachiocephalicus and omotransversarius muscles, which exert a forward traction on the lower extremity of the scapula (**1.18**).

◀ **1.18** Note the suspension of the forelimbs during the swing phase of the stride. The brachiocephalicus muscle pulls the humerus forward; the biceps brachii and the brachialis muscles flex the elbow. The distal limb is brought forward through a passive movement, which assists the caudal antebrachial muscles in carpal flexion.

Flexion of the elbow is facilitated by action of the biceps brachii and brachialis muscles. Having reached maximal flexion, the shoulder, carpal and digital joints then undergo extension, thus preparing the limb for the next part of the swing phase.

Cranial part (protraction phase)

Having guided the rest of the limb forwards, the scapula reaches its maximal range in forward motion, the degree to which varies relative to the speed of the gait. The length of the stride is therefore correlated to the degree of proximal joint opening during protraction. The distal limb is thrust forward by extension of the shoulder joint and elbow, made possible through concentric contraction of the supraspinatus and triceps brachii muscles. It should be noted that extension of these two joints is synergistic and opening of the shoulder joint by the brachiocephalicus and supraspinatus muscles potentiates the action of the triceps.

The extensor muscles of the forearm open the carpal and digital joints, resulting in complete extension of the limb.

Sporting considerations

This chapter has clarified some key concepts of muscle physiology directly applicable to equine sport disciplines.

Traditionally, the flexor and extensor muscles have been considered as antagonists. For example, the biceps brachii and triceps brachii muscles act antagonistically during the swing phase of the stride. However, they also work synergistically during the propulsion phase. Extension of the elbow by the triceps muscles facilitates extension of the shoulder joint by the biceps brachii muscle at the end of the stance phase of the stride (i.e. during the propulsion phase). This concept will be revisited and become more evident when the biomechanics of the hindlimb (pelvic limb) are discussed.

A single muscle group can have different actions depending on the phase of the stride. For example, the supraspinatus muscle exhibits cyclical contractions: concentric during the protraction phase, eccentric during the cranial part of the stance phase (load absorption) and concentric again during the propulsion phase.

Being aware of muscle groups and understanding their actions is important when deciding which exercises are appropriate when training a horse. One simple example of this (which will be expanded on in later chapters) is when a horse works on a slope. Concentric contraction of the supraspinatus, triceps brachii, latissimus dorsi and ascending pectoral muscles is favoured during propulsion. However, working on a downhill slope imposes eccentric work on the brachiocephalicus, omotransversarius and supraspinatus muscles and the short heads of the triceps brachii muscle. It is therefore evident that a combination of various exercises can lead to the complete muscular development of an athletic horse.

The aim of the following chapters is to combine scientific knowledge with a practical approach to training in order to understand more fully the biomechanics and physical conditioning of the equine athlete.

2 The hindlimb

Having examined the biomechanics of the forelimb, primarily focusing on landing and loading, attention now focuses on the muscular components of the hindlimb, which are concerned particularly with propulsion and powerful spring movements.

The primary aim of this chapter is to concentrate on the fundamentals involved in understanding the locomotion of the horse. The secondary objective is to provide the sport horse trainer, both professional and amateur, with sufficient, useful information to be able adequately to physically prepare their horses. The fundamental ideas discussed in these first two chapters will, therefore, serve as a sound basis that can be applied directly to the training of the horse and the improvement of its athletic fitness.

To provide a better understanding of the biomechanics of the hindlimbs (**2.1**) and how to improve the efficiency of the hind end of the horse, this chapter is divided into three sections: the levers that facilitate movement in the hindlimb; the different muscular groups and their actions on these levers; and the actions of these muscles during the gaits and the different phases of the stride.

▲ **2.1** Mid-stance phase of the left hindlimb (supporting the weight of the body). All the muscles of the pelvis and the thigh are contracted. The common calcanean tendon locks the calcaneus and prevents flexion of the hock joint. The flexor tendons and the suspensory ligament support the fetlock.

Levers of the hindlimb

The hindlimb of the horse is specifically involved in propulsion (**2.2**) and it is the principal motor agent in all jumping and dressage gaits, regardless of the exercise being undertaken. This important role is made possible by a very efficient first-type of lever (2nd class) system and the occasional second-type of lever (3rd class) (**2.3**).

FIRST-TYPE OF LEVER

As discussed in Chapter 1, this type of lever is involved primarily during the generation of impulse and secondarily during load absorption. The efficiency of this lever is dependent on the power of the muscles involved and the length of the lever arm. In the upper limb, the pelvis, femur and tibia each have their own lever system.

Trochanteric lever

This lever pivots around the hip (coxofemoral joint). The lever arm is the greater trochanter, which forms the uppermost prominent protuberance of the femur. It is mobilized by the powerful middle gluteal (gluteus medius) muscle. Contraction of this muscle thrusts the whole limb backwards.

Patellar lever

This lever is comprised of the patella, which is attached to the tibia by three strong patellar ligaments that transmit the action of the quadriceps femoris muscle. Contraction of the quadriceps femoris muscle pulls the patella upwards, resulting in extension of the stifle (femorotibiopatellar joint).

Calcanean lever

The calcanean tendon inserts on the calcaneus, forming a long lever arm. It is mostly comprised of the superficial digital flexor tendon and the two tendons of the gastrocnemius muscle. Contraction of the gastrocnemius results in powerful extension of the hock, in particular the tibiotarsal joint.

SECOND-TYPE OF LEVER

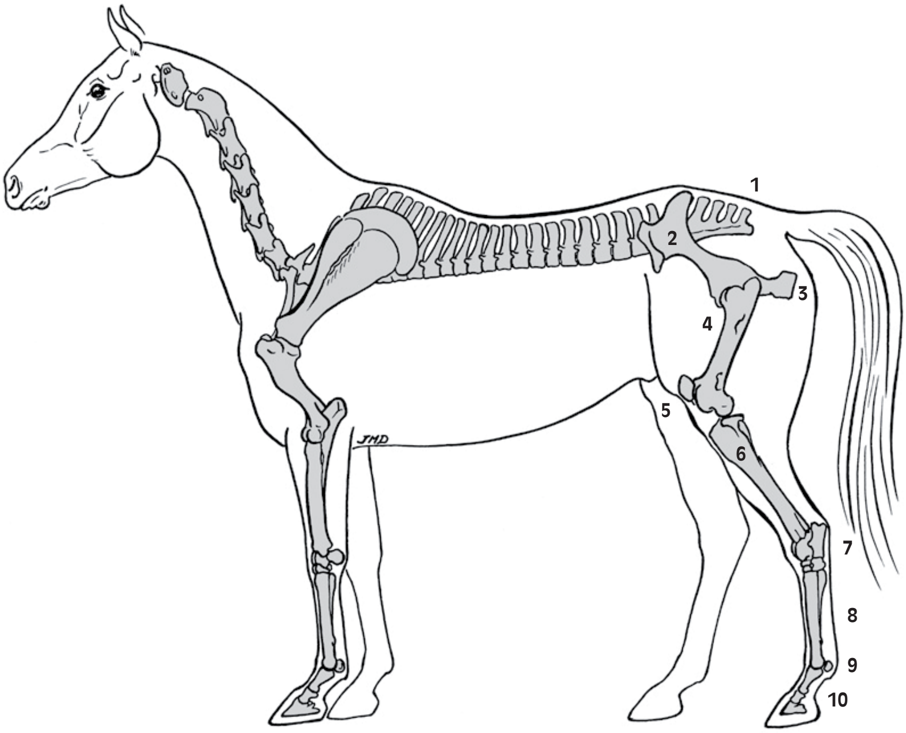
This type of lever acts predominantly during the non-weight-bearing (swing) phase of the stride and induces flexion of the joints. It is important to remember that these two lever systems act directly on the upper areas of the limb; however, consequently and indirectly, they also act on the lower limb (see Reciprocal apparatus, p. 32).

Iliopsoas lever

This lever is very important in equine disciplines. It is comprised of the iliopsoas muscle, which inserts on the lesser trochanter of the femur. Contraction of this muscle results in flexion of the hip joint, the degree of which determines the overall engagement of the limb at the end of the non-weight-bearing phase.

Caudal femoral lever

This lever is comprised of the strong caudal femoral muscles, which insert on the upper extremity of the tibia. Contraction of these muscles initiates flexion of the stifle during the non-weight-bearing (swing) phase.



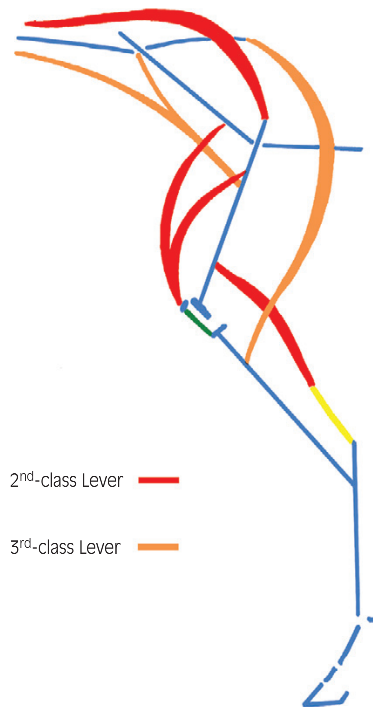
◀ **2.2** Skeletal anatomy of the hindlimb.

Pelvis

1 Sacrum
2 Ilium
3 Ischium

Limb

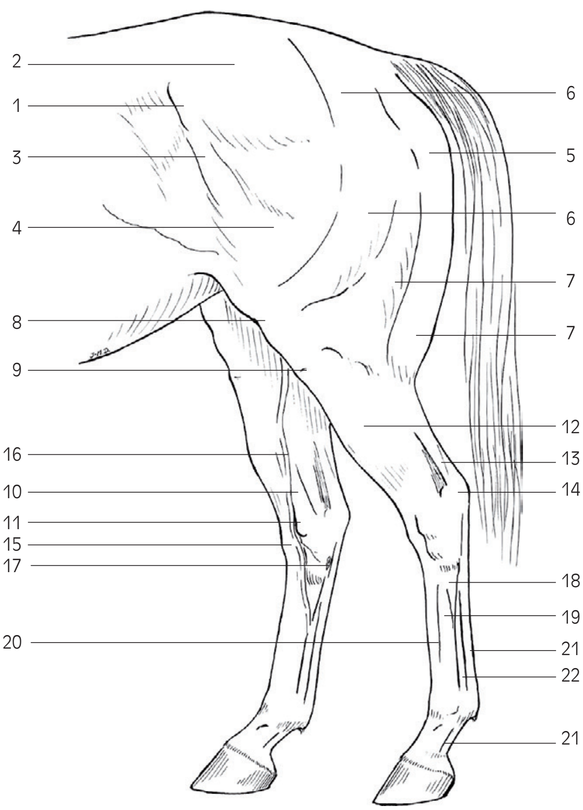
4 Femur
5 Patella
6 Tibia
7 Hock (tarsal joints)
8 Metatarsus
9 Fetlock (metatarsophalangeal joint)
10 Digit comprised of 3 phalanges



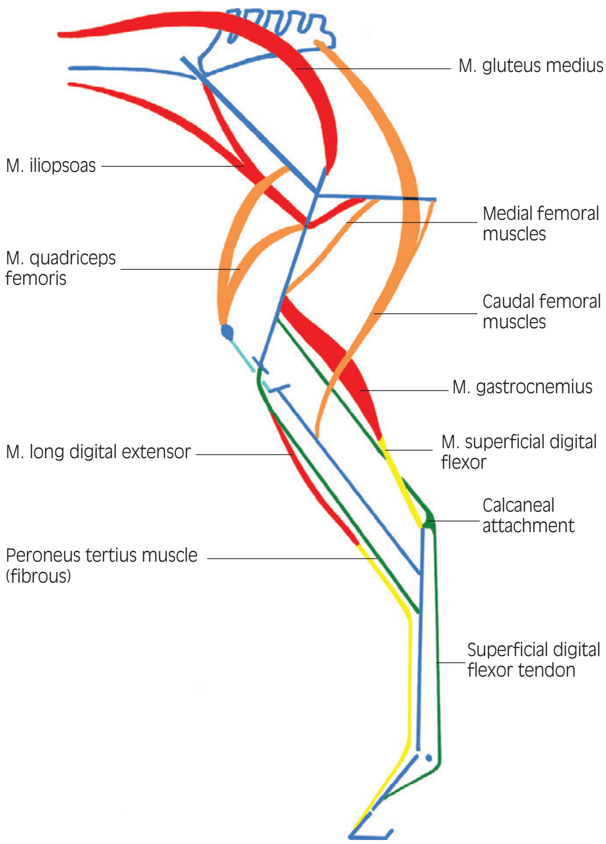
◀ **2.3** The levers of the hindlimb.

Muscle groups and their actions (2.4, 2.5)

Muscular groups will be discussed according to region, centered on a bone axis and described in the following order: pelvic muscles, which are grouped around the coxal bone; thigh muscles grouped around the femur; and crural (leg) muscles, which are located over different aspects of the tibia. A key point with regard to the organization of muscular groups is that muscles distributed around a bone insert on the bone directly beneath it or on more distal segments. Therefore, actions of these muscles result in mobilization of the joint between the adjacent bone segments. For each muscular group only the fundamentals required to understand the biomechanics and functional anatomy of the horse will be described.



▲ **2.4** Superficial anatomy of the hind limb.



▲ **2.5** Muscular groups of the hindlimb.

1 Ilium
2 Middle gluteal (gluteus medius) muscle

Cranial femoral muscles
3 Tensor fascia latae muscle
4 Quadriceps femoris muscle

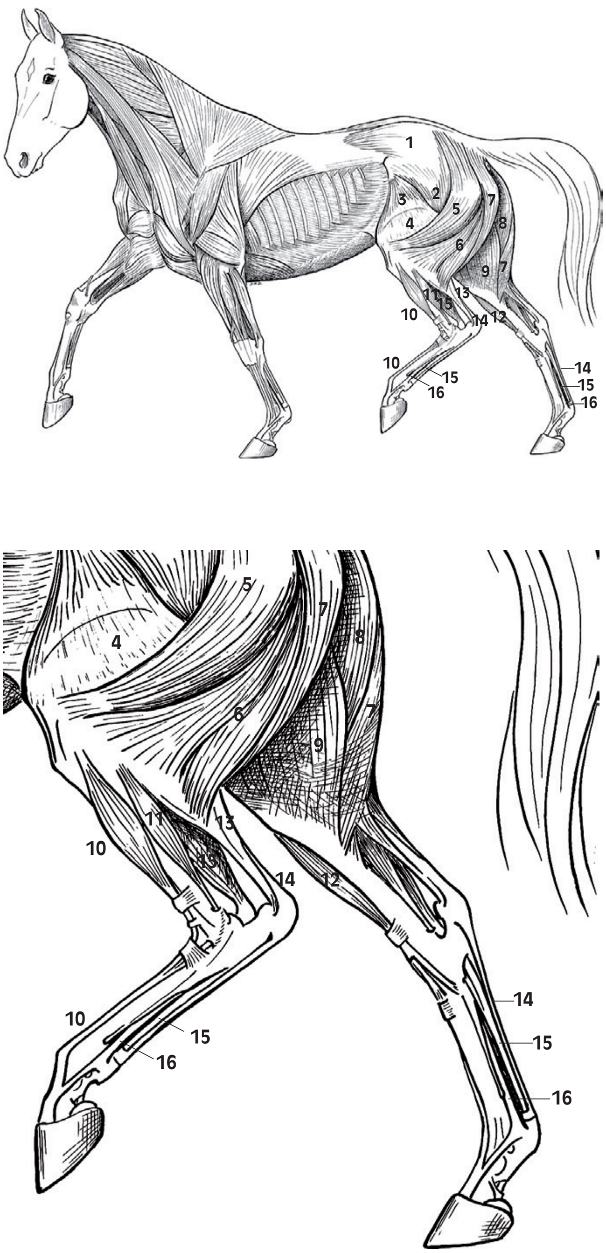
Caudal femoral muscles
5 Semitendinosus muscle
6 Gluteofemoralis muscle
7 Biceps femoris muscle
8 Patella
9 Tibial tuberosity
10 Tibia
11 Medial malleolus of the tibia
12 Cranial crural muscles
13 Common calcaneal tendon (tendon of the caudal crural muscles)
14 Calcaneus
15 Dorsal recess of the tarsocrural joint
16 Medial saphenous vein
17 Chestnut
18 4th metatarsal bone
19 3rd metatarsal bone (cannon bone)
20 Digital extensor tendons
21 Digital flexor tendons
22 Suspensory ligament

PELVIC MUSCLES

The muscles in this group insert on the upper aspect of the femur and mobilize the coxofemoral (hip) joint.

Extensors of the hip: gluteal muscles

The gluteal muscles are a very large group and form the outline of the rump. The most powerful of these muscles is the middle gluteal muscle, which originates in the lumbar region of the trunk covering the erector spinae muscle, and inserts on the greater trochanter (trochanteric lever) of the femur (**2.6**). This is the most efficient extensor in the whole of the equine musculoskeletal system and is the largest contributor to propulsion and impulsion.



◀ **2.6** Muscles of the pelvis and the hindlimb.

Muscles of the pelvis
1 Middle gluteal muscle
2 Superficial gluteal muscle

Cranial femoral muscles
3 Tensor fascia latae muscle
4 Quadriceps femoris muscle

Caudal femoral muscles
5 Gluteofemoralis muscle
6 Biceps femoris muscle
7 Semitendinosus muscle
8 Semimembranosus muscle

Medial femoral muscles
9 Gracilis and adductor muscles

Cranial crural muscles
10 Long digital extensor muscle
11 Lateral digital extensor muscle
12 Tibialis cranialis muscle

Caudal crural muscles
13 Gastrocnemius muscle
14 Superficial digital flexor muscle and tendon
15 Lateral digital flexor muscle

Muscles and tendons of the metatarsus and digit
14 Superficial digital flexor tendon
15 Deep digital flexor tendon
16 Suspensory ligament (3rd interosseous muscle)

Flexors of the hip: iliopsoas muscle

Although the iliopsoas muscle strictly belongs to the sublumbar region (and will be described further in the chapter dedicated to the biomechanics of the trunk [Chapter 3, The neck and trunk]), because of its location at the front of the pelvis, it warrants mention in this chapter. This powerful muscle originates from the ventral aspect of the lumbar vertebrae (and last thoracic vertebrae) and ilium and inserts on the upper extremity of the femur. Consequently, it flexes not only the lumbar and lumbosacral intervertebral joints, but it is also the most efficient flexor of the hip. As a result it is the most important muscle involved in engagement of the hindquarters.

THIGH OR FEMORAL MUSCLES (2.6)

These muscles are located around the femur and they may be divided into three groups according to their location and role.

Cranial or anterior femoral muscles

There are two muscles of importance in this group. The first is the quadriceps femoris muscle, which originates from the pubis (rectus femoris) and the femur (vastus muscles) and inserts on the patella. This muscle serves primarily to extend the stifle and it also acts as an accessory flexor of the hip. The second muscle is the tensor fascia latae muscle, which extends between the ilium and the patella and is primarily a flexor of the hip.

Caudal or posterior femoral muscles (2.6, 2.7)

This group is more extensive than the cranial femoral muscles and includes three important muscles: the gluteobiceps muscle (made from the gluteofemoralis and the biceps femoris muscles), the semitendinosus muscle and the semimembranosus muscle. These muscles originate either from the sacrum or the ischium and have their distal insertions on the lower (distal) extremity of the femur and upper (proximal) aspect of the tibia. They are particularly important in locomotion; however, their actions are quite complex and vary according to the phase of the stride. For example, during the non-weight-bearing (swing) phase they act as flexors of the stifle, while during the weight-bearing (stance) phase they become extensors of the stifle and hip (see Muscular actions during the gaits, p. 34).

◀ **2.7** The caudal femoral muscles in action.

Medial or internal femoral muscles

These muscles are located on the internal (medial) aspect of the thigh and extend from the pubis and ischium to the distal aspect of the femur and proximal tibia. Contraction of these muscles results in a pulling of the limb towards the midline. Therefore, they are adductors, effectively antagonizing the gluteal muscles responsible for abduction of the limb. The large muscles of this group (the adductor and gracilis muscles) also contribute to propulsion by acting synergistically with the other femoral muscles (**2.8**).

LEG MUSCLES

These muscles can be divided into two groups, which act as antagonists to each other, with one group located in front of the tibia and the other located behind the tibia. They end as long tendons inserting either on the tarsal bones or on the proximal extremity of the metatarsus, thus mobilizing the hock joint, or on the phalanges, mobilizing the fetlock and interphalangeal joints. In addition to these muscles, a unique synchronization mechanism of flexion–extension movements of the hindlimb joints, called the reciprocal apparatus, and a stabilizing mechanism of the hindlimb, called the stay apparatus, will also be discussed.

Cranial or anterior leg muscles

These muscles are located firmly on the front (cranial aspect) of the tibia (the fibula is vestigial in the horse). The muscles that insert on the tarsal bones or the proximal extremity of the metatarsus are solely flexors of the hock. The muscles that insert on the front (dorsal aspect) of the phalanges (digital extensors) are also extensors of the fetlock and interphalangeal joints.

Caudal or posterior leg muscles

These muscles are located on the back (caudal aspect) of the tibia and are partially covered by the caudal femoral muscles. The largest of them, the gastrocnemius muscle, is made up of two heads, which insert on the apex (tuber calcanei) of the calcaneus. The calcaneus acts as a lever arm, thus allowing the gastrocnemius to become a very effective extensor of the hock. The other muscles contributing to this group are the digital flexor muscles, which follow the back (plantar aspect) of the cannon via strong tendons and insert on the phalanges. They are therefore flexors of the fetlock and interphalangeal joints during the swing phase and, most importantly, have an essential role in supporting the fetlock during the weight-bearing (stance) phase of the stride.

▲ **2.8** Muscular groups of the thigh in action. Left hindlimb: the cranial femoral muscles flex the hip and extend the stifle; the caudal femoral muscles are at their maximal length. Right hindlimb: the medial femoral muscles stabilize the stifle and assist in propulsion.

Reciprocal apparatus

The reciprocal apparatus (**2.9, 2.10**) is unique to the horse and is an illustration of an adaptation to high speed. It is comprised of two entirely fibrous components, the peroneus tertius muscle and the superficial digital flexor muscle, which couple the joint angles of the stifle, hock and digital joints.

The peroneus tertius muscle is completely fibrous and acts as a tendon, which is located on the cranial aspect of the tibia and extends between the lower extremity of the femur and the proximal metatarsus. The superficial digital flexor muscle body, which is also mainly fibrous, is located on the caudal aspect of the tibia. It originates from the lower (distal) extremity of the femur and attaches briefly to the apex of the calcaneus before continuing via a long tendinous extension, the superficial digital flexor tendon (stay apparatus – the caudal part of the reciprocal apparatus), until its distal insertion on the middle phalanx.

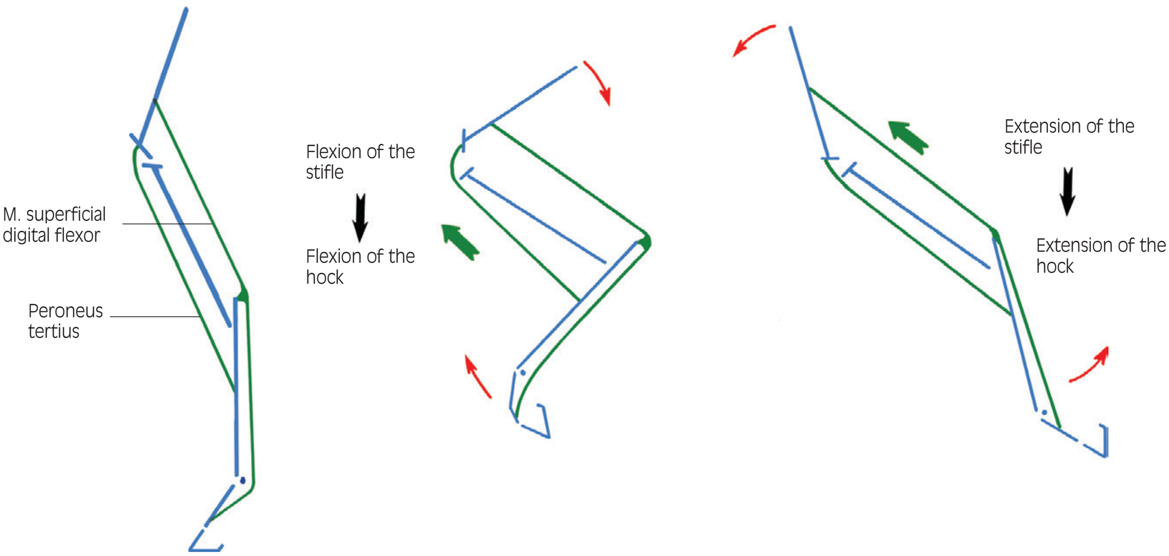
Mechanism of action (**2.11, 2.12**)

Flexion of the stifle, as a result of action of the powerful femoral muscles, results in an upward (proximal) pull of the peroneus tertius, therefore drawing on its distal insertion. This results in simultaneous flexion of the hock. When the hock is flexed, the apex of the calcaneus drops eccentrically, placing the superficial digital flexor tendon under tension and resulting in synchronous flexion of the fetlock and phalanges.

Extension of the stifle imposes traction on the proximal extremity of the superficial digital flexor muscle, thus inducing action on the calcaneal lever arm, which results in extension of the hock.

▲ **2.9** Reciprocal apparatus of the stifle and hock joints during extension (medial view). Pressure is applied over the femur (from above) and the patella is locked. During the stance phase (weight-bearing phase) the superficial digital flexor muscle at the back of the tibia prevents flexion of the hock when the stifle is in extension.

▲ **2.10** Reciprocal apparatus of the stifle and hock joints during flexion (lateral view). Flexion of the stifle results in upward traction on the peroneus tertius muscle, which induces simultaneous and equal flexion of the hock.



▲ **2.11** Reciprocal apparatus of the stifle and hock joints during different phases of the stride. Flexion of the stifle pulls the peroneus tertius muscle upwards, provoking simultaneous flexion of the hock. Extension of the stifle places upward traction on the superficial digital flexor muscle, placing the hock in extension.

◀ **2.12** Reciprocal apparatus of the hindlimb during the swing (non-weight-bearing) phase of the stride. All the joints of the right hindlimb are under more flexion than those of the left hindlimb. Note the flexion of the pelvis (lumbosacral flexion) facilitating engagement of the hindquarters.

Therefore, through this completely passive reciprocal system, which is entirely fibrous, the muscles of the thigh are able to mobilize all the joints of the hindlimb, including the interphalangeal joints. It is by evaluation of this apparatus that the coordination and balanced function of the hindlimbs during motion can be appreciated.

Any lesions within the structures of this system will therefore result in significant implications in terms of lameness. For example, rupture of the peroneus tertius muscle/tendon results in an inability to flex the hock, while luxation of the calcaneal attachments of the superficial digital flexor tendon results in a lack of extension of the hock.

Muscular actions during the gaits ❑

Having discussed the basic functional anatomy of the hindlimb, the phases of the stride and the chronological order of muscular interventions will now be examined. As with the forelimb, the chronological order of the different muscular actions during the stride, including the three parts of the stance (weight-bearing) and swing (non-weight-bearing) phases of the stride, will be described.

STANCE (WEIGHT-BEARING) PHASE (2.13)

Landing of the foot and ground contact signify the start of the stance (weight-bearing) phase of the stride, which begins with a period of load absorption.

Cranial part (load absorption phase) (2.14)

This phase of the stride is characterized by eccentric contraction (lengthening) of different muscle groups, limiting joint closure when the body weight is loaded onto the limb. This contraction also assists with shock absorption, which occurs inherently when the foot impacts on landing.

Flexion of the hip is limited by eccentric contraction of the middle gluteal and caudal femoral muscles. Flexion of the stifle is regulated by action of the quadriceps femoris muscle (in particular the vastus muscles).

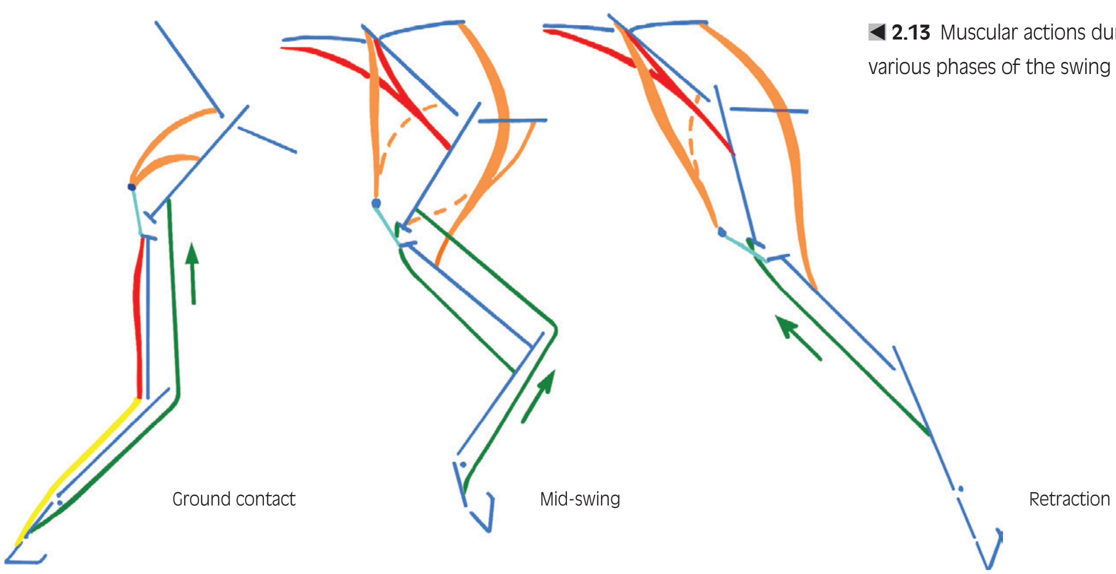
Stability of the hock is created through tension on the superficial digital flexor tendon and eccentric contraction of the gastrocnemius muscle, which are linked to the femorotibial joint. The elasticity of the tendinous structures of the metatarsus prevents collapse of the limb during loading and is a major contributor to load absorption and stability during this phase.

Intermediate part (mid-stance phase) (2.15)

Lengthening of muscles during loading contributes to their stored energy, thereby improving their efficiency and power as the limb pushes off during the propulsion phases of the stride.

To provide resistance to the weight of the body during motion, muscles must limit the degree to which the joint angles close during loading. The middle gluteal and caudal femoral muscles together maintain extension of the hip and stifle joints. The hock is maintained in extension partly by passive action of the superficial digital flexor tendon (stay apparatus) and partly by active contraction of the gastrocnemius muscle.

Finally, the fetlock is supported by tension of the suspensory ligament assisted by tendinous extensions of the flexor muscles of the crus, such as the superficial digital flexor and the deep digital flexor tendons.



◀ **2.13** Muscular actions during the various phases of the swing phase.

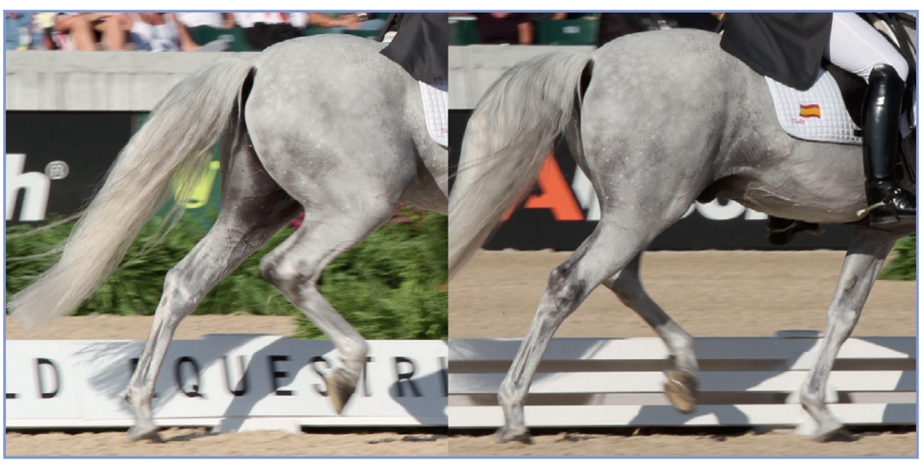
Caudal part (propulsion phase) (2.16)

The energy stored during the previous two phases of the stride is released and optimized by concentric contraction of the muscle groups responsible for the rapid opening of the joint angles. Powerful extension of the hip is a result of the action of the large middle gluteal and caudal femoral muscles.

In conjunction with extension of the hip there is also a very active extension of the stifle. Opening of this joint angle is completed by efficient concentric contraction of the quadriceps femoris muscle. Rapid extension of the hock is initiated by contraction of the gastrocnemius muscle. Action of the digital flexor muscles and tendons, assisted by the elasticity of the suspensory ligament, initiates lifting of the fetlock and the phalangeal lever arm.

▲ **2.14** Load absorption of the right hindlimb at a canter. The stifle and the hock are flexed simultaneously in order to support the weight of the body. The digital joint angles close (extension of the fetlock and flexion of the interphalangeal joints). The hip is the first joint to reverse its movement towards extension, initiating the mid-stance and propulsion phases of the stride.

▲ **2.15** Mid-stance phase on the right hindlimb at a trot. There is maximal flexion of the stifle, hock and distal interphalangeal joints and maximal extension of the fetlock. The limb stores energy, which is released during the propulsion phase of the stride. The hip continues to extend, initiating propulsion.



◀ **2.16** Propulsion of the hindlimbs at a trot. All the joints actively open in a synchronous and proportional fashion: extension of the hip, stifle, hock and interphalangeal joints; lifting of the fetlock.

It is therefore evident that the stance (weight-bearing) phase of the stride is characterized by involvement of all the muscles of the croup and thigh, which work firstly in an eccentric (lengthening) manner during loading and then generate concentric contraction (shortening) during propulsion.

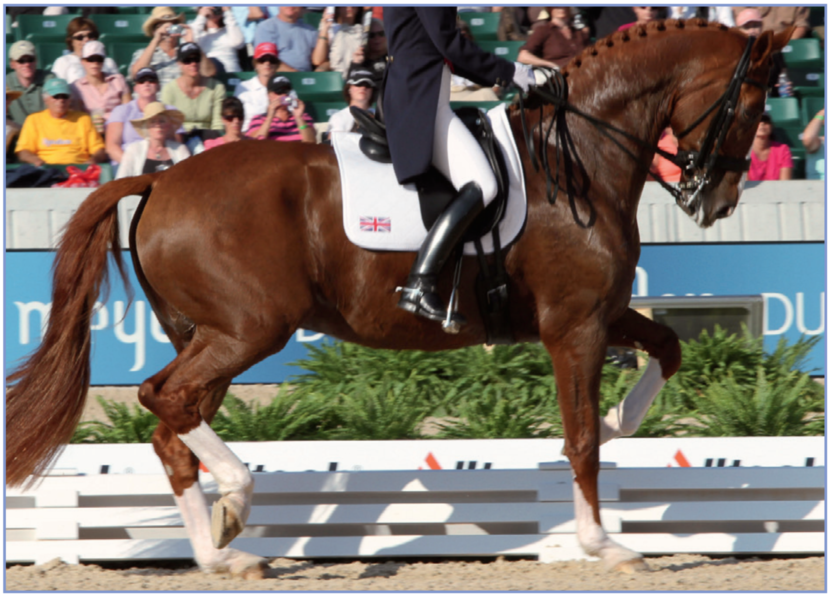
SWING (NON-WEIGHT-BEARING) PHASE (2.17)

Caudal part (retraction phase)

The muscular forces involved during this part of the stride start to act as soon as the foot leaves the ground (take-off). After limb extension, which comes at the end of propulsion, retraction of the limb is facilitated through flexion of the joints:

◀ **2.17** Muscular actions during the various phases of the stance phase.

▲ **2.18** Retraction of the limb at high speed following concentric contraction (shortening) of the iliopsoas and cranial femoral muscles. Note the elasticity of the peroneus tertius muscle (**left**), subjected to inertia of the distal portion of the limb. This results in delayed flexion of the hock and relaxation of the common calcaneal tendon. The delayed flexion of the hock with increased tension on the common calcaneal tendon is shown (**right**).



◀ **2.19** Swing phase of the right hindlimb during passage. All the joints are synchronously flexed to the same degree (hip, stifle, hock, fetlock and interphalangeal joints).

- Flexion of the coxofemoral (hip) joint lifts the entire limb and brings it underneath the trunk. It is made possible by the actions of two muscular groups, the iliopsoas muscle and the cranial femoral muscles, which vary in efficiency:
  - The iliopsoas muscle is very powerful and is the primary force in bringing the limb forward during the swing (non-weight-bearing) phase (remembering that it also flexes the pelvis and the lumbar vertebral region).
  - The cranial femoral muscles, in particular the tensor fascia latae muscle and the rectus femoris muscle, contribute actively to flexion of the hip through concentric contraction.
- Flexion of the femorotibial joint occurs following action of the caudal femoral muscles and promotes closure of the distal limb joints during the swing phase thanks to the reciprocal apparatus.

Intermediate part (mid-swing phase)

During this part of the stride all the joints are flexed to varying degrees depending on the gait and speed (**2.18, 2.19**). Flexion of the hip is accentuated through concentric contraction of the iliopsoas and cranial femoral muscles. Maximal closure of the femorotibial joint occurs through marked shortening of the caudal femoral muscles. The hock then automatically follows into flexion through upward traction of the peroneus tertius muscle. Horizontalization of the calcaneus places tension on the superficial digital flexor tendon, which flexes the digital joints (fetlock and interphalangeal joints).

Cranial part (protraction phase): engagement (2.20, 2.21, overleaf)

On ground contact, a disunion in joint movements occurs: mobilization of the hip joint reduces significantly, while all the other joints open rapidly to increase the length of the limb at landing.

Extension of the stifle is controlled by concentric contraction of the cranial femoral muscles, in particular the quadriceps femoris muscle. This movement can, however, be hampered by a lack of elasticity or elongation (stretch) in the caudal femoral muscles. It is therefore important to understand the determining and limiting factors of a particular movement so that appropriate exercises can be selected.

Extension of the hock automatically follows the upward traction created by the superficial digital flexor tendon (and gastrocnemius muscle) on the calcaneal lever (see Calcaneal lever, p. 26).

Extension of the fetlock and the interphalangeal joints prepares the foot for landing and occurs as a result of inertia of the limb and active contraction of the cranial crural (leg) muscles (long and lateral digital extensor muscles).

◀ **2.20** Engagement of the left hindlimb at a working canter. The lumbosacral and hip joints are flexed, facilitating protraction of the limb. All the other joints (stifle, hock, fetlock and interphalangeal joints) are simultaneously opened to the same extent. The gluteal and caudal femoral muscles are maximally lengthened.

◀ **2.21** Engagement of the left hindlimb (leading limb) at a canter in an endurance horse. The lumbosacral joint is starting to extend, initiating propulsion of the right hindlimb. The left stifle, hock, fetlock and interphalangeal joints are simultaneously extended to equal degrees. The caudal femoral muscles are maximally lengthened.

Summary

The concepts that have been discussed in this chapter allow for a better understanding of the mechanisms behind athletic movement of the horse. It is now possible to look deeper into a horse's gait rather than just assessing whether it is engaging its hind end or not. The concepts presented here allow the reader to explore and to understand which muscles and joints are responsible for engagement of the hind end and which muscles limit the degree of engagement due to a lack of elasticity and stretch.

By the same method of motion analysis, an understanding of the biomechanics of different gaits allows for selection of exercises that are best adapted to the development of the muscles involved in engagement of the hind end, the suppleness of joints and the lengthening of antagonistic muscles.

Analysis of the movement of the horse is performed in a similar way to human sport disciplines and gymnastics in an attempt to enhance performance and athletic ability. Interpretation and analysis of movements are based on knowledge of the muscular insertions on the skeleton and on an understanding of the different types of muscle contraction. Continuing with these concepts, the biomechanics of the trunk will be analysed in the next chapter.

3 The neck and trunk

Although the biomechanics of the trunk and vertebral column have been the subject of discussion in many texts studying the movement of the horse and equitation, it is still, however, a poorly understood topic. This is for two main reasons: firstly, a lack of objective knowledge because of the limited range of intrinsic movements at the intervertebral level, and secondly, a lack of consistency in terminology when discussing the biomechanics or locomotion of the horse.

The vertebral column has a fundamental role in the locomotion of the horse and in equitation. It is a true, real suspension bridge between the forelimbs (thoracic limbs) and the hindlimbs (pelvic limbs). In the majority of equine disciplines this 'bridge' supports the weight of the rider and it is important to note that it is not a rigid structure. The vertebral column possesses a certain flexibility that is indispensable in riding sports and it also plays an important role in the propulsion phase of the stride. It is for these reasons that the biomechanics and the gymnastics through exercises that contribute to the fitness of the trunk are some of the major concerns of trainers and riders alike.

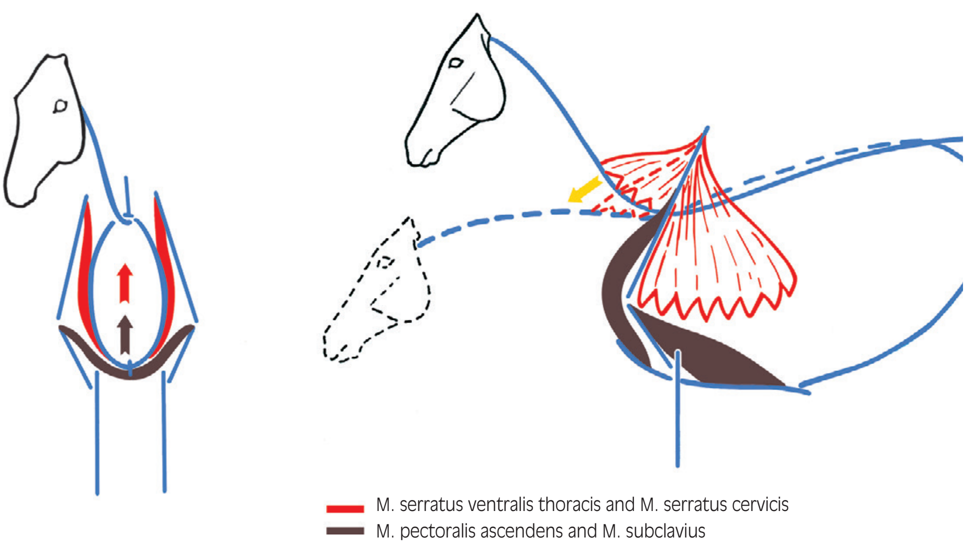
It is not possible to improve a system or structure without understanding its inner workings; therefore, the main objective of this chapter is to review the fundamental concepts of the biomechanics of the vertebral column. This will not only allow a better understanding of the importance of certain exercises from a training perspective, but will also assist in choosing those exercises that are best adapted to the discipline of the horse.

Muscular groups and actions

Before discussing the different structures responsible for the intrinsic mobilization of the vertebral column, attention should be paid to the structures responsible for the suspension of the trunk between the four bony pillars of the fore- and hindlimbs.

SUSPENSION OF THE TRUNK (3.1)

Suspension of the trunk by the hindlimbs does not involve any muscular intervention, but relies on a low mobile joint, the sacroiliac joint, which has very strong ligamentous attachments connecting the sacrum to the



3.1 The muscular girdle suspending the thorax between the forelimbs. The serratus muscles attach to the internal aspect of the scapula, ribs and cervical vertebrae; the pectoral muscles stretch between the sternum, scapula and humerus.

◀ **3.2** Suspension of the thorax at landing after a jump. Note the controlled drop of the entire trunk between the forelimbs.

ventral aspect of the left and right ileal wings. Suspension of the trunk by the forelimbs is the complete opposite to that of the hindlimbs. Horses do not have a clavicle, so the trunk is only supported by a very powerful muscular girdle.

Two groups of muscles are involved in suspension of the trunk between the forelimbs: the serratus muscles, which attach to the upper part of the scapula and support the lower neck (serratus cervicis muscle) and the first eight ribs (serratus thoracis muscle); and the pectoral muscles, which anchor the sternum to the upper humerus (pectoralis ascendens muscle) and the anterior margin of the shoulder (subclavius muscle).

Development and strengthening of these muscles are crucial to equine sports. Essentially, their power and strength are what ensures the lightness of the forehand during locomotion. The efficiency of their concentric contraction ensures elevation of the forehand at take-off in front of a jump. Eccentric contraction of these muscles controls dropping of the trunk between the forelimbs at landing and limits the stresses imposed on the lower limbs during the loading phase of the stride (**3.2**).

FLEXION–EXTENSION MOVEMENTS

Classification of the muscles responsible for mobilizing the vertebral column in the median plane is simple: muscles located above the vertebral column (dorsally) are extensors; those situated below (ventrally) are flexors. These muscles in the neck and the thoraco-lumbar regions will be considered separately.

Neck (3.3)

Extensors

The dorsal cervical muscles stretch between the tall thoracic spinous processes caudally (towards the rear), the cervical vertebrae and the head cranially (towards the front). These muscles are therefore extensors of the cervical spine; they elevate the neck and extend the poll (resulting in horizontalization of the head). The most powerful of these muscles are the splenius and the semispinalis capitus muscles (dorsal cervical muscles).

Flexors

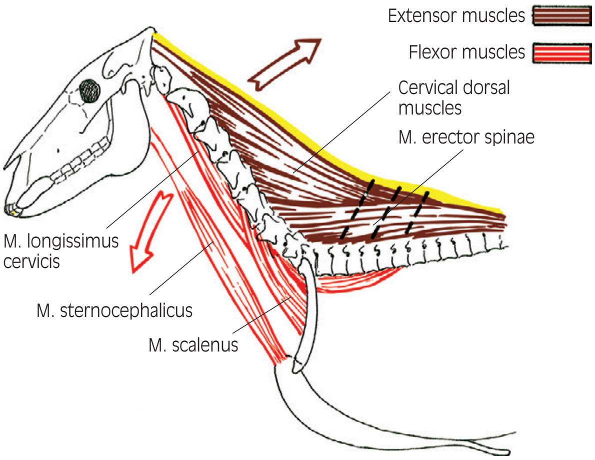
Of the ventral cervical muscles, only the brachiocephalicus and sternocephalicus muscles (named according to their insertions) and the scalenus muscle extending between the first rib and the cervical vertebrae will be cited. These muscles are flexors of the cervical spine; they lower the neck and are also flexors of the poll. (**Note:** Lowering of the neck corresponds to a cervical flexion and not extension.)

Thoracolumbar spine (3.4)

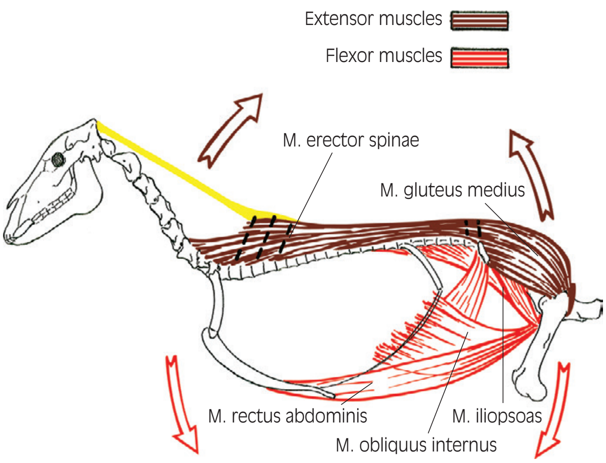
Extensors (3.5, 3.6)

This group of muscles is primarily composed of a large muscle, the erector spinae muscle, which attaches caudally (towards to the rear) onto the ilium and extends cranially (forward) to the base of the neck, inserting on all the vertebrae along its length as well as the upper margins of the ribs. Concentric contraction of the erector spinae muscle results in a powerful extension of the thoracolumbar spine, which brings the spinous processes closer. Because of its insertion onto the ileal wing, contraction also results in an upward tilt of the pelvis, inducing extension of the lumbosacral joint.

The lumbosacral joint is of particular importance in vertebral mobility as it is also moved by the powerful action of the middle gluteal muscle, which extends to and inserts onto the lumbar spine.



◀ **3.3** Mobilizing muscles of the neck. Muscles dorsal to the vertebrae are extensors, while those located ventrally are flexors.



▲ **3.4** Mobilizing muscles of the thoracolumbar spine. The epaxial muscles (located dorsal to the spine) are extensors; the hypaxial muscles (ventral to the spine) and the abdominal wall muscles are flexors.

▲ **3.5** Powerful extension of the vertebral column in the cervicothoracic and thoracolumbar spine at landing following a drop jump. The lumbosacral region is beginning to flex in order to facilitate landing of the hindlimbs.

◀ **3.6** Flexion (horse number 12) and extension (horse number 10) of the lumbosacral junction in two steeplechase horses. Note the large range of motion in lumbosacral flexion and extension.

◀ **3.7** Powerful dynamic flexion of the lumbosacral junction at landing following a cross-country jump. Flexion of the lumbosacral joint facilitates positioning of the hindlimbs.

◀ **3.8** Simultaneous and coordinated action of the flexor and extensor muscles. Note the flexion of the lumbosacral joint by the abdominal muscles (especially the iliopsoas muscle) and elevation of the forehand by the dorsal extensor muscles (erector spinae muscles, beneath the saddle).

◀ **3.9** Right lateroflexion of the neck and thoracolumbar spine. This movement is associated with a right rotation of the thorax relative to the pelvis.

Flexors **(3.6, 3.7)**

This group of muscles is located ventral to (below) the vertebral column and includes the abdominal muscles. There are two main groups:

- The **abdominal wall** muscles (the rectus abdominal and oblique abdominal muscles) extend between the sternum and the last ribs cranially and the pubis caudally. Shortening of these muscles (concentric contraction) induces flexion of the entire thoracolumbar spine and the lumbosacral joint, forcing the back of the pelvis to tilt downwards.
- The **sublumbar** muscles (iliopsoas muscles) attach to the lower aspect of the lumbar vertebrae and the ilium and continue on to insert primarily on the upper femur. This group of muscles not only flexes the hip joint (see Chapter 2, The hindlimb) but also, through concentric contraction, flexes the lumbosacral joint and the lumbar spine. They therefore participate in the two components of the engagement of the hind end: tilting of the pelvis forwards and flexion of the coxofemoral joint.

Although the flexors and extensors are antagonistic to each other, their actions are often simultaneous and therefore balance the stresses and forces occurring around the vertebral axis as well as specifically mobilizing different regions of the trunk (**3.8**).

LATERAL BENDING MOVEMENTS (LATEROFLEXION)

Lateral bending or lateroflexion of the spine can be defined as a bending or curvature to one side in a horizontal plane. It is important to point out, however, that this movement is rarely absolute and is almost always associated with a secondary rotation.

Lateroflexion is not induced by specific muscles, rather it is the action of the flexors and extensors, as previously mentioned, that induces concentric contraction on one side of the spine (unilateral or asymmetric contraction), resulting in bending of the vertebral column to the same side. Thus, right cervical lateroflexion is induced by concentric contraction of the dorsal and ventral cervical muscles on the right hand side (**3.9**).

Lateral bending of the thoracolumbar region is most pronounced in the caudal half of the thoracic spine. It is a result of unilateral contraction of the erector spinae muscle and the oblique abdominal muscles.

The iliopsoas muscle has a minor role in lateroflexion as the lumbar intervertebral joint does not allow much in the way of horizontal movement. True lateroflexion is virtually non-existent in the lumbosacral joint.

▲ **3.10** Left active rotation of the thoracolumbar spine during the airborne phase of a jump. The lower edge of the pelvis is shifted to the right side of the horse, resulting in a left spinal rotation.

ROTATIONAL MOVEMENTS

Rotational movements are angular movements that occur around the vertebral axis. The vertebral column does not bend, as discussed above, but undergoes a torsional movement in the transverse plane. This action is often associated with movements of latero-flexion. The rotation is defined by the side to which the lower (ventral) aspect of the vertebrae moves relative to the pelvis and hindlimbs (see Chapter 8, The vertebral column and trunk muscles), which are considered to be 'fixed' structures.

These movements may be active, initiated by concentric muscular contraction (**3.10**), or they may also be a passive reaction to positioning of the limbs. In this instance, eccentric contraction of the rotating muscles controls the amount of movement (**3.11, 3.12**).

The muscles responsible for these movements are small and located adjacent to the vertebrae and are therefore known as juxtavertebral muscles (e.g. the multifidus muscle). Each muscle spans obliquely over 2–3 vertebrae, crossing over each other from the sacrum up to the poll. During wide movement of the trunk these muscles are still very much auxiliary to the larger muscle groups previously discussed, but they have a paramount role in the proprioceptive control of complex vertebral movements.

An example of rotational movements in the neck can be demonstrated by the unilateral contraction of the splenius muscle, which initiates rotation of the cervical spine (and therefore the head) to the same side.

In the thoracolumbar spine, the area undergoing the most rotational movement is the caudal half of the thoracic spine. The oblique abdominal muscles (in particular the internal oblique muscle) are by far the most active muscles in these movements. Rotation is limited in the caudal lumbar spine. In the lumbosacral region, rotation is significantly limited due to the vertebrae being locked into position by ligaments during flexion and extension. Therefore, rotation is only possible in or around a neutral position.

◀ **3.11** Passive right rotation of the thoracolumbar spine at a trot. Loading on the left hindlimb initiates a rotation of the pelvis towards the left; loading of the right forelimb is accompanied by a right rotation of the thorax and the vertebral column.

◀ **3.12** Passive left rotation of the thoracolumbar spine at a trot. Loading of the right hindlimb results in a swing of the pelvis to the right; loading of the left forelimb is accompanied by a left rotation of the thorax and the vertebral column relative to the pelvis.

Muscular actions during the stride ❑

Now that the mechanisms and the structures responsible for mobilizing the spine have been discussed, it is time to return to the objective of this discussion: to understand from a kinesiological (the study of movement) point of view the events that occur during motion.

The biomechanics of the vertebral column vary in different gaits. It is for this reason that the biomechanics of the spine at a trot and canter will be evaluated separately.

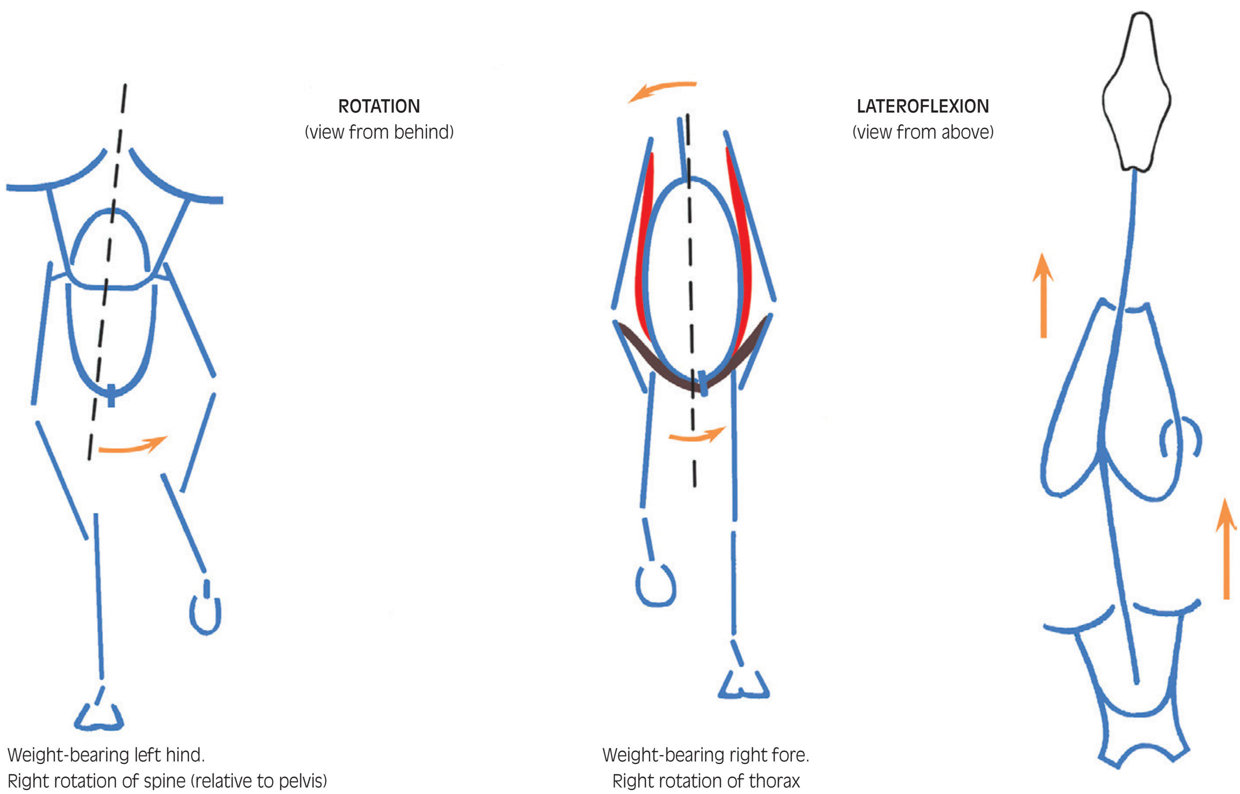
TROT (3.13)

During this gait, flexion–extension movements of the trunk are passive and are a result of the inertia of the abdominal mass. During the stance phase (**3.11, 3.12**), ventral displacement of the abdomen pulls the thoracolumbar spine into extension, while the abdominal muscles contract eccentrically to limit this movement. Thus, paradoxically, abdominal muscle contraction is seen simultaneously with a movement of spinal extension. In contrast, during the suspension phase of the stride the abdominal mass is projected dorsally and pushes the vertebral column into flexion. This movement is controlled by the extensor muscles of the spine.

The vertebral column also undergoes lateral bending and rotation at the trot. To simplify the discussion and to facilitate readers' understanding, the mechanical events that occur in the vertebral column during half a stride (given each half of the stride is symmetrical) will be described, starting, arbitrarily, with the diagonal right stage of the stride during which the right forelimb and left hindlimb are weight bearing (reversed during the second half of the stride).

Lateral bending

The recoil of the weight-bearing diagonal (left hindlimb–right forelimb) along with the forward movement of the opposing non-weight-bearing diagonal (right hindlimb–left forelimb) is accompanied by a



▲ **3.13** Rotational and lateral bending movements at a trot.

lateral deviation of the pelvis and thorax. This results in curvature of the vertebral column to the right (concave aspect to the right). Thus, at the trot, the vertebral column undergoes lateroflexion to the side of the weight-bearing forelimb (**3.13**).

Because of the conical shape of the thorax, this curvature facilitates sliding of the weight-bearing forelimb backwards. It is essentially as a result of contraction of the oblique abdominal muscles and the lateral part of the erector spinae muscle group (in particular the iliocostalis muscle).

Rotation

Again, the horse will be considered on the right diagonal.

Forehand

When the left forelimb is non-weight bearing, the thorax is suspended only by the muscular girdle on the right side of the body. This results in a left drop of the thorax and, therefore, the spinous processes tilting towards the left and the sternum to the right (counterclockwise rotation when viewed from behind, **3.13**). In terms of vertebral biomechanics, this is called a right rotation, as the cranial part of the horse has a tendency to turn to the right side.

Hindquarters

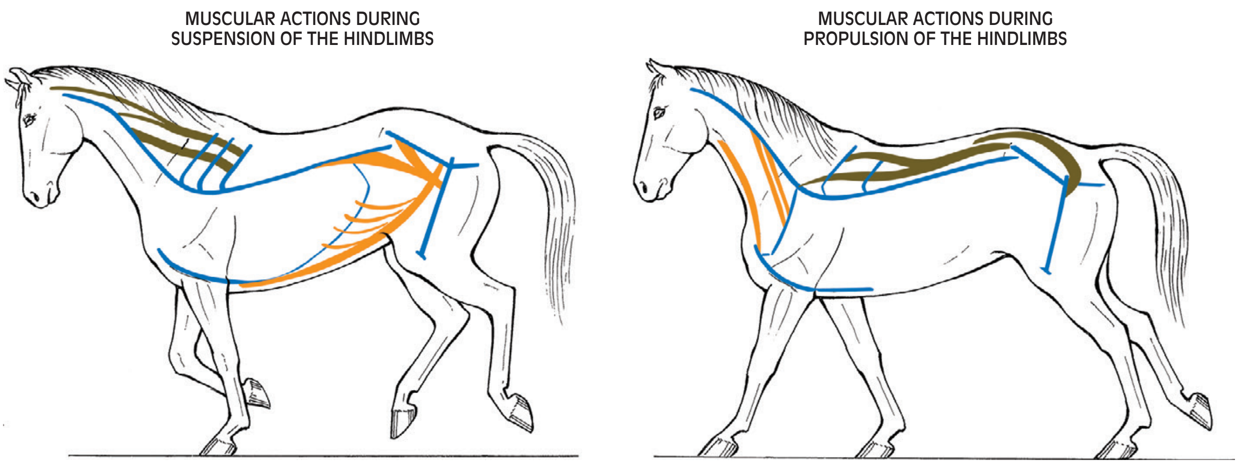
When the right hindlimb is non-weight bearing and the left hindlimb is weight bearing, the result is a tilt of the pelvis. In biomechanical terms, a rotational movement is usually classified by displacement of the forelimbs relative to the hindlimbs (see above). Therefore, the thorax in this situation undergoes a rotational movement to the right relative to the sacrum (which is considered a fixed structure). At a trot, the entire length of the spine (from rear regions to front regions) undergoes a rotation to the side of the weight-bearing forelimb.

These movements are completely passive and the muscles of the trunk act more to limit the degree of rotation. In the following chapters it will be shown how this movement of lateroflexion and spinal rotation can be further developed with the aim of improving flexibility of the spine.

CANTER (3.14)

The vertebral biomechanics during a canter is completely different to that during a trot for two main reasons:

- Movements of the spine are primarily flexion–extension.
- It is an active movement, resulting in concentric contraction of the trunk muscles.



▲ **3.14** Muscular actions during a canter. The dorsal cervical and abdominal muscles are activated during the suspension phase; the ventral cervical, erector spinae and the middle gluteal muscles have simultaneous actions during the propulsion phase.

◀ **3.15** End of the propulsion phase of the stride by the non-leading (right) forelimb. Elevation (extension) of the neck and thoracolumbar and lumbosacral flexion will continue during the suspension phase and contribute to engagement of the hind end.

To simplify the discussion and to stress the key points with regard to exercises that will improve fitness and strength, only two phases of the stride, hindlimb suspension (thoracolumbar flexion) and propulsion of the hindlimbs (thoracolumbar extension), will be discussed.

Suspension phase

During this phase there is elevation of the neck and joint engagement in the hindlimbs (**3.14, 3.15**).

Elevation of the neck

Elevation of the neck corresponds to extension of the cervical spine and is induced by concentric contraction of the dorsal cervical muscles. Concurrently, the supraspinous ligament relaxes, thus facilitating thoracolumbar flexion.

Engagement of the hindlimbs (3.16)

Engagement of the hind end corresponds to vertebral flexion and is made possible because of the synergistic and synchronous concentric contraction of the abdominal muscles. The iliopsoas muscle flexes the lumbosacral and hip joints, initiating forward movement of the hindlimbs. The abdominal wall muscles contribute to engagement of the hind end by flexing the thoracolumbar and lumbosacral intervertebral joints.

Hindlimb propulsion

During hindlimb propulsion, the movements described above reverse. Lowering of the neck is accompanied by extension of the thoracolumbar spine.

Lowering of the neck

This movement is both passive, through the weight of the head and neck, and active through contraction of the ventral cervical muscles, in particular the scalenus muscles.

Flexion

Neck flexion places the supraspinous ligament under tension, cupping the thoracolumbar vertebral bodies that facilitate transmission of the forces generated at propulsion by the hind end.

Extension of the thoracolumbar spine (3.17)

This movement contributes very effectively to the propulsion pushing the horse's body forward and can be attributed to concentric contraction of the erector spinae muscle along the length of the spine (excluding the neck). Lumbosacral extension is enhanced by the action of the middle gluteal muscle, which also extends the hip joint (see Chapter 2, The hindlimb).

◀ **3.16** Suspension phase during a canter with powerful engagement of the hindlimbs due to extensive lumbosacral and thoracolumbar flexion.

◀ **3.17** Extension of the thoracolumbar and lumbosacral spine at the end of hindlimb propulsion. Note the contraction of the abdominal muscles, which are preparing for flexion of the spine as soon as the right hindlimb has finished its propulsion.

Conclusion

This chapter, which has described the fundamental concepts underpinning the biomechanics of the neck and trunk completes the initial discussion required before going on to consider concepts that relate to the physical training of the athlete horse. These ideas will allow an analysis of the most commonly employed exercises used for flexibility, strength and coordination training.

Understanding the muscular insertions and the roles of different muscles is indispensable for initiating a rational and suitable training regime. The training of the horse will depend on its particular strengths and weaknesses relative to the chosen discipline. Appropriate exercises must be selected based on their advantages, indications and potential disadvantages. It is this understanding of training through analysis of every exercise and movement that constitutes the aim of the following chapters of this book.

PART 2:

Biomechanical analysis of longitudinal movements

CHAPTER

4 Lowering of the neck

The first three chapters have explored the functional anatomy of different parts of the equine body. The basic concepts discussed in those chapters will assist in understanding the biomechanics of the present topic: lowering of the neck. Although this particular movement is employed to a variable extent depending on the discipline, it belongs to the basic training exercises for a lot of sport disciplines. It is important to remember that any exercise focused on basic strength training, joint flexibility and psychomotor coordination will provide a sound base for balanced physical and mental training, whatever the horse discipline.

The aim of this chapter is to identify and analyse the vertebral movements, muscular actions and biomechanical stresses taking place during exercises involving lowering of the neck. This allows for an evaluation of the advantages and disadvantages of this body position in relation to the various disciplines. Based on this information, a decision can be made on whether an exercise should be incorporated, limited or avoided during training considering the inherent strengths and weaknesses of a given horse.

In this chapter, lowering of the neck is discussed as distinct from extension of the neck. Because of the biomechanics of the vertebral column, lowering of the head and neck results in flexion of the lower cervical spine (see Chapter 3, The neck and trunk) (**4.1**). In addition, discussion of this movement will be based on a biomechanical point of view only rather than on an equitation point of view. This means that the functional changes imposed on the moving horse is the focus regardless of whether the movement is spontaneous or induced using appropriate reins. The biomechanical analysis of a horse working with a lowered neck position can be evaluated through its effects on different parts of the body: the forehand, the back (broadly speaking) and the hindquarters.

Effects on the forehand

Regardless of the gait (walk, trot or canter), lowering of the head and neck results in several biomechanical changes to the forehand.

Firstly, horizontalization of the head and neck results in forward displacement of the centre of mass of the horse. The immediate consequence of this is increased loading of the forehand, with subsequent offloading of the hindquarters (**4.2**). Overloading of the forehand in this particular attitude increases the work on the thoracic muscular girdle that suspends the trunk of the body between the two forelimbs (see Chapter 3, The neck and trunk). As a consequence, development of the pectoral and serratus muscles is enhanced, resulting in improved support and lightening of the forehand when the neck is in a natural position. Despite the importance of this movement in the various disciplines, it is important to remember that it must not be overly repeated or implemented for prolonged periods. This is because overloading of the forehand results in additional stress on the joints and tendinous structures of the forelimbs. Therefore, this movement is contraindicated in horses with a history of tendinitis or joint problems in the forelimbs.

Secondly, horizontalization of the neck also results in forward displacement of the centre of mass of the head and neck, which is supported by the dorsal cervical muscles. Lengthening of these muscles elicits an isometric contraction (**4.1**). This contraction has two advantages: it prevents muscular stiffness and improves the efficiency of muscular contraction. The muscles that are recruited during these events are those that mobilize the junction between the neck and the thorax (cervicothoracic junction). The development of muscles involved with lifting the head and neck is of particular importance in dressage (**4.3**) and showjumping. Their role is to facilitate a rapid extension of the neck, assisting the opening of the joints of the forelimbs to realize lifting of the forehand.

▲ **4.1** Lowered neck during collected flat work. Note the degree of flexion of the vertebral segments of the neck and back and of the coxofemoral (hip) joint. There is simultaneous lengthening of the dorsal cervical, erector spinae (under the saddle), gluteal and caudal femoral muscles.

▲ **4.2** Lowering of the neck during a canter (with mild left lateroflexion). Note the loading of the forehand and the thoracic muscular girdle (the serratus and pectoral muscles) suspending the thorax between the forelimbs.

▲ **4.3** Lowering of the neck during a working canter (left). Note the loading of the forehand and contraction of the abdominal muscles assisting engagement of the hind end. Lowering of the neck promotes strong support of the forehand during sport exercises (e.g. the change of lead during a canter, as shown right) and engagement of the hindlimbs when the neck, because it is in a natural position, reduces tension of the supraspinal ligament.

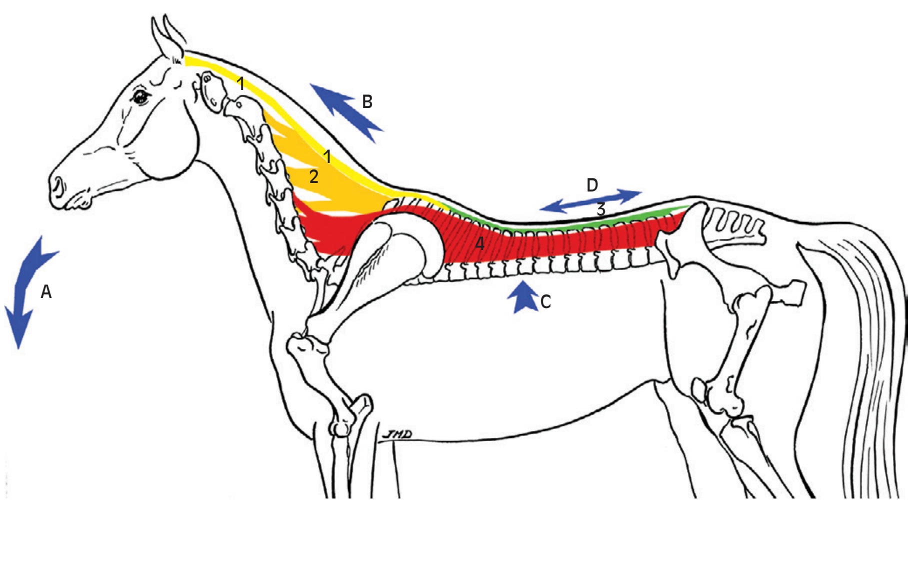
Finally, lowering of the neck and, therefore, flexion of the cervical spine are accompanied by an opening of the cervical intervertebral foramen. Foramina are spaces formed by the apposition of two vertebrae and they allow passage of large segmental nerves arising from the spinal cord (**4.4**). The opening of this space during cervical flexion can provide a relieving action, particularly in horses that have nerve compression or irritation at the foramina. Nerve compression or irritation at these sites may contribute to neck stiffness, forelimb lameness and defensive, fighting behaviour.

▲ **4.4** Cervical spine at the junction between the neck and the thorax (cervicothoracic junction). The apposition of adjacent vertebrae results in formation of an intervertebral foramen. This foramen allows for the passage of a large segmental nerve, which will continue on to contribute to the brachial plexus, providing motor and sensory innervation to the forelimb.

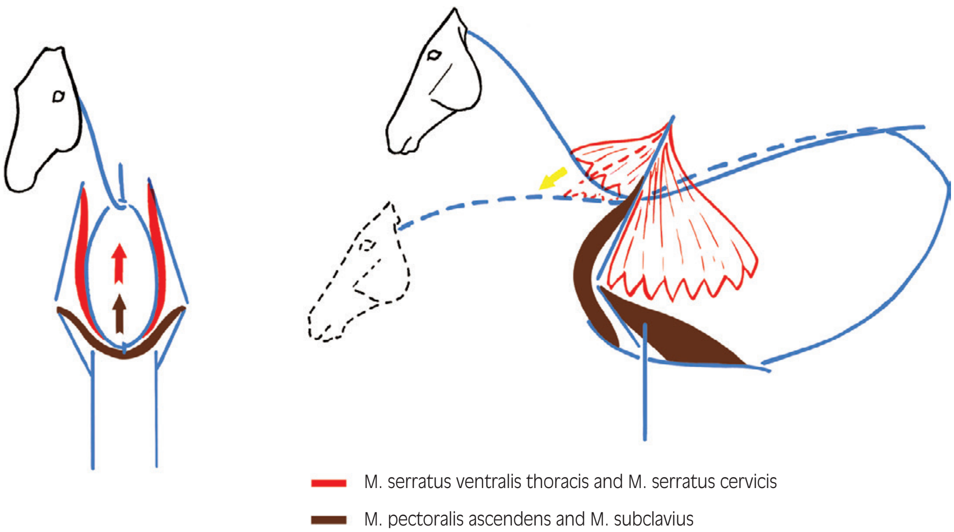
Effects on the trunk

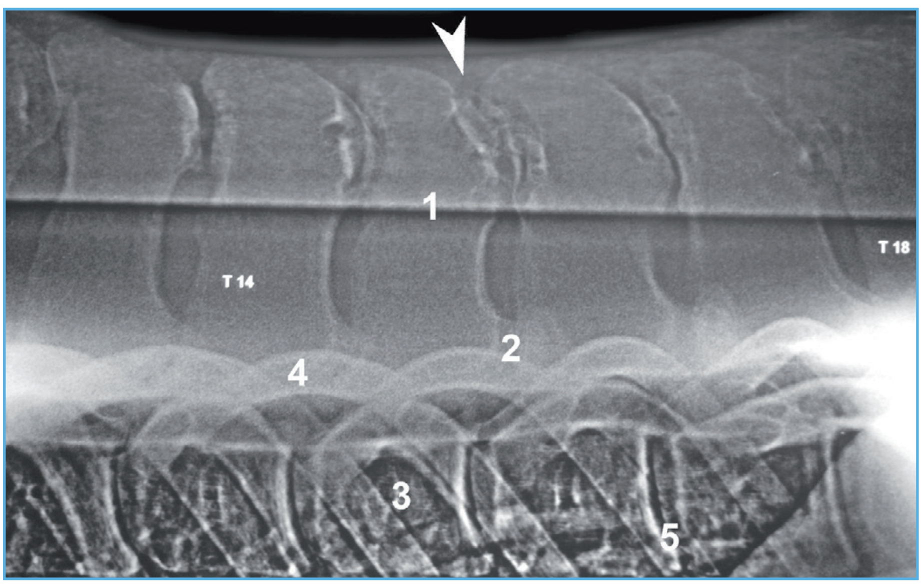
Generally speaking, lowering of the neck provokes flexion of the thoracic spine through elongation of the strong and elastic nuchal ligament, creating a forward traction on the high spinous processes of the withers (**4.5**). This thoracic flexion stretches and elongates anatomical structures located above the vertebral axis (**4.6, 4.7**) and triggers an increase in work from the abdominal muscles (**4.8, 4.9**). The magnitude of the forces imposed on these structures will vary depending on whether there is concurrent hindlimb engagement.

▼ **4.5** Effects of lowering the head and neck on the ligamentous apparatus attaching to the apices of the spinous processes of the vertebral column. Lowering of the neck (A) results in tension of the nuchal ligament creating a forward traction on the spinous processes of the withers (B), flexion of the thoracic region (C), tension on the supraspinous ligament and elongation of the epaxial muscles (D). 1, nuchal ligament (funicular part) attaching on the occipital bone; 2, lamellar part of the nuchal ligament attaching along the middle cervical vertebrae; 3, supraspinous ligament inserting on the apices of the spinous processes of the thoracic and lumbar spine; 4, longissimus muscle, a major component of the epaxial musculature (situated above the vertebral axis).

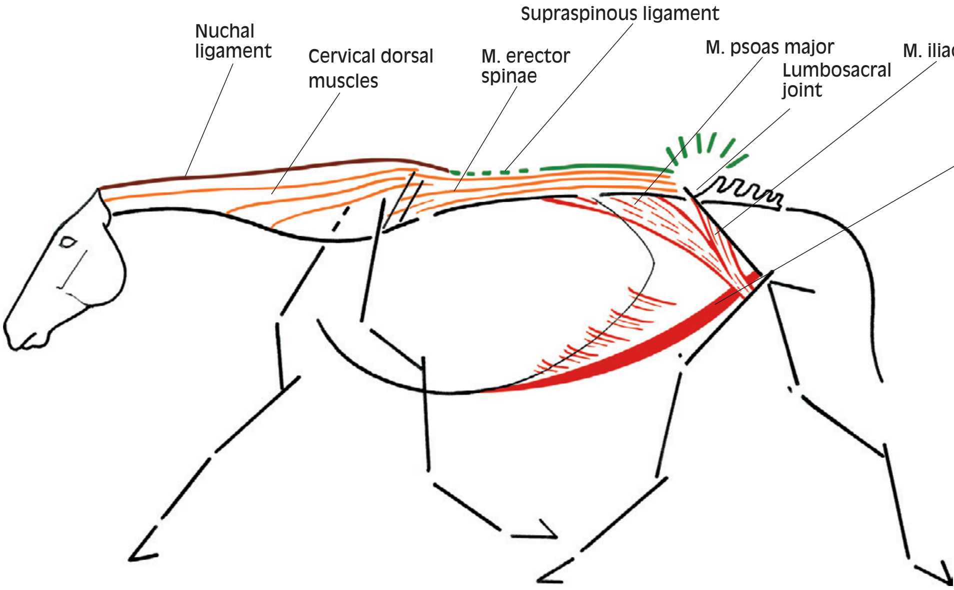


4.6 Lowered neck during a relaxed walk. Note the thoracic flexion and the elongation of the muscles at the base of the neck and along the back. The serratus and pectoral muscles are loaded and their strengthening facilitates suspension of the thorax, while the neck is in a natural balanced position (left drawing, below).





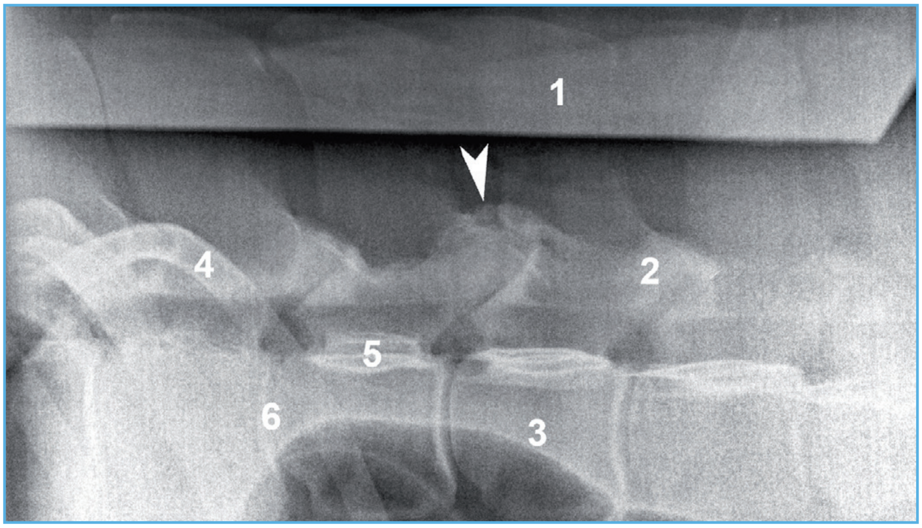
4.7 Severe impinging dorsal spinous processes ('kissing spines') in the caudal thoracic region between the 12th and the 18 th thoracic vertebrae (arrowhead). Lowering of the neck induces flexion of the thoracic spine and thus reduces pressure between the affected vertebrae. 1, spinous process; 2, articular process; 3, vertebral body; 4, rib; 5, intervertebral disc.



4.8 Muscles and ligaments involved in lowering of the neck. Tension on the supraspinous ligament limits thoracolumbar flexion and increases the work of the abdominal muscles, facilitating engagement of the hind end. The combination of this ligamentous tension and abdominal muscle contraction focuses flexion at the lumbosacral joint.

4.9 Cervical flexion during a trot. Note the lifting (and flexion) of the back, tension on the supraspinous ligament and recruitment of the abdominal muscles facilitating engagement of the left hindlimb.

4.10 Lowering of the neck induces thoracic flexion (directly beneath the saddle), promoting lengthening of the back epaxial muscles and support of the rider's weight by the vertebral column.



◀ **4.11** Severe arthritis of the articular processes (arrowhead) betweeen the 2nd and 3rd lumbar vertebrae. Lowering of the neck reduces the muscular spasms associated with intervertebral pain. 1, spinous process; 2, articular process; 3, vertebral body; 4, last (18th) rib; 5, transverse process; 6, intervertebral disc.

WITHOUT HINDLIMB ENGAGEMENT

Lowering the neck affects structures above the vertebral axis up to and including the thoracolumbar junction.

Effects on the vertebrae and ligaments

Flexion of the neck and, therefore, the thoracic spine results in a separation between each of the spinous processes of the thoracic vertebrae. It is therefore a pain relieving (antalgic) position in horses suffering from impinging dorsal spinous processes ('kissing spines', **4.7**) and represents a real physiotherapeutic treatment allowing them to continue their sport career.

Strong traction by the nuchal ligament, which inserts onto the spinous processes of the withers, results in flexion of the thoracic spine along its entire length (**4.10**). The degree of flexion is most marked between the 5th and 9th thoracic vertebrae and is also significant between the 9th and 14th thoracic vertebrae. The consequent arching of the back takes place directly under the saddle and therefore supports the rider. This can be used to advantage in a couple of situations. Firstly, in the schooling of young horses where muscles are not yet adapted to the weight of a rider, and secondly, in horses suffering from impinging dorsal spinous processes where extension of the thoracic spine contributes to the origin and persistence of pain.

Arching of the thoracic spine induces an elongation of the erector spinae muscle and the juxtavertebral (multifidus) muscles, which work during lengthening (**4.1, 4.8**). Elongation of these extensor muscles of the vertebral column increases the efficiency of their contraction during sport exercises; therefore, thoracic flexion along with efficient abdominal contraction is a valuable tool in the preparation of athletic fitness. This muscular lengthening helps to counter the reflex muscle spasms that occur with impinging spinous processes (**4.7**) or arthritis of the thoracic and lumbar intervertebral joints (**4.11**).

WITH HINDLIMB ENGAGEMENT

Thoracic flexion initiated by lowering of the neck is accompanied by tension on the supraspinous ligament (**4.5, 4.8**). In order to engage the hind end, the horse has to fight against this tension, which has several advantages and disadvantages from a sporting and gymnastic perspective.

Advantages

Lowering of the neck combined with engagement of the hindlimbs imposes flexural stresses at either end of the spine. The advantages of this movement have already been highlighted relative to an absence of hind end engagement. However, engagement of the hindquarters increases the flexion of the thoracolumbar spine, thus magnifying the above-mentioned biomechanical effects induced by lowering of the neck. Therefore, in the thoracic region there is amplification of the separation of the spinous processes, an increased bending of the vertebral arch underneath the rider and stretching of the erector spinae (primarily the longissimus muscle) and juxtavertebral muscles.

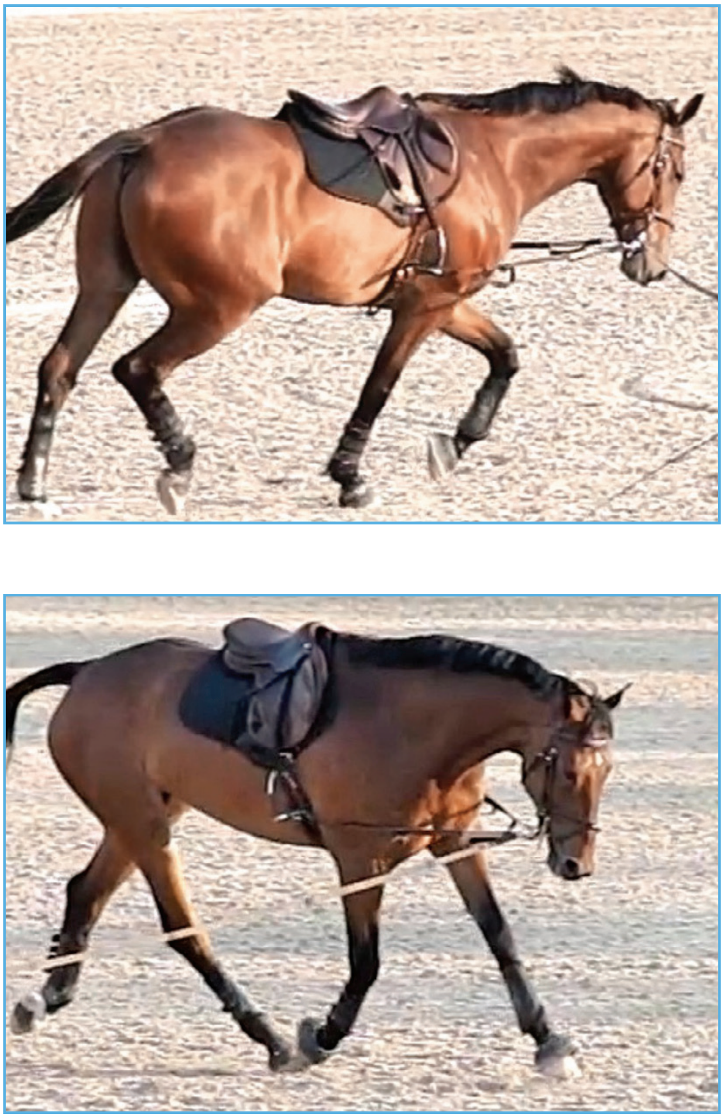
In the lumbar region, tension on the supraspinous ligament resulting from lowering of the neck reduces the ability of the spine to flex further. This results in a functional reorganization of muscular activity and of the sites where mobilization occurs along the spine:

- For hind end engagement the abdominal muscles must counter the inflexibility of the supraspinous ligament in the caudal thoracic and lumbar spine. This additional workload facilitates strengthening of the abdominal muscles. These muscles can be divided into two groups (see Chapter 3, The neck and trunk): the rectus abdominis and oblique abdominal muscles forming the abdominal wall, and the sublumbar muscles, including the psoas and iliacus muscles, located at the ventral aspect of the lumbar spine.
- With regard to the vertebral axis, lengthening of the supraspinous ligament through forward traction of the nuchal ligament contributes to improving the flexibility of the vertebral column during flexion and extension.
- To compensate for a reduction in lumbar flexion the vertebral column undergoes lateroflexion and rotation (**4.12**). As seen in Chapter 3 (The neck and trunk), these movements occur mostly in the second half of the thoracic spine (from the 9th to the 14th thoracic vertebrae) and very little in the lumbar region, the lumbosacral joint allowing only minimal rotation. The primary muscles involved in these movements are the external and internal oblique abdominal muscles and the juxtavertebral (multifidus) muscles. The combination of muscular actions that occur while the horse works with a lowered neck therefore contributes to an increase in proprioception and mobility of the vertebral column in all planes.

Disadvantages

Despite all the advantages, application of this particular exercise must be restricted for two specific reasons relating to the mechanical resistance and the anatomy of the spine:

- Excessive tension on the supraspinous ligament may result in lesions of the ligament itself or at its insertions (desmopathy or enthesopathy).
- Tension on the supraspinous ligament results in compression of the vertebral bodies and, therefore, the intervertebral discs. This can result in injury to these structures, particularly in the lower cervical spine.



▲ **4.12** Lowering of the neck at a trot in lunge. There is an increase in the range of lateral movement and rotation of the thoracolumbar and lumbosacral spine.

Effects on the hindquarters

Lowering of the neck not only alters the equilibrium of the horse and disrupts the biomechanics of the vertebral column, from an athletic point of view it also has repercussions on the mechanical functioning of two specific joints: the lumbosacral joint and the coxofemoral (hip) joint.

LUMBOSACRAL JOINT

The reduction in mobility of the lumbar spine associated with lowering of the neck has been demonstrated by research undertaken at the National Veterinary School of Lyon in France and followed up at the National Veterinary School of Alfort, also in France. Results of this work suggest that to compensate for the relative restriction of mobility of the lumbar region during engagement of the hindquarters, the lumbosacral joint has a more active role in flexion during hindlimb engagement (**4.13**). This compensation is made possible because of the inherent weakness in the supraspinous ligament in this region of the spine and the laxity of the interspinous ligament, as well as the thickness of the last lumbar intervertebral disc.

Increased flexion of the lumbosacral joint has three favourable effects from a sporting and gymnastic perspective:

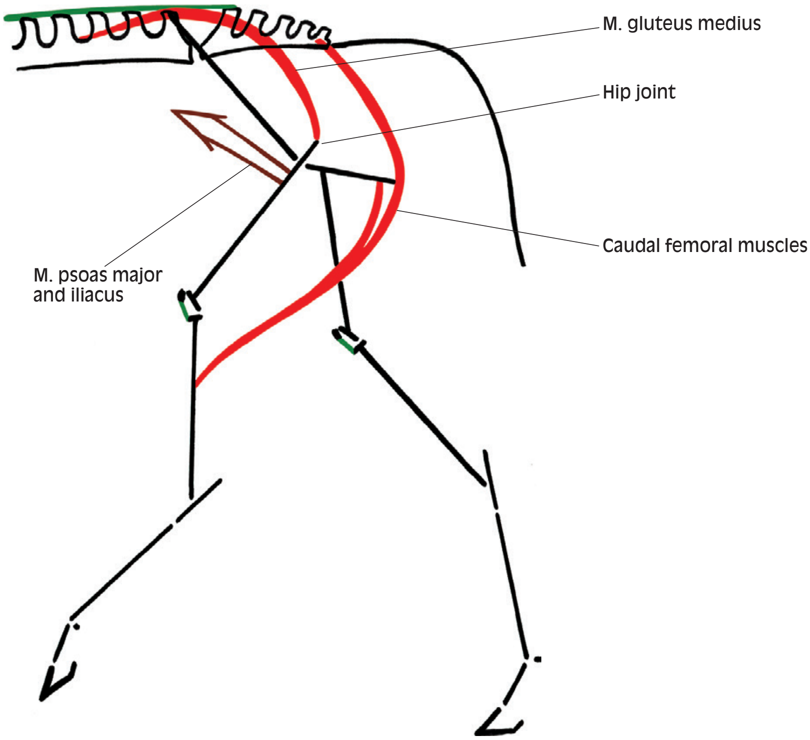
- Flexibility of the lumbosacral joint during flexion as a result of continued and prolonged muscular tension.
- Flexion induces a downward swing of the pelvis, resulting in traction of the erector spinae muscles backwards as well as a forward traction of the large middle gluteal muscle. These two powerful muscle groups are the primary agents in propulsion and their lengthening is beneficial to their efficiency in athletic exercises.
- Restriction of lumbar region mobility increases the work of muscles flexing the lumbar spine and the lumbosacral joint, thus contributing to their development. These muscles, as previously discussed, are the abdominal wall muscles (mainly the rectus abdominis and oblique muscles) and the muscles of the sublumbar region. The most powerful sublumbar muscles are the psoas major muscle and the iliacus muscle, which insert on the proximal femur. They therefore have a direct impact on mobilization of the lumbosacral and hip joints.

COXOFEMORAL JOINT

The tension created by the iliopsoas muscle is applied to the upper extremity of the femur and acts to counter the restriction in lumbar mobility. This results in increased flexion of the coxofemoral joint during engagement of the hindlimbs (**4.1, 4.13**). In conjunction with lumbosacral flexion there is also lengthening of the gluteal muscles (**4.14**). Synchronous extension of the stifle during engagement elicits lengthening of the caudal femoral muscles (gluteobiceps, semitendinosus and semimembranosus muscles; **4.14, 4.15**).

Movement of the joints is therefore associated with lengthening of all the muscles that contribute to propulsion, favouring development of strength and effective push off (propulsion).

◀ **4.13** Lowered neck at a trot with engagement of the hind end. Thoracic flexion helps support the weight of the rider. The supraspinous ligament and the back muscles are lengthened. The contraction of the abdominal muscles increases lumbosacral flexion.



◀ **4.14** Muscular lengthening during hind end engagement. The psoas major and iliacus muscles accomplish the hindquarter protraction through concentric contraction. The middle gluteal and caudal femoral muscles are lengthened and work in elongation.

◀ **4.15** Lengthening of the epaxial muscles (located above the vertebral column) and the gluteal and caudal femoral muscles during engagement of the hind end. All of the muscles contributing to propulsion are lengthened; the left iliopsoas muscle body has undergone a slow but intense contraction to facilitate engagement of the left hindlimb.

Conclusion

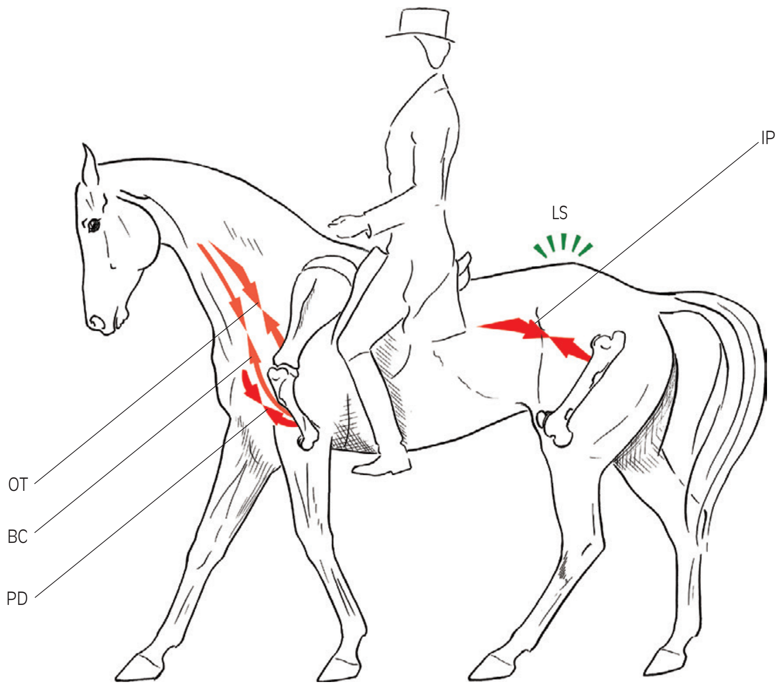
It has become evident that because of the recognized advantages, exercises involving lowering of the neck contribute to the physical preparation of the horse. It should be noted, however, that excessive use of these exercises may have some detrimental impact on the forelimbs and the vertebral column.

Ultimately, it must be remembered that harmonious physical development of the competition horse relies on a combination of exercises, such as working the lower neck at the three gaits (walk, trot, canter), along with other dynamic exercises that will be addressed in the following chapters.

5 Biomechanics of rein-back

Among the various exercises used in the physical training and gymnastics of the musculoskeletal system of the horse, as well as for warming up before events, rein-back is one of the most common. This particular exercise takes place at relatively low speed and poses few risks to the locomotor apparatus of the horse, which is often heavily stressed by training and competition. Nevertheless, it activates specific muscle groups and is therefore an excellent preparatory exercise for a variety of disciplines. In addition, it enhances control of the balance of the horse during work and is a valuable educational tool in learning and development of collected gaits.

Rein-back is a symmetric diagonal gait without a swing phase (**5.1, 5.2**). For this reason it is appropriate to evaluate the biomechanics of the forehand and the hindquarters separately.



▶ **5.1** Primary biomechanical elements of rein-back. On the left-hand side of the body, the iliopsoas muscle undergoes maximal concentric contraction. This muscle initiates flexion of the lumbosacral joint. Its action is followed by activation of muscles of the forehand, shown here in a lengthened position, pulling the neck backwards. OT, omotransversarius muscle; BC, brachiocephalicus muscle; PD, pectoralis descendens muscle; IP, iliopsoas muscle; LS, lumbosacral joint flexion.

▶ **5.2** Action of the diagonal pairs during rein-back. Start of protraction of the left forelimb and end of protraction of the right forelimb: the diagonal right finishes its protraction through strong engagement of the left hindlimb. The quadriceps femoris relaxes. The diagonal left takes the load: the extensor muscles of the left forearm are contracted in order to open the carpus (knee). The right hindlimb is flexed and initiates protraction so as to move the body of the horse backwards.

Biomechanics of the forehand

Two principal phases can be described with regard to the biomechanics of the forelimbs and the head and neck (cervicocephalic) balance system. Contrary to the usual gaits, protraction of the forelimb takes place during weight bearing and pushes the horse backwards. Retraction of the limb takes place in the non-weight-bearing phase and leads to ground contact through the point of the toe.

PROTRACTION OF THE FORELIMB

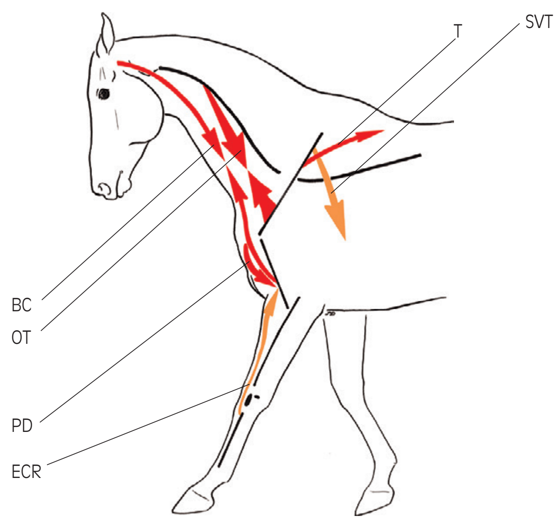
This movement is initiated by a forward swing of the lower aspect of the scapula. The rest of the limb is maintained in extension by isometric contraction of the extensor muscles, most notably the extensor carpi radialis (**5.3, left**). At the end of this phase, the supraspinatus muscle extends the scapulohumeral joint (point of the shoulder), thus increasing the range of movement of the limb (**5.3, right**).

Extension of the scapulohumeral joint angle

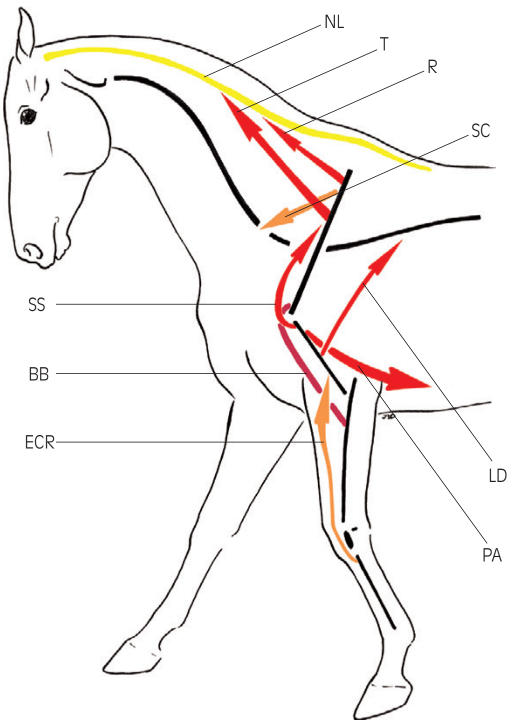
Forward movement of the scapula is associated with a swing motion as well as a sliding motion. This movement results from the action of the same muscles that bring the limb forwards during the non-weight-bearing phase of the stride in the normal forward gaits. In this situation, however, as the foot is fixed on the ground, protraction of the limb will result in shifting of the body backwards.

The pectoralis descendens muscle acts during the first part of the movement, while the brachiocephalicus and omotransversarius muscles contribute during the entire duration of the movement. The upper extremity of the scapula is fixed in a backwards position by the trapezius (thoracic part) and serratus ventralis thoracis muscles (**5.3, right**).

These muscles work in reverse from a fixed point and mobilize the horse relative to the limb, which is considered fixed. This is a beneficial gymnastic exercise in the development of control and will assist in other exercises. This reversal in movement combined with the full horse body displacement places more stress on the muscles involved in protraction than during forward movements. The muscles discussed above have a determining role during the protraction phase of the stride



▲ **5.3** Protraction of the forelimb. (**Left**) End of protraction of the left forelimb through action of the pectoralis descendens, brachiocephalicus and omotransversarius muscles. Extension of the shoulder joint and advancing of the elbow are primarily due to concentric contraction of the supraspinatus muscle. (**Right**) The brachiocephalicus, omotransversarius and pectoralis descendens muscles work in reverse; they pull the head and neck backwards. BC, brachiocephalicus muscle; OT, omotransversarius muscle; PD, pectoralis descendens muscle; ECR, extensor carpi radialis muscle; T, trapezius muscle; SVT, serratus ventralis thoracis muscle.



▲ **5.4** Retraction of the forelimb. (**Right**) Flexion and backward swing movement of the left forelimb takes place due to contraction of the pectoralis ascendens and latissimus dorsi muscles. Extension of the carpus (knee) facilitates ground contact by the toe. (**Left**) Ground contact. The extensor carpi radialis muscle re-establishes alignment of the forearm and the cannon. The biceps brachii muscle stabilizes the shoulder and elbow. SS, supraspinatus muscle; BB, biceps brachii muscle; ECR, extensor carpi radialis muscle; NL, nuchal ligament; T, trapezius muscle; R, rhomboideus muscle; SC, serratus cervicis muscle; LD, latissimus dorsi muscle; PA, pectoralis ascendens muscle.

and the folding and elevation ('tuck') of the forelimbs during jumping. Rein-back is therefore a useful exercise to improve the power and efficiency of the muscles during these movements.

Extension of the distal limb

Primarily, this involves maintenance of the alignment of the bone segments located beneath the elbow. All the extensor muscles, the most powerful of which is the extensor carpi radialis muscle (**5.3, right**), participate in locking the joints in this position.

RETRACTION OF THE FORELIMB

This movement occurs while the limb is non-weight bearing. The stresses involved with this motion are a lot less than during forward gaits. Although there may be a reduction in the work involved, rein-back requires greater control, thereby training muscles in precise movements. Overall, retraction of the limb is initiated by a backward swing of the entire limb associated with flexion of the joints, finishing with extension of the limb and ground contact (**5.4, left**).

Retraction of the scapulohumeral joint angle

Retraction of the limb determines the overall range of motion of the limb during rein-back. The rhomboideus, trapezius and serratus cervicis muscles pull the upper extremity of the scapula forwards, while at the same time the latissimus dorsi and the pectoralis ascendens muscles pull the humerus backwards (**5.4, right**). Compared with the effort required during forward motion, the biomechanical involvement of these strong muscles is relatively weak. Nevertheless, they are required to perform a precise and defined action that will assist the development of coordinated movements.

Flexion of the forelimb

Synchronous flexion movement of the limb results from the following actions: the deltoideus, teres major and triceps brachii muscles act on the shoulder joint; the biceps brachii muscle acts on the elbow; and the carpal and digital flexor muscles act on the distal limb joints.

Extension of the forelimb

Extension of the forelimb takes place following retraction of the scapulohumeral regions and facilitates placement of the foot during ground contact (**5.4, left**). This action is the result of the supraspinatus (shoulder), triceps (elbow) and carpal and digital extensor muscles. Towards the end of this movement, there is an intense contraction of the extensor carpi radialis muscle. This muscle, which normally mobilizes the limb in forward motion, must instead place and maintain the limb in extension during backward displacement of the horse's body. Rein-back, therefore, helps develop the strength of this muscle, which assists in flexion of the elbow during the tuck of the forelimbs during jumping and stabilizes the carpus at landing and during weight bearing in the regular gaits. It is also important to note that at the beginning of protraction, the angle of the elbow is controlled by active contraction of the biceps brachii muscle, which also has a role in the tuck of the forelimbs over jumps.

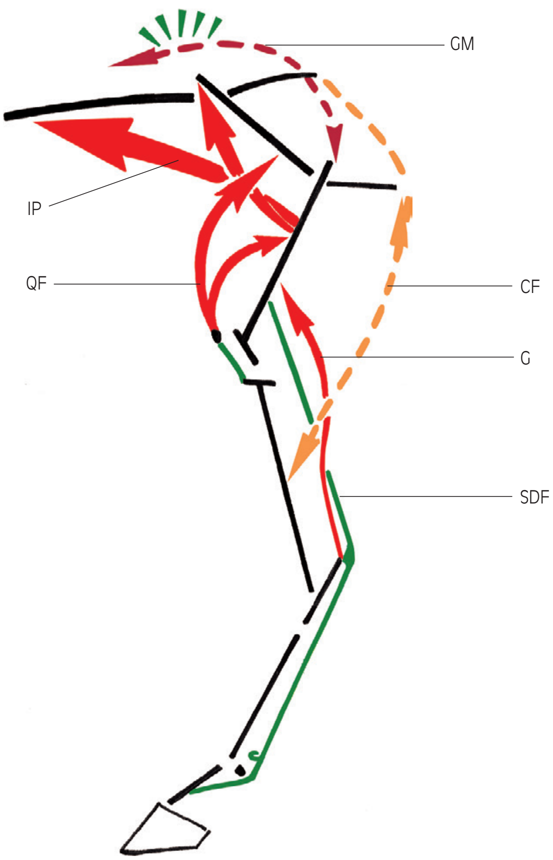
Biomechanics of the hindquarters ❑

The two phases in movement of the hindlimb (protraction and retraction) and their biomechanical actions and advantages will also be looked at from a sporting perspective.

PROTRACTION OF THE HINDLIMB

Protraction is assisted by flexion of the hip and is associated with extension of the stifle and hock (**5.5**).

▲ **5.5** Actions of the diagonal pairs during rein-back. At the end of protraction the right hindlimb is fully engaged and the left forelimb is in full extension. Overall backward movement is continued by engagement of the left hindlimb through the action of the iliopsoas muscle. This pulls the body of the horse backwards.



▲ **5.6** Protraction of the hindlimb. (**Top**) End of protraction of the left hindlimb. Engagement of the limb is due to flexion of the hip and lumbosacral junction by the iliopsoas muscle. Start of protraction of the left forelimb. The extensor carpi radialis muscle extends the carpus. The limb is therefore stabilized and will support and assist the muscles of the forehand to pull the neck backwards. (**Bottom**) In flexing the lumbosacral joint and the hip, the iliopsoas muscle pulls the trunk backwards. This flexion induces lengthening of the gluteus medius muscle. Flexion of the hip and extension of the stifle initiate lengthening of the caudal femoral muscles. IP, iliopsoas muscle; QF, quadriceps femoris muscle; GM, gluteus medius muscle; CF, caudal femoral muscles; G, gastrocnemius muscle; SDF, superficial digital flexor muscle and tendon.

▶ **5.7** Protraction of the hindlimb. (**Left**) Rein-back on an incline. Note the intense engagement of the hindlimbs and lumbosacral flexion. The abdominal wall muscles are weakly involved, thus highlighting that the main agent in this movement is the iliopsoas muscle. (**Right**) End of protraction of the left hindlimb. Contraction of the quadriceps femoris muscle initiates extension of the stifle and pulls the patella upwards.

Flexion of the hip

Flexion of the hip is initiated by the iliopsoas muscles and is assisted by the tensor fascia latae and rectus femoris muscles (**5.1, 5.2, 5.5, 5.6**). In this movement, the role of the psoas major muscle is prominent. It initiates lumbosacral flexion, thus inducing lengthening of the gluteus medius muscle, and assists in engagement of the hind end (**5.5, 5.6**).

One of the main advantages of the rein-back movement is the involvement of the iliopsoas muscle. This muscle promotes ligamentous and muscular flexibility of the entire lumbosacral region. Mobilization of this region is essential from an athletic point of view and is pronounced during the rein-back movement. Due to the change in direction of movement, the workload of the psoas major muscle increases in order to pull the whole body of the horse backwards, whereas during normal forward movement it only moves the limb on the same side as the contraction for assisting hindlimb engagement. Therefore, rein-back is an essential physical exercise for improving the development and strengthening of the psoas major muscle.

Regardless of its advantages, the rein-back movement should only be performed after an adequate warm-up. It is contraindicated in horses recovering from thoracolumbar myositis in order to avoid any additional stress on the inflamed muscles.

The recruitment of the tensor fascia latae muscle and lengthening of the caudal femoral muscles (notably the gluteofemoral muscle) during this phase of rein-back assists in release of the patella in cases of upward fixation (locking). This condition results in a mechanical hyperextension of the limb, thus immobilizing the horse, and can sometimes be confused with thoracolumbar myositis.

Extension of the limb

The muscles acting during this phase of rein-back are the same as those responsible for supporting the limb during the stance phase in normal forward gaits (**5.6, 5.7, right**). The quadriceps femoris muscle maintains extension of the stifle, the gastrocnemius and the superficial digital flexor muscles extend the hock, and the fetlock is supported by the tendinous extensions of the digital flexor muscles and the suspensory ligament. Flexion of the hip and extension of the stifle result in lengthening (stretching) of the caudal femoral muscles.

RETRACTION OF THE HINDLIMB

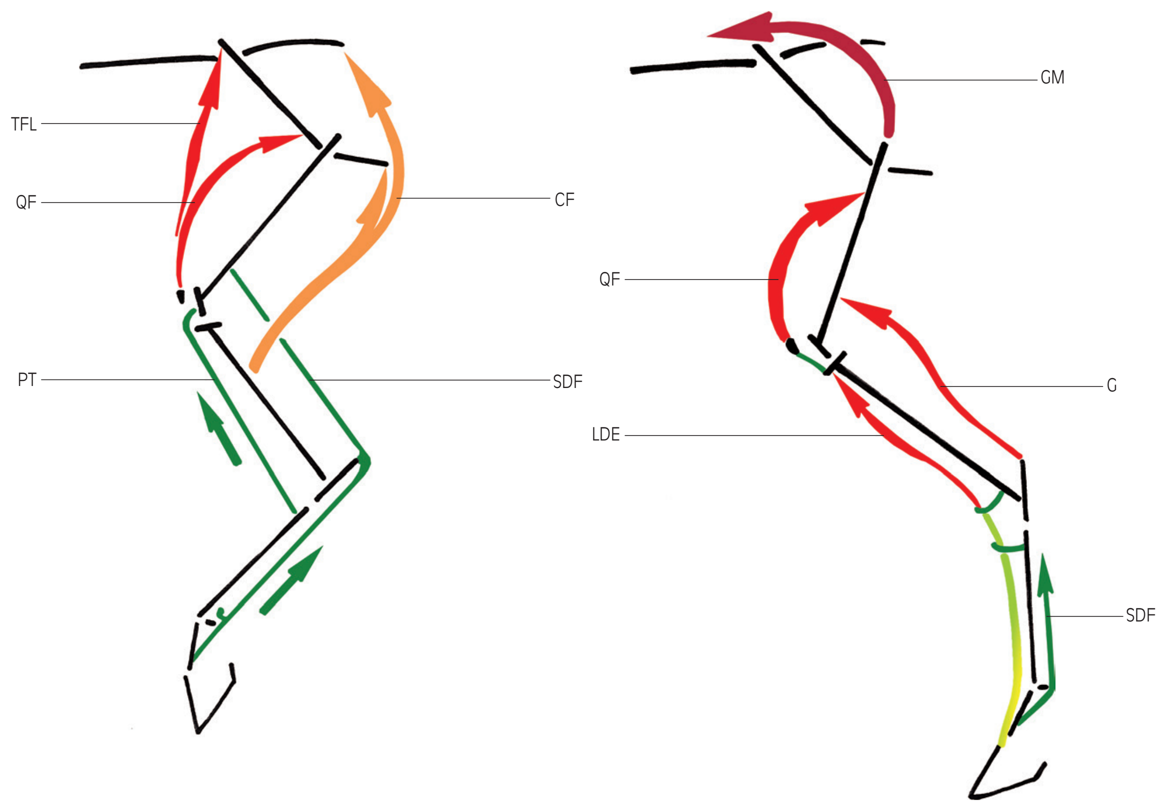
This is a fairly easy movement to understand from a biomechanical perspective. Flexion of the joints precedes extension of the limb towards the rear (**5.7, left, 5.8**).

Flexion of the joints

Flexion of the hip in this movement is due to the actions of the tensor fascia latae and rectus femoris muscles only. The iliopsoas muscle in this circumstance is inactive so as not to oppose the backward movement of the limb. The powerful caudal femoral muscle flexes the stifle and, via the reciprocal apparatus (see Chapter 2, The hindlimb), automatic flexion of the hock and distal limb takes place.

Backward extension

Contraction of the gluteus medius muscle results in an overall backward movement of the limb (**5.7**). The quadriceps femoris muscle extends the stifle, inducing extension of the hock via the reciprocal apparatus.



▲ **5.8** Retraction of the hindlimb. Flexion of the stifle (**Left**) initiated by action of the caudal femoral muscles results in automatic flexion of the hock via the peroneus tertius muscle and flexion of the distal limb joints via the superficial digital flexor tendon. Extension of the hindlimb backwards (**Right**) is initated by the concentric contraction of the gluteus medius (extension of the hip joint), quadriceps femoris (extension of the stifle) and gastrocnemius muscles (extension of the hock). The dorsal digital extensor muscle extends the foot and prevents flexion of the digital joints. TFL, tensor fascia latae muscle; QF, quadriceps femoris muscle; PT, peroneus tertius muscle; CF, caudal femoral muscles; SDF, superficial digital flexor muscles and tendon; LDE, long digital extensor muscle and tendon; GM, gluteus medius muscle; G, gastrocnemius muscle.

The gastrocnemius muscle assists in extension of the hock, while the digital extensor muscles extend the phalanges and facilitate ground contact with the toe.

From a biomechanical perspective, the major difficulty involved with this movement is extension of the fetlock and phalanges while there is simultaneous flexion of the stifle and hock. Effectively, flexion of the stifle has a tendency to spontaneously flex the joints of the lower limb (see Chapter 2, The hindlimb), a force that the extensor muscles must counter. Therefore, the rein-back movement can be used as a re-education tool for the digital extensor muscles following trauma to the front of the hock and leg, which is a quite common occurrence.

Another difficulty in this movement is the absence of visual control by the horse. It must therefore rely on proprioceptive control of the limbs. Development of proprioceptive control refines the precision of hindlimb movements.

Conclusion

Rein-back presents several advantages from a neurological, biomechanical and preventive perspective. It forces the horse to become more aware of the positioning and displacement of the different parts of its body and results in development of coordination through a complete reorganization of synergistic muscular actions and sequences. From a biomechanical perspective, this movement develops the strength of the iliopsoas muscle and the flexibility of the lumbosacral region, two essential components in engagement of the hind end. It also assists in strengthening the forelimbs at landing following jumps. In the carriage horse, it physically prepares the horse for slowing down and braking movements.

All these advantages are possible because the movement is slow and, therefore, produces limited biomechanical stress. Therefore, rational use of this exercise (after warming up and without excess) may benefit a lot of horses competing in different disciplines. The only contraindication to its use is in horses suffering recent bouts of thoracolumbar muscular inflammation.

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PART 3:

Biomechanical analysis of lateral movements

CHAPTER

6 The forelimbs

The exercises that will be analysed in this chapter involve some of the most technical concepts from a biomechanical perspective. They have several advantages from a sporting perspective; they provide equilibrium and flexibility to the shoulder and hip and work the adductor as well as the abductor muscles. However, the functional anatomy and sequence of locomotor events that take place are often poorly understood.

In order to understand and assimilate these elements during the physical preparation of the horse, it is necessary to revisit the primary muscle groups involved. Next, an analysis of simple movements, such as half pass (**6.1**) and shoulder-in at a trot, can be undertaken. As mentioned above, the objective of this chapter is to improve our understanding of movement and thus be able to select exercises that are advantageous rather than detrimental to the preparation of the athlete horse. Only the biomechanics of the forelimbs will be analysed in this chapter. The biomechanics of the hindlimbs and the vertebral column during lateral movements will be discussed in the following chapters.

▲ **6.1** Half pass to the right at a trot. Abduction of the forelimbs results in lengthening of the pectoral muscles, while adduction of the hindlimbs is achieved through concentric contraction of the iliopsoas and medial femoral muscles.

Muscular groups and joints

Displacement of the body in a transverse plane is the result of lateral motion of the limbs. When a limb moves towards the median plane (or opposite limb) it is called adduction, when a limb moves towards the exterior it is called abduction.

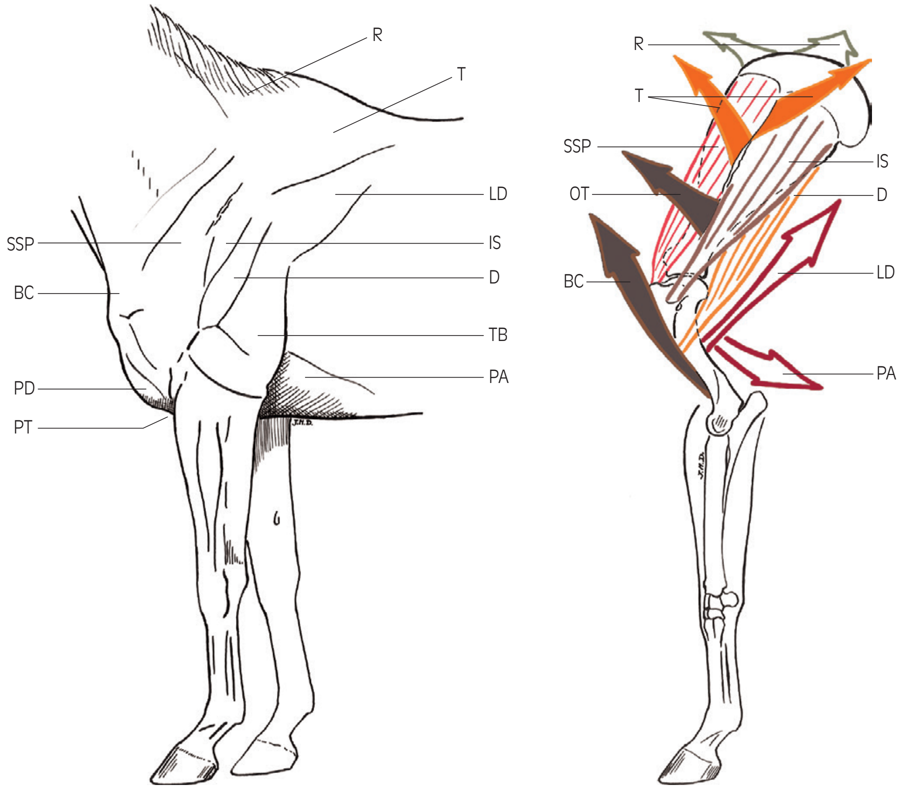
This action is only possible in the horse through the most proximal joints of the limbs: the shoulder (scapulohumeral) joint in the forelimb and the hip (coxofemoral) joint in the hindlimb. In both of these joints, lateral movements are accompanied by a simultaneous rotation within the joint. The joints located below the shoulder and hip (elbow and carpus in the forelimb and stifle and hock in the hindlimb) can only undergo flexion and extension movements. Lateral movement is not possible in these more distal joints because of the shape of the articular surfaces and the strong ligamentous attachments either side of the joint.

During lateral movements, only the muscles capable of mobilizing the shoulder or the hip in a lateral motion are elicited. Thus, adductors and abductors can become conditioned and supple during these exercises and their actions become coordinated. The fact that these muscles are mentioned again in this chapter highlights their importance.

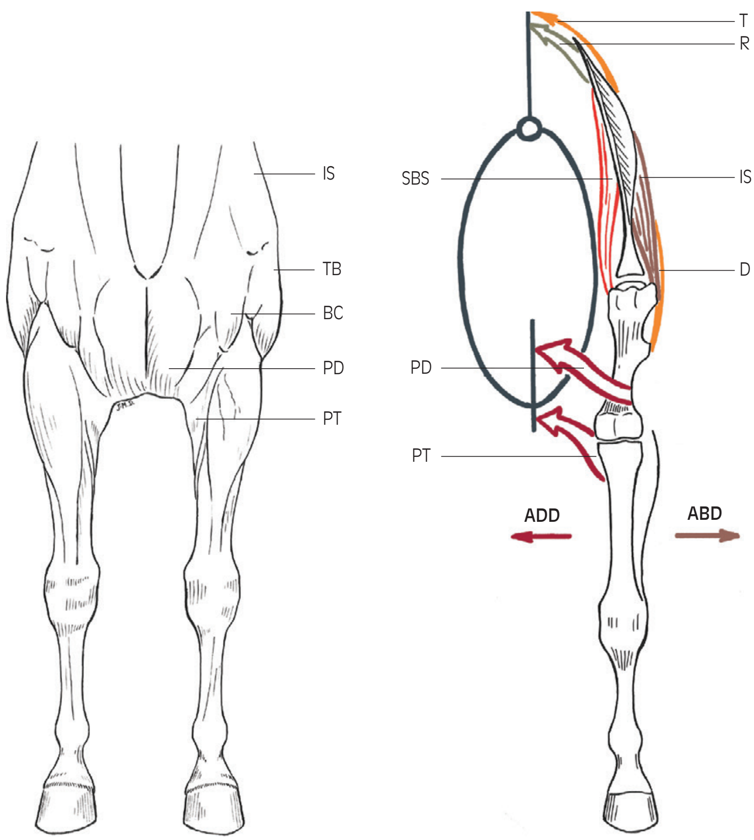
ABDUCTORS AND ADDUCTORS OF THE FORELIMB (6.2, 6.3)

Abductor muscles

Action of the abductor muscles results in movement of the limb away from the midline. There are four muscles that contribute to abduction. The trapezius and rhomboideus muscles pull the upper border of the scapula towards the midline, making the lower extremity swing laterally. The other two muscles, the deltoideus muscle



▶ **6.2** Muscles of the forearm involved in lateral movements (lateral view). Adductors: PD, pectoralis descendens muscle; PT, pectoralis transversus muscle; PA, pectoralis ascendens muscle. Abductors: IS, infraspinatus muscle; D, deltoideus muscle; R, rhomboideus muscle; T, trapezius muscle. Propulsion: PA, pectoralis ascendens muscle; LD, latissimus dorsi muscle; TB, triceps brachii muscle. Protraction (responsible for the cranial part of the swing phase): BC, brachiocephalicus muscle; OT, omotransversarius muscle; SSP, supraspinatus muscle.



▶ **6.3** Muscles of the forearm involved in lateral movements (cranial view). Adductors: PD, pectoralis descendens muscle; PT, pectoralis transversus muscle; SBS, subscapularis muscle. Abductors: IS, infraspinatus muscle; D, deltoideus muscle; R, rhomboideus muscle; T, trapezius muscle. Protractors: BC, brachiocephalicus muscle; TB, triceps brachii.

and the infraspinatus muscle, attach on the scapula and insert on the lateral aspect of the humerus. Their role is to induce a lateral deviation (and mild lateral rotation) of the humerus.

Adductor muscles

The adductor muscles are more efficient than the abductors due to their location, strength and insertions. The pectoralis descendens and transversus muscles extend between the sternum and the lower extremity of the humerus and upper arm. The third adductor, the subscapularis muscle, is less active and is located on the deep surface of the scapula.

During the propulsion phase of the stride it is difficult for the limb to be placed in adduction because of the shape of the thorax and its close apposition to the scapula. Therefore, in this phase of the stride, adduction is only achieved through ventral displacement and rotational movement of the humerus. This results in the point of the shoulder joint being lowered, bringing the elbow against the body. Therefore, the limb becomes angled towards the midline.

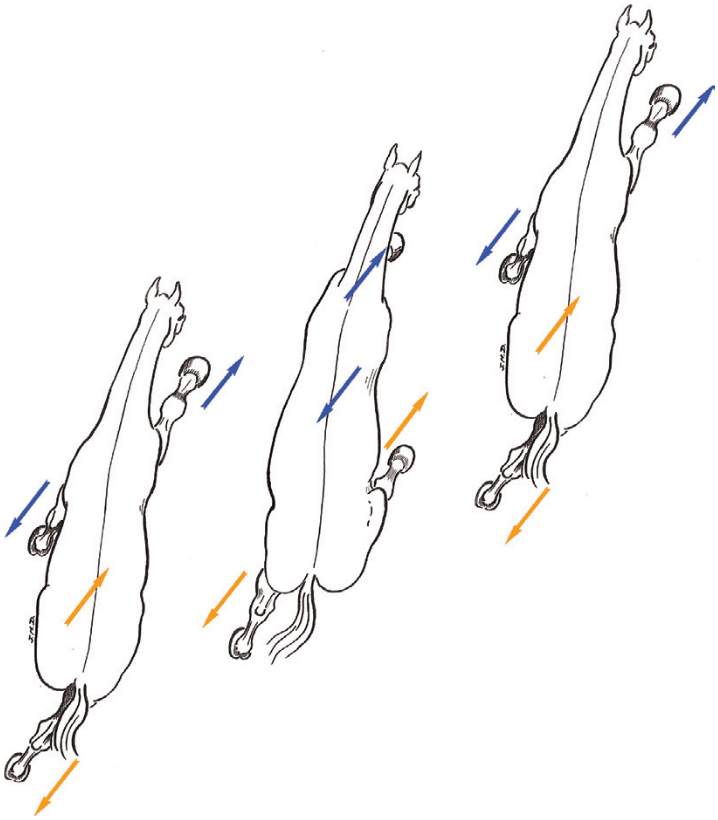
Kinesiological analysis of the forelimbs during lateral movements

Having covered the structures involved in lateral movements, the half pass and shoulder-in exercises will be analysed separately. Other lateral movements (turn on the forehand, turn on the haunches and pirouettes) involve the same fundamental musculoskeletal actions but in different gymnastic exercises and combinations.

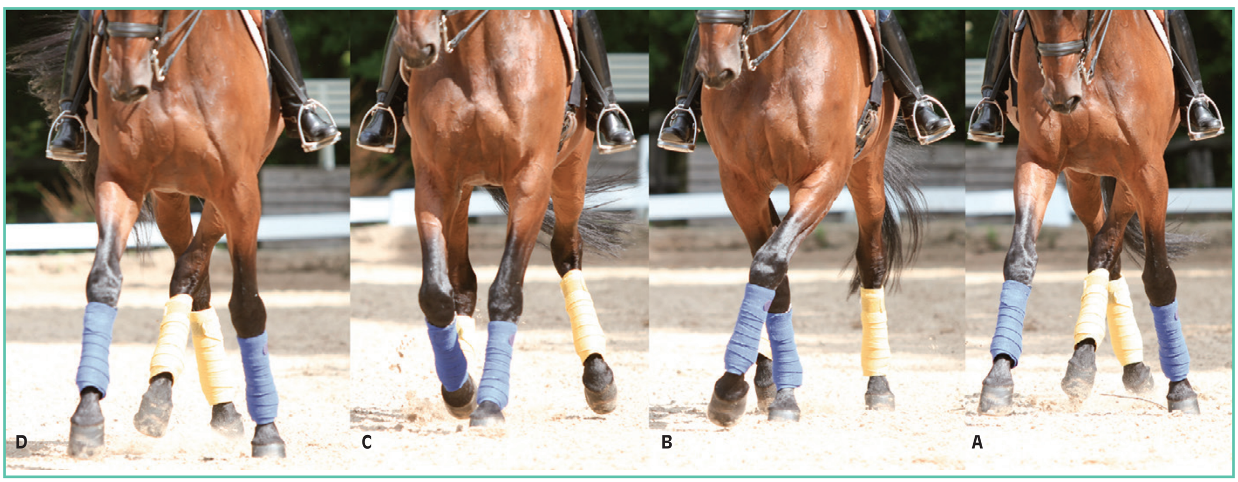
During lateral movements at a walk or trot, two phases in particular can be identified (**6.4, 6.5**):

- During the abduction (opening) phase, the limb situated on the side to which the lateral movement is occurring shifts away from the median plane. At the same time, the weight-bearing limb pushes away from the median plane and displaces the body of the horse in the direction of the lateral movement.
- During the adduction (crossing) phase, the limb located on the side to which the movement is occurring is weight bearing and pulls the body of the horse in that direction. The opposite limb is non-weight bearing and crosses in front of the leading leg during protraction (initiating ground contact).

In each of these cases, the musculoskeletal actions are particular and specific to the resulting movement.



◀ **6.4** Direction of movement of the limbs during a right half pass at a trot (dorsal view).



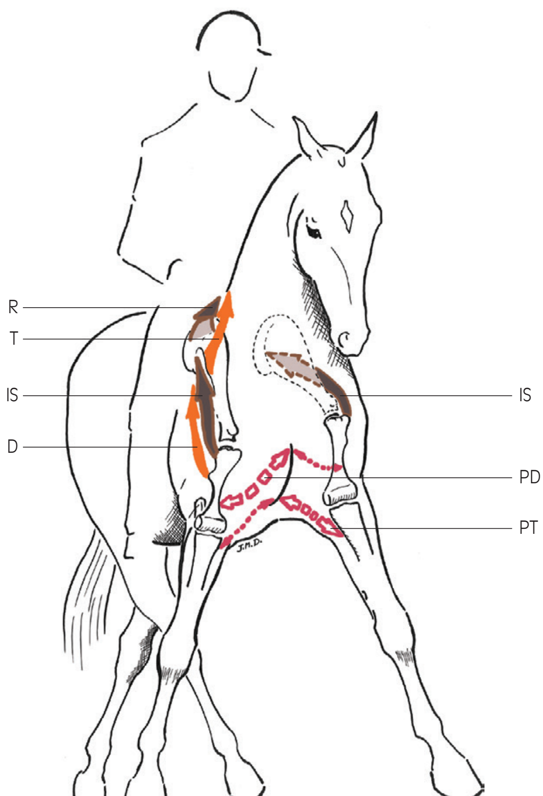
▲ **6.5A–D** Right half pass at a trot. Left forelimb. **6.5A, 6.5B**: the left forelimb is adducted during the swing (non-weight-bearing) phase following concentric contraction of the pectoralis descendens and transversus muscles; **6.5C, 6.5D**: abduction of the left forelimb by the deltoideus and infraspinatus muscles during the weight-bearing phase continues the movement of the horse to the right. Right forelimb. **6.5B**: the right forelimb is weight bearing and undergoes adduction through action of the pectoralis ascendens muscle; **6.5C, 6.5D**: the right forelimb abducts following action of the infraspinatus muscle.

ABDUCTION (OPENING) PHASE (6.5–6.8)

Abduction of the non-weight-bearing forelimb on the side to which the movement is occurring is a result of concentric contraction (shortening) of the trapezius and rhomboideus muscles, which originate from the upper aspect of the scapula and shift the lower extremity of this bone laterally. This contraction is accompanied by activation of the deltoideus and infraspinatus muscles, which initiate a lateral movement and external rotation of the humerus. The distal aspect of the limb is guided by the lateral motion of the upper limb. The degree of movement is dependent on the suppleness and lengthening of the pectoralis muscles, in particular the pectoralis descendens and pectoralis transversus muscles.

Abduction of the weight-bearing forelimb results in a continuation of the lateral motion of the forehand (**6.6–6.8**). This is due to the same muscular actions as described above, although it is primarily the cervical parts of the trapezius and rhomboideus muscles that contract. The most active contribution, however, comes from contraction of the deltoideus and infraspinatus muscles. The external rotational effect of these muscles on the humerus is balanced by a powerful internal pull of the ascending pectoral and longissimus dorsi muscles, which facilitates propulsion. This movement induces a strong elongation of the adductor muscles (pectoralis descendens and transversus).

Abduction of the forelimbs during lateral movements therefore promotes the development of muscles located on the lateral aspect of the shoulder and withers (infraspinatus, deltoideus, trapezius and rhomboideus muscles) and induces lengthening and suppleness of the pectoral muscles (in particular the pectoralis descendens and transversus muscles).



▲ **6.7** Left half pass at a trot. Abduction of the left forelimb is initiated by concentric contraction of the infraspinatus and deltoideus muscles. Contraction of the supraspinatus muscle opens the shoulder.

◀ **6.6** Muscular actions during abduction of the forelimbs. Abductors undergoing concentric contraction: IS, infraspinatus muscle; D, deltoideus muscle; R, rhomboideus muscle; T, trapezius muscle. Adductors undergoing lengthening: PD, pectoralis descendens muscle; PT, pectoralis transversus muscle.

As the work done by the same muscles on either side of the horse is not identical during lateral movements, symmetrical training and education of these muscle groups must be made by combining left and right lateral movements.

Lengthening of the pectoral muscles facilitates independent activity of the forelimbs relative to the thorax and contributes to an increase in the length of the stride (**6.9**).

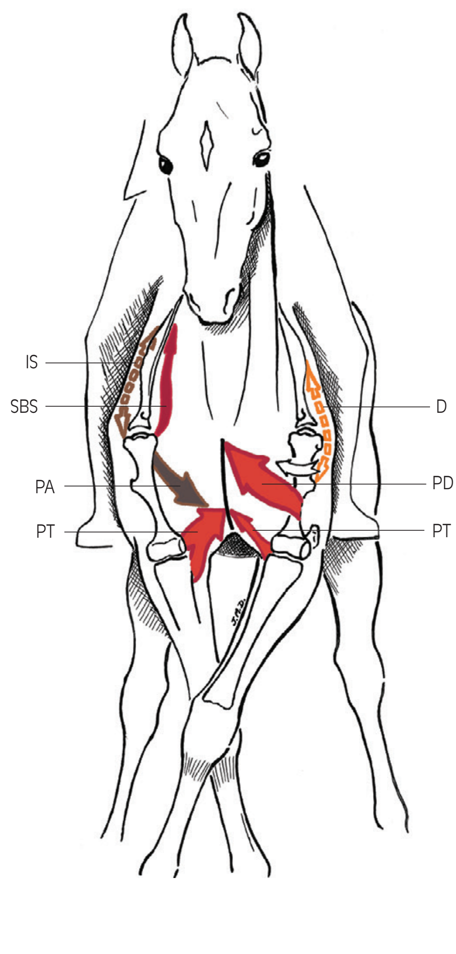
▲ **6.8** Half pass to the left at a trot. Abduction (opening) of the forelimbs results in lengthening of the pectoralis descendens and transversus muscles (left and right) and the right brachiocephalicus muscle. Adduction (crossing) of the hindlimbs is a result of concentric contraction of the adductor, pectineus and semimembranosus muscles. 1, pectoralis transversus muscle; 2, pectoralis descendens muscle; 3, brachiocephalicus muscle.

◀ **6.9** Suspension phase during an extended trot. The length of the stride depends on the suppleness and elongation capacity of the pectoral muscles. Flexibility is improved through exercises involving lateral movements, particularly abduction.

ADDUCTION (CROSSING) PHASE (6.10, 6.11)
Adduction of the non-weight-bearing limb opposite to the direction of the lateral movement results from a dynamic concentric contraction of the transverse pectoral muscle and, to a larger extent, the pectoral descendens muscle. These muscle contractions also cause internal rotation of the humerus, which contributes to the degree that the forelimbs cross and movement amplitude. Humeral rotation is coupled with protraction of the limb and results in lengthening of the deltoideus, infraspinatus and triceps brachii muscles.

Adduction of the limb on the same side that the movement is occurring during the weight-bearing phase of the stride is made possible through concentric contraction of the transverse pectoral muscles in conjunction with contraction of the pectoralis ascendens and latissimus dorsi muscles, which are major contributors to propulsion of the forelimbs. The subscapularis muscle also contributes to adduction at the level of the scapulohumeral (shoulder) joint. Adduction results in lengthening of the deltoideus and infraspinatus muscles.

Adduction and crossing of the forelimbs during lateral movements requires intense concentric contraction of the transverse and pectoral descendens muscles. Strengthening of these muscles prepares the horse for undertaking more complex movements such as the pirouette (**6.12**). Contraction of the pectoral muscles also facilitates the 'tuck up' of the forelimbs over a jump (**6.13**). During this movement, flexion of the knee (carpus) and elbow is a result of the action of the flexor muscles (primarily the biceps brachii muscle). Elevation of the humerus (arm) and shoulder is achieved through intense contraction of the pectoralis descendens muscle. Internal rotation of the humerus is achieved simultaneously due to the insertion of the pectoralis descendens muscle, which also acts to bring the distal extremities of the limbs closer together (as can be seen in **6.13**). Finally, adduction of the forelimbs during lateral movements results in lengthening of the deltoideus and triceps brachii muscles, which is necessary for opening of the joint angles prior to landing after a jump (**6.14**).



▶ **6.10** Muscular actions during adduction of the forelimbs. Adductors undergoing concentric contraction: PD, pectoralis descendens muscle; PT, pectoralis transversus muscle; PA, pectoralis ascendens muscle; SBS, subscapularis muscle. Abductors undergoing lengthening: IS, infraspinatus muscle; D, deltoideus muscle.

▲ **6.11** Half pass to the right at a trot. Adduction of the forelimbs through strong concentric contraction (shortening) of the pectoralis descendens and transversus muscles. Note the lengthening of the abductors (deltoideus and infraspinatus muscles) at the lateral aspect of the left shoulder.

▲ **6.12** Adduction of the forelimbs during a pirouette. Note the intense concentric contraction of the pectoralis descendens muscles.

▲ **6.13** 'Tuck up' and adduction of the forelimbs over a jump. These two movements take place because of maximal concentric contraction of the pectoralis descendens muscles.

▲ **6.14** Extension of the forelimbs when preparing for landing following a jump. Note the lengthening of the deltoideus and triceps brachii muscles.

Summary

In this chapter it has been shown that lateral movements are an excellent basic exercise, where variations in lengthening (concentric–eccentric contractions) promote development and flexibility of the lateral shoulder and pectoral muscles. Activation of these muscles allows execution of specific and complicated movements such as the 'tuck up' of the forelimbs over a jump or a pirouette. Lateral movements are a dynamic expression of a combination of collateral movements (adduction–abduction) and rotation, which take place primarily in the shoulder joint (scapulohumeral joint).

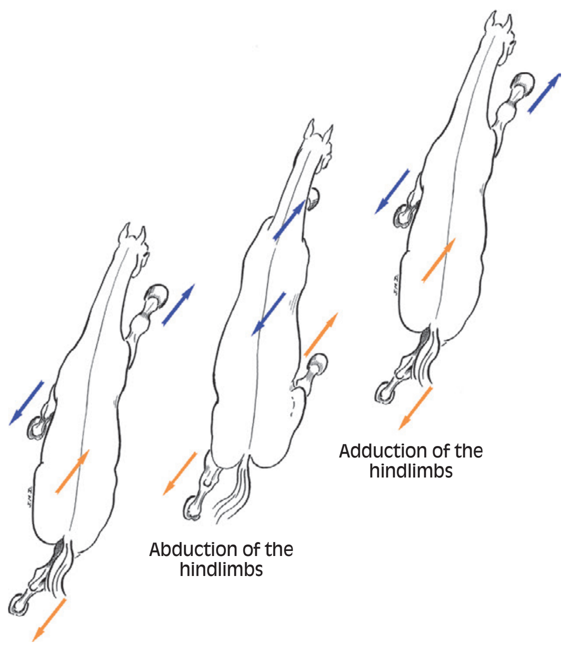
7 The hindlimbs

Lateral movement exercises train the horse to develop and diversify normal movements in the hindlimbs. This is made possible by angle displacement of the joints and muscular actions mobilizing the limbs away from an anteroposterior plane (from front to back). Lateral movements encourage mobility and equilibrium of the horse in all directions.

Muscular groups and joints

Lateral movements are the result of voluntary action of the limbs. As described in Chapter 6 (The forelimbs), movement of a limb towards the median plane is known as adduction, while movement away from the midline is called abduction (**7.1, 7.2**).

◀ **7.1** Half pass to the right at a walk. (**Left**) Marked adduction of the hindlimbs with the left hindlimb fully engaged and the right hindlimb undergoing propulsion. (**Right**) Abduction of the left hindlimb contributing to propulsion and protraction (engagement) of the right hindlimb.



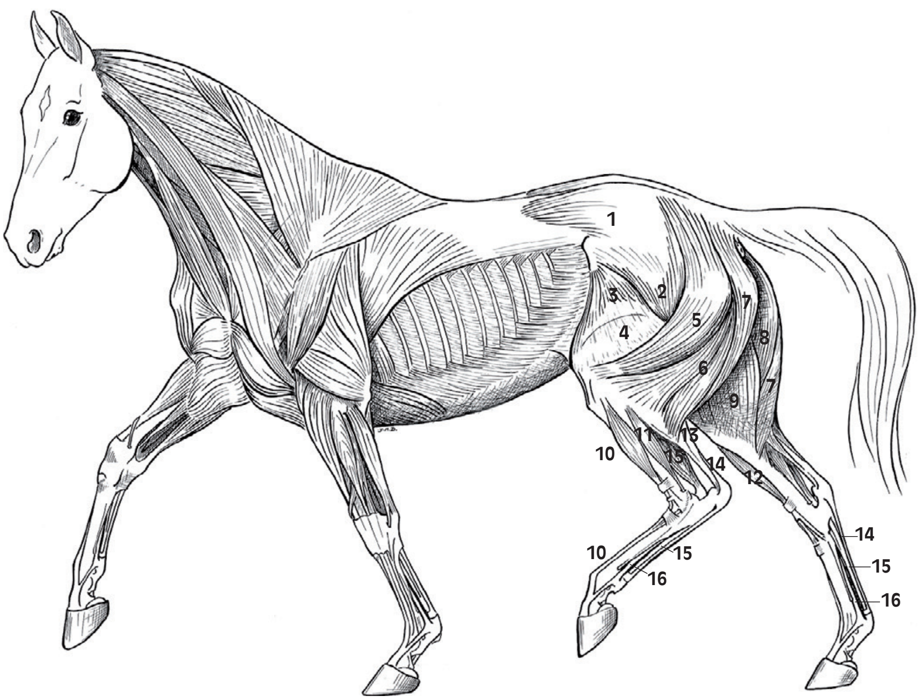
◀ **7.2** Abduction and adduction of the hindlimbs during lateral movements (shown: half pass to the right at a trot).

Lateral movements in the hindlimb are only possible through the hip joint. The lower joints (stifle and hock) can only execute flexion and extension movements and do not allow for any active lateral motion (abduction or adduction). This is due to the shape of their articular surfaces and the strong collateral ligaments located either side of the joint. Therefore, only muscles that have the capacity to mobilize the hip joint in a lateral or medial motion are activated during lateral movement exercises. These adductor and abductor muscles belong to either the pelvis or the thigh (**7.3**). They are the muscles that are educated, developed and stretched during lateral movements.

ABDUCTORS AND ADDUCTORS OF THE HINDLIMB (7.3, 7.4)

Abductor muscles

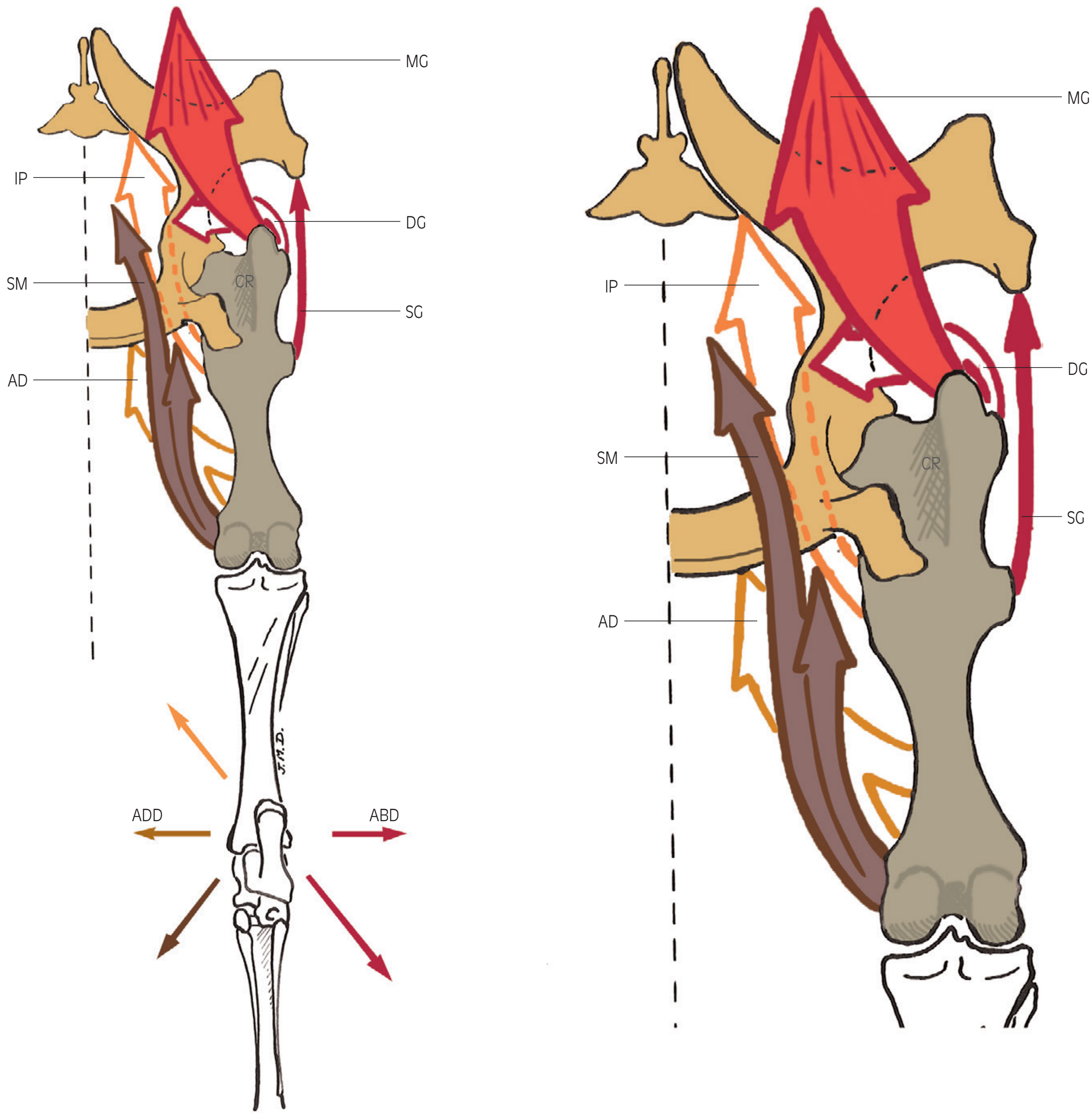
The abductor muscles are comprised essentially of the gluteal muscle group, the most powerful of which is the middle gluteal muscle, which acts mostly during propulsion. Action of this muscle on the trochanteric lever arm results in deviation of the lower extremity of the femur and, therefore, the rest of the limb, away from the midline of the horse. This action is most marked during the propulsion phase of the stride. The deep gluteal muscle, although less powerful than the middle gluteal muscle, is the most specialized muscle involved in abduction of the limb. It also acts on the greater trochanteric lever during protraction (engagement) of the limb.



▲ **7.3** Pelvic and hindlimb muscles. Abductor muscles: 1, middle gluteal muscle; 2, superficial gluteal muscle; 5, gluteofemoral muscle; 6, biceps femoris muscle (5 + 6 = gluteobiceps muscle). Adductor muscles: 8, semimembranosus muscle; 9, gracilis and adductor muscles. Cranial femoral muscles: 3, tensor fascia latae muscle; 4, quadriceps femoris muscle. Caudal femoral muscle: 7, semitendinosus muscle. Cranial crural muscles: 10, long digital extensor muscle; 11, lateral digital extensor muscle; 12, tibialis cranialis muscle. Caudal crural muscles: 13, gastrocnemius muscle; 14, superficial digital flexor muscle and tendon; 15, lateral digital flexor muscle, major contributor to the deep digital flexor tendon (15′). Muscles and tendons of the metatarsus and digit: 14, superficial digital flexor tendon; 15′, deep digital flexor tendon; 16, suspensory ligament (3rd interosseous muscle).

Adductor muscles

The adductor muscles are numerous and are located at the medial aspect of the thigh. Contraction of these muscles results in the femur being pulled towards the midline of the horse. The adductor magnus muscle acts during all phases of the stride. The semimembranosus muscle adducts the limb during propulsion, while the pectineus and iliopsoas muscles adduct the limb during engagement.



▲ **7.4** Abductors and adductors of the hindlimb. Abductor muscles (ABD): MG, middle gluteal muscle; DG, deep gluteal muscle; SG, superficial gluteal muscle. Adductor muscles (ADD): IP, iliopsoas muscle; SM, semimembranosus muscle (two heads of origin: from the ischium and sacrum); AD, adductor (two heads of origin: magnus and brevis). CR, centre of rotation of the femoral head.

Kinesiological analysis of the hindlimbs during lateral movements

Two principal phases can be identified in this movement at a walk or trot (**7.1, 7.2**):

- During the abduction (opening) phase the hindlimb located on the side to which the movement is occurring is non-weight bearing and deviates from the median plane. Abduction of the limb which is weight bearing pushes it away from the median plane, shifting the body of the horse in the direction of the lateral movement.
- During the adduction (crossing) phase the hindlimb on the side to which the movement is occurring is weight bearing and its adduction pulls the body of the horse in the direction of the lateral movement. The opposite limb is non-weight bearing and crosses in front of the leading leg to achieve engagement before contacting the ground. At a canter (**7.5**), adduction of the hindlimbs takes place during propulsion by the leading leg (the non-leading leg undergoing protraction) and abduction takes place during propulsion of the non-leading limb while the leading limb achieves protraction.

The muscular actions required for each of these phases is specific for the desired movement.

These two opposing phases, which result in alternating movement of the hindlimbs (separation of the limbs during abduction and crossing of the limbs during adduction), will now be considered. As previously discussed (see Chapter 2, The hindlimb), lateral movement in the hind end is made possible exclusively by the coxofemoral (hip) joint. Movement of the lower parts of the limb is guided by the orientation of the femur. The stifle and the hock do not allow for any active rotational or lateroflexion movements.

ABDUCTION (OPENING) PHASE (7.6)

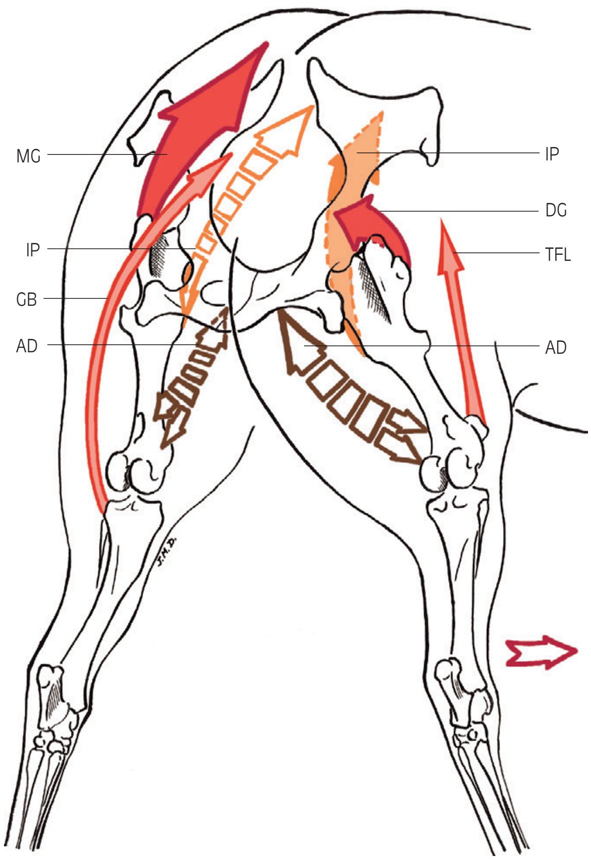
In horses, separation of the hindlimbs and abduction (opening) of the coxofemoral joint are limited by the accessory ligament of the hip, which prevents horses from swiping sideways (cow kick) and channels kicking movements towards the rear. Nevertheless, this ligament allows for some degree of abduction through the action of various muscles during lateral movement.

◀ **7.5** Half pass to the right at a canter. (**Left**) Marked adduction of the hindlimbs at the start of the non-weight-bearing phase of the stride. (**Right**) Abduction during engagement (protraction) of the right hindlimb (leading leg). Note the lengthening of the caudal femoral muscles. The left hindlimb is achieving a coupled abduction and propulsion movement because of the action of the gluteal muscles.

Abduction of the limb in the direction of the lateral movement (leading leg) occurs during the non-weight-bearing phase and is made possible by concentric contraction (shortening) of the tensor fascia latae muscle and the deep gluteal muscle. Simultaneous contraction of the iliopsoas muscle results in engagement of the limb. This also induces external rotation of the femur and, therefore, the stifle, thus placing the semimembranosus muscle under tension. The magnitude of this movement depends on the ability of the adductor muscles to lengthen.

Abduction of the weight-bearing hindlimb opposite to the direction of the lateral movement (non-leading leg) results in propulsion. The combination of these two movements is made possible by the powerful action of the middle gluteal muscle. This muscle acts through the trochanteric lever, directing the greater trochanter forwards and towards the midline. This force occurs above the centre of rotation of the hip and pushes the stifle backwards and away from the midline. The gluteofemoral and deep gluteal muscles also contribute to this movement.

The backward and lateral movement of the lower extremity of the femur activates lengthening of the adductor, iliopsoas and pectineus muscles located at the internal aspect of the thigh.



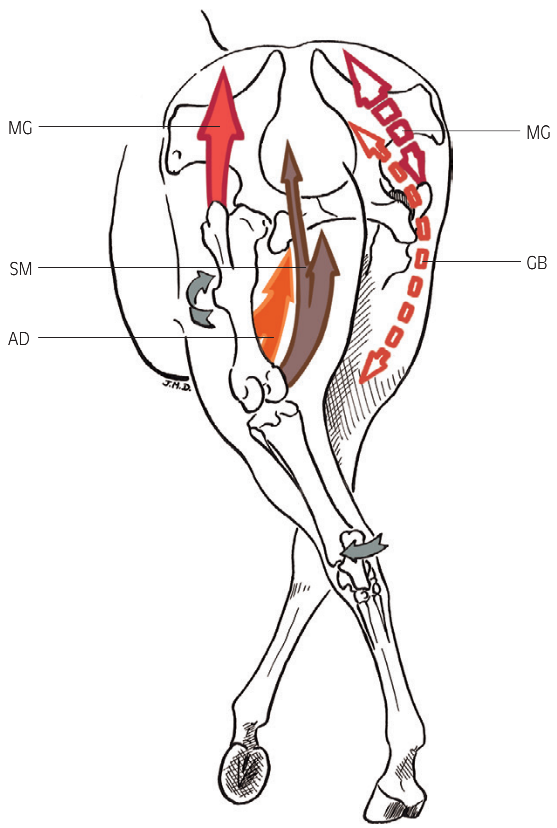
▲ **7.6** Abduction of the hindlimbs during a half pass movement to the right at a trot. Abductors undergoing concentric contraction: MG, middle gluteal muscle; DG, deep gluteal muscle; GB, gluteobiceps muscle. Adductors undergoing lengthening: IP, iliopsoas muscle; AD adductor (magnus and brevis) muscles. Muscles inducing protraction of the right hindlimb: IP, right iliopsoas muscle; TFL, tensor fascia latae muscle.

ADDUCTION (CROSSING) PHASE (7.7–7.9)

This movement is made possible not only through the action of adductor muscles but also through other muscle groups, which may be antagonistic depending on the limb being considered.

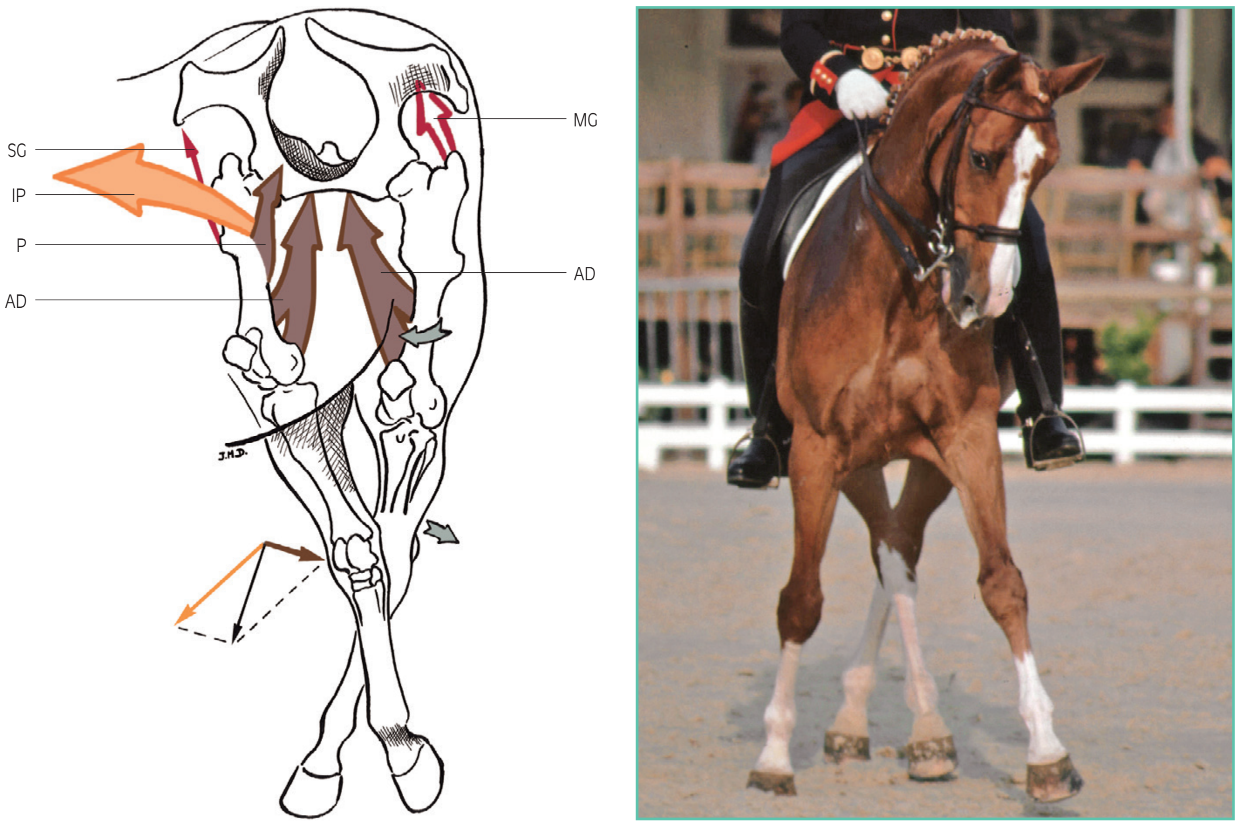
Adduction and therefore engagement of the hindlimb opposite to the direction of the lateral movement (non-leading leg) takes place during the non-weight-bearing phase of the stride. These movements are a result of concentric and synchronous contraction of the iliopsoas muscle (mostly responsible for engaging the limb) and the adductor and pectineus muscles, causing the limb to deviate medially. This stimulates lengthening of the middle and deep gluteal muscles as well as the gluteobiceps muscle group.

Adduction of the weight-bearing hindlimb on the side to which the lateral movement is occurring (leading leg) requires the action of antagonistic muscles. Effectively, extension of the hip and propulsion of the limb are the results of action of the middle gluteal muscle, which has been previously described as an abductor. Medial deviation of the limb is also a result of contraction of the adductors of the thigh and the semimembranosus muscle. Contraction of these muscles results in internal rotation of the femur and, therefore, a lateral deviation of the point of the hock. The orientation of the femur relative to the pelvis induces lengthening of the deep gluteal muscles as well as the tensor fascia latae muscle.



▲ **7.7** Adduction of the hindlimbs during a half pass movement to the left at a trot. Adductors undergoing concentric contraction: AD, adductor (magnus and brevis) muscles; SM, semimembranosus muscle. Abductors undergoing lengthening: MG, middle gluteal muscle; GB, gluteobiceps muscle. Note the internal (medial) rotation of the femur as a result of contraction of the semimembranosus muscle, inducing an external (lateral) rotation of the point of the hock.

7.8 Adduction and engagement of the non-leading leg (right hindlimb [**left**] and left hindlimb [**right**]). Adduction is initiated by the iliopsoas muscle, which pulls the internal aspect of the femur forwards, resulting in lateral (external) rotation of the limb (the toe and stifle are rotated towards the exterior, the point of the hock towards the interior).



7.9 Adduction of the hindlimbs during a half pass movement to the left at a trot. Adductors undergoing concentric contraction: AD, adductor (magnus and brevis) muscles; IP, iliopsoas muscle; P, pectineus muscle. Abductors undergoing lengthening: MG, middle gluteal muscle. Muscles contributing to protraction (engagement) of the right hindlimb: IP, iliopsoas muscle; P, pectineus muscle; SG, superficial gluteal muscle.

Crossing of the hindlimbs requires involvement of symmetrical muscles (adductors) in both limbs, but it also results in concentric contraction or lengthening of different muscles depending on the limb. The horse must therefore work alternately to the left and to the right to develop its muscles harmoniously and improve the proprioceptive control of its locomotion. For example, during protraction of the non-weight-bearing limb (non-leading leg), flexion and external rotation of the femur initiates lengthening of the middle gluteal muscle, while on the weight-bearing limb (leading leg) the tensor fascia latae muscle undergoes maximal lengthening.

For a particular gait at a given speed, muscular lengthening is far greater during lateral movements than during work in a straight line.

Lateral movements are beneficial in the development of the range of motion allowed by the coxofemoral (hip) joint, which guides the whole limb during movement. This joint is fundamental from a locomotor point of view and can be illustrated by a simple test. Take the hindlimb of a horse and pull it forwards then backwards. It will soon be appreciated (on a cooperative and healthy horse) that what limits the overall range of motion of this limb is not flexion or extension of the hock or stifle, but of the hip. The hock and stifle depend on the ability of the gluteal, caudal femoral and tensor fascia latae muscles to lengthen. Therefore, by inducing wide variations in muscle length, lateral movements improve elasticity and regulation of muscular tone, thus conferring a greater range of motion on the hip itself.

Moreover, by using opposing muscular actions (gluteals and adductors), these exercises refine the voluntary control of muscle groups, improving coordination of basic movements. From a sporting perspective this means that the ease of the gait improves. From a pathophysiological point of view, proprioceptive control of movement is intensified, reducing the risk of 'incorrect movements' that may contribute to locomotor problems. Finally, development of supporting muscles around joints (deep gluteal and pectineus muscles, for example) improves the support and stability of the coxofemoral joint, whose ligamentous apparatus is reduced to one structure – the ligament of the head of the femur and its branch (the accessory ligament). In the athlete horse, this muscular stabilization of the joint has an essential role in prevention, and possibly even in the supportive treatment, of joint disease (ligamentous and cartilaginous).

Conclusion

As discussed at the beginning of this chapter, lateral movements present several advantages from a sporting and gymnastic perspective. They improve coordination and proprioceptive control of movements through simultaneous muscular actions that are sometimes antagonistic. They are an excellent gymnastic exercise for the shoulder (scapulohumeral) and hip (coxofemoral) joints as well as their mobilizing structures. The muscles involved become conditioned, improving the scope and range of movement in the different gaits.

Finally, the work of certain muscles results in improvement of specific movements. For example, the action of the pectoral descendens muscle in lateral movements is replicated during jumping. It undergoes an intense concentric contraction required to 'tuck up' the forelimbs in order to clear a jump. Similarly, elongation of the middle gluteal and semimembranosus muscles facilitates landing of the hindlimbs at reception after a jump.

8 The vertebral column and trunk muscles

Having described the work of the fore- and hindlimbs during lateral movements and the advantages this confers, the biomechanics of the trunk during lateral movements will now be discussed.

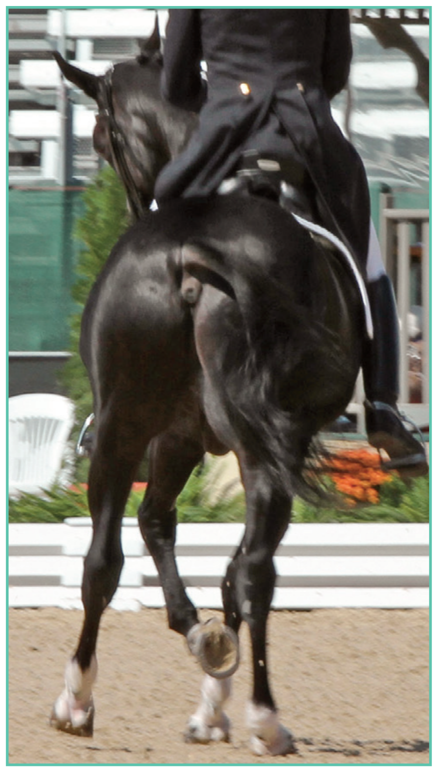
The main differences between the two basic exercises, half pass and shoulder-in, will be evaluated in Chapter 9. The stresses imposed on the limbs during these exercises will be highlighted in order to improve the selection of exercises (or to limit their use) based on the strengths and weaknesses of the horse.

The biomechanics of the trunk is complicated to analyse because of the small range of movement in this region, the large number of joints involved (32 intervertebral joints from the head to the sacrum) and a certain functional independence seen in some vertebral segments. Despite this, it is still worth discussing in order to better understand these lateral movements and their benefits from a sporting perspective.

The biomechanics of the vertebral column varies considerably depending on the gait (walk, trot or canter, **8.1, 8.2**). To simplify the discussion, analysis will be limited to work at a trot. This gait is relatively easy to study and will highlight some of the functional changes that occur at the level of the trunk.

To understand the vertebral changes that occur during lateral movements at a trot, it is necessary to discuss the basic vertebral biomechanics at a trot on a single track.

▲ **8.1** Marked rotation of the thoracolumbar spine during a half pass to the left at a trot. **Left**: the right part of the pelvis is lifted through the pushing action of the right hindlimb. **Right**: the right part of the pelvis has dropped, facilitating engagement of the limb.



▶ **8.2** Marked left lateroflexion of the thoracolumbar and cervical spine during a half pass to the left at a canter. This bend is induced by concentric contraction of the dorsal musculature (erector spinae muscle) and the abdominal muscles on the left.

Vertebral biomechanics at a trot (8.3–8.6)

KINESIOLOGICAL ANALYSIS OF THE TROT IN A STRAIGHT LINE

Given that the trot is a symmetrical gait, only a half stride will be discussed so that changes that occur in the axial region, diagonal left (left fore/right hind) or diagonal right (right fore/left hind) pairs can be analysed.

During this gait, movements of the vertebral column in the median plane (flexion–extension) are reduced and entirely passive, controlled by the muscular tone of the back and the abdominal wall. After landing and at the beginning of the stance phase, the horse's trunk drops down and induces a passive extension of the thoracolumbar spine, which is limited by eccentric contraction of the abdominal muscles. At the end of the stance phase, the trunk is elevated and pushed up as a result of the propulsion achieved by the limbs. This induces a thoracolumbar flexion limited by the eccentric contraction of the erector spinae muscle.

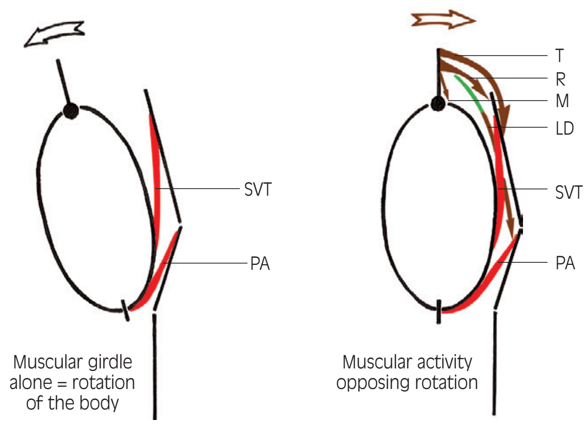
Lateral movements have a more significant impact on rotation and lateroflexion of the spine and will therefore be discussed in more detail.

Rotation

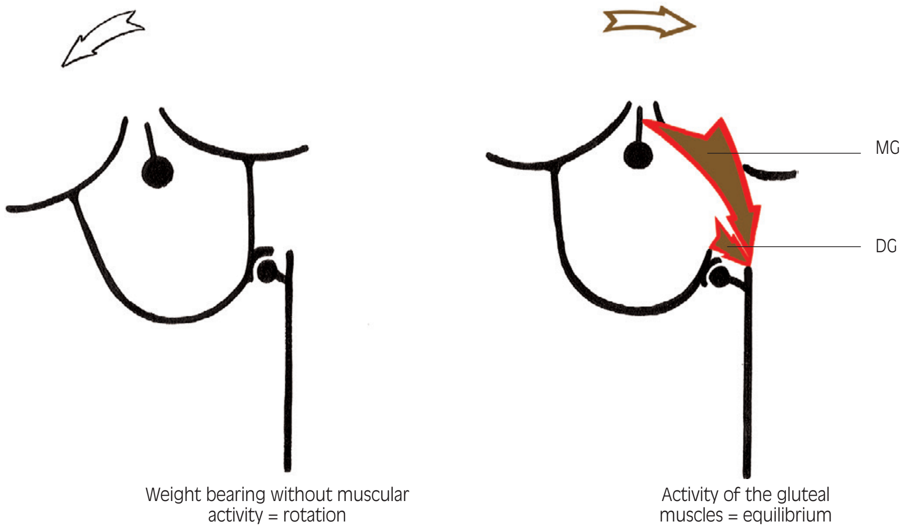
The rotation of the spine is defined by the side to which the lower (ventral) aspect of the vertebrae moves relative to the hindlimbs.

During loading of a fore- and hindlimb diagonal pair the corresponding part of the body (forehand or hindquarters) on the opposite side to the weight-bearing limb has a tendency to drop in the absence of muscular activity (**8.3–8.6**). As the stride progresses on the weigh-bearing limb into the propulsion phase, the corresponding part of the body (forehand and hindquarters) on the opposite side to the weight-bearing limb will lift, facilitating protraction and ground contact by the non-weight-bearing limb.

▲ **8.3** Mid-stance phase (full weight bearing) of the diagonal right during passage. Muscular relaxation results in a drop of the left shoulder and the right hip due to inertia of the joined limb segments. This results in a right rotation of the thoracolumbar spine.



▲ **8.4** Muscular support of the forehand during unilateral weight bearing (front view). SVT, serratus ventralis thoracis muscle; PA, pectoralis ascendens muscle; T, trapezius muscle; R, rhomboideus muscle; M, multifidus muscle (thoracic part); LD, latissimus dorsi muscle.



▲ **8.5** Establishment of equilibrium in the hindquarters through action of the gluteal muscles during unilateral weight bearing (viewed from behind). MG, middle gluteal muscle; DG, deep gluteal muscle.

▲ **8.6** Rotation of the pelvis during piaffe. The croup lifts on the side of the weight-bearing hindlimb, increasing the thoracolumbar rotation on the side of the weight-bearing forelimb.

◀ **8.7** Right lateroflexion of the vertebral column at a trot during protraction of the left diagonal. Bending (concave aspect to the right and convex aspect to the left) to the right assists in protraction of the left shoulder and right hindlimb.

For example, during loading of the diagonal right, muscular contractions act to counter the drop of the left shoulder and right hip and, therefore, counteract **passive** rotation of the thoracolumbar spine (to the right) (**8.6**). During propulsion of the diagonal right (protraction of the left fore) the length of the stride is dependent on the extent of elevation of the left shoulder and the right hip. The thoracolumbar spine contributes to these movements, achieving an **active** rotation in the direction opposite to the passive rotation (to the left) (**8.7**).

Lateroflexion

During weight bearing of the diagonal right, protraction (engagement) of the diagonal left is facilitated by lateroflexion of the vertebral column to the right. This is a result of simultaneous concentric contraction of the abdominal and epaxial (erector spinae) muscles on the side of the lateroflexion (concave side).

MUSCULAR ACTIONS IN A STRAIGHT LINE

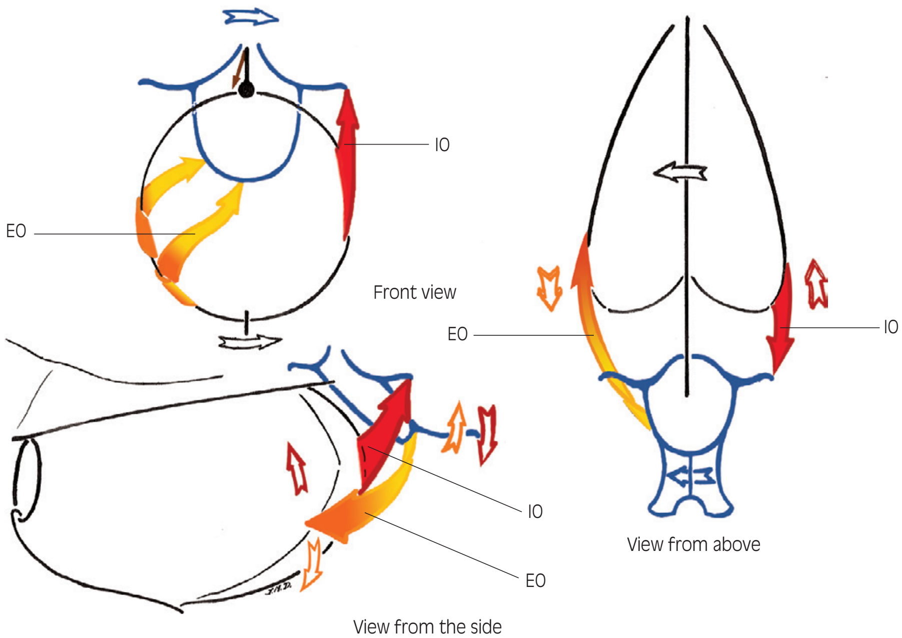
Rotation

During the weight-bearing phase on the diagonal, reversal of the direction of spinal rotation (from passive to active) is the result of a sequence of muscular contractions in three main regions of the horse's body. First, there is eccentric contraction controlling passive rotation, followed by a concentric contraction resulting in active rotation. These muscular actions can be evaluated by body region:

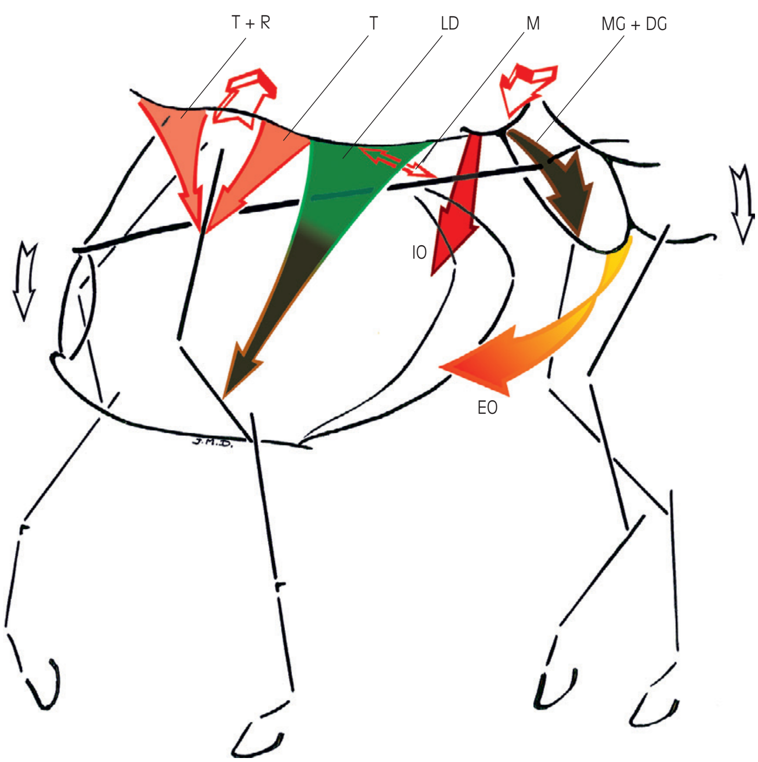
- The forehand (**8.4, 8.7**). Lifting of the shoulder opposite to the weight-bearing side is assisted by active rotation of the thorax in the direction of the limb undergoing protraction. This is the result of contraction by the trapezius, rhomboideus and latissimus dorsi muscles on the weight-bearing side. For example, in **8.7**, during protraction of the diagonal left there is an active rotation of the thorax to the left, assisted through contraction of the right trapezius, rhomboideus and latissimus dorsi muscles.
- The hindquarters (**8.5, 8.7**). Lifting of the hip opposite to the weight-bearing side occurs due to action of the deep and middle gluteal muscles as well as the gluteofemoral muscle.
- The vertebral column. Active rotation to the side of the forelimb in protraction is assisted by contraction of the juxtavertebral muscles (thoracolumbar component of the multifidus) on the opposite side of the body. The external and internal oblique abdominal muscles also make an essential contribution to rotation of the vertebral column (**8.8, 8.9**).

Lateroflexion

Lateroflexion of the spine is the result of concentric contraction of the epaxial (erector spinae) muscles and the sublumbar muscles (iliopsoas) in conjunction with the internal and external oblique abdominal muscles on the same side. The sublumbar muscles contribute to flexion of the coxofemoral joint and assist in protraction (engagement) of the hindlimb on the same side as the bending (concave aspect, **8.7**).



◀ **8.8** Muscular actions of the oblique abdominal muscles during rotation of the vertebral column and pelvis. The internal and external oblique muscles on the same side act synergistically to induce lateroflexion of the spine; however, they also act antagonistically during rotation (see view from the side). The internal oblique on one side and the external oblique on the opposite side act synergistically during rotation: they work together to induce rotation of the pelvis and vertebral column in the same direction (front and above views). IO, internal oblique muscle; EO, external oblique muscle.

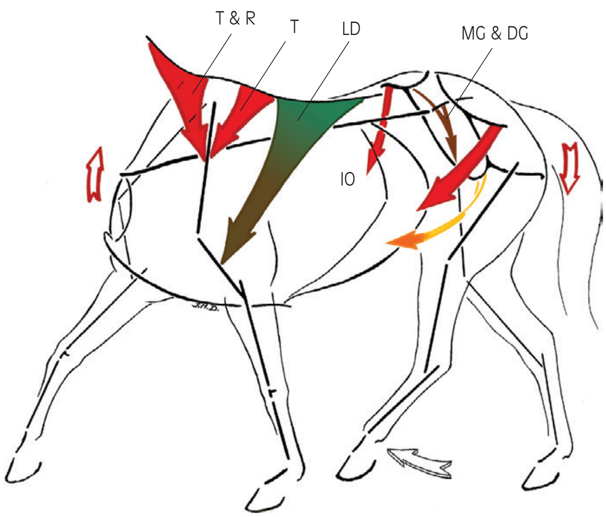


◀ **8.9** Protraction of the diagonal right in a straight line. **Hindquarters**: as the stride progresses, right passive rotation of the pelvis is transferred into an active left rotation following contraction of the right middle and deep gluteal muscles (MG and DG). **Forehand**: as the stride progresses, left passive rotation of the thorax is transferred into an active right rotation through contraction of the left trapezius (T), rhomboideus (R) and latissimus dorsi (LD) muscles. **Lumbar region and abdomen**: the internal and external oblique abdominal muscles (IO and EO) and the multifidus (thoracolumbar component) muscle (M) stabilize the spine between the thorax and the pelvis (lumbar spine).

Changes in the biomechanics of the vertebral column during lateral movements (8.6–8.9)

ROTATION

During the cranial part of the swing phase (protraction), displacement of the proximal limbs situated opposite the side of the movement is subjected to (or needs to combine with) two opposing objectives during lateral movements. Lifting of the shoulder and hip assists the length of the overall movement, but crossing of the limbs during lateral movements needs a lowering of these regions. Conversely, there is a greater elevation of the hip and shoulder on the side to which the lateral movement is occurring. Therefore, during a right lateral movement (**8.10**) during protraction of the right forelimb and engagement of the left hindlimb, elevation of the left hip is limited by the degree of left hindlimb adduction (crossing) (**8.11**). Lifting of the right shoulder is amplified by the degree of abduction of the right



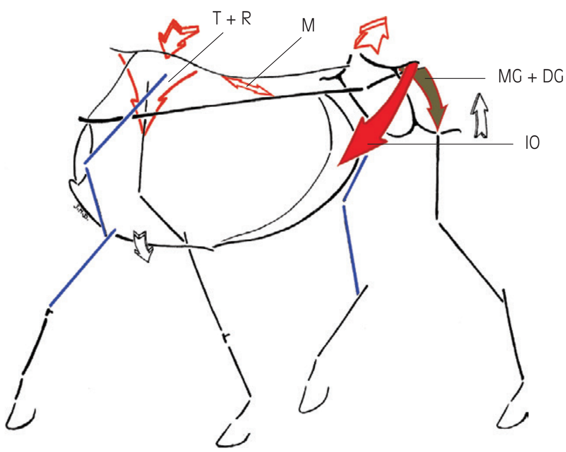
8.10 Half pass to the right at a trot: protraction of the diagonal right. **Hindquarters**: adduction of the left hindlimb is assisted through dropping of the left hip. Activity of the right middle and deep gluteal muscles (MG and DG) is reduced, allowing a right rotation of the pelvis. **Forehand**: lifting of the right shoulder is assisted by right rotation of the thorax following intense action of the left trapezius (T), rhomboideus (R) and latissimus dorsi (LD) muscles. **Lumbar region and abdomen**: the left internal oblique muscle (IO) assists in dropping of the left hip.

8.11 Half pass to the right at a trot with rotation of the body. Engagement and crossing of the left hindlimb (**left**) is assisted by rotation of the pelvis to the right. At the same time, right rotation of the thorax assists abduction of the right forelimb. With a shift in weight bearing to the diagonal right (**right**) there is a transient rotation in opposite directions of the thorax (to the right) and the pelvis (to the left). Both regions then align in the same direction (right rotation) during protraction of the diagonal left.

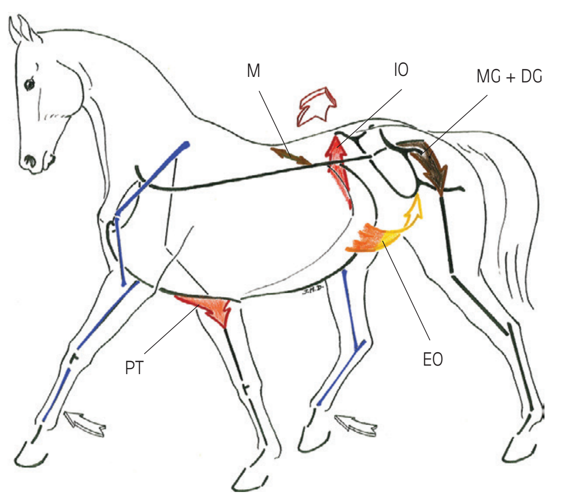
forelimb. Active rotational movements of the vertebral column are accentuated and confined to the cranial (anterior) segments, where concentric contraction of the above-mentioned muscles is intense.

During protraction of the diagonal left (**8.12**), adduction (crossing) of the left forelimb limits lifting of the left shoulder (**8.13, 8.14**), while abduction of the right hindlimb increases lifting of the right hip. These functional demands result in an amplification of the active rotation that occurs in the caudal (towards the rear) part of the vertebral column as well as an increase in the muscular activity controlling these rotational movements.

Therefore, lateral movements induce a variety of rotational movements at the level of the vertebral column, requiring adjustment and adaptation of neuromuscular coordination. These rotational movements occur to a greater extent in the part of the spine adjacent to the limbs moving in abduction. Each step results in an alternation of rotational movements between the anterior and posterior sections of the spine.



◀ **8.12** Protraction of the diagonal left in a straight line. **Hindquarters**: as the stride progresses, left passive rotation of the pelvis (upward pointing black arrow) is transferred into an active right rotation (upward pointing red arrow) following the contraction of the left middle and deep gluteal muscles (MG and DG) and the left internal oblique abdominal muscle (IO). **Forehand**: as the stride progresses, right passive rotation of the thorax (downward pointing black arrow) is transferred into an active left rotation (downward pointing red arrow) through contraction of the right trapezius (T), rhomboideus (R) and latissimus dorsi muscles. **Lumbar region and abdomen**: the thorax and pelvis rotate in opposite directions. The internal oblique (IO) and multifidus (thoracolumbar component) (M) muscles control the degree of torsion of the lumbar spine.



◀ **8.13** Half pass to the right at a trot: protraction of the diagonal left. **Hindquarters**: to promote abduction of the right hindlimb, the pelvic swing is amplified towards the right through intense concentric contraction of the left middle and deep gluteal muscles (MG and DG). **Forehand**: rotation of the thorax to the right through the action of the right pectoralis transversus muscle (PT) facilitates adduction of the left forelimb. Action of the right trapezius (T) and rhomboideus (R) muscles is reduced. **Lumbar region and abdomen**: because of the rotation of the thorax and pelvis in the same direction (to the right), there is a reversal in the actions of the internal oblique (IO), external oblique (EO) and multifidus (thoracolumbar component) (M) muscles compared with the trot in a straight line.

▲ **8.14** Half pass towards the right at a trot: protraction of the diagonal left. The left shoulder has reduced elevation to allow the limb to move around the thorax. The right hip lifts, favouring rotation of the pelvis to the right.

Note: This rotation takes place through contraction of unilateral muscle groups (**8.10, 8.13**). Symmetrical flexibility of the vertebral column and muscle work requires alternation of left and right lateral movements.

LATEROFLEXION

During shoulder-in, curvature of the spine is increased during engagement of the hindlimb opposite to the direction of movement. These movements are the result of action of the same muscular group, the iliopsoas muscle, that undergoes maximal concentric contraction.

During half pass, however, curvature of the spine is at its most during engagement and abduction of the hindlimb on the same side to which the movement is occurring (**8.13–8.15**). This exercise provides optimal conditions to produce maximal lengthening of the ilio-psoas muscle, which occurs during propulsion of the hindlimb opposite to the direction of displacement (**8.1, left, 8.11, 8.15**). Propulsion and abduction of this limb, combined with the spinal curvature, therefore provoke maximal lengthening between the muscular insertions of the iliopsoas muscle.

▲ **8.15** Half pass towards the left at a trot: protraction of the diagonal right. Left lateroflexion of the vertebral column is at its maximum at the end of protraction (engagement) of the left hindlimb (**left**). Combined with extension of the right hip (at the end of the propulsion phase), it induces significant lengthening of the right iliopsoas muscle (**right**).

Conclusion

Once the primary role of the iliopsoas muscle in all different types of exercises is understood, it can be appreciated that alternation of lateral movement exercises (shoulder-in and half pass, on both sides) are excellent physical gymnastic and training exercises for all horses in competition. The biomechanical differences between half pass and shoulder-in will be the focus of the next chapter.

9 The biomechanical differences between half pass and shoulder-in

WITHOUT CONSIDERING the technical equestrian aspects, the main objective of this chapter is to highlight and analyse, from a biomechanical perspective, the differences in muscular demands and actions of the two exercises, half pass and shoulder-in. The same principles can similarly be applied to other exercises, such as counter-shoulder-in, turn on the haunches or on the forehand and pirouettes, in order to analyse every manoeuvre and extract their advantages for the gymnastic education of horses. The three essential regions involved in these exercises will be discussed: hindquarters, trunk and forehand.

Hindquarters

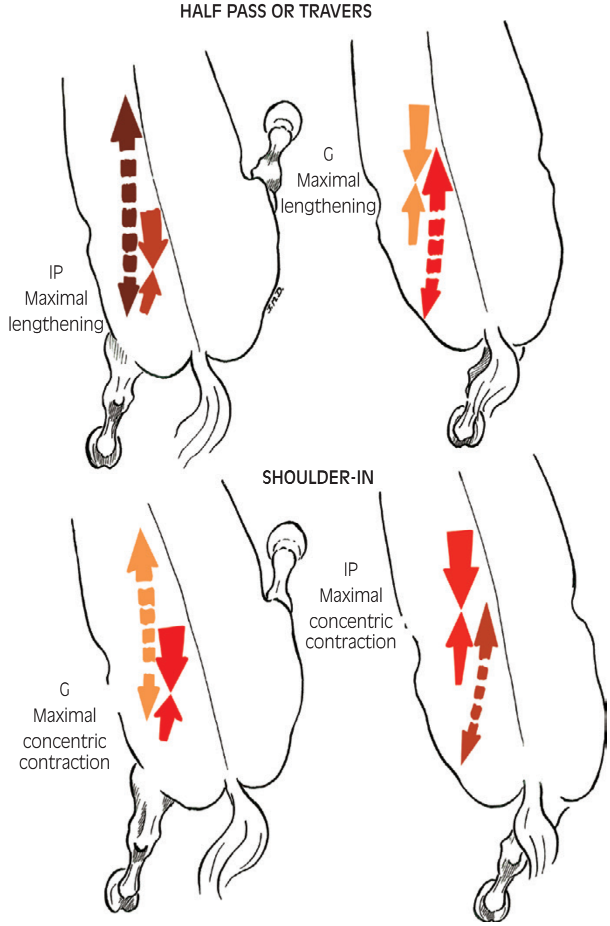
During shoulder-in, the horse moves in the opposite direction to the bend of the spine. This results in a reduction in the oblique movement of the hindlimbs relative to the median plane of the horse (**9.1**).

Conversely, during the half pass, and more so during travers, swinging of the pelvis in the direction to which the lateral movement is occurring increases the transverse component in hindlimb movement. Therefore, during both these exercises, the extent to which the limbs separate and cross as well as the work of the adductor and abductor muscles is far greater than seen during shoulder-in.

◀ **9.1** Right shoulder-in at a trot. Because of right lateroflexion of the vertebral column (**left**), during adduction the right hindlimb is placed inside the right forelimb. In the **right** image, the left hindlimb moves to the outside of the left forelimb during abduction.

Trunk

As previously discussed, muscular elongation in this area is most marked on the opposite side to which the lateral movement is occurring. Shoulder-in forces a maximal concentric contraction (shortening) of the iliopsoas muscle during engagement of the hindlimb on the same side as the bend of the body (**9.2, 9.3**). Lateroflexion of the spine during half pass (or travers) to the direction in which the movement is occurring induces maximal lengthening of the iliopsoas muscle opposite to the direction of movement during propulsion of the limb.

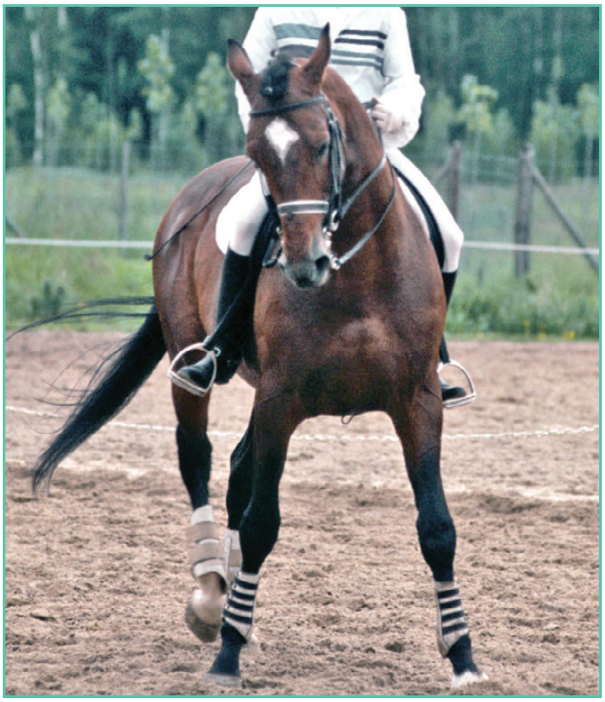


▶ **9.2** Activity of the gluteal (G) and the iliopsoas (IP) muscles during lateral movements. The maximal stresses on the gluteal muscles occur with adduction of the hindlimbs during half pass or travers (maximal lengthening) (**top**) and with abduction during shoulder-in (maximal concentric contraction) (**bottom**). The maximal lengthening of the iliopsoas muscle takes place with abduction of the hindlimbs during half pass or travers (**top**) and with adduction (maximal concentric contraction) during shoulder-in (**bottom**). **Note:** It is the muscles located on the opposite side to which the lateral movement is occurring that undergo the largest variations in length.

▶ **9.3** Right shoulder-in at a trot. (**Left**) Because of right spinal lateroflexion, the left iliopsoas muscle undergoes maximal lengthening at the end of left hindlimb propulsion. The right iliopsoas undergoes marked concentric contraction during protraction of the right hindlimb. (**Right**) During protraction of the diagonal right (right forelimb/left hindlimb), shortening of the left iliopsoas muscle and lengthening of the right iliopsoas muscle are less intense and are concentrated in the most caudal part.

Forehand

Bending of the spine, although different in the two exercises, is accompanied by abduction and adduction movements of the forelimbs. These movements are more marked during shoulder-in than during half pass. Of particular interest is the variation in length of the muscles mobilizing the forelimb that occur during protraction (cranial part of the swing phase) and propulsion (caudal part of the stance phase) (**9.4–9.6**).



◀ **9.4** Right shoulder-in with lateral movement to the left at a walk. Note the marked curvature of the vertebral column. Abduction of the forelimbs takes place in conjunction with lengthening of the descending and transverse pectoral muscles, particularly on the right-hand side. Protraction of the left forelimb along with bending of the trunk results in lengthening of the left ascending pectoral muscle.

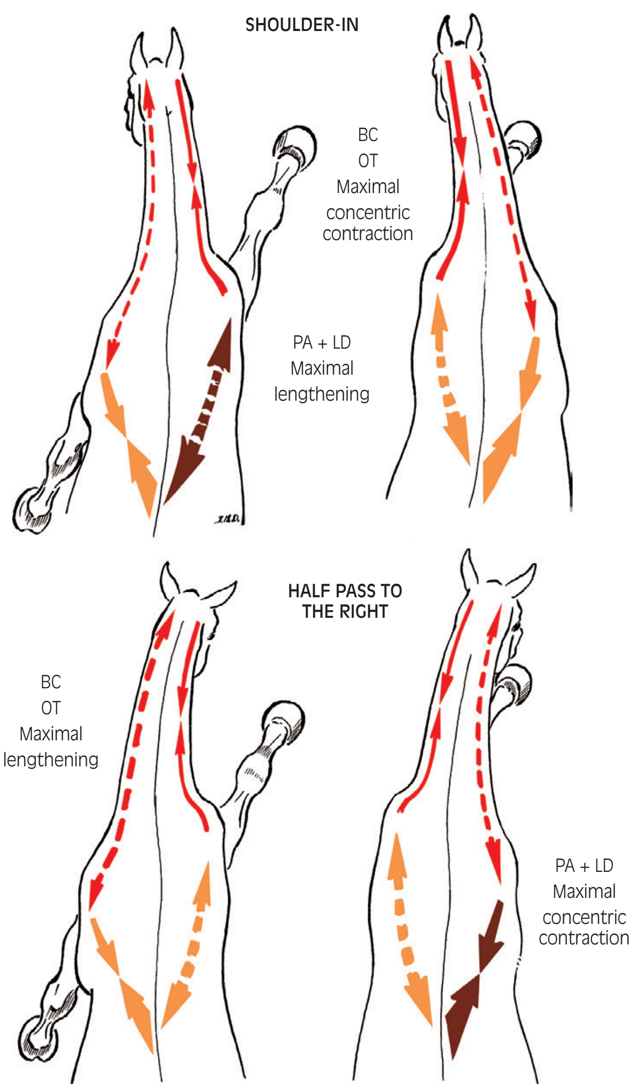
◀ **9.5** Right shoulder-in at a trot. Protraction (cranial part of the swing phase) of the right forelimb results in maximal concentric contraction of the right brachiocephalicus and omotransversarius muscles. Retraction (propulsion) of the left forelimb elicits marked lengthening of the same muscles on the left-hand side of the horse.

MUSCLES INDUCING PROTRACTION OF THE LIMB (CRANIAL PART OF THE SWING PHASE)

The muscles involved primarily with protraction of the limb, as discussed in Chapter 1, are the brachiocephalicus and omotransversarius muscles.

- **Shoulder-in.** Because of the mild curvature of the cervical spine and orientation of the head, the brachiocephalicus and omotransversarius muscles undergo significant variations in length during the **adduction** (crossing) phase. On the weight-bearing limb, on the side to which the movement is occurring, these muscles undergo an intense passive lengthening, while on the non-weight-bearing limb (the side of spinal lateroflexion) these muscles undergo a maximal concentric contraction (**9.5, 9.6**).
- **Half pass.** Both the brachiocephalicus and the omotransversarius muscles undergo maximum lengthening during the **abduction** (opening) phase of the forelimbs (**9.6**). Effectively, in this position, propulsion and abduction of the limb during weight bearing, along with the curvature of the spine, contribute to an increase in the distance between the muscular insertions and the lengthening of the muscles.

Therefore, because of the muscular insertions and the curvature of the vertebral column, the brachiocephalicus and omotransversarius muscles undergo an intense lengthening and shortening during adduction of the forelimbs in the shoulder-in and during abduction of the forelimbs of the half pass.



◀ **9.6** Shoulder-in and half pass: actions of the brachiocephalicus (BC), omotransversarius (OT), pectoralis ascendens (PA) and latissimus dorsi (LD) muscles. Maximal concentric contraction (shortening) of the left brachiocephalicus and omotransversarius muscles occurs during adduction with a left shoulder-in (**top**) and maximal lengthening occurs during abduction with a right half pass (**bottom**). Maximal elongation (lengthening) of the right pectoralis ascendens and latissimus dorsi muscles occurs during abduction with a left shoulder-in (**top**) and maximal concentric contraction takes place during adduction with a right half pass (**bottom**).

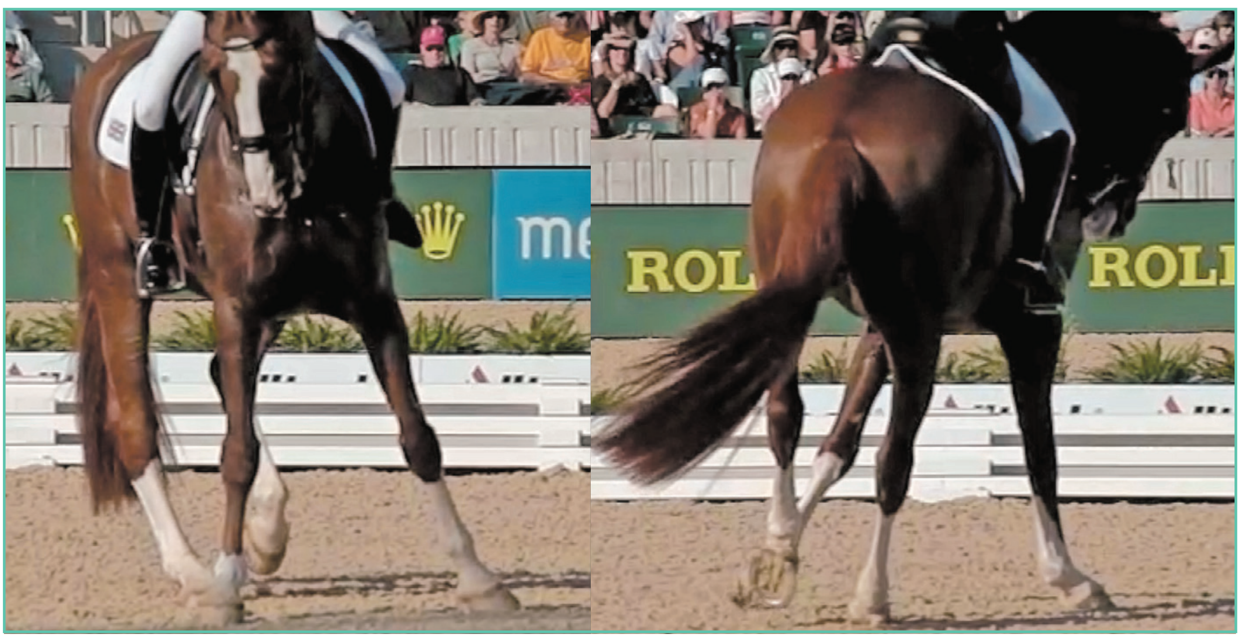
MUSCLES ACHIEVING THE PROPULSION PART OF THE STANCE PHASE (9.6)

In the same way, shortening and lengthening of the muscles involved in propulsion (the latissimus dorsi and pectoralis ascendens muscles) are evident, with adduction during a half pass and abduction during a shoulder-in movement.

- During a **half pass** to the right (**9.7**), adduction of the right weight-bearing forelimb requires an intense concentric contraction of the right pectoralis ascendens muscle. This acts to adduct the limb and is a powerful contributor to propulsion. The latissimus dorsi muscle contributes only to propulsion, with lateroflexion of the spine contributing to its shortening. Adduction of the left non-weight-bearing forelimb occurs through concentric contraction of the descending and transverse pectoral muscles (see Chapter 6, The forelimbs). This forces lengthening of the ascending pectoral (pectoralis ascendens) and the latissimus dorsi muscles opposite to the side of lateroflexion.
- Following the analysis as described above, during **shoulder-in** the maximal variation in the length of these muscles takes place either side of the trunk during abduction of the forelimbs.

Finally, the lengthening and concentric contraction of the muscles (brachiocephalicus and omotransversarius) involved in the protraction part of the swing phase, especially during shoulder-in, improves the expression of movement of the forelimbs and increases the extent of the gait amplitude. In conjunction with this, lengthening and shortening of the pectoralis ascendens and latissimus dorsi muscles are most pronounced during half pass and improve the overall impulsion of the forelimbs.

These two exercises are, therefore, complementary to the fitness and gymnastics of the forehand of the athlete horse.



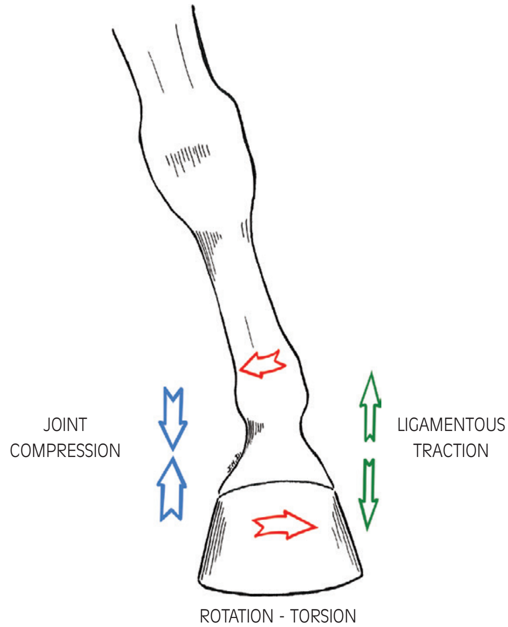
▲ **9.7** Half pass to the right: maximal shortening of the right pectoralis ascendens muscle at the end of the right forelimb propulsion.

10 Advantages and disadvantages of lateral movements

As they are usually performed on good ground at relatively slow gaits, lateral movements pose few problems to the musculoskeletal apparatus of clinically healthy horses.

A key point to note is that during the stance phase of a limb, landing is initiated on one aspect of the foot (**10.1**), while propulsion is initiated on the opposite side of the foot. This results in placement of asymmetrical

▲ **10.1** Half pass to the left at a trot. In this position, loading of the foot is uneven. On the diagonal right, loading takes place at the dorsomedial (inside front) aspect of the limb. Ground impact on the diagonal left will also occur at the medial (inside) aspect of the foot. Asymmetrical loading of the interphalangeal and fetlock joints induces collateromotion (lateromedial movements in the frontal plane) and sliding on one side of the joint and rotation on the other.

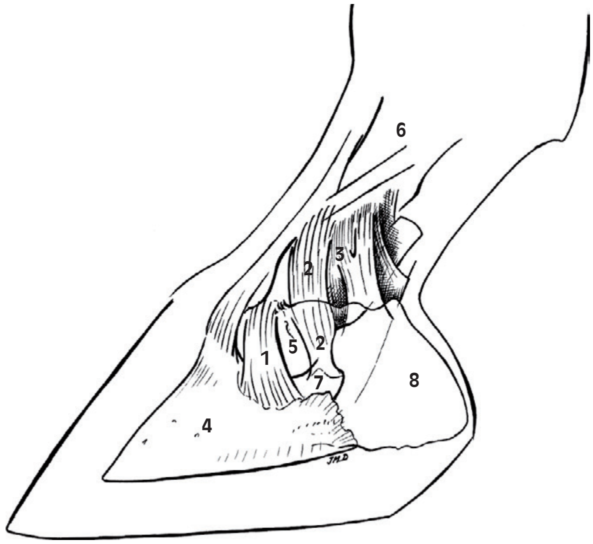


▲ **10.2** Asymmetrical loading of the foot during lateral movements. (**Left**) At the end of propulsion the left forelimb pushes off from the external (lateral) aspect of the toe and the right hindlimb pushes off from the internal (medial) aspect of the toe, while the right forelimb will land on the inside heel. (**Right**) Collateromotion (lateromedial movements in the frontal plane) results in compression of the joint surfaces on the same side as landing occurs and tension of the collateral ligaments on the opposite side. Rotational movements accentuate these stresses and result in torsion of the bone segments and joint capsules.

loads at the articular surface as well as asymmetrical traction on the collateral ligaments, which could be deleterious to horses with existing ligament or joint pathology (**10.2**).

In the hindlimb, preferential loading on the medial aspect of the foot during landing or propulsion results in a concentration of compressional forces on the internal (medial) aspect of the hock in a site where the joint is already most susceptible to the degenerative arthritic changes that lead to bone spavin.

During asymmetrical loading of the forelimbs and, to a certain extent, of the hindlimbs, the metacarpophalangeal (or metatarsophalangeal, fetlock joints) and interphalangeal joints undergo collateromotion (lateral and medial movements in the frontal plane) associated with rotation and sliding (**10.3–10.5**). During each step the pressures on the foot pass from one side to the other, placing asymmetrical stress on the ligaments (tension) and joint surfaces (pressure) with translocation of these forces. This means that horses with pre-existing articular



◀ **10.3** Collateral ligaments of the interphalangeal joints. These ligaments and their insertions undergo significant tension during asymmetrical loading of the foot. 1, collateral ligament of the distal interphalangeal joint; 2, collateral sesamoidean ligament; 3, collateral ligament of the proximal interphalangeal joint; 4, distal phalanx; 5, middle phalanx; 6, proximal phalanx; 7, navicular bone (distal sesamoid bone); 8, ungular cartilage (accessory fibrocartilage).

◀ **10.4** Illustration of the changes in stress during the stance phase of a limb during a left half pass movement at a walk. In the cranial part of the stance phase of the forelimbs (**left**) the stresses occur mostly at the medial (internal) aspect of the joint surfaces. In the second half of the stance phase (**right**) the pressure is shifted towards the lateral (external) aspect of the joint and the ligamentous tension increases at the medial (internal) aspect. This is particularly evident in the left forelimb, which is the leading limb while the lateral movement is occurring.

◀ **10.5** Illustration of the changes in stresses on the distal limb during the stance phase in a right half pass movement at a trot. In the cranial part of the stance phase of the right forelimb (**right**) the initial compressions occur at the medial (internal) aspect of the joint surfaces. In the caudal part of the stance phase (**left**) the pressures across the joint shift towards the lateral (external) aspect, with tension increasing in the medial (internal) collateral ligaments of the joints.

problems should not undertake these exercises, or they should be done with caution, as they are at risk of perpetuating the problem.

The addition of these ligamentous stresses to the normal biomechanical loads means that exercises involving lateral movements should only be undertaken after a long warm-up, which stretches the collateral ligaments through their viscoelastic nature. However, the excessive biomechanical stresses can be limited if the horse is trained on soft ground. Alternatively, lateral movements can be used to warm-up the collateral ligaments of the lower joints in order to prepare the horse for more stressful exercises, such as the pirouette (**10.6, 10.7**).

▶ **10.6** Left pirouette at a canter. Asymmetrical loading is combined with rotational movements (particularly in the hindlimbs). The articular stresses and ligamentous tension increase. A good warm-up is required prior to undertaking this exercise.

▼ **10.7** Right pirouette at a canter. Asymmetrical loading on the forelimbs and marked rotational movement of the weight-bearing right hindlimb. All the joints of this limb undergo combined stresses with pressure, rotation and sliding on the articular surfaces associated with tension and shearing on the ligaments.

Summary of the advantages and disadvantages of lateral movements

Despite the few musculoskeletal disadvantages, lateral movements offer several advantages in physical preparation and training of the athlete horse.

They place certain prominent muscular groups under variable degrees of contraction and lengthening and improve the overall length and efficacy of movement. For example, the gluteal muscles improve overall impulsion of the hindlimbs, the iliopsoas muscle facilitates an increase in lumbosacral mobility and hindlimb engagement, and the pectoral muscles increase the forwardness of the forehand (**10.8**). Furthermore, lateral movements work groups of muscles that are infrequently or rarely used. In particular, they encourage development of the adductor and abductor muscles and activate certain deep muscles such as the thoracolumbar multifidus and the deep gluteal muscles. Despite these muscles not being superficially visible, they have a very important role in the mobility and stability of the intervertebral and coxofemoral joints. It is for this reason that lateral movements can be considered as a physiotherapeutic treatment (preventive as well as curative) for many conditions of the vertebral column and hip.

As previously discussed, lateral movements result in a rearranging of neuromuscular coordination. This assists in the development of proprioception of the joints, tendons and muscles of not only the limbs but, most importantly, the vertebral column. Increased perception and motor control of locomotion, combined with an improved efficiency in muscular activity, aid the development of fluid and harmonious movement.

▲ **10.8** Educating the horse in lateral movements with ground work. The horse is being asked to move the left hindlimb into abduction. Curvature of the neck promotes elongation of the left brachiocephalicus and omotransversarius muscles, while protraction and adduction of the right forelimb elicit a marked concentric contraction of the descending pectoral muscle.

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PART 4:

Biomechanical analysis of jumping

CHAPTER

Understanding the different phases of jumping, the body positions that benefit overall action and the analysis of individual style can lead to improved training and physical preparation of the athlete horse. Therefore, it is important to understand poorly controlled and unwanted movements. Identifying the strengths and weaknesses of a horse enables better selection of exercises that are best adapted to improving athletic movement. It is then up to the trainer to recognize any weaknesses and to overcome them with a specific training programme.

In high-level competition, talent alone does not suffice. One must increasingly rely on objective scientific knowledge and an ability to evaluate the horse impartially.

The next seven chapters are dedicated to a biomechanical analysis of jumping. The goal is to develop a sound understanding of the functional anatomy of jumping movements as a basis for selecting essential exercises that are useful for training as well as for evaluating and selecting a suitable horse. The biomechanical concepts and the muscular groups previously discussed will not be revisited, but will be discussed in a new light in relation to the dynamic action of jumping. The chapters will be divided into a biomechanical analysis of the limbs and axial skeleton during take-off and propulsion, the suspension phase and finally landing.

BIOMECHANICAL ANALYSIS OF JUMPING

11 Approach, take-off and propulsion

This chapter will discuss the principal phases of the approach, take-off and propulsion, thus allowing an evaluation of the actions of the horse at the approach to a jump. Understanding the underlying biomechanics allows identification of joints that have restricted movement and muscular groups that are weak or poorly used. Depending on the features identified, different exercises can be indicated and training programmes can be tailored to best suit the action of any given horse. Approach, take-off and propulsion take place during the last strides before the jump itself (**11.1**).

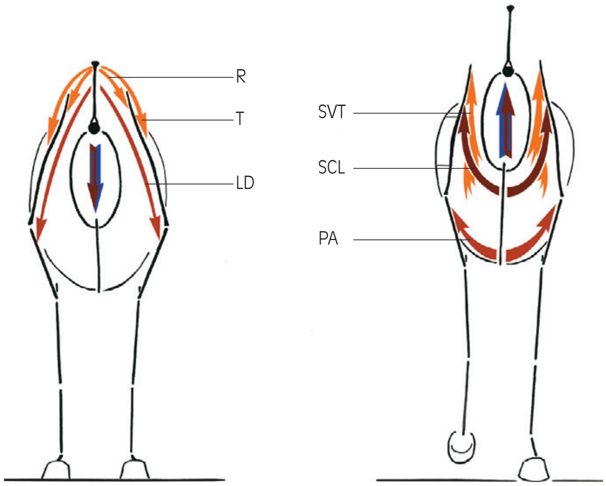
Biomechanics of the forelimbs at take-off and propulsion ❑

A proper action of the forelimbs over a jump is just as important as the height of the obstacle (**11.2, 11.3**). The action can be evaluated relative to the different bone segments and intrinsic muscles of the limb. This evaluation must also take into account the role of the muscles that attach the thorax to the scapula and humerus (extrinsic muscles).

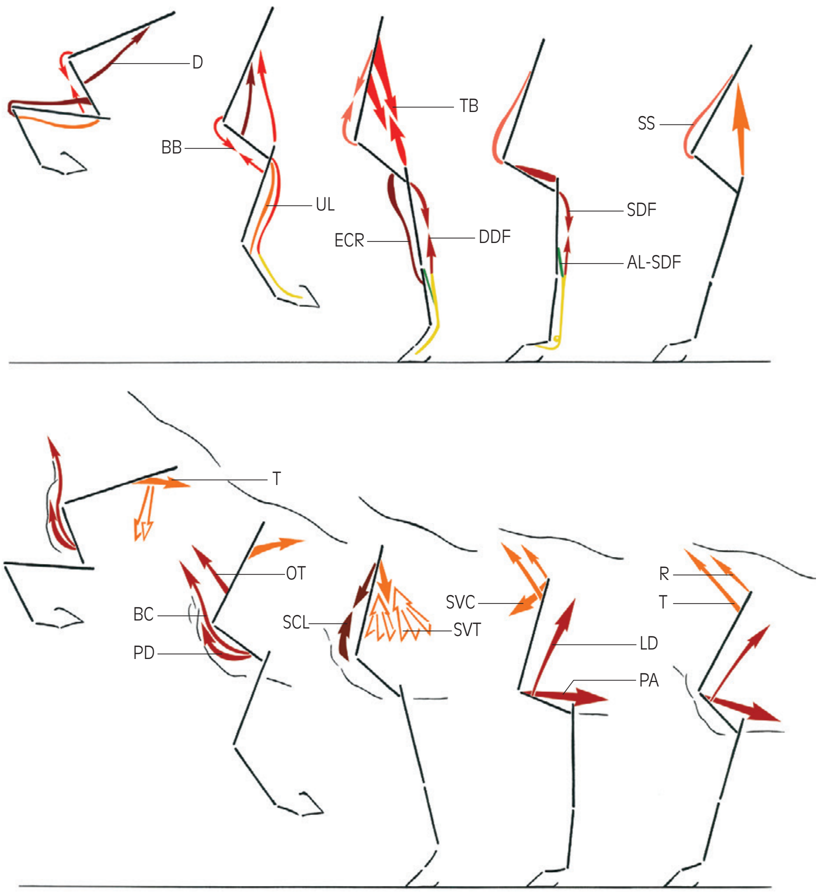
▲ **11.1** Breakdown of the stance phase of the forelimbs and engagement of the hindlimbs during take-off before a jump.

◀ **11.2** Preparation of the forelimbs for impact in front of a jump. The diagonal right pair (right forelimb, left hindlimb) undergo significant forward lengthening to reduce the horizontal momentum of the horse. The right hindlimb is fully loaded (see fetlock extension) and the left forelimb is undergoing protraction.

◀ **11.3** Approach to the jump and preparation for ground contact on the left forelimb at take-off in front of a jump. The left forelimb is significantly lengthened so as to facilitate the transformation of a horizontal movement to a vertical movement of the horse's body mass. The right forelimb is fully loaded, signified by a drop of the fetlock and closure of the elbow joint.



◀ **11.4** Muscular actions that regulate dropping and lifting of the thorax during take-off. (**Left**) This illustrates dropping of the trunk due to the weight of the body, with concentric contraction of the latissimus dorsi, trapezius and rhomboideus muscles. (**Right**) This illustrates the concentric contraction of the pectoralis ascendens, subclavius and serratus ventralis thoracis muscles, which act to lift the trunk between the forelimbs. Muscles lowering the thorax: LD, latissimus dorsi muscle; R, rhomboideus muscle; T, trapezius muscle. Muscles lifting the thorax: SVT, serratus ventralis thoracis muscle; PA, pectoralis ascendens muscle; SCL, subclavius muscle.



◀ **11.5** Muscular actions of the forelimb during the different phases of take-off. (**Top**) This illustrates the action of intrinsic muscles of the forelimb (spanning between two bone segments of this limb). (**Bottom**) This demonstrates the extrinsic muscles (spanning between the scapula or humerus and the thoracic wall and neck). Muscles of the shoulder: D, deltoideus muscle; SS, supraspinatus muscle. Muscles of the arm: BB, biceps brachii muscle; TB, triceps brachii muscle. Muscles of the forearm: UL, ulnaris lateralis muscle; ECR, extensor carpi radialis muscle; DDF, deep digital flexor muscle; SDF, superficial digital flexor muscle; AL-SDF, accessory ligament of the superficial digital flexor muscle. Muscles of the neck: BC, brachiocephalicus muscle; OT, omotransversarius muscle; SVC, serratus ventralis cervicis muscle. Muscles of the thorax: SVT, serratus ventralis thoracis muscle; LD, latissimus dorsi muscle; R, rhomboideus muscle; T, trapezius muscle. Pectoral muscles: PA, pectoralis ascendens muscle; PD, pectoralis descendens muscle; SCL, subclavius muscle.

The intrinsic and extrinsic muscles (**11.4, 11.5**) act synergistically and result in a sequence that takes place in five stages from approach, take-off to propulsion: preparation for forelimb landing, ground contact and dropping of the forehand, minimal joint angulation concurrent with horizontal propulsion, vertical propulsion (opening of the joints), protraction and tucking of the forelimbs.

APPROACH: PREPARATION FOR GROUND CONTACT

This movement precedes landing of the forelimbs. During the last stride before take-off, the forelimbs are fully protracted in a strutted out forward position in order to prepare elevation of the forehand at take-off. The forelimbs have a similar mechanical action to that of a pole vaulter where horizontal movement becomes translated into vertical movement.

GROUND CONTACT AND DROPPING OF THE FOREHAND

Landing of the forelimbs is made through the heels at the end of the protraction phase of the last stride before the jump. Loading of the forelimbs is accompanied by dropping of the forehand and trunk. Increasing the load on the forehand brings into action the same structures (muscles, tendons and ligaments) that function to produce the propulsion phase of the stride.

MAXIMAL JOINT CLOSURE (MINIMAL JOINT ANGULATION) CONCURRENT WITH HORIZONTAL PROPULSION

These actions take place during the mid-stance phase of the forelimbs just after ground contact.

Maximal joint closure and eccentric contraction

Eccentric contraction is essential for activating the muscle structures and preparing for vertical propulsion. Joint closure leading to minimal joint angulation is controlled by eccentric contraction of the extensor muscles (supraspinatus and triceps brachii). Dropping of the trunk is also controlled through eccentric contraction of the muscles suspending the thorax between the forelimbs (serratus muscles, pectoralis ascendens and subclavius). Dropping of the thorax is due to the momentum of the body and concentric contraction of the trapezius, rhomboideus and latissimus dorsi muscles (**11.3, 11.4**). At the same time, maximal closure of the joints (flexion of the shoulder, elbow and interphalangeal joints with extension of the carpus and fetlock) places the passive and elastic structures (flexor tendons, accessory ligaments and the suspensory ligament) under tension. This results in an accumulation of stored energy which, in combination with synergistic muscle activity, will contribute to achieving efficient vertical propulsion.

Horizontal propulsion

Horizontal propulsion results from the swing of the shoulder and arm. This action occurs when synergistic muscles pull the humerus backwards and displace the upper extremity of the scapula forwards:

- Retraction of the humerus is achieved through concentric contraction of three strong and extensive muscles: the latissimus dorsi muscle, the pectoralis ascendens muscle and the triceps brachii muscle. The latissimus dorsi muscle acts primarily during the first part of the movement. The pectoralis ascendens muscle (the most powerful) is active during the entire retraction and continues to act during the elevation of the forehand. The triceps brachii muscle (primarily the long head) actively closes the scapulohumeral joint angle and assists in retraction of the humerus during the cranial part of the stance phase of the forelimb.
- Protraction of the upper extremity of the scapula is induced primarily through action of the cervical part of the trapezius and rhomboideus muscles. These muscles are assisted by the serratus ventralis cervicis muscle at the end of the movement. The serratus ventralis cervicis muscle also supports and acts synergistically with the serratus ventralis thoracis muscle to lift the forehand.

▲ **11.6** Maximal closure of the joint angles of the forelimbs at take-off in front of a jump. Note the marked flexion of the shoulder and elbow joints, the hyperextension of the carpus and fetlock joint and the marked flexion of the interphalangeal joints. The straightening of the shoulder ends horizontal propulsion. The hindlimbs are undergoing protraction following concentric contraction of the sublumbar (iliopsoas) muscles and cranial femoral muscles.

VERTICAL PROPULSION

In front of a jump, elevation of the forehand is a result of a combination of impulsion (drive) of the forelimbs and lifting of the trunk between the limbs.

Suspension and elevation of the forehand (11.5–11.7)

The thorax is suspended between the forelimbs by a muscular girdle that has a very effective role during vertical propulsion, as initial eccentric muscular contraction increases the efficiency of the concentric contraction responsible for lifting of the forehand.

Just after landing of the forelimbs, the upper joints flex and the thorax drops between them, placing the muscles responsible for propulsion in a lengthened state. This lengthening assists and contributes to efficient concentric contraction, thus lifting the forehand up (**11.6**).

Lifting of the forehand (and therefore the withers) precedes ground contact of the hindlimbs. There is rapid opening of the joint angles of the forelimb along with powerful concentric contraction of the muscular girdle suspending the thorax between the forelimbs. There are four muscles that contribute to this 'girdle': two serratus muscles (the ventralis cervicis and the ventralis thoracis muscles) and two pectoral muscles (the ascendens and the subclavius muscles). The latter are efficient muscles and assist in the breadth of movement and forward displacement of the horse.

▲ **11.7** Impulsion (offloading) of the forelimbs at take-off: all the joint angles are open. There is extension of the shoulder and elbow joints. Lifting of the fetlock joint brings the distal bone segments (pastern and foot) into a vertical position. The fetlock is able to lift due to the elastic nature of the suspensory apparatus and the digital flexor tendons, which therefore act to extend the interphalangeal joints. Simultaneously, the thorax (and therefore the withers) lifts between the shoulders. The hindquarters continue to drop and the hindlimbs prepare for ground contact.

Upward impulsion of the forelimbs

At the end of the loading phase, upward impulsion of the forelimbs results in a sudden opening of all joint angles. This is initiated by concentric contraction of the intrinsic muscles of the limb. Their efficiency is pronounced due to the lengthening and eccentric contraction that occur during landing and loading of the limb (compare figures **11.6** and **11.7**).

Opening of the scapulohumeral (shoulder) joint angle is a result of action of the supraspinatus muscle (**11.5**). Opening of this joint potentiates the action of the triceps brachii muscle in opening the elbow joint. Isometric contraction of the extensor carpi radialis muscle stabilizes the carpus (knee). Straightening of the pastern axis with extension of the interphalangeal joints and lifting of the fetlock results from concentric contraction of the digital flexor muscles and elastic shortening of their tendinous extensions (**Note:** During propulsion these digital flexors act as **extensors** of the distal joints). At the end of this movement (take-off), the toe is the last part of the foot to leave the ground and because of its length it acts as a springboard, pushing the horse upwards. Once the toe has left the ground, the suspension phase begins, during which the hindlimbs become fully engaged.

11.8 Flexion of the forelimbs during take-off. All the joint angles close to assist clearing the jump. Muscular activity under the saddle and in the lower neck region brings the shoulder into a horizontal position. Contraction of the pectoralis descendens muscle (chest) pulls the limb forward, while the extensor carpi radialis muscle contributes to flexion of the elbow.

PROTRACTION, FOLDING AND TUCKING OF THE FORELIMBS

This movement is the end result of forward traction of the scapula and humerus and flexion of all the joints in the limb (**11.8**).

Protraction of the scapula and humerus

This movement is due to a pairing of muscular actions. The upper extremity of the scapula is pulled backwards, while its lower extremity and the humerus are lifted and brought forward. This movement therefore results in horizontalization of the shoulder.

- During the first phase, which starts after take-off, the trapezius muscle (thoracic part) pulls the upper part of the scapula backwards, while the brachiocephalicus, omotransversarius and pectoralis descendens muscles bring the humerus forward.
- During the limb tuck, horizontalization of the scapula is increased through two actions. Firstly, the caudal layers of the serratus ventralis thoracis muscle, in combination with the trapezius muscle, pull the upper extremity of the scapula backwards. Secondly, the pectoralis descendens muscle intensifies its concentric contraction, pulling the humerus up and lifting the shoulder and elbow joints.

  This action is identical to the one that occurs during adduction of the forelimbs in lateral movements (see Chapter 6, The Forelimbs).

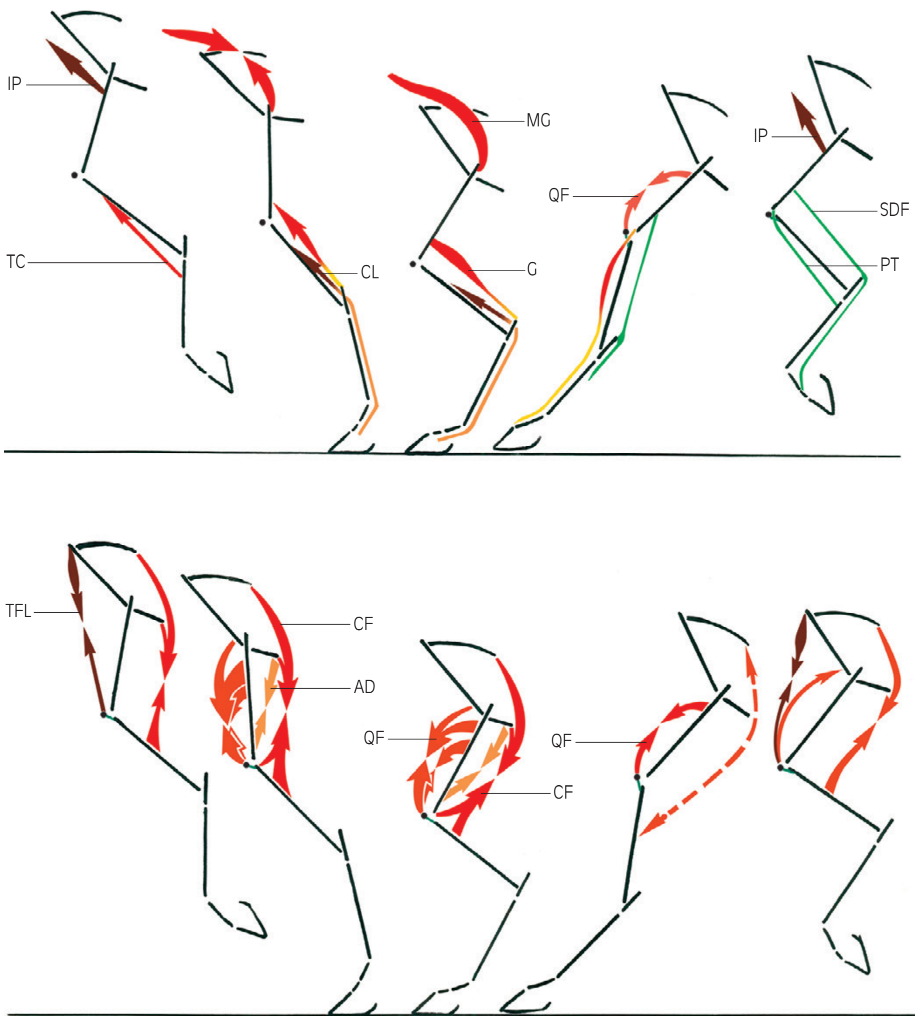
Flexion of the joints

Flexion of all the joints of the forelimb takes place due to concentric muscular contractions and the overall inertia of the limb:

- Scapulohumeral joint flexion is the result of concentric contraction of the triceps brachii (long head), deltoideus and teres major muscles.
- Flexion of the elbow is initiated through synergistic action of the biceps brachii, brachialis and extensor carpi radialis muscles (**11.8**).
- Flexion of the distal limb joints (carpus, fetlock and interphalangeal joints) is initiated first through concentric contraction of the muscles at the back of the forearm. This flexion is then continued through the inertia of the limb, which is closely related to rapid flexion of the elbow, the distal limb acting like a flail. (**Note:** In relation to this, two morphometric studies undertaken at the veterinary schools of Lyon and Alfort demonstrated that horses with long cannons had a greater ability to show jump than horses with short cannons.)

Biomechanics of the hindlimbs during take-off and propulsion ❑

The last stride in the approach to a jump until take-off can be broken down into several phases (**11.9**): engagement of the limbs while they are non-weight bearing, a load absorption phase after ground contact, maximal flexion with loading of active and passive structures of propulsion, and finally straightening of the hindlimbs achieving propulsion (upwards impulsion) and pushing the horse's body over the fence.



▲ **11.9** Muscular activity in the hindlimbs during the different phases of take-off. (**Top**) This series of images illustrates the actions of the sublumbar muscles, the pelvis and the leg (crural) muscles. (**Bottom**) This series illustrates the actions of the thigh muscles.
Sublumbar and pelvic muscles: IP, iliopsoas muscle; MG, middle gluteal muscle. Thigh muscles: QF, quadriceps femoris muscle; TFL, tensor fascia latae muscle; AD, adductors; CF, caudal femoral muscles (gluteofemoral, semitendinosus and semimembranosus). Leg (crural) muscles: TC, tibialis cranialis muscle; CL, caudal leg muscles (muscular bodies connected with the deep digital flexor tendon); G, gastrocnemius muscle; SDF, superficial digital flexor muscle; PT, peroneus tertius muscle.

▲ **11.10** Preparation for ground contact of the hindlimbs at take-off: suspension (non-weight-bearing) phase of the last stride. The forelimbs have finished working to elevate the forehand. In the hindlimbs, all the joints are flexed, in particular the lumbosacral joint and the hip joint, facilitating engagement.

ENGAGEMENT OF THE LIMB AND PREPARATION FOR LANDING

Engagement of the hind end takes place during the swing phase while the limbs are non-weight bearing. It ends during the suspension phase of the last stride and after take-off of the forelimbs (**11.10**). During this particular phase the hip joint is flexed, while the other joints (stifle, hock and digits) are in transition from flexion to extension (**11.10**). Protraction of the hindlimbs is assisted by horizontal and then vertical propulsion of the forelimbs, which pulls the hindlimbs forward.

Flexion of the hip

This movement is achieved through action of the superficial gluteal, tensor fascia latae and rectus femoris muscles, the cutaneous trunci muscle and, most importantly, the iliopsoas muscle, which also flexes the lumbosacral joint and assists in engagement of the entire hind end. It is important to note that this flexion ends just before contact with the ground; to facilitate landing the hip then undergoes a very mild extension.

Flexion of the other joints of the limb

Flexion of the stifle (femorotibial joint) takes place because of the action of the caudal femoral muscles, in particular the semitendinosus and biceps femoris muscles. We have already described (see Chapter 2, The hindlimb) how this movement automatically induces flexion of the hock because of the structures that make up the reciprocal apparatus (the peroneus tertius and superficial digital flexor muscles). Flexion of the hock joint induces flexion of the fetlock because of tension on the superficial digital flexor tendon resulting from eccentricity of the top of the calcaneus.

▲ **11.11** Joint angulations and muscular actions during landing (ground contact) of the hindlimbs. The lumbosacral joint and the hip are flexed, facilitating engagement of the hindlimbs. All the other joints (stifle, hock and distal limb) are in extension, placing the foot in line with the centre of gravity of the horse. The forelimbs have lifted the forehand in readiness for propulsion from the hind end.

Extension of the joints of the limb

Extension of the middle and distal joints of the limb takes place just before ground contact. It slightly precedes, and occurs to a greater degree than, extension of the hip. Just before landing, the extent of stifle extension is often greater than that which takes place during propulsion (**11.11**).

- Opening of the femorotibial angle is initiated by the quadriceps femoris and tensor fascia latae muscles.
- This results in automatic extension of the hock by the fibrous superficial digital flexor muscle. The caudal leg muscles, in particular the gastrocnemius muscle, also assist this movement.
- Extension of the fetlock and interphalangeal joints takes place through action of the two digital extensor muscles, which unite on the front of the cannon.
- At the end of the non-weight-bearing (swing) phase, just prior to ground impact, isometric muscular contractions place the articular surfaces and the menisci into a pre-stressed state. This facilitates absorption of some of the extreme pressure variations generated at ground impact of the foot.

LOADING OF THE LIMB FOLLOWING GROUND CONTACT

Elevation of the forehand (following take-off of the forelimbs), in combination with loading of the hindlimbs, is accompanied by a drop in the hindquarters of the horse (**11.12**). During this phase, flexion of the joints is controlled and limited by eccentric contraction of different muscle groups:

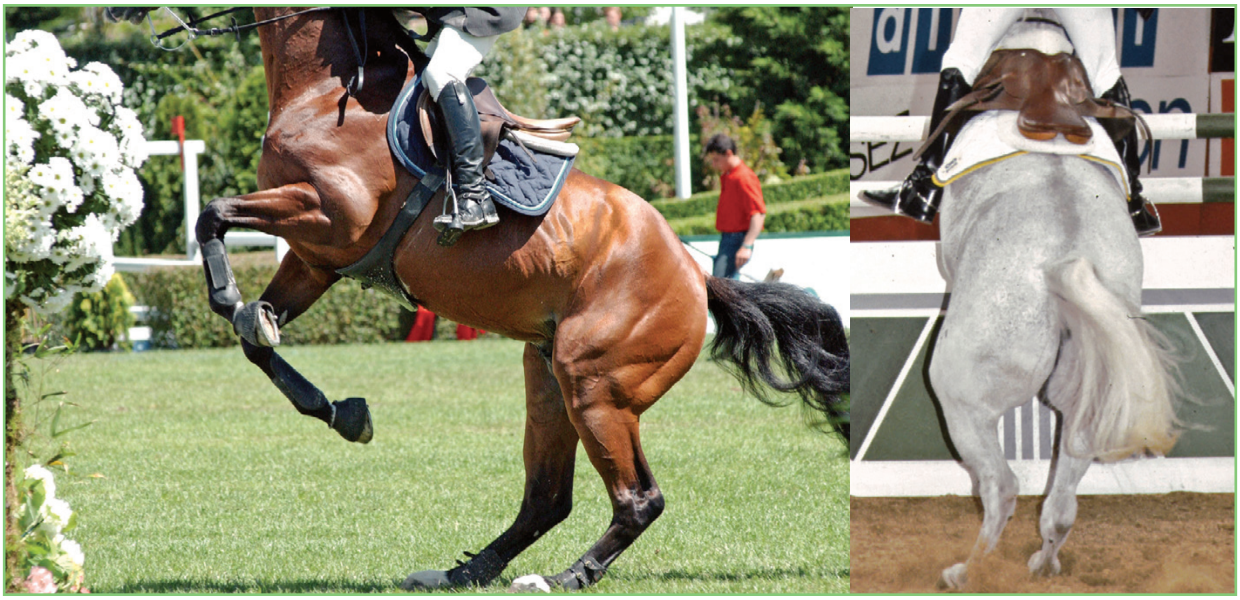
- Flexion of the hip is controlled and limited by the middle gluteal muscle.
- Flexion of the stifle is controlled by the quadriceps femoris muscle.
- Closure (flexion) of the hock is limited by the superficial digital flexor and gastrocnemius muscles.
- Dropping of the fetlock is countered by tension on the superficial and deep digital flexor tendons as well as the suspensory apparatus (suspensory ligament and sesamoidean ligaments).

MID-STANCE PHASE: MAXIMAL JOINT FLEXION

It is during this brief intermediary period between load absorption and propulsion that maximal loading of the active and passive elements of the propulsion phase occurs (**11.13, 11.14**).

The gluteal and cranial femoral muscles undergo intense lengthening; this eccentric contraction will be translated into a powerful concentric contraction during propulsion. The elastic and passive structures of the hindlimb are also markedly lengthened, storing energy that will contribute to joint opening and thus propulsion.

▲ **11.12** Loading of the right hindlimb following ground contact. In both images the left hindlimb is fully engaged ready for ground contact below the centre of gravity of the horse. The caudal femoral muscles are fully lengthened. The forelimbs are flexing, beginning the 'tuck', which becomes more pronounced during the following phases.



▲ **11.13** Mid-stance phase of the hindlimbs at take-off. There is maximal flexion of all joints. The gluteal (croup) and femoral (thigh) muscles are intensely contracted, moving from eccentric to concentric contraction. Flexion of the hock is limited through high tension on the superficial digital flexor muscle and tendon and gastrocnemius muscle contraction, while the fetlock is supported by the digital flexor tendons and the suspensory apparatus. Note the proximal interphalangeal (pastern) joint flexion.

▲ **11.14** Additional views of the mid-stance phase of the hindlimbs prior to propulsion. There is maximal flexion of all the joints of the limb. The lumbosacral joint begins extending so as to facilitate propulsion of the hindlimbs.

▲ **11.15** Start of propulsion of the hindlimbs at take-off. The lumbosacral and hip joints open first through action of the gluteal muscles. In the left image the fetlock lifts slightly despite hyperextension of the metatarsophalangeal joint. The thigh muscles are under tension, extending the stifle and hock joints.

PROPULSION

This is the last phase of take-off, prepared by all the above-mentioned movements and facilitated by the ascending angulation of the body that is created through the forelimb action. There is a synchronous and sudden opening of all the joints of the hindlimb (**11.15, 11.16**), initiated by powerful muscular contractions:

- Extension of the hip essentially occurs through action of the middle gluteal muscle, which also extends the lumbosacral joint. The caudal femoral muscles pull the stifle backwards and initiate straightening of the pelvis (downward traction on the ischium).
- Opening of the femorotibial joint angle takes place from action of the thigh muscles: the quadriceps femoris muscle pulls the patella up (action of the rectus femoris muscle is potentiated by extension of the hip); the caudal femoral muscles pull the stifle caudally and align the femur and tibia; the medial femoral muscles (in particular the adductor magnus muscle) also have a powerful role in coxofemoral and femorotibial extension.
- Extension of the hock results from passive action of the superficial digital flexor muscle and active concentric contraction of the gastrocnemius muscle (potentiated by stifle extension).
- Lifting of the fetlock and verticalization (straightening) of the pastern (interphalangeal joint extension) are assisted by the elasticity of the digital flexor tendons and the suspensory apparatus as well as by active concentric contraction of the deep digital flexor muscles (**11.17**).

Conclusion

All of the mechanical energy liberated during the take-off and propulsion phases of a jump pushes the horse into the second phase, the airborne (or flying) phase, which will be discussed in the next chapter.

◀ **11.16** End of propulsion of the hindlimbs at take-off. Note the significant extension of the hip, stifle and hock joints through concentric contraction of the gluteal and femoral muscles. The lumbosacral joint continues its extension during the airborne (flying) phase of the jump. The fetlocks continue lifting through the elastic action of the plantar tendinous structures. 'Tucking' of the forelimbs assists clearing of the jump.

◀ **11.17** End of propulsion of the hindlimbs at take-off. There is maximal extension of the hip, stifle and hock joints. Verticalization of the pastern leads to rotation of the foot around the toe (break-over), ending propulsion at take-off. This jump is 2.05 m high.

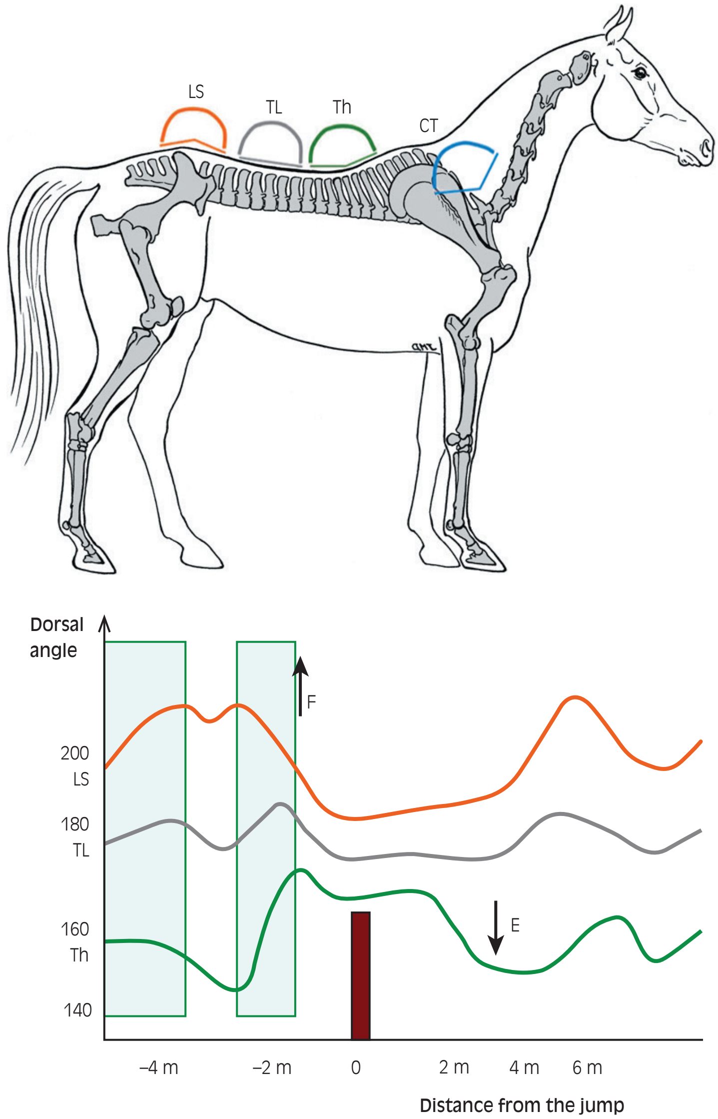
12 Take-off and propulsion: biomechanics of the axial regions (head, neck, trunk and pelvis)

THE AXIAL regions are comprised of the head, neck, trunk and pelvic regions. These regions have a major role in jumping, particularly during take-off. They extend the action of the forelimbs and prepare the hind end for propulsion. The aim of this chapter is to describe the movements of the vertebral column, which connects the regions, and the important muscle actions that contribute to take-off (**12.1**).

In discussing the biomechanics of the axial regions, three phases can be identified at take-off in front of a jump:

- Initiation of take-off where thoracolumbar and lumbosacral flexion predominates in conjunction with engagement of the hindlimbs. Propulsion of the forelimbs is facilitated by extension (lifting) of the neck.
- Stabilization of the axial regions as a result of reverse muscular activity during loading of the hindlimbs.
- Propulsion of the hindlimbs in synchrony with lumbosacral extension and thoracic flexion (**12.2**).

▲ **12.1** Alternation of flexion and extension of the spine between the lumbosacral (behind the saddle) and the thoracic (under the saddle) spine. (**Left**) The horse demonstrates lumbosacral flexion with engagement of the hindlimbs and thoracic extension, assisting lifting of the neck. (**Right**) The lumbosacral region is extended and ends in propulsion of the hindquarters; the thoracic and lower cervical spine are flexed. (Jump height: 1.95 m)



▲ **12.2** Nature and magnitude of flexion and extension movements of the different regions of the vertebral column during jumping. (**Top**) The different axial regions are indicated. LS, lumbosacral; TL, thoracolumbar; Th, thoracic; CT, cervicothoracic junction (base of the neck). (**Bottom**) The variations in the dorsal angle of the thoracic, thoracolumbar and lumbosacral spine are indicated. Upward curvature of the line indicates flexion (F) of the corresponding region and downward curvature indicates extension (E). At take-off before a jump the lumbosacral region moves in the opposite direction to the thoracic spine.

Initiation of take-off (12.3–12.5)

This phase takes place during the stance phase of the forelimbs and facilitates hindlimb engagement. Towards the end of this phase there is a powerful lifting of the forehand in conjunction with impulsion of the forelimbs.

MOBILE REGIONS OF THE SPINE (12.2–12.5)

In the trunk region there are two primary sites of mobility in the spine that allow flexion and extension:

- The **lumbosacral junction** corresponds to two intervertebral spaces in particular, the last lumbar (L5/L6) joint space and the lumbosacral (L6/S1) joint space. The degree of mobility in flexion–extension at these points can be between 20 degrees and 30 degrees. It is important to remember that lateral and rotational movements in this region are virtually non-existent.
- The **thoracolumbar junction** is located between T16 and L2 and is comprised of four intervertebral joint spaces. Due to their anatomical form these joints allow for the largest degree of mobility.

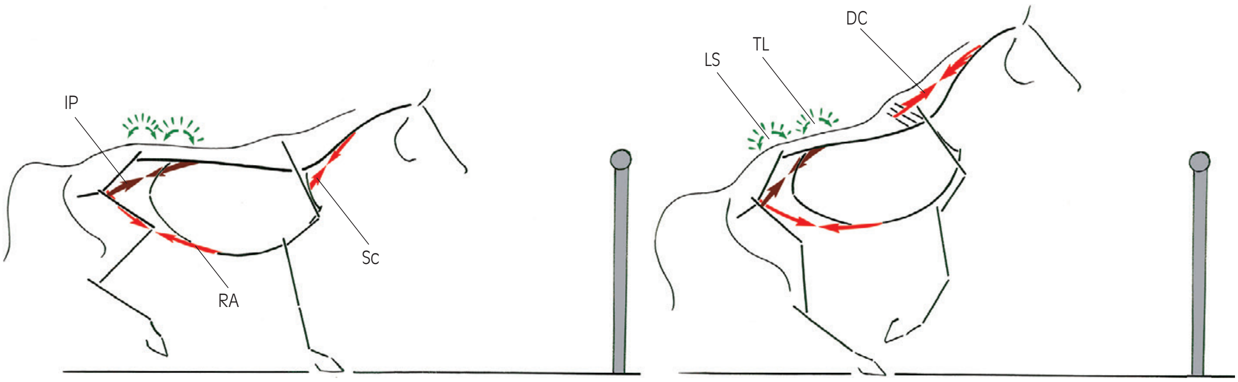
During take-off, thoracolumbar flexion is accompanied by lumbosacral flexion, while the lower cervical and thoracic regions are in extension. This facilitates lifting of the neck and, therefore, the forehand (**12.2, 12.5**).

MUSCLES INVOLVED

There are two important groups of muscles contributing to flexion of the thoracolumbar vertebral column and engagement of the hind end:

- The **iliopsoas muscle**, which flexes the lumbosacral junction and coxofemoral joint (**12.4**).
- The **abdominal wall muscles** (rectus abdominis and oblique abdominal muscles), which are responsible for flexion of the lumbosacral and thoracolumbar junctions as well as other segments of the vertebral column (**12.6**). Contraction of these muscles shortens the frame of the horse.

▲ **12.3** Powerful flexion of the lumbosacral joint facilitating engagement of the hindlimbs during take-off in front of a water jump. Extension of the stifle and distal articulations optimizes positioning of the limb for ground contact.



▲ **12.4** Biomechanics of the trunk and neck during take-off of the fore- (**left**) and hindlimbs (**right**). Muscular activity assists in lumbosacral and thoracolumbar flexion on one hand and thoracic and cervical extension on the other. IP, iliopsoas muscle; RA, rectus abdominis muscle; Sc, scalenus muscle; DC, dorsal cervical muscles; LS, lumbosacral junction; TL, thoracolumbar junction.

▲ **12.5** Positioning of the trunk prior to take-off before a 1.90 m jump. Engagement of the hind end and lifting of the forehand result in an overall upward swing of the body.

▶ **12.6** Contraction of the abdominal muscles facilitating engagement of the hindlimbs in conjunction with lumbosacral and coxofemoral joint flexion prior to ground contact of the hindlimbs at take-off.

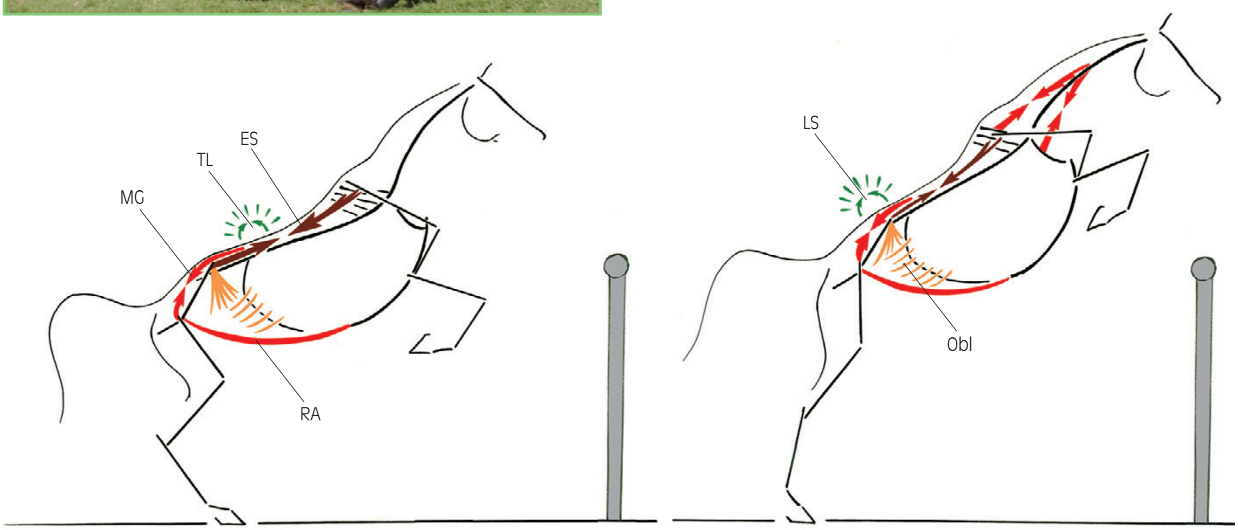
Stabilization of the trunk and reverse muscle action (12.7–12.9)

Just after landing, loading of the hindlimbs while the forehand is elevated introduces a new concept that needs to be considered: support and stabilization of the trunk by the vertebral axis.

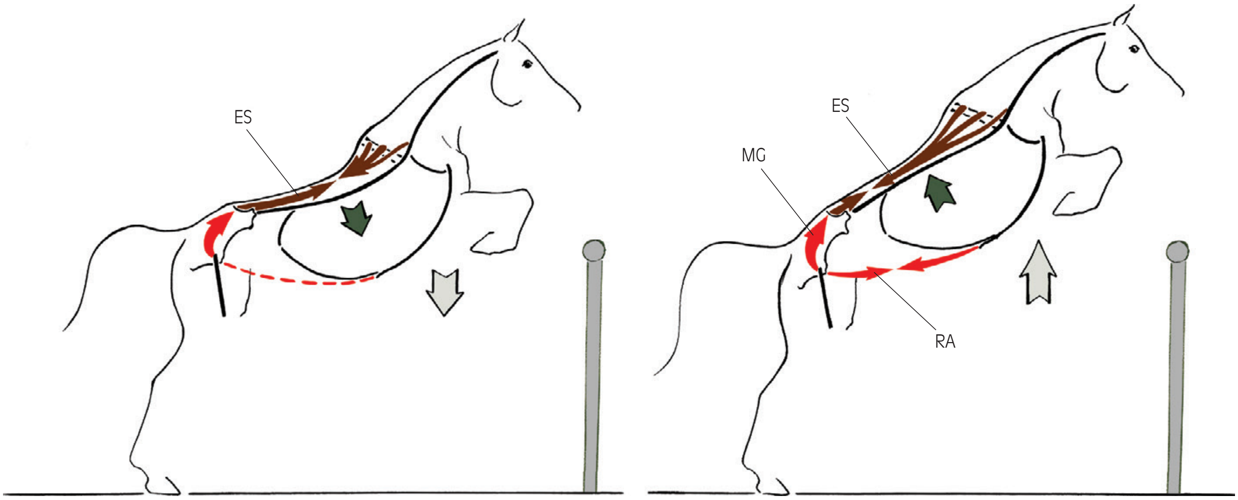
The mechanisms through which this occurs are complex. Basically, this position, which prepares the hind end for propulsion, requires a simultaneous isometric contraction of the abdominal and erector spinae muscles. The activity of these muscles lasts for a short period of time and is synergistic and complementary such that four specific events take place (**12.8–12.10**):

- Elevation and support of the trunk are facilitated through action of the middle gluteal and erector spinae muscles. Contraction of the latter has a tendency to place the vertebral column in extension, which would counter efficient movement. Vertebral alignment is therefore only possible through a simultaneous isometric contraction of the abdominal muscles (the rectus abdominis muscle in particular).

12.7 Stabilization of the trunk preceding inversion of flexion–extension movements of the vertebral column. Note the contraction of the abdominal muscles. These muscles stabilize the thoracolumbar spine during propulsion of the hindlimbs. Contraction of these muscles opposes extension of the spine by the erector spinae muscle, which assists lifting of the forehand. The force of this contraction is centred on the lumbosacral joint.

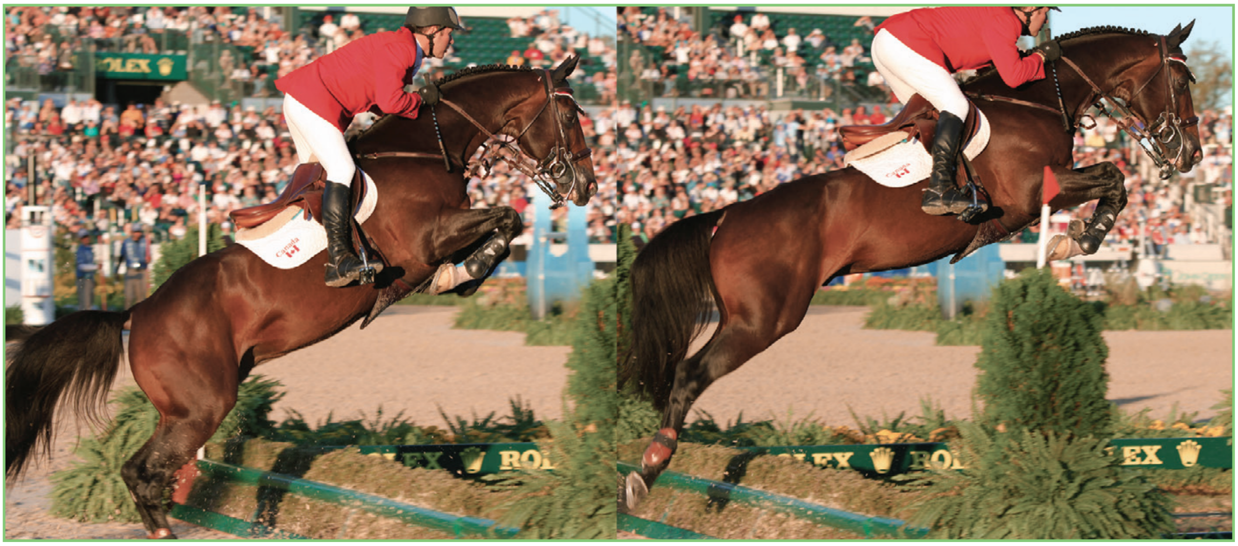


12.8 Biomechanics of the trunk and neck during take-off on the hindlimbs. (**Left**) Stabilization of the trunk and activity of the extensors of the spine. (**Right**) Extension of the lumbosacral junction and flexion of the lower neck and thoracic spine. RA, rectus abdominis muscle; MG, middle gluteal muscle; ES, erector spinae muscle; Obl, internal and external oblique abdominal muscles; TL, thoracolumbar junction; LS, lumbosacral joint.



▲ **12.9** Biomechanics of the trunk during take-off without and with abdominal muscle intervention. (**Left**) Propulsion without abdominal muscle intervention: the erector spinae (ES) muscle elicits extension of the thoracolumbar spine. The horse will therefore jump with a 'hollow back' and the forehand will drop. (**Right**) Propulsion with abdominal muscle intervention (RA, rectus abdominis muscle). The middle gluteal (MG) and the erector spinae (ES) muscles act to lift the forehand.

▲ **12.10** Effect of abdominal contraction on the thoracolumbar spine at take-off. (**Left**) Propulsion with concurrent abdominal contraction; the back of the horse is straight and will therefore efficiently transmit the forces of the hindlimbs at push off. (**Right**) Inadequate contraction of the flexor muscles of the vertebral column (ventral cervical and abdominal muscles), resulting in extension of the cervical and thoracolumbar spine.



▲ **12.11** Cervical and thoracic flexion with lumbosacral extension over a water jump. Powerful lumbosacral extension takes place following propulsion that is generated through extension of the hindlimbs. **Note:** This photo shows the continuation of the movement of the horse in **12.3**.

- Synchronous contraction of the abdominal and erector spinae muscles balances the pressures placed across the vertebral column, in particular at the level of the intervertebral discs. Contraction of the abdominal wall (oblique and transverse abdominal muscles) contributes to the development of a stable core, which has an essential role in distribution of stresses within the internal abdominal and vertebral structures.
- Simultaneous contraction of the flexor and extensor muscles of the vertebral column results in stiffening of the spine, facilitating transmission of forces to the trunk and forehand from the hindlimbs during propulsion. This synchronous contraction also places the vertebrae in a pre-stressed state, allowing for absorption of the sudden variable pressures encountered during propulsion in various sport exercises.
- Finally, contraction of the abdominal wall muscles balances the action of the erector spinae muscle on the thoracolumbar spine, resulting in a concentration of its action on the lumbosacral joint (**12.11**).

These events precede the onset of concentric contraction of the extensor muscles, which accompanies impulsion of the hindlimbs.

Propulsion phase (12.11) ❑

During this last phase of take-off, flexion at the cervicothoracic junction (junction between the neck and the thorax located between the shoulders and resulting in a relative lowering of the head and neck) and flexion of the thoracic spine precede and potentiate thoracolumbar flexion. Lumbosacral extension increases the push of the hindlimbs (**12.2, 12.11**).

- **Cervical and thoracic flexion.** This occurs because of contraction of the ventral cervical muscles. They promote tension of the nuchal ligament, pulling the dorsal spinous processes of the withers forwards, which results in thoracic flexion (see Chapter 3, The neck and trunk). These movements result in flattening of the spine and prepare the vertebral axis for pushing off from the hind end.

- **Lumbosacral extension.** This movement potentiates propulsion of the hind end. It is the result of concentric contraction of the most powerful muscles in the horse, the erector spinae and middle gluteal muscles (**12.11**). The middle gluteal muscle is also a very effective extensor of the coxofemoral (hip) joint.

During this entire phase, isometric contraction of the abdominal wall muscles contributes to the support and stability of the vertebral axis. Meanwhile, the iliopsoas muscle relaxes so that lumbosacral and coxofemoral extension is not inhibited.

Biomechanics of the neck

The biomechanics of the neck effectively contributes to movements of the entire trunk.

LOWERING OF THE NECK

Lowering of the neck at ground contact of the forelimbs loads the forelimbs and promotes two actions:

- Lightening and engagement of the hindquarters.
- Lengthening of the muscular girdle that supports the forehand. This potentiates concentric contraction of these muscles during subsequent vertical propulsion by the forelimbs.

The muscles primarily responsible for lowering of the neck are the scalenus muscle (**12.4**) and the sternocephalicus muscle.

RAPID ELEVATION OF THE NECK

Rapid elevation of the neck during propulsion of the forelimbs lightens the forehand. It also assists in vertical impulsion and releases the nuchal and supraspinous ligaments. This facilitates thoracolumbar flexion and engagement of the hind end (**12.12**).

The muscles associated with this movement are the dorsal cervical muscles, in particular the semispinalis and splenius muscles. They attach onto the high spinous processes of the withers, which, in addition, also undergo traction towards the rear induced by the erector spinae muscle.

◀ **12.12** Elevation of the head and neck along with extension of the cervicothoracic junction (junction between the neck and the thorax, between the shoulders). This movement initiates lifting of the forehand in front of the jump. At the same time, the supraspinous ligament is released, facilitating flexion of the thoracolumbar spine and engagement of the hind end.

PROPULSION OF THE HINDLIMBS

During propulsion of the hindlimbs, action of the scalenus and sternocephalicus muscles results in cervicothoracic flexion. This results in a straightening and stabilization of the thoracolumbar bridge. Cervicothoracic flexion is also coupled with contraction of the dorsal cervical muscles and places the nuchal and the supraspinous ligaments under tension.

These two actions pull the spinous processes of the withers forward, resulting in flexion of the thoracic spine, which in turn potentiates extension of the lumbosacral spine by the erector spinae muscle (**12.13, 12.14**).

◀ **12.13** Lowering of the head and neck during propulsion of the hind end. Flexion of the cervicothoracic junction along with contraction of the dorsal cervical and abdominal muscles increases intervertebral pressures in the back, favouring transmission of forces generated during hindlimb propulsion. At the same time, cranial lengthening of the erector spinae muscle (underneath the saddle) promotes extension of the lumbosacral junction.

◀ **12.14** Substantial flexion of the head and neck places tension on the topline (increased intervertebral pressure) and extension of the lumbosacral junction. The position of this horse during cross-country clearly demonstrates the functional relationship between the various axial regions.

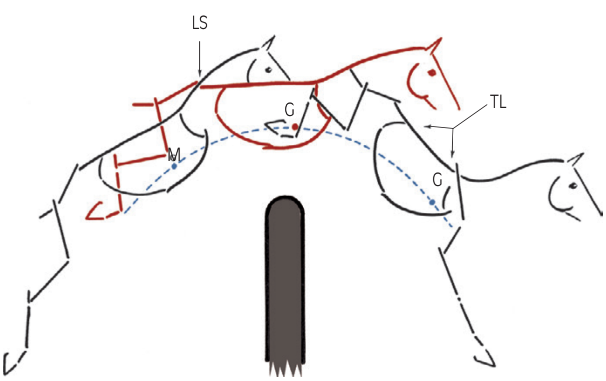
13 Airborne (flying) phase: biomechanics of the trunk and vertebral column

Having discussed the biomechanics that take place during take-off and propulsion, it is now necessary to analyse the movements of the horse during the airborne (flying) phase (**13.1**), which may vary substantially from one horse to another. This chapter will allow the inherent style of any given horse to be characterized and thus identify its strengths and also any weaknesses that need improving.

This phase of jumping involves muscular activity that is less intense than during take-off or landing. Nevertheless, it is important to discuss this phase, as any irregularities in the position of the limbs or the vertebral column can result in a fault.

As with the take-off and propulsion chapters, the biomechanics of the trunk and vertebral column and those of the limbs will be addressed separately. Analysis of the airborne (flying) phase will be in three parts (**13.2**): the first phase (the upward or ascending phase) starts once the hindlimbs leave the ground after propulsion; the second phase (the peak phase) corresponds to the true airborne component; and the third phase (the downward or descending phase) prepares the horse for landing and finishes once the forelimbs touch the ground. For each phase, the muscular activity and the resulting joint movements that take place will be discussed.

13.1 Good illustration of the jump suspension (airborne phase) over a water jump. Note the light rotation of the pelvis.



13.2 The three main components of the jump suspension. Note the variations in extension of the different regions of the vertebral column. LS, lumbosacral extension; TL, thoracolumbar extension. Note also that the centre of gravity (G) follows a parabolic curve determined during take-off.

Upward or ascending phase

KINESIOLOGY

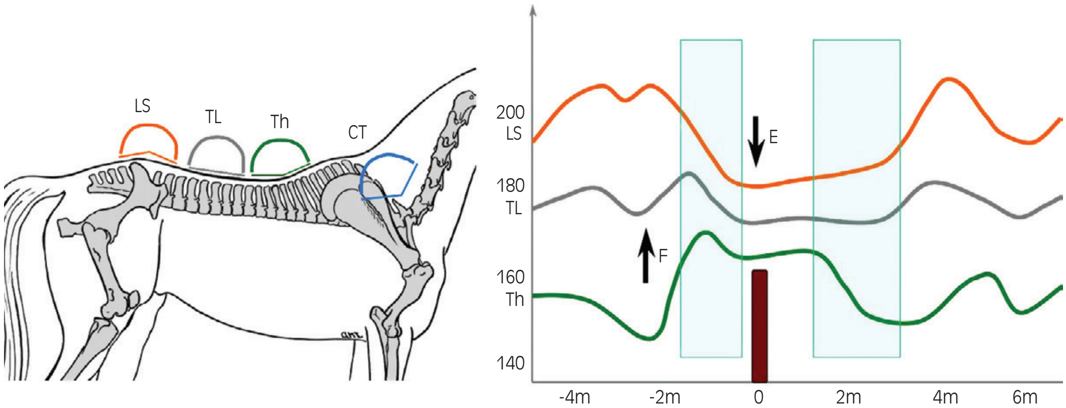
Flexion of the lower neck takes place at the end of propulsion of the hindlimbs and continues during the upward phase of the airborne (flying) phase. This flexion results in a flattening of the normal curvature of the spine at the cervicothoracic junction (**13.3, 13.4**) and is sometimes associated with extension of the poll. Its resultant effect is a mild flexion of the thoracic spine (see Chapter 3, The neck and trunk).

As soon as the hindlimbs lift off the ground surface there is a rapid alleviation of compressive forces (generated during propulsion) in the thoracolumbar spine. The thoracolumbar spine experiences little movement other than a mild and progressive extension while the horse's body is moving upwards (**13.4, 13.5**).

MUSCULAR ACTIONS

The most active muscular contractions during the upward phase of the airborne (flying) phase are by the scaleni muscles. They initiates flexion of the cervicothoracic junction and the muscles of the upper neck, which act to extend the head. In the thoracolumbar and abdominal regions, the muscle groups that during propulsion acted to support the vertebral axis and balance compressive forces have a change in role. During the peak (second) phase of the airborne (flying) phase, release of the abdominal muscles and contraction of the erector spinae result in extension of the thoracolumbar and lumbosacral spine.

◀ **13.3** Upward (ascending) phase of the jump suspension. The lumbosacral joint continues in extension and the neck drops, aligning with the back and initiating thoracic flexion underneath the saddle (where the cantle is lifting in the photo).



▲ **13.4** Nature and magnitude of flexion and extension movements in the different regions of the vertebral column of the horse during jumping. (**Left**) The different regions of the spine are illustrated. LS, lumbosacral junction; TL, thoracolumbar junction; Th, thoracic region; CT, cervicothoracic junction (base of the neck). (**Right**) This drawing illustrates the variations in the dorsal angle of the thoracic, thoracolumbar and lumbosacral spine. Upward curvature of the line indicates flexion (F) of the corresponding region, while downward curvature indicates extension (E). The two light green strips indicate the upward and downward phases of the jump suspension separated by the peak phase.

▲ **13.5** Upward phase of the jump suspension. There is a release in the stresses on the lumbosacral and lower cervical regions, with the joint angles shifting into a neutral position. The lumbosacral and thoracolumbar junctions continue in extension.

Peak phase

At this stage of the jump there are no muscular actions that can affect the trajectory of the horse's body mass. However, the horse can change the relative position of its body segments: axial (head, neck, trunk and pelvis) and appendicular structures (fore- and hind-limbs) (**13.6**). The peak phase of the airborne (flying) phase allows the most independent movement of the various regions of the trunk (**13.7**). The vertebral movements can take place in two different planes: median (or longitudinal) and transverse.

MOVEMENTS IN THE MEDIAN PLANE

Mobilization of the vertebral segments takes place around two key mobile regions: the cervicothoracic junction and the lumbosacral junction (**13.7**).

Cervicothoracic junction

The action of the cervicothoracic junction depends on the type of jump and on the horse's style:

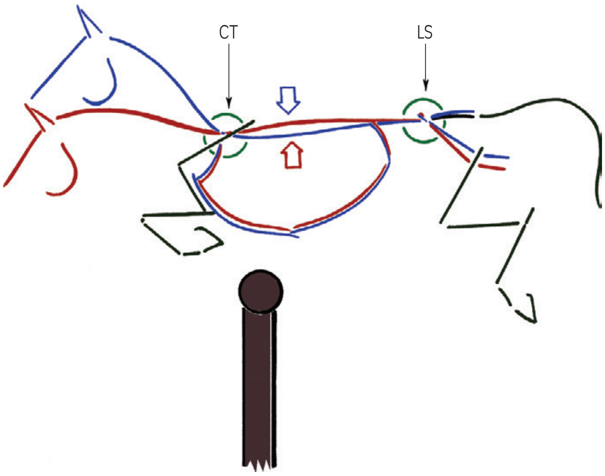
- In a long jump (e.g. water jump) or a bascule jump, the cervical and thoracic spine adopts a certain degree of extension. The horse appears to be jumping with a hollow back. This extension is primarily due to contraction of the most cranial (thoracic) part of the erector spinae muscle.
- In an upright jump (e.g. wall) or a roll top jump, lowering of the neck is accompanied by thoracic flexion (**13.8**). The horse therefore jumps with a rounded arch. This cervicothoracic flexion is initiated by the scalene and longus colli muscles.

Lumbosacral junction

The lumbosacral junction amplifies the gradual increase in extension initiated during take-off. This extension is displayed sooner when placement of the hindlimbs at take-off is far from the fence. Extension is achieved by concentric contraction of the lumbar part of the erector spinae muscle. At the same time, the middle gluteal muscle reduces its action, which facilitates flexion of the hip (coxofemoral) joint.

Depending on the limb placements during the approach phase of the jump, the horse may then undertake thoracolumbar and lumbosacral flexion to assist passage of the hindlimbs over the jump, especially if it is already experiencing any difficulties in making clearance (**13.9**). In this situation, the abdominal wall muscles and the iliopsoas muscles contract to facilitate the movement (**13.10**).

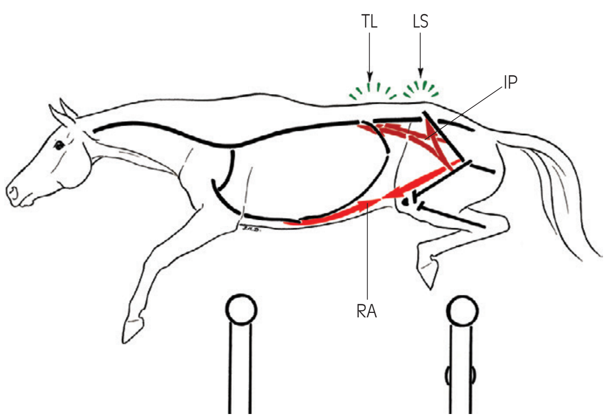
◀ **13.6** Peak phase of the jump suspension. The release of the abdominal muscles allows for lumbosacral extension.



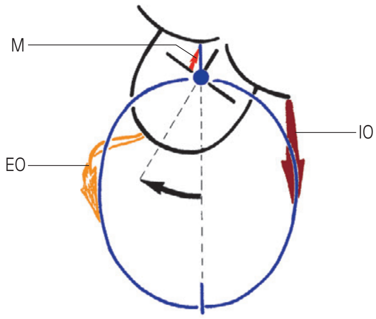
▲ **13.7** Position of the different vertebral segments during the peak phase of the jump suspension. Lifting of the neck (extension of the cervicothoracic junction) is accompanied by thoracic extension, while lowering of the neck (cervicothoracic flexion) results in concurrent thoracic flexion. CT, cervicothoracic junction; LS, lumbosacral junction.

▲ **13.8** Peak phase during jump suspension. To be able to clear this very high jump (2.05 m), lowering of the neck is increased to facilitate clearance of the hindlimbs over the jump.

▲ **13.9** Extension of the thoracolumbar spine and the beginning of lumbosacral flexion during the jump suspension. This horse is experiencing difficulty in clearing the jump after taking off too far from the fence.



▲ **13.10** The position of a horse attempting to clear a jump and avoid a fault during the peak phase of the jump suspension. The protraction movement of the hindquarters and flexion of the hindlimbs is intense. These movements are the result of contraction of the rectus abdominis (RA) and iliopsoas (IP) muscles. The thoracolumbar (TL) and lumbosacral (LS) junctions undergo significant flexion. Flexion of the hip is not limited by lengthening of the caudal femoral muscles in this situation, as there is minimal tension on their distal insertions because of flexion of the stifle.



◀ **13.11** Vertebral rotation during the jump suspension. (**Right**) Downward (descending) phase of the jump suspension. The deviation of the hindlimbs to the right is allowed through rotation of the thoracic vertebral column (underneath the saddle) and is associated with right lateroflexion of the spine. The oblique abdominal muscles have a crucial role in this movement. (**Left**) This drawing illustrates the thorax and pelvis front on. The muscles responsible for thoracolumbar rotation are the internal oblique (IO) and external oblique (EO) muscles, as well as the thoracolumbar portion of the multifidus (M) muscle.

MOVEMENTS IN THE TRANSVERSE PLANE

The majority of horses demonstrate little lateral or rotational vertebral movements during the suspension phase of the jump. However, there are some horses that exhibit remarkable rotational movements (**13.11**) over jumps, often in the same direction.

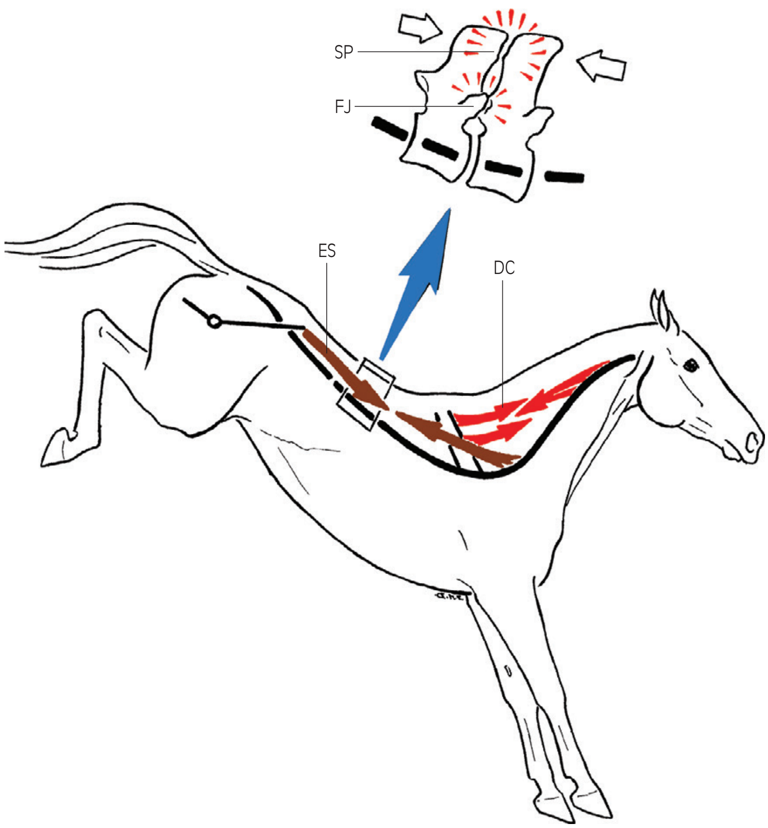
Spinal rotation takes place primarily in the middle of the thoracic region between the 9th and 14th thoracic vertebrae (the horse has 18 thoracic vertebrae in total). It is associated with lateroflexion of the spine, which takes place in the same location. This movement is controlled mostly by concentric contraction of the internal and external oblique abdominal muscles and, to a lesser extent, by the thoracolumbar portion of the multifidus muscle (**13.11**).

Downward or descending phase

This movement requires maximal extension of the vertebral column. Vertebral extension takes place at three locations in the trunk (**13.2**):

- **Cervicothoracic extension.** Extension between the lower cervical and thoracic spine assists preparation for landing (**13.12**). This is made possible through concentric contraction of the dorsal cervical muscles and the thoracic portion of the erector spinae muscle.
- **Thoracic and thoracolumbar extension.** These two regions rapidly reach maximal extension with the dorsal spinous processes becoming very close (**13.13**). This movement may be responsible for vertebral pain in horses with impinging dorsal spinous processes or arthritis of the small synovial joints of the back (facet joints). These two conditions can be the cause of, or contribute to, back and lumbar pain in a number of sport horses. Contraction of the entire length of the erector spinae muscle results in this extension and facilitates clearance of the hindlimbs over the fence.

◀ **13.12** Extension of the vertebral column during the downward (descending) phase of the jump suspension. The neck lifts, preparing for landing of the forelimbs. This movement results in thoracic extension. The thoracolumbar and lumbosacral junctions are in full extension to facilitate clearance of the hindlimbs over the fence.



◀ **13.13** Vertebral extension during the downward (descending) phase of the jump suspension. The dorsal cervical (DC) and erector spinae (ES) muscles are extensors of the spine. This movement can cause contact of the spinous processes (SP) and can increase pressure in the facet joints (FJ) of the back. This may result in back or lumbar pain.

▲ **13.14** Extension of the thoracolumbar spine during the downward phase of the jump suspension. This movement facilitates clearance of the hindquarters. The lumbosacral joint transitions from extension to flexion, preparing the hindlimbs for ground contact.

- **Lumbosacral extension.** In this last phase of a jump, there is a high degree of extension at the lumbosacral junction (**13.12**), which facilitates clearance of the hindlimbs. This is made possible because of the diverging nature of the spinous processes between the last lumbar vertebra and first sacral spinous process. This movement, which displaces only the hindquarters, is more easily achieved than the same movement during propulsion. It results from concentric contraction of the lumbar portion of the erector spinae muscle.

Once maximal extension has been reached, there is a rapid initiation of flexion of the lumbosacral and coxofemoral (hip) joints (**13.14, 13.15**), which will be discussed in the chapter dedicated to the landing phase (Chapter 15: Landing phase: biomechanics of the vertebral column). This alternation between maximal extension and flexion may take place before the forelimbs actually contact the ground.

▲ **13.15** Thoracolumbar extension and the beginning of lumbosacral flexion at the end of the downward phase of the jump suspension. Lifting of the neck is accompanied by a powerful thoracic extension. This extension is responsible for significant stresses on the thoracic and thoracolumbar spinous processes, the dorsal facet joints and the intervertebral discs.

14 Airborne (flying) phase: biomechanics of the limbs

Having discussed the movements of the vertebral column during the airborne (flying) phase of jumping, the biomechanics of the fore- and hindlimbs will now be discussed. The nature and extent to which the limbs move over a jump contribute to the agility of the horse.

Biomechanics of the forelimbs

The biomechanics of the forelimbs during the airborne (flying) phase can be broken down into two components: flexion during the upward and peak phases (**14.1**) and extension during the downward phase.

FLEXION ('TUCK UP')

'Tuck up' of the forelimbs is mostly initiated during take-off and is associated with a horizontalization of the shoulder and flexion of the rest of the joints of the limb (**14.1–14.4**).

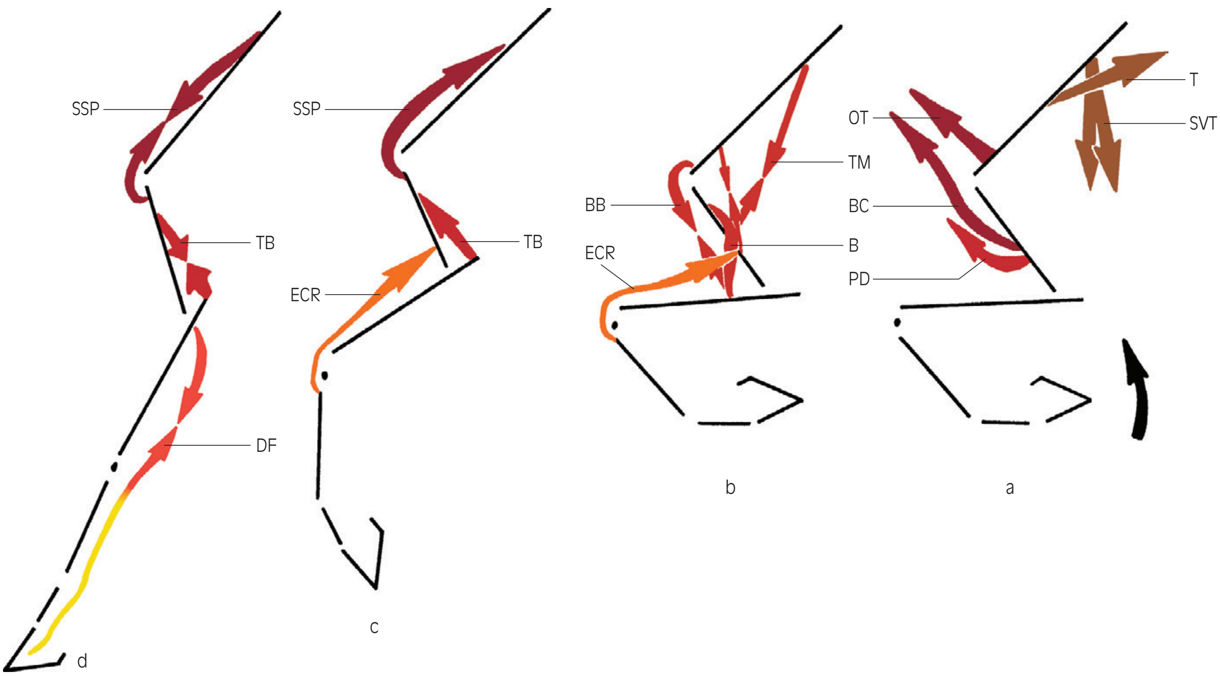
HORIZONTALIZATION OF THE SHOULDER

This action is essential to the efficiency of movement during the upward (ascending) phase (**14.2–14.4**). There is a swing of the scapula where the upper extremity is pulled backwards and the lower extremity upwards. The extent of this movement can sometimes be greater than 20 degrees.

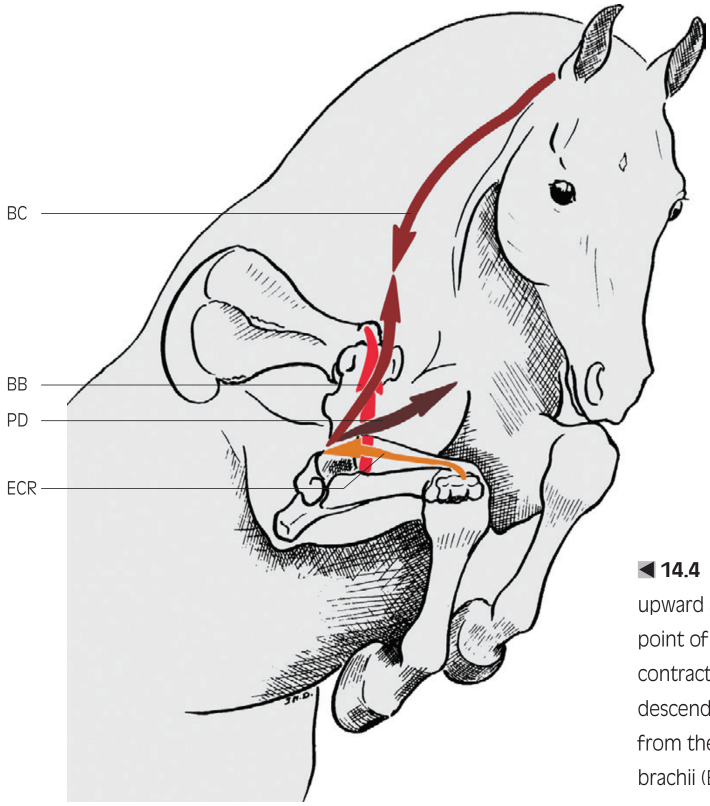
- Backward sliding of the upper extremity of the scapula occurs because of concentric contraction of the thoracic component of the trapezius muscle as well as the caudal fasciculi of the serratus ventralis thoracis muscle (**14.3**).

14.1 Flexion of the fore- and hindlimbs during the jump suspension.

◀ **14.2** Flexion ('tuck up') of the forelimbs during the upward phase of the jump suspension. Note the horizontalization of the shoulder and the forearm, with flexion of the carpus resulting partly from a flail effect.



▲ **14.3** Active muscles during flexion of the forelimbs during the upward phase and extension during the downward phase, preparing the forelimbs for ground contact. (**a**) Elevation of the shoulder. T, trapezius (thoracic component) muscle; SVT, serratus ventralis thoracis muscle; OT, omotransversarius muscle; BC, brachiocephalicus muscle; PD, pectoralis descendens muscle. (**b**) Flexion of the joints. TM, teres major muscle; B, brachialis muscle; BB, biceps brachii muscle; ECR, extensor carpi radialis muscle. (**c**) Extension of the joints preparing for landing. SSP, supraspinatus muscle; TB, triceps brachii muscle (short heads); ECR, extensor carpi radialis muscle. (**d**) Full extension of the forelimb before landing. SSP, supraspinatus muscle; TB, triceps brachii muscle (short heads); DF, digital flexor muscles.



◀ **14.4** Flexion ('tuck up') of the forelimbs during the upward and peak phases of the jump. Elevation of the point of the shoulder is performed through concentric contraction of the brachiocephalicus (BC) and pectoralis descendens (PD) muscles; flexion of the elbow results from the synergistic concentric contraction of the biceps brachii (BB) and extensor carpi radialis (ERC) muscles.

- Lifting of the point of the shoulder is due to concentric contraction of the pectoralis descendens, brachiocephalicus (**14.4**) and omotransversarius muscles.

JOINT FLEXION

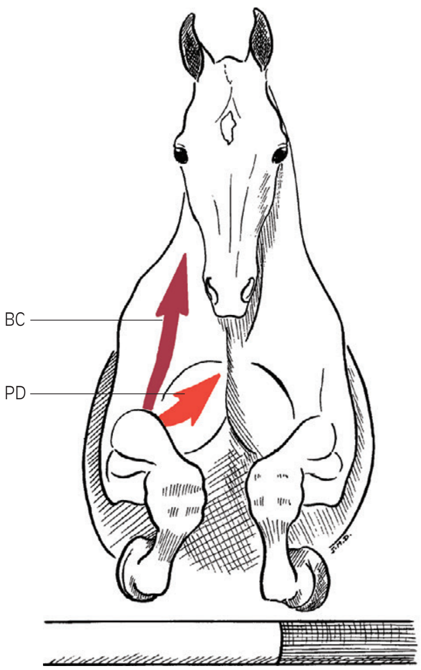
In the forelimb, closure of all the joint angles takes place at the same time. Flexion of the upper limb joints results in a flow-on effect to the distal limb segments (metacarpus and digit, **14.2, 14.5**).

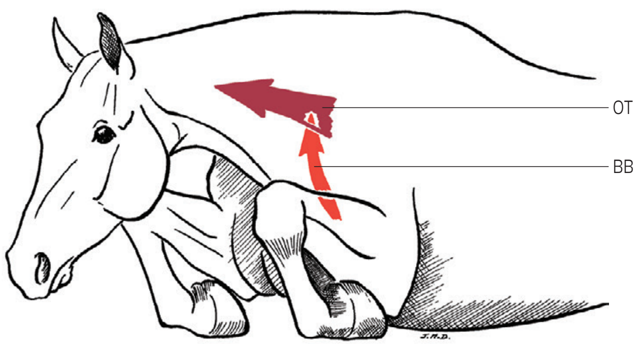
- The degree of flexion of the shoulder joint is small, approximately 20° (the scapulohumoral joint angle is reduced to approximately 70°). This flexion is initiated by contraction of the long head of the triceps brachii, deltoideus and teres major muscles.
- The elbow flexes to a much larger degree. The joint angle shifts to about 90° relative to the position of the limb during weight bearing, only remaining open to approximately 45°. This flexion is achieved through a combined action of the biceps brachii, brachialis and extensor carpi radialis muscles (**14.4, 14.5**).
- Flexion of the carpus and digital joints is partly the result of a flail reaction resulting from rapid flexion of the elbow pulling the distal segments by inertia as well as concentric contraction of the caudal antebrachial muscles.

Individual characteristics (style)

Other than flexion and extension, in some horses the limb undergoes movement in the transverse plane (**14.6**).

◀ **14.5** Perfect symmetry of the fore- and hindlimbs during the peak phase of the jump suspension. All the joints of the forelimb are flexed. The horizontalization of the shoulder assists in lifting the knees. The point of the shoulder is lifted upwards and forwards through concentric contraction of the brachiocephalicus and omotransversarius muscles. The upper extremity of the shoulder, under the saddle, drops through contraction of the serratus ventralis thoracis muscle. There is maximal flexion of the elbow and shoulder. Flexion of the carpus and fetlock brings the foot into contact with the elbow.





▲ **14.6** Individual variations in sport gesture (style of the jump) during the forelimb flexion. (**Left**) Adduction of the forelimbs through action of the pectoralis descendens (PD) and brachiocephalicus (BC) muscles. (**Right**) Forelimbs (knees) in light abduction. Flexion of the elbow is initiated by the biceps brachii muscle (BB), while forward lifting of the shoulder occurs through concentric contraction of the omotransversarius muscle (OT).

- In general, flexion of the elbow and lifting of the shoulder brings the carpi (knees) closer together. This is an adduction movement and is primarily controlled by contraction of the pectoralis descendens muscle, which induces a medial rotation of the humerus (**14.6, 14.7**). It is often accompanied by medial rotation of the canons and lateral deviation of the feet (**14.6**).
- In some horses this adduction does not take place. In these horses, the tuck of the forelimbs is less attributable to the pectoralis descendens muscle and instead takes place because of action of the omotransversarius muscle. Contraction of the omotransversarius muscle lifts the shoulder, while the biceps brachii and brachialis muscles flex the elbow. In some instances, adduction is followed quickly by abduction of the limbs during the same jump.
- Other horses, which are not necessarily skilled in jumping, may lack elevation of the shoulders and flexion of the elbows during the airborne (flying) phase (**14.8**).
- In contrast, during jumping at high speed, where the take-off and landing are further from the jump, horizontalization and protraction of the shoulder are more marked in order to facilitate clearance of the jump (**14.9**).

▲ **14.7** Tuck of the forelimbs during the jump suspension. Contraction of the pectoralis descendens and brachiocephalicus muscles lifts the humerus and the point of the shoulder. Flexion of the elbow occurs through concentric contraction of the biceps brachii, brachialis and extensor carpi radialis muscles.

▲ **14.8** Failure to flex the elbows and lift the shoulders and knees during the jump suspension. Note the lack of elbow flexion; the shoulder and the forearm remain vertical. In this horse, the brachiocephalicus and pectoralis descendens muscles have not mobilized the humerus and scapula. There is a lack of contraction of the biceps brachii and brachialis muscles, limiting flexion of the elbow.

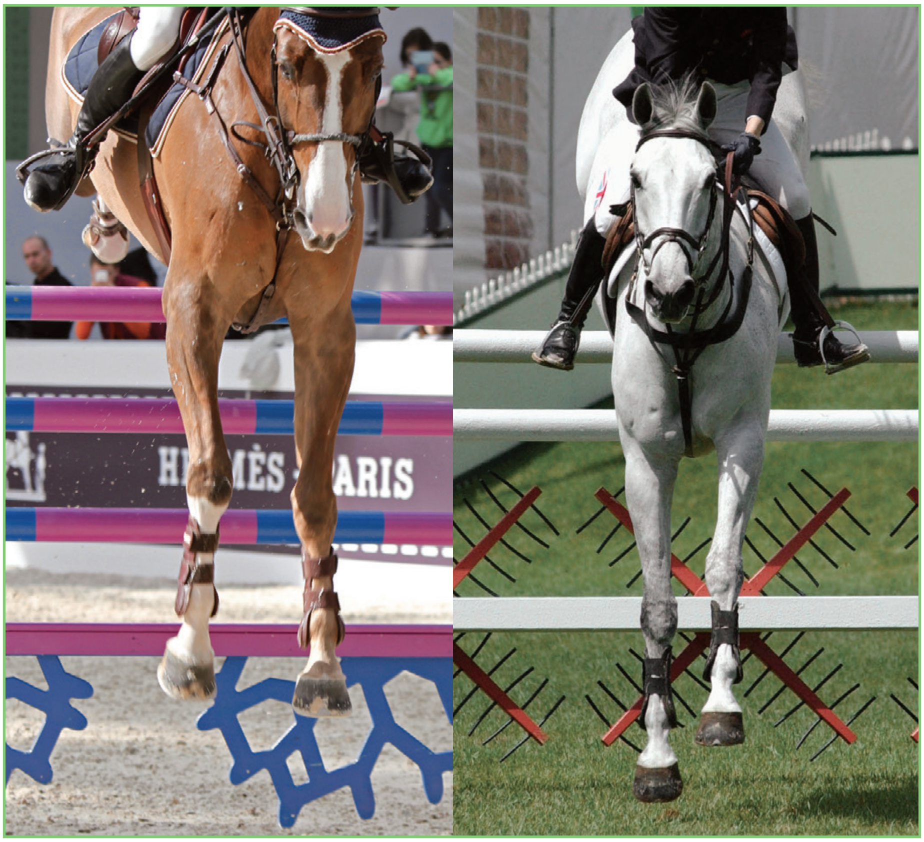
▲ **14.9** Horizontalization of the shoulder and protraction of the humerus and elbow at the start of the jump suspension in an event horse. The brachiocephalicus and pectoralis descendens muscles have undergone an intense concentric contraction to pull the humerus (and therefore the point of the shoulder and elbow) forward. The biceps brachii and brachialis muscles flex the elbow.

◀ **14.10** Initiation of extension of the carpus, preparing the horse for landing. Contraction of the dorsal antebrachial muscles is evident. The upper joints of the shoulder and elbow begin to open.

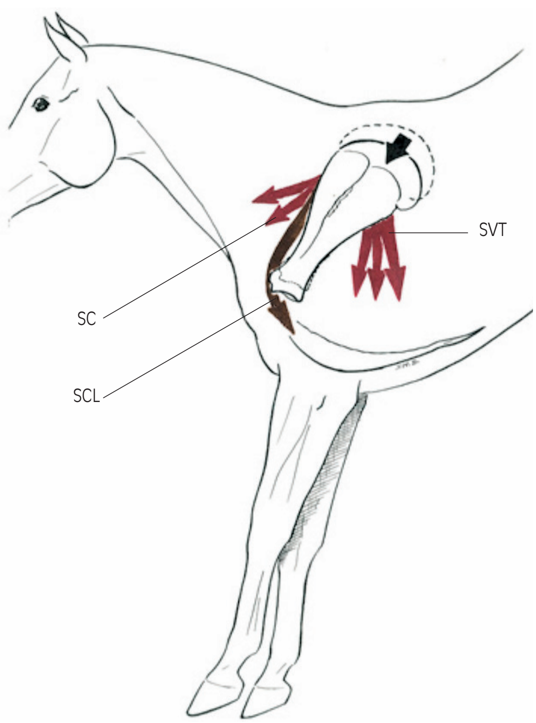
EXTENSION PHASE

Opening of the joint angles, thus preparing the horse for landing, sometimes takes place at the peak phase of the jump suspension. Extension of the scapulohumeral (shoulder) joint and the carpus occurs before the elbow (**14.10**). This is followed by extension of the rest of the joints (**14.11**) with the shoulder sliding and dropping down towards the end of the movement (**14.12**).

- Extension of the shoulder (scapulohumeral) joint is initiated by concentric contraction of the supraspinatus muscle (**14.3**). At the end of the movement, just prior to ground contact, extension of the shoulder is maximal. The scapulohumeral joint angle can reach 120°.
- Extension of the elbow is at first mild and then increases rapidly to an open angle of approximately 140°, the forearm becoming vertical in orientation. This extension is a result of the concentric contraction of the lateral and medial heads of the triceps brachii muscle.
- Extension of the carpus (knee) is primarily initiated by concentric contraction of the extensor carpi radialis muscle, which re-establishes the alignment of the forearm and cannon (180° angle).
- Extension of the fetlock and interphalangeal joints is delayed relative to the upper limb and is the result of concentric contraction of the dorsal and lateral digital extensors. When evaluated during slow motion, this extension is wave-like (extension of the fetlock, pastern then foot) just prior to landing. This movement is the result of gradual tension placed on the digital flexor muscles, which contract, preparing the digital flexor muscles and tendons for absorption of the forces that are inherent on landing.
- Finally, to slow the drop of the trunk between the forelimbs at landing, the shoulders undergo a downward sliding. This precipitates ground contact and increases the duration of loading of the forelimbs (**14.11, 14.12**).
- Downward sliding of the scapula is the result of concentric contraction of the serratus (serratus ventralis thoracis and cervicis) muscles and the subclavius muscles. This places the muscles in a pre-stressed state and allows them to play a role in loading of the limb at landing, through a controlled eccentric contraction.



◀ **14.11** Extension of the joints of the forelimb preparing the horse for ground contact. Extension of the shoulder and elbow prepares the muscles for an eccentric contraction, which will take place during loading after ground contact. Opening of the scapulohumeral joint is initiated by the concentric contraction of the supraspinatus muscle. Extension of the elbow is a result of concentric contraction of the triceps brachii muscle. The whole limb slides downwards following a drop in the scapula that is caused by concentric contraction of the serratus and subclavius muscles.



▼ **14.12** Distal displacement of the distal forelimb, preparing the upper limb for loading on landing. The drop of the scapula is the result of concentric contraction of the serratus ventralis thoracis (SVT), serratus cervicis (SC) and subclavius (SCL) muscles.

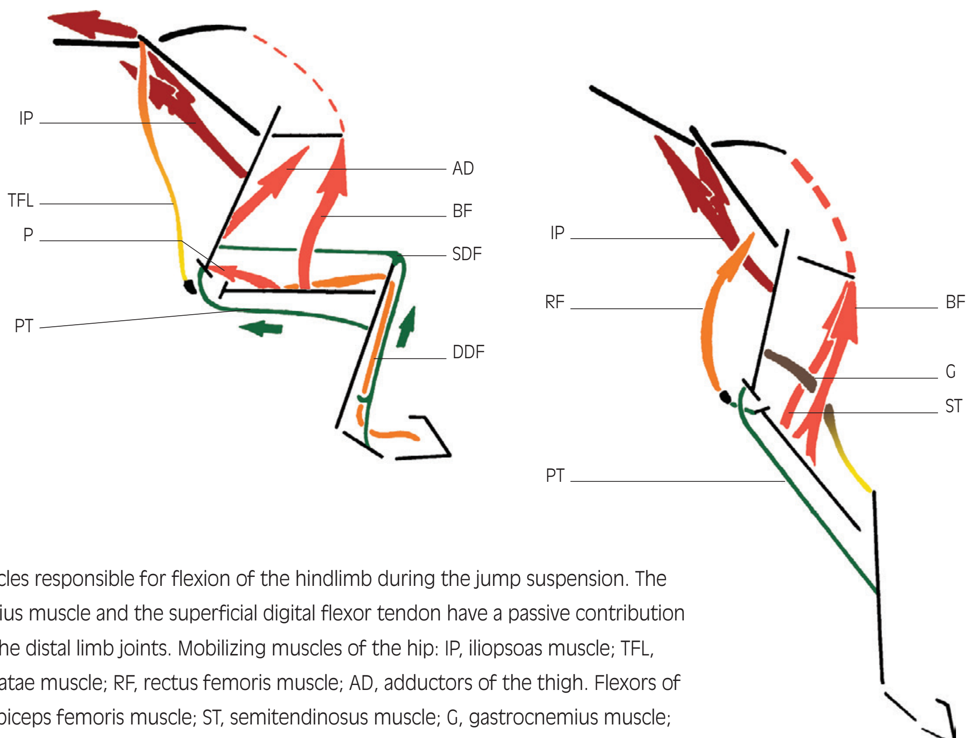
Biomechanics of the hindlimbs

During the airborne (flying) phase, the primary movement in the hindlimbs is flexion of all the joints; however, there are important associated movements that must also be discussed. As with the forelimbs, important individual variations characterize the style of each horse.

JOINT FLEXION

At the end of take-off and propulsion, when the hindlimb is under maximal extension, joint angles start to close, gradually and increasingly, until the downward phase of the airborne (flying) phase is reached (**14.13**).

- Flexion of the coxofemoral (hip) joint essentially takes place due to the action of the iliacus muscle. The psoas major muscle has minimal action so as not to counter lumbosacral extension. The iliofemoral angle can sometimes be less than 80°.
- Flexion of the stifle occurs due to contraction of the semitendinosus and biceps femoris muscles. The gastrocnemius (with participation from the superficial digital flexor muscle) and the popliteus muscles act towards the end of flexion. These muscular actions can reduce the femorotibial angle to less than 50°.
- Flexion of the hock automatically follows flexion of the stifle. This is due to the action of the reciprocal apparatus, which is made up of the peroneus tertius muscle (completely fibrous and elastic in horses) in front and the superficial digital flexor muscle behind the tibia. It acts to couple together the lower joints of the limb (see Chapter 2, The hindlimb). During flexion, especially at the beginning of the movement, closure of the femorotibial joint angle places upward traction on the peroneus tertius muscle, resulting in automatic flexion of the hock.



▲ **14.13** Muscles responsible for flexion of the hindlimb during the jump suspension. The peroneus tertius muscle and the superficial digital flexor tendon have a passive contribution to flexion of the distal limb joints. Mobilizing muscles of the hip: IP, iliopsoas muscle; TFL, tensor fascia latae muscle; RF, rectus femoris muscle; AD, adductors of the thigh. Flexors of the stifle: BF, biceps femoris muscle; ST, semitendinosus muscle; G, gastrocnemius muscle; P, popliteus muscle. Flexors of the hock and digit: PT, peroneus tertius muscle; DDF, deep digital flexor muscle and tendon; SDF, superficial digital flexor muscle and tendon.

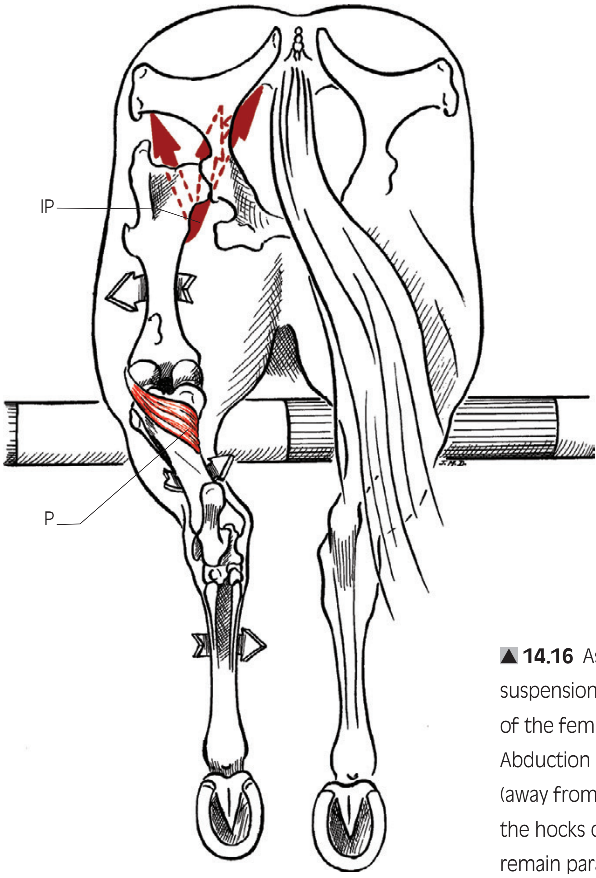
The tibiometatarsal (hock) joint angle can close up to approximately 35°.

- The fetlock is also influenced by the reciprocal apparatus (**14.13**). Closure of the hock joint increases the eccentricity of the top of the calcaneus, which acts like a pulley system on the superficial digital flexor tendon. This tendon is therefore placed under tension, resulting in automatic flexion of the fetlock and the proximal interphalangeal joints.
- The distal interphalangeal joint, along with the other above-mentioned mechanisms, flexes following concentric contraction of the deep digital flexor muscle prolonged by the long deep digital flexor tendon reaching the distal phalanx.

At the beginning of the downward phase and, occasionally, even during the peak phase of the airborne (flying) phase, flexion of the limbs is accompanied by lumbosacral extension (**14.14, 14.15**). This opens the hip joint and swings the pelvis up and backwards while the rest of the limb is still in flexion to facilitate clearance of the hindlimbs.

◀ **14.14** Ideal positioning of the hindlimbs during the peak phase of the jump suspension. There is intense flexion of the stifle, hock and digit. The distal extremity of the limb is lifted through extension of the hip and lumbosacral junction. This movement (extension of the hip and flexion of the stifle) results in marked lengthening of the rectus femoris muscle. Flexibility of this muscle improves the overall action of this movement.

◀ **14.15** Lumbosacral extension during the peak phase of the jump suspension. The entire limb is flexed and swings backwards following lumbosacral and hip extension.



▲ **14.16** Associated movements in flexion of the hindlimbs during the jump suspension. Semiflexion of the limb is accompanied by a lateral (external) rotation of the femur. This is compensated for by a medial (internal) rotation of the tibia. Abduction and external rotation of the femurs result in the stifles facing outwards (away from the median plane). Internal rotation and adduction of the tibias bring the hocks closer together. The end result of these movements is that the cannons remain parallel to each other. IP, iliopsoas muscle; P, popliteus muscle.

ASSOCIATED MOVEMENTS

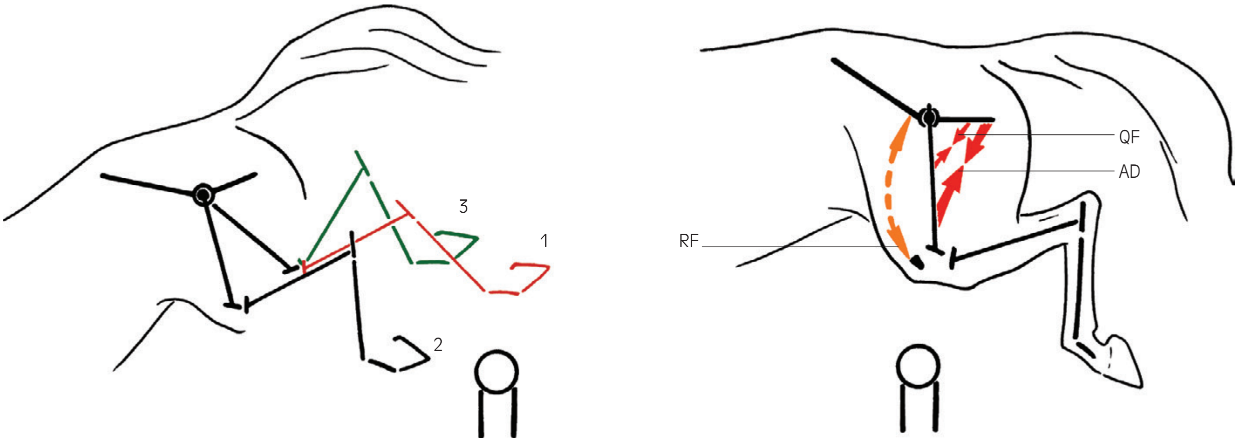
Flexion of the hindlimbs is combined with lateral and rotational movements, even more so than in the forelimbs (**14.16**).

- The iliacus muscle places traction on the medial aspect of the femur, resulting in a lateral rotation. This induces a medial deviation of the tibia and the hock. Concurrent action of the deep gluteal muscle results in abduction of the stifle.
- Flexion of the stifle is always coupled with a medial rotation of the tibia. This is due to the uneven shape of the femoral condyles as well as the action of the popliteus muscle.
- The medial rotation of the tibia places its distal joint surface in a longitudinal (vertical) plane. This movement compensates for the twisting motion that takes place between the tibia and the hock during flexion and ensures that the cannons remain parallel.

INDIVIDUAL VARIATIONS (STYLE)

The hindlimbs are often responsible for jumping faults. There are three actions that can be employed to avoid these faults, particularly during the downward phase of the airborne (flying) phase (**14.17, 14.18**). Depending on the ability of the horse and its jumping style, as well as the type of jump, different sport gestures will be adopted:

- **First type of move (position 1 in 14.17 [left]).** There is compensation for a lack of hindlimb flexion through a greater degree of thoracolumbar and lumbosacral extension. This action requires the most physical effort to avoid a fault. The hock angle is greater than 90°.
- **Second type of move (position 2 in 14.17 [left]).** All the joint angles are closed including the hip. The hindlimbs are in flexion under the pelvis. There is less vertebral extension than in the first type of gesture. The hock joint angle is less than 90°.



▲ **14.17** Individual variations in the position of the hindlimbs during the jump suspension. (**Left**) 1, semiflexion (or semiextension) of all the joints; 2, flexion of all the joints; 3, extension of the hip with flexion of the middle and distal limb joints. (**Right**) Muscular actions: concentric contraction of the adductors of the thigh (AD) and quadratus femoris (QF) muscles; lengthening of the rectus femoris (RF) muscle.

▲ **14.18** Swing of the hindlimbs at the end of the jump suspension. Extension of the hip and the lumbosacral joint lifts the path of the distal limbs and improves clearance of the hindlimbs.

▲ **14.19** Semiflexion of the hindlimbs during the peak phase of the jump suspension of a cross-country wide jump. Due to the speed at which the jump has been approached, the horse has not had time to fully flex the joints during the peak phase of the jump.

- **Third type of move (position 3 in 14.17 [left]).** This movement is the best suited action to jumping, both over the peak phase as well as in the downward phase of the jump. There is flexion of the stifle and hock with extension of the hip. There is marked lengthening of the rectus femoris muscle, which is the limiting factor in this movement (based on its ability to lengthen). The major contributors to this movement are the adductor and quadratus femoris muscles.

The overall action of the hindlimbs during the airborne (flying) phase is subject to the speed of displacement. At speed, the horse must ensure efficient propulsion through adequate extension of the limbs, and then rapidly prepare for landing. This results in less flexion of the joints during the airborne (flying) phase (**14.19**).

Finally, as in the forelimbs, the biomechanics of the hindlimbs can be disrupted when the horse is experiencing difficulties during a jump (**14.20**). When the jump is too high, too wide or the point of take-off too far from the fence, the horse must hyperflex its limbs to avoid a fault.

▲ **14.20** Hyperflexion of the hindlimbs during the peak phase of the jump suspension of a high vertical fence (2.05 m). The fetlock is located medial to the stifle because of hyperflexion of the hock and medial rotation of the tibia.

Summary

As has been seen, the movement of a horse over a jump can be analysed from a biomechanical and a gymnastic point of view. This enables appropriate selection of horses for a specific discipline. In addition, it allows correct training through taking advantage of movements and exercises that are least harmful to the locomotor apparatus. This promotes attainment of the highest level of expression of the horse's physical capabilities.

15 Landing phase: biomechanics of the vertebral column

THE LANDING phase follows the downward (descending) phase of the jump suspension. The agility of the horse and the propulsive forces are significantly drawn on during the first phases of jumping. However, during the final phase, the functional and biomechanical demands on the horse are far from over and they reappear suddenly and to a significant degree. During this phase, the speed of joint angular movement is maximal and there is an increase in numerous mechanical stresses. Most importantly, the horse must re-establish its equilibrium, which is an essential component in jumping competitions.

During landing, three phases can be identified, highlighting the muscular actions, joint movements and forces involved: the stance phase of the forelimbs, during which the vertebral column undergoes progressive flexion (**15.1**); the suspension phase, which is very brief and often absent and is characterized by maximal vertebral flexion; and the stance phase of the hindlimbs, which facilitates establishment of equilibrium.

Stance phase of the forelimbs

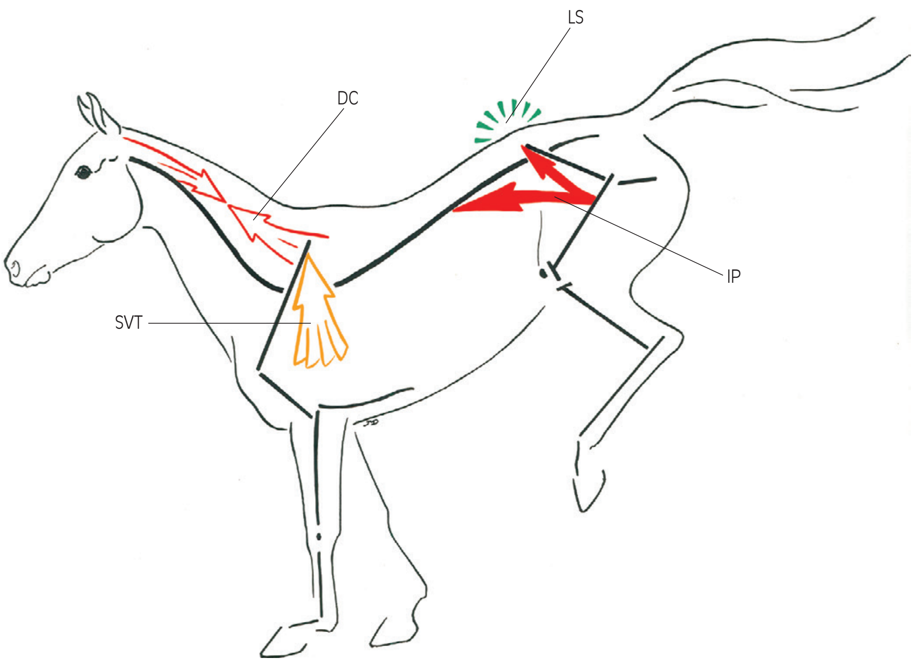
At the level of the trunk this phase is characterized by a significant and rapid flexion of the vertebral column and is often initiated during the downward phase of the jump suspension (**15.2**). Several vertebral junctions are involved successively during this movement (**15.3, 15.4**).

LUMBOSACRAL JUNCTION

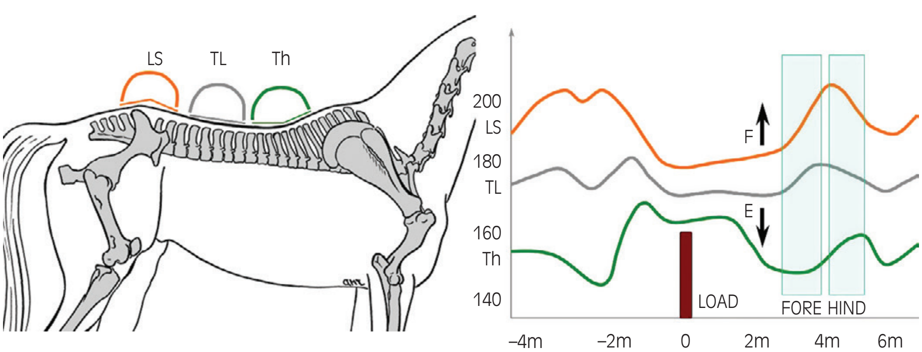
The lumbosacral junction is made up of the lumbosacral (L6/S1) joint space and the last lumbar joint space (L5/L6), and in many horses this joint can also present significant mobility. This region is the first to transition into flexion during the downward phase of the jump

◀ **15.1** Loading of the forelimbs at landing. There is maximal stress on the forehand, cervical and thoracolumbar regions. There is powerful extension of the cervicothoracic junction and of the cranial part of the thoracic spine (withers). Protraction of the hindlimbs and dropping of the entire hindquarters result in flexion of the lumbosacral joint. The two parts of the iliopsoas (psoas major and iliacus) muscle assist these movements.

◀ **15.2** Marked extension of the thoracolumbar and lumbosacral spine during loading of the forelimbs at landing. During this warm-up jump at slow speed, the horse illustrates prolonged extension of the back and pelvis. This results from a combined action of the erector spinae (underneath and behind the saddle) and middle gluteal (forming the outline of the croup) muscles. The hip joints are simultaneously flexed through action of the iliacus and pectineus muscles. Flexion of the hip precedes lumbosacral and thoracolumbar flexion.



◀ **15.3** Stance phase of the forelimbs at landing. The serratus ventralis thoracis muscle (SVT) ensures support of the forehand. The dorsal cervical muscles (DC) control lowering of the neck. The iliopsoas muscle (IP) initiates lumbosacral (LS) flexion and protraction of the hindlimbs.



◀ **15.4** Flexion and extension movements of the lumbosacral junction (LS), thoracolumbar junction (TL) and the thoracic region (Th) at landing. During the stance phase of the forelimbs, the entire vertebral column moves in flexion. As soon as the hindlimbs land, the lumbosacral and thoracolumbar junctions extend to facilitate forward movement.

▲ **15.5** Protraction of the hindlimbs during the stance phase of the forelimbs at landing. Lumbosacral flexion is the result of contraction of the rectus abdominis muscle, as is clearly seen in the right image. The hindlimbs begin extending in preparation for ground contact.

suspension (**15.1, 15.3**). The overall variation in displacement of the joints, from the position of maximal extension during the jump suspension, can reach 20–30 degrees.

Flexion first takes place through intense concentric contraction of the iliopsoas muscle, which also flexes the hip (coxofemoral) joint. In the second phase, contraction of the abdominal wall muscles, in particular the rectus abdominis muscle, accentuates the overall movement (**15.5**).

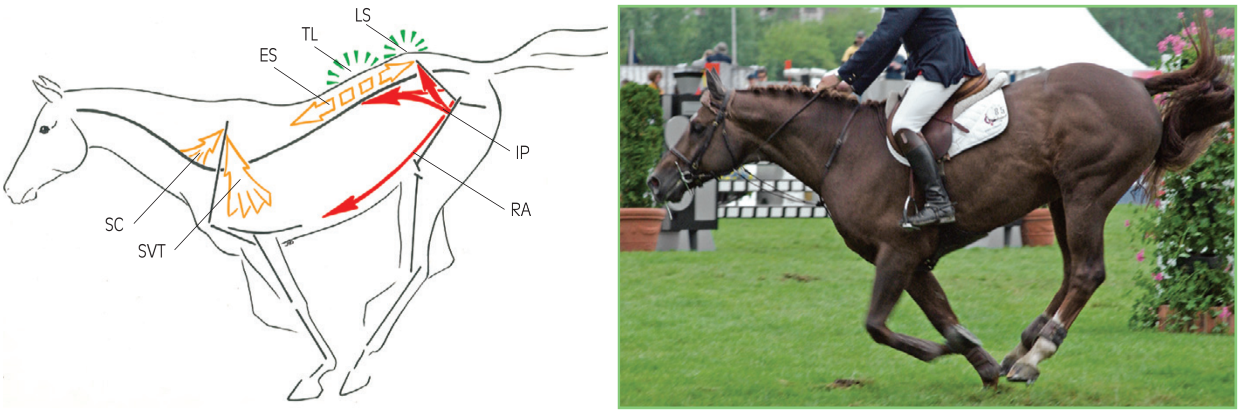
THORACOLUMBAR JUNCTION

As with the lumbosacral junction, this region assists in protraction of the hindlimbs. Engagement of the hindlimbs is one of the major determining factors in re-establishing the balance of the horse's forward movement. The four intervertebral joint spaces located between the 16th thoracic vertebra and the 2nd lumbar vertebra undergo up to 3 degrees of movement per joint. It is the combined mobility of each of these joints that results in substantial flexion of the spine in this region.

During flexion of the spine, the rectus abdominis muscle is by far the most efficient because of the distance between its insertions and the vertebral column allowing maximal torque, and the length of the muscular belly allowing a wide shortening during concentric contraction (**15.6**). As soon as the forelimbs land, the spontaneous drop of the hindquarters passively contributes to thoracolumbar and lumbosacral flexion.

CERVICOTHORACIC JUNCTION

Lowering of the neck significantly contributes to load absorption by the forelimbs at landing (**15.7**) and corresponds to cervicothoracic flexion. This flexion is not the result of activity of the flexor muscles of the neck. It is a spontaneous movement that takes place due to inertia of the mass of the head and neck. It is limited, however, by the elasticity of the nuchal ligament and eccentric contraction of the dorsal cervical muscles. Therefore, loading of the forelimbs at landing is the only phase during jumping where all the vertebral junctions are undergoing flexion simultaneously.



▲ **15.6** Marked engagement of the hindlimbs and illustration of a brief suspension at landing. The serratus muscles control the drop of the thorax between the forelimbs on loading (SC, serratus cervicis muscle; SVT, serratus ventralis thoracis muscle). The iliopsoas (IP) and rectus abdominis (RA) muscles result in powerful flexion of the lumbosacral (LS) and thoracolumbar (TL) junctions. The erector spinae (ES) muscle undergoes significant lengthening. Contraction of the abdominal muscles (rectus abdominis and oblique abdominals) is clearly evident in the right image. The caudal femoral muscles are maximally lengthened.

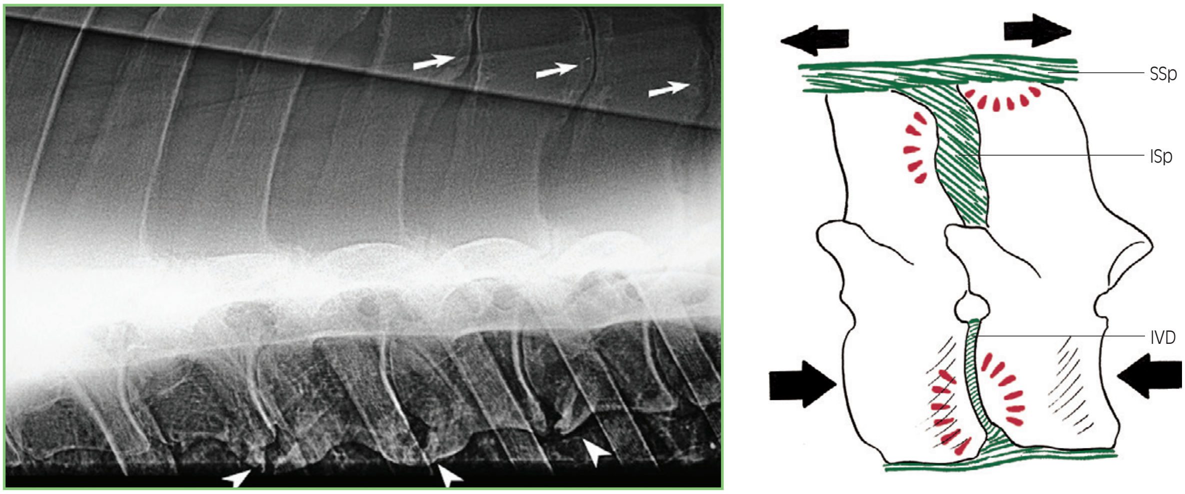
▲ **15.7** Lowering of the head and neck reducing the overload of the forehand associated with the drop of the trunk between the forelimbs at landing. Moreover, cervicothoracic flexion reduces the risk of compression of the spinous processes of the withers.

Suspension phase

The duration of this phase is highly variable depending on the horse and the duration of the stance phase of the forelimbs. This, in turn, is dependent on the height of the jump and the speed at which it is cleared. There is always an intermediary state between the stance phase of the forelimbs and the subsequent stance phase of the hindlimbs, which can be characterized by several features:

- The lumbosacral and thoracolumbar junctions reach maximal flexion, which is often greater than the flexion that occured during take-off (**15.6, 15.8**). This results in intense compression of the vertebral bodies and intervertebral discs (**15.9**). Furthermore, the interspinous ligaments are placed under tension and the supraspinous ligament undergoes intense traction. These mechanical stresses appear to be one of the main causes of back pain in show jumpers. One condition in particular that can result in back pain is desmopathy of the supraspinous ligament at its insertions (**15.9**). The erector spinae muscle undergoes maximal lengthening. Flexibility and elasticity of this strong muscle dictate the degree of spinal flexion and contribute to efficient re-establishment of equilibrium. In order to improve this movement, training of the horse must aim to improve the suppleness of the topline as well as the tone of the ventral muscle chain (see Chapter 4, Lowering of the neck).
- The cervicothoracic junction undergoes an initial extension, which assists in lifting the neck. This results in a reduction of the load on the forehand and assists in the establishment of equilibrium. This movement is a result of concentric contraction of the dorsal cervical muscles (**15.10**).

▲ **15.8** Preparation for a brief suspension phase at landing, which takes place between the stance phase of the fore- and hindlimbs. The leading leg (in this case the left forelimb) is undergoing propulsion. The hindlimbs continue to extend and prepare for ground contact. The degree of hindlimb engagement depends on the degree of lumbosacral flexion (and eccentric elongation of the powerful middle gluteal muscle) as well as lengthening of the caudal femoral muscles.



▲ **15.9** Vertebral stresses during flexion of the thoracolumbar spine and the resulting lesions from flexion–extension movements of the thoracic spine. The supraspinous ligament (SSp) undergoes intense traction, which can lead to lesions at its insertions at the top of the spinous processes. The tensions on the interspinous ligament (ISp) can equally result in lesions at the cranial and caudal borders of the spinous processes. The intervertebral discs (IVD) are the sites that undergo the most intense compression, especially at their ventral aspect. The radiographic image (**left**), taken of a Grand Prix level horse, demonstrates marked impingement of the spinous processes (arrows) just behind the withers (T10, 10th thoracic vertebra). There is also significant evidence of vertebral spondylosis (bridging between the vertebrae, arrowheads) of the vertebral bodies from the 10th to the 14th thoracic vertebrae.

▲ **15.10** Establishment of equilibrium at landing through impulsion of the leading forelimb (left forelimb in the photogaphs) assisting elevation of the forehand. Propulsion of the left forelimb finishes before ground contact of the hindlimbs. This results in a short phase of suspension. This phase becomes more marked with an increase in speed of the horse over the jump. Contraction of the serratus and dorsal cervical muscles actively assists lifting of the forehand, which takes place between the stance phase of the forelimbs and the suspension phase.

Stance phase of the hindlimbs

Loading of the hindlimbs and suspension of the forehand result in intense contraction of the dorsal vertebral muscles and increased compression of the intervertebral discs (**15.11**). These concepts can be illustrated by undertaking a simple inverse dynamic analysis. If the stresses are considered in a static situation, the following statements can be made relative to the lumbosacral junction:

- **W** is the weight of the rider and the body of the horse (pelvis and hindlimbs excluded);
- **l** is the distance between the lumbosacral joint and **M**, the centre of mass of the horse's forehand and trunk;
- **h** is the average height of the lumbar and sacral spinous processes and iliac crest.

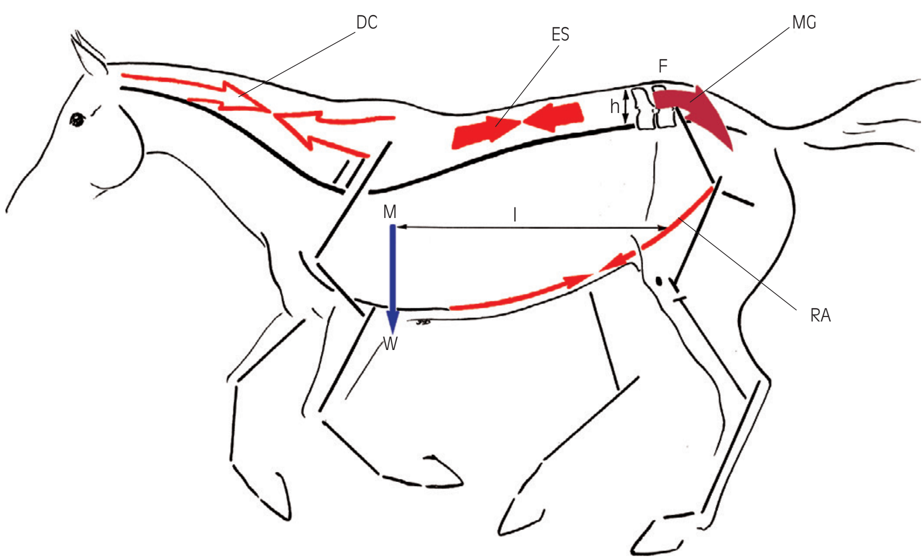
Therefore, the resulting force (**F**) created by the extensor muscles to support the forehand corresponds to the formula: $\mathbf{W} \times \mathbf{l} = \mathbf{F} \times \mathbf{h}$ or, $\mathbf{F} = \mathbf{W} \times \mathbf{l}/\mathbf{h}$.

For example, in a situation involving minimal stresses, where **W** = 4,000 N (N: newton), **l** = 100 cm, **h** = 10 cm:

$$\mathbf{F} = 4{,}000 \times 100/10 = 40{,}000 \text{ N (4 tonnes)}$$

From this estimation, it is clearly evident that the intervertebral discs undergo stresses of several hundreds of N/cm^2, particularly in their ventral part.

In reality, these forces are a lot greater than in the example above because in a live, moving animal, and with the difficulties in evaluating variations in acceleration, instantaneous stresses can be multiplied by a factor of 2 or 3. Fortunately, these stresses only take place over a fraction of a second. This estimation makes it easier to understand why athlete horses develop back and vertebral pain.



▲ **15.11** Vertebral stresses during loading of the hindlimbs. In the absence of forelimb loading, the weight of the horse (W) must be supported by the vertebral axis in order for equilibrium of the horse to be re-established. The dorsal cervical (DC) and the erector spinae (ES) muscles exert strong tension to stiffen the vertebral axis, which is lifted by the powerful middle gluteal muscle (MG). The rectus abdominis (RA) muscle contracts to balance the stresses on the vertebral axis.

◀ **15.12** Establishment of equilibrium at landing. The forehand is beginning to lift during loading of the hindlimbs. The powerful middle gluteal muscle changes the orientation of the trunk from a downward to an upward positioning. The dorsal cervical muscles and the erector spinae muscle (under and behind the saddle) are under tension. The entire trunk and forehand are suspended by the contraction of these muscles while they are under intense lengthening. The magnitude of vertebral compression is elevated. Distribution of these forces along the thoracolumbar spine axis is assisted through contraction of the abdominal wall muscles.

◀ **15.13** Propulsion of the hindlimbs and initiation of forward movement of the departure stride following landing. Lumbosacral and thoracolumbar extension is synchronous with cervical and cervicothoracic flexion. Lowering of the head and neck prepares for protraction of the hindlimbs.

In evaluating the stresses in the more cranial intervertebral joint spaces, **W** is reduced because the suspended part of the body is less, **l** reduces because the centre of mass of the forehand is closer to the intervertebral space considered, and **h** is greater in front of the 12th thoracic vertebra.

Therefore, during forelimb suspension (the trunk is not supported by the forelimbs), the concentration of intervertebral stresses is higher in the lumbar region. These stresses progressively reduce further forward (in the thoracic region) and become relatively weak in the withers.

All the extensor muscles are very active during the stance phase of the hindlimbs at landing after a jump. They have to invert the trunk attitude and lift the forehand in a forward displacement, leading to re-establishment of the horse's balance (**15.12, 15.13**):

- The dorsal cervical muscles actively support the weight of the head and neck.
- The thoracic component of the erector spinae muscle actively participates in thoracolumbar extension and lifting of the head and neck.
- The lumbar part of the erector spinae muscle is assisted by the action of the middle gluteal muscle, and ensures lumbosacral extension and, therefore, support of the entire forehand and trunk.

Summary

During the second half of the jump, the vertebral column transitions from a state of maximal extension during the downward phase of the jump suspension (**15.2**) to a state of maximal flexion during landing (**15.12**). The degree of these movements determines the skill and ability of the horse. However, this large variation in movement can also be the cause of a number of joint, ligament and muscular problems in the thoracolumbar spine.

Treatment of these problems is often non-specific and disappointing. It is therefore evident that prevention of these lesions must be the constant concern of the trainer and rider. In particular, a progressive warm-up of the muscles and joints and an adequate cool-down programme must be consistently instigated, regardless of the circumstances (training or competition) and the level of the test.

16 Landing phase: biomechanics of the limbs

As the persons responsible for the physical care of the horse, riders know all too well that the landing phase of jumping is one of the most stressful situations in riding for the musculoskeletal system of a horse. Riders and trainers should therefore know that to ensure longevity of the locomotor apparatus, reducing the duration or frequency of jumping sessions is one of the first methods that should be adopted.

Nevertheless, the most vulnerable regions are not necessarily the most commonly thought about. For example, in the forelimbs, the fetlocks undergo relatively larger stresses than the feet (and the navicular bone in particular). In the hindlimbs, the suspensory ligament and the femorotibial menisci are particularly susceptible to the risk of lesions.

Before discussing the biomechanical events in the limbs, it is essential to present the sequence in which the limbs make ground contact at landing. This directly determines the intensity and distribution of forces in the fore- and hindlimbs (**16.1**). When the horse lands at canter on the left lead, the first limb to make contact with the ground (the contact limb or trailing limb) is the right forelimb. The left forelimb (leading limb) then makes contact. If the horse is coordinated in its movement, the right hindlimb then contacts the ground (contact limb or trailing limb) followed by the left hindlimb (leading limb). This finishes the sequence of limb placement in the first stride at landing.

▲ **16.1** Chronology of fore- and hindlimb placement at landing following a cross country jump. (**Right**) The horse lands on the right forelimb, the first of the limbs to make ground contact (trailing or contact limb). The left forelimb (leading limb) then follows in second position. (**Left**) After a short suspension phase, the right hindlimb is placed (trailing or contact limb) followed by the left hindlimb (leading limb), which continues its protraction (engagement).

Biomechanics of the forelimbs

The shock absorbing function of the forelimbs is ensured at two levels. Firstly, through the muscular aponeurosis structures, which connect the trunk to the limbs, and secondly, through the several levels of bone segments and the articular angles between each of these (**16.2**). A failure or injury of any one of these structures will result in a tendency to overload others. This is why in the athlete horse there is a high frequency of associated lesions.

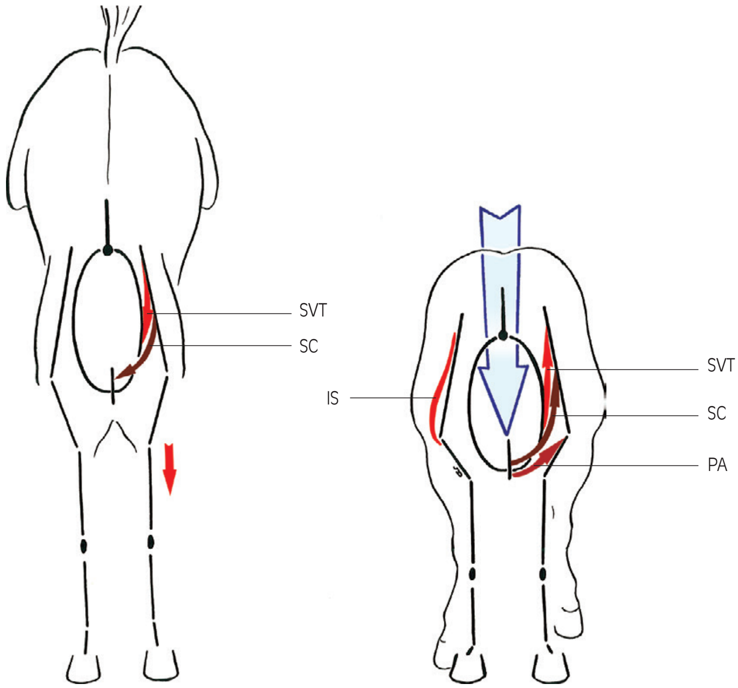
CONTROLLING THE DROP OF THE TRUNK

The drop of the trunk between the forelimbs at landing is controlled by two muscular girdles that attach the upper limbs to the wall of the thorax. During the downward phase of the jump suspension, these muscles (serratus muscles, pectoralis ascendens and subclavius muscles) undergo a concentric contraction, pulling down the scapula and humerus. This contraction continues until ground contact, conferring on these muscles a large amount of elastic lengthening in reserve and, therefore, the ability to absorb energy (**16.3**).

As soon as the limbs touch the ground, the trunk begins to drop between the forelimbs. The degree of drop is slowed and limited by eccentric contraction of the thoracic muscular girdles (**16.4, 16.5**). This mechanism is often underestimated, but it has a key role in shock absorption at landing. It requires powerful muscles that are toned but not contracting. They will absorb a large portion of the forces on impact, thereby protecting the more vulnerable structures at the extremities of the limbs.

▲ **16.2** Loading of the forelimbs at landing. The horse lands first on the right forelimb (contact or trailing limb). There is maximal closure of the joint angles on the left forelimb (leading limb). Hyperextension of the fetlock and carpus in conjunction with flexion of the elbow induces extreme tension on the digital flexor tendons as well as the caudal antebrachial muscles.

▲ **16.3** Position of the forelimbs prior to landing. The shoulder and elbow joint angles are opened by the supraspinatus muscle and the short heads of the triceps brachii muscle. Note the marked lengthening of the triceps brachii (long head) and deltoideus muscles. There is a forward sliding and drop of the shoulder through concentric contraction of the serratus muscles, preparing the limb for landing and load absorption.



◀ **16.4** Control of the drop of the trunk at landing: biomechanics of the serratus and pectoral girdles. (**Left**) Ground contact is precipitated by a downward slide of the forelimbs, made possible by concentric contraction of the serratus ventralis thoracis (SVT) and subclavius (SC) muscles. (**Right**) Dropping of the trunk is slowed and then limited by eccentric contraction of these muscles, their action supported by the powerful pectoralis ascendens (PA) muscle. The infraspinatus (IS) muscle stabilizes the shoulder joint.

◀ **16.5** Dropping of the trunk and shock absorption during landing. (**Left**) Extension of the forelimbs preparing for ground impact, optimizing the position of the limbs for shock absorption. (**Right**) End of load absorption and support of the forehand with distribution of forces between the forelimbs (trailing and leading limbs). All the joint angles are closed.

Muscular spasms or cramps induced by fatigue reduce the ability of these muscles to absorb shock and thus increase stresses on the joints, bones and tendons. During a fault in show jumping, particularly with excessive loading of a single limb at landing (rather than distribution of forces between the pair), partial or full tears of the serratus muscles can arise. The management of this requires several months of rehabilitation.

Development of these muscular girdles must be the focus of adequate preparation of the athlete horse. Different exercises can be used to assist conditioning, such as work in a lowered neck position, work on different terrain (in particular on a downward slope) and bounce jump exercises (the focus of the next Chapter).

Intrinsic biomechanics of the forelimb

This can be broken down into three phases: load absorption, mid-stance and propulsion (which precedes or coincides with landing of the hindlimbs).

LOAD ABSORPTION PHASE

This phase starts with ground contact (or landing) (**16.6**). There is controlled closure of the joint angles and activation of the thoracic muscular girdles. Both contribute to absorption of the large forces associated with vertical landing and the drop of the horse's body mass (**16.3**).

Control of joint closure is by eccentric contraction of the muscles located at the open angle of the joints:

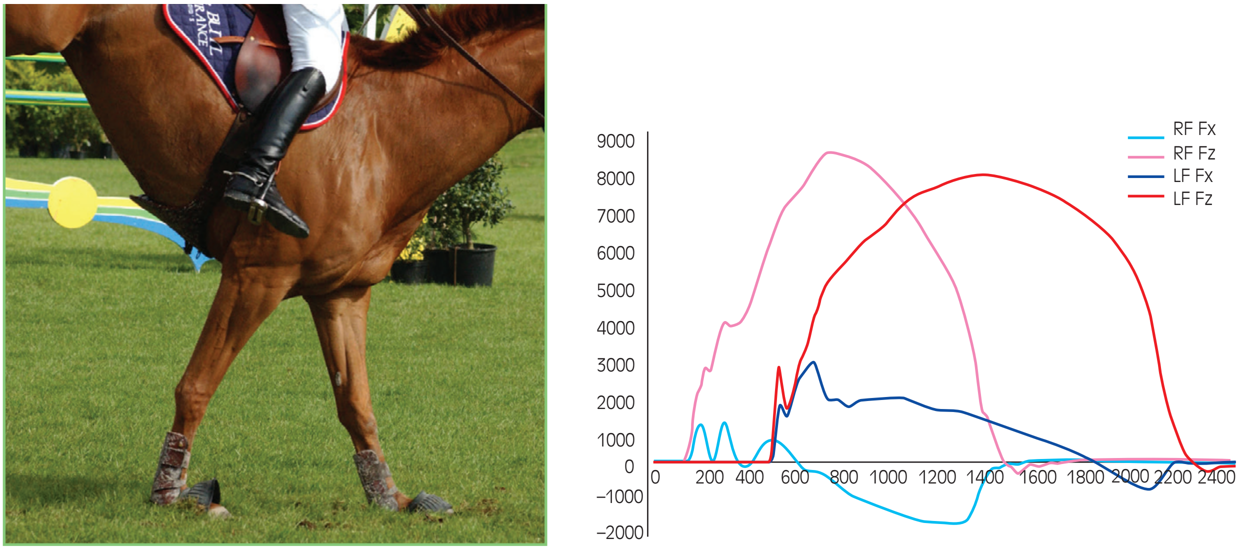
- The supraspinatus muscle controls and limits closure of the scapulohumeral joint.
- The triceps brachii muscle slows the horizontalization of the humerus and flexion of the elbow.
- The extensor carpi radialis muscle keeps the knee in extension; as loading of the limb progresses, the carpal joint is placed into hyperextension.
- The digital flexor muscles, along with participation from their accessory ligaments (superior and inferior check ligaments), limit dropping of the fetlock and horizontalization of the pastern.

During this phase of landing, the joint surfaces and ligaments undergo the most intense vibrational forces. The other forces (horizontal and vertical) are differently distributed between the contact and leading limbs (**16.7**). The contact limb undergoes a peak vertical force greater than that sustained by the leading limb. It has a specific role in propulsion, initiating forward movement after the jump. The leading limb also receives both vertical and horizontal forces associated with loading over a longer period. Thus, the total cumulative load (impulse) of forces absorbed is greater than that of the contact limb.

MID-STANCE PHASE

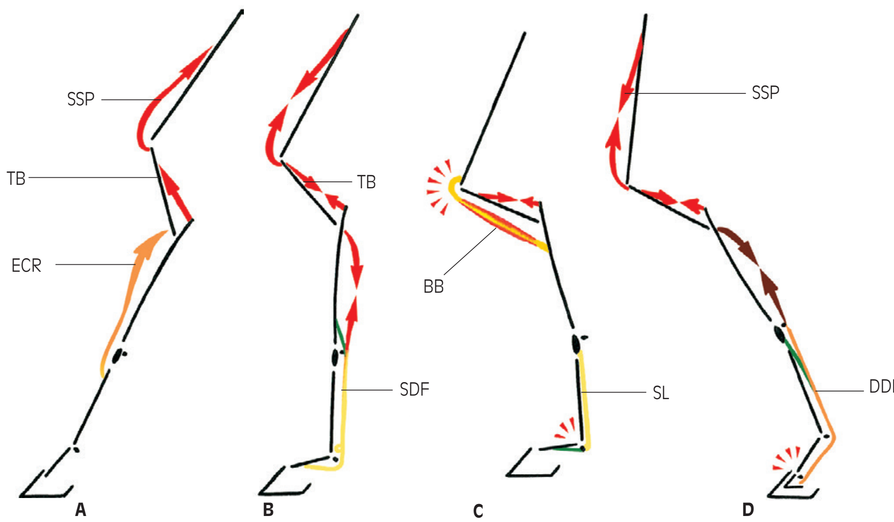
This phase is characterized by maximal closure of the joint angles (**16.2, 16.7, 16.8**). The muscles that act during the load absorption phase undergo an intense eccentric contraction and finish their action in a marked lengthened state (**16.9**). Two zones that undergo particular stress need mentioning: the shoulder and the distal limb (fetlock, pastern and foot).

◀ **16.6** Load absorption of the trailing limb (right forelimb) following landing. The fetlock has started to drop despite the carpus not being in full extension. The shoulder and elbow joint angles are still significantly opened. The leading leg (left forelimb) is in preparation for ground contact.



▲ **16.7** Distribution of vertical (Fz) and horizontal (Fx) forces between the trailing and leading limbs (right and left forelimb, respectively, **left**) during the stance phase of the forelimbs at landing. (**Right**) The peak of the vertical load is greater in the trailing limb. The cumulative load (or impulse, combination of the instant ground forces and the prolongation of these forces during loading), which is reflected by the area below the curve, is greater in the leading limb. In the trailing limb (the right forelimb [RF]) the horizontal force (Fx) is mostly negative, reflecting the role of this limb in propulsion. Conversely, the leading limb (the left forelimb [LF]) has a positive horizontal force (Fx), essentially a braking action, which in combination with the vertical forces, increases the compression stresses on this limb. (Y axis: N, newtons; X axis, ms, milliseconds.) (**Right** drawing courtesy Unit INRA-ENVA BPLC, Dir. Pr N. Crevier-Denoix).

◀ **16.8** Stance phase of the forelimbs at landing. On the left forelimb (trailing limb), there is a maximal drop of the fetlock and hyperextension of the carpus. Nevertheless, this limb is still able to undergo shock absorption, which takes place during flexion of the shoulder joint. (**Note:** The shoulder joint angle is still quite open.)



▲ **16.9** Biomechanics of the forelimb at landing. Closure of the joint angles during load absorption and mid-stance phases (**A–C**). The muscular, tendinous and ligamentous structures all contribute to storage of energy. Maximal stresses on the shoulder and fetlock joints take place at the end of the mid-stance pahse (**C**). During the propulsion phase (**D**) there is both passive and active opening of the joints. Maximal extension of the interphalangeal joints takes place before break-over (**D**). SSP, supraspinatus muscle; TB, triceps brachii muscle; BB, biceps brachii muscle; ECR, extensor carpi radialis muscle; SDF, superficial digital flexor muscle and tendon; DDF, deep digital flexor muscle and tendon; SL, suspensory ligament.

Shoulder

Closure of the scapulohumeral joint angle is associated with the start of elbow joint extension. This places tension on the biceps brachii muscle and compression of its proximal tendon against the upper aspect of the humerus (**16.9**). These biomechanical stresses may be the cause of bursitis or biceps tendinitis.

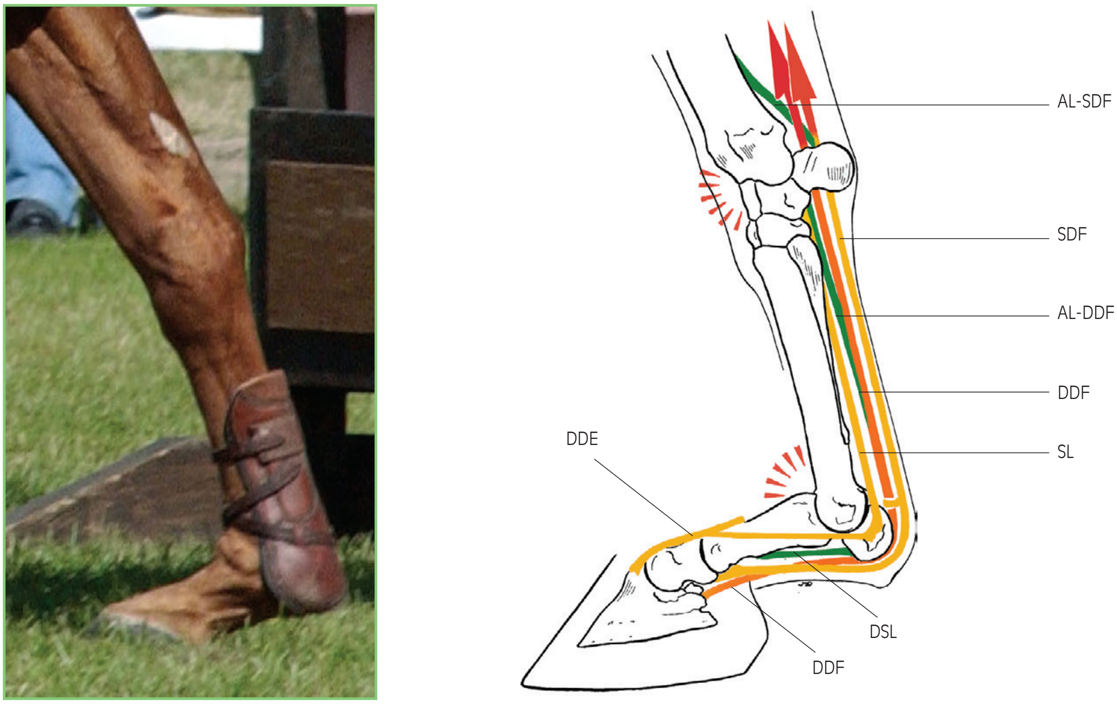
Fetlock and pastern

The pronounced drop of the fetlock and horizontalization of the pastern place significant tension on the suspensory apparatus of the fetlock, the flexor tendons (superficial and deep) and their accessory ligaments (**16.10**). With this degree of tension on these structures, the slightest overreach by a hindlimb toe can easily result in transection of one or several of the tendons. This justifies utilization of protective boots on the forelimbs.

Hyperextension of the fetlock and carpus results in tension on the inferior check ligament (accessory ligament to the deep digital flexor tendon), while forward movement of the trunk increases the compressional forces on the dorsal margins of the joints (**16.10**). This can result in the development of joint surface or bone lesions in these joints.

PROPULSION

Propulsion by the forelimbs at landing after a jump involves opening of joint angles and requires lifting of the forehand (**16.11, 16.12, 16.13**). This is possible because of the concentric contraction of the muscular girdles of the thorax (serratus and pectoral muscles) in synergy with the extensor muscles of the shoulder and elbow joints, as well as the flexor muscles and tendons elevating the fetlock.



▲ **16.10** Stresses on the distal limb bone segments during the mid-stance phase at landing. (**Left**) Medial (internal) view of the limb. (**Right**) Lateral (external) view. The carpus and fetlock support the strong loads on the anterior aspect of the joints. The suspensory ligament and superficial digital flexor tendon at this point undergo greater stresses than the deep digital flexor tendon. AL-SDF, superior check ligament (accessory ligament to the superficial digital flexor tendon); SDF, superficial digital flexor tendon; AL-DDF, inferior check ligament (accessory ligament to the deep digital flexor); SL, suspensory ligament; DSL, distal sesamoidean ligaments; DDE, dorsal digital extensor tendon; DDF, deep digital flexon tendon.

▲ **16.11** Propulsion by the trailing limb (left forelimb) at landing. The left fore pastern becomes vertical and the foot pivots around the point of the toe. The leading limb (right forelimb) is fully loaded and undergoing strong vertical forces.

▲ **16.12** Propulsion by the leading limb (right forelimb) at landing. With these two photographs we can see the progressive lift of the fetlock through action of the suspensory ligament assisted by the digital flexor muscles and tendons. Opening of the elbow joint takes place due to forward action of the body and contraction of the triceps brachii muscle. The supraspinatus muscle controls closure of the shoulder joint (eccentric contraction, **left**) and brings this joint into extension (concentric contraction, **right**).

▲ **16.13** End of propulsion by the leading limb (right forelimb) and the start of the swing phase by the forelimbs initiating a short suspension phase of the horse (**left**). The deep digital flexor tendon will initiate break over and rotation of the right forefoot around the toe. (**Right**) The right hindlimb (trailing limb) is about to make ground contact. The fetlock will extend under the vertical load of the hindquarters.

To recap what has been already discussed in Chapter 1 (The forelimb), lifting of the fetlock and straightening (verticalization) of the pastern (interphalangeal extension) are the results of both passive (elastic recoil of the tendons and accessory ligaments) and active (flexor muscle concentric contraction) actions. Additionally, the compressional and tensional stresses on the entire podotrochlear apparatus (navicular bone, sesamoidean ligaments and deep digital flexor tendon) are a lot more intense during propulsion than during the previous phases of landing (load absorption and mid-stance phases).

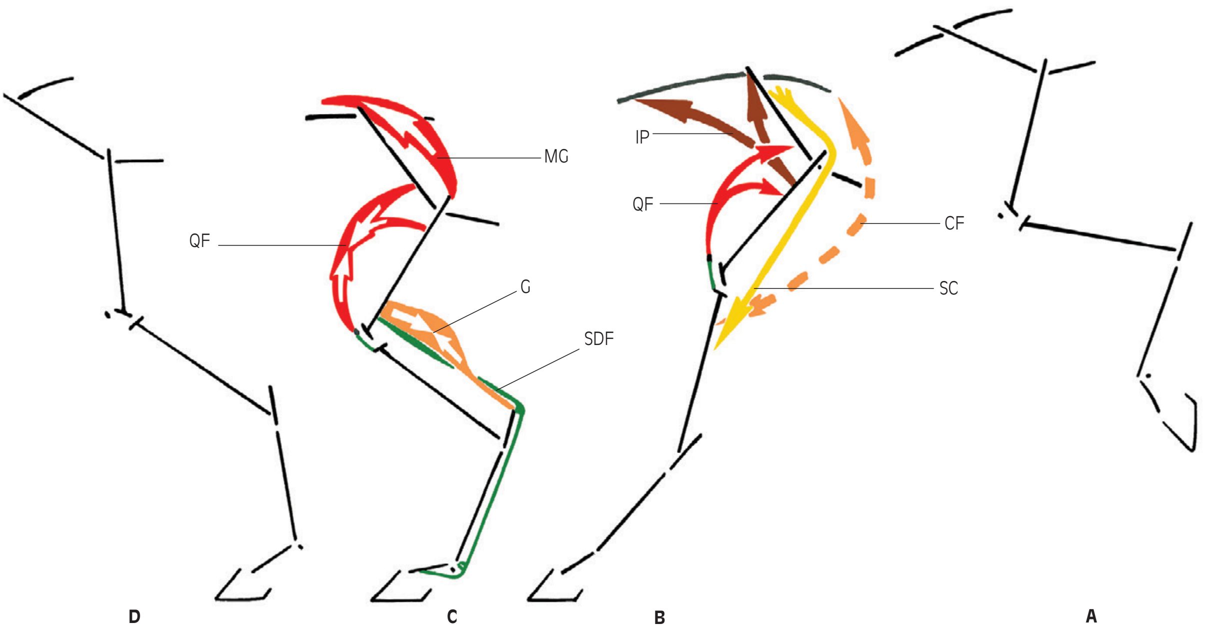
Biomechanics of the hindlimbs

At landing, between the stance phase of the forelimbs and ground contact of the hindlimbs, there is sometimes a brief suspension phase. The duration of this phase is highly variable depending on the horse, the type of jump and the speed at which the jump is taken. The initial stage before landing of the hindlimbs is protraction (engagement), which takes place during the stance phase of the forelimbs. After landing, the loading and propulsion phases of the hindlimbs take place while the forelimbs are non-weight bearing.

PROTRACTION (ENGAGEMENT)

This phase of landing is characterized by high-speed joint movements transitioning from intense flexion to maximal extension (**16.14, 16.15, 16.16**). The exception to these rapid movements is the hip joint:

- The hip (coxofemoral) joint is different to the other joints as it undergoes flexion that is indispensable to engagement of the hindlimbs (**16.14–16.16**). This flexion is due to the action of the iliopsoas muscle (which also contributes to lumbosacral flexion) and two thigh muscles, the rectus femoris muscle and the tensor fascia latae muscle.
- Concentric contraction of the quadriceps muscle group in conjunction with action of the tensor fascia latae muscle results in a powerful extension of the stifle, which is accompanied by rapid forward sliding of the menisci.



▲ **16.14** Biomechanics of the hindlimb at landing. Prior to ground contact (**B**) the hip is flexed by the iliopsoas muscle (IP). Extension of the stifle by the quadriceps femoris muscle (QF) precedes ground contact and places tension on the sciatic nerve (SC) and the caudal femoral muscles (CF). During load absorption and the mid-stance phase (**C**), tension on the gastrocnemius (G) muscle and the superficial digital flexor (SDF) muscle is maximal. Pelvic muscles: MG, middle gluteal muscle; IP, iliopsoas muscle. Thigh muscles: QF, quadriceps femoris muscle; CF, caudal femoral muscles. Leg muscles: G, gastrocnemius muscle; SDF, superficial digital flexor muscle and tendon.

▲ **16.15** Ground contact of the hindlimbs by the trailing limb (left hindlimb) at landing. (**Left**) Note the lumbosacral hyperflexion and hyperextension of the stifles. The caudal femoral muscles and sciatic nerves are maximally lengthened. (**Right**) Note the sequential placement of the hindlimbs. The trailing hindlimb makes ground contact, while the leading limb is undergoing protraction (engagement).

▲ **16.16** Ground contact by the trailing hindlimb and the start of the swing phase of the forelimbs at landing. Ground contact is assisted by substantial extension of the hindlimb joints. Lengthening of the caudal femoral muscles and strong flexion of the lumbosacral joint are assisted by the downward orientation of the trunk and engagement of the hindlimbs.

- Because of the reciprocal apparatus (see Chapter 2, The hindlimb), the hock opens to the same degree as the stifle and is assisted by concentric contraction of the gastrocnemius muscle (**16.14–16.16**).
- The fetlock and interphalangeal joints prolong the movement with assistance from the extensor muscles located at the front of the crus.

Just before ground impact, the movements mentioned above reach their maximal range of extension to a greater degree than is seen during take-off and propulsion.

Extension of the stifle pinches the cranial attachment of the lateral meniscus, which can result in the development of pressure lesions. The combination of hip flexion and femorotibial extension provides a circumstance in which sciatic nerve lesions and neuralgia (pain of nerve

▲ **16.17** Mid-stance phase of the trailing hindlimb and loading of the leading hindlimb at landing. The forelimbs are displaying their swing phase. The fetlock joint of the trailing hindlimb (left hindlimb, **left**; right hindlimb, **right**) is in hyperextension, which, in combination with the closure of the hock joint angle, places strong tension on the suspensory ligament. In order to reduce these forces, the stifle joint flexes in a controlled fashion through eccentric contraction of the quadriceps femoris muscle. Flexion of the hock is restricted by the superficial digital flexor tendon (see Chapter 2: The hindlimb) and eccentric contraction of the gastrocnemius muscle.

origin) can arise. Athlete horses (such as show jumpers) may therefore be exposed to these types of lesion.

These movements also result in significant lengthening of the caudal femoral muscles (**16.14–16.16**). A lack of suppleness of these muscles or muscular pain can limit the engagement of the hindlimbs and compromise the ability of the horse to establish equilibrium at landing. Conditioning of these muscles to lengthening can be achieved through basic exercises, such as working with a lowered neck position, which promotes engagement of the hind end, or walking on fairly steep (non slippery) slopes.

LOAD ABSORPTION

This phase begins with or is synchronous with the end of propulsion, break over or the start of the suspension phase of the forelimbs.

The pelvis is directly attached to the trunk via the sacroiliac joints and, therefore, loading of the hind end does not benefit from the flexibility of the supporting muscles of the trunk as in the forehand. Therefore, load absorption of the hindlimbs depends on controlled closure of the joints because of to regulated eccentric contraction of the muscles of the thigh and crus (**16.14, 16.17**). Internal mechanisms, such as the elasticity of the articular cartilage, sliding of the menisci in the stifles and sliding of the hock bones, also contribute to load absorption.

The quadriceps femoris muscle controls the closure of the stifle through an eccentric contraction. Closure of the hock joint is slowed by the elasticity of the common calcanean tendon (strong tendinous structure made up of the gastrocnemius and superficial digital flexor tendons) and contraction of the gastrocnemius muscle. The drop of the fetlock and horizontalization of the pastern are controlled by the elasticity of the digital flexor tendons and the suspensory apparatus. It is important to remember that the superficial digital flexor muscle, which originates from the femur, is entirely fibrous in composition and therefore acts in a completely passive fashion.

MID-STANCE AND PROPULSION PHASES

During these last two phases of the jump itself, intense contractions occur at the level of the vertebral axis (see Chapter 13: Airborne (flying) phase: biomechanics of the trunk and vertebral column) and the hindlimbs. This influences the direction of movement (from vertical to horizontal) and assists in the establishment of a suitable horizontal speed.

All of the muscles contributing to propulsion are activated:

▲ **16.18** Mid-stance phase of the leading hindlimb and propulsion by the trailing limb at the end of the landing phase of the jump. In the trailing hindlimb (right hindlimb, **left**, left hindlimb, **right**), synchronous extension of the stifle and hock precedes lifting of the fetlock. The deep digital flexor tendon is under tension and initiates rotation of the foot, assisting in propulsion. The leading leg (left hindlimb, **left**, right hindlimb, **right**) is achieving its mid-stance phase. This phase is characterized by closure of all the joint angles (hip, stifle, hock, fetlock and interphalangeal joints) and by a powerful lengthening (eccentric contraction) of the quadriceps femoris, gastrocnemius muscles and common calcanean tendon.

- The middle gluteal and caudal femoral muscles initiate a strong extension of the hip.
- The cranial, caudal and medial femoral muscles control extension of the stifle.
- Finally, opening of the stifle joint angle, in combination with concentric contraction of the gastrocnemius and digital flexor muscles, induces extension of the hock and verticalization of the pastern (**16.18**).

Tension of the common calcanean tendon is so strong (several thousands of kg) that a small degree of flexion takes place between the hock and the metatarsus (cannon) despite the resistance of the plantar ligaments (notably the long plantar ligament). The repercussion of this tension is significantly elevated pressure on the joint and bone surface, particularly at the front of the joint. These biomechanical events result in a variety of lesions such as bone contusion of the lower hock joints, arthritis (bone spavin) and even ligamentous lesions such as suspensory ligament or plantar ligament desmopathies.

Summary

Throughout this analysis of the biomechanics of jumping there has been a focus on the different body regions as well as specific joints. This allows for a more precise idea of the active elements and the demands on the musculoskeletal system that can contribute to the development of sport injuries.

Analysis of the different phases of jumping could have been simplified. Without being exhaustive, the choice was made to bring an original interpretation to the biomechanics of this sport exercise. This interpretation may at times be confusing to the reader due to the complexity of the different mechanisms and concepts brought to light. However, without such interpretations, progress and development within the knowledge of a sport discipline become based on intuition rather than objective data. The author's wish is to succeed in improving understanding of movement and attaining precision through the provision of objective data (anatomical and biomechanical). With this information to hand, it is hoped that a rational approach to training can be developed.

The author hopes that these last six chapters will provide riders and trainers with key ideas that will enhance their understanding of horse movements during jumping and improve the athletic ability of the show jumping horse with adequate and rational gymnastic exercises.

17 Biomechanics of the bounce jump

THE INTENSITY and frequency of show jumping sessions always pose problems in the preparation of the show jumper or event horse. The bone, joint and tendon systems are exposed to repeated biomechanical stresses. If the sessions are poorly organized by the trainer, they can be harmful to the integrity of the musculoskeletal system and prematurely disrupt the career of the horse.

Certain exercises that have already been analysed (lateral movements, lowering of the neck and rein-back) have several advantages and can replace or supplement a jumping session, thereby imposing less stress on the musculoskeletal system of the horse.

The bounce jump consists of jumping two jumps close enough together such that the horse is only able to load the limbs once between the jumps and not take a stride. This is significant from both a biomechanical and a gymnastic perspective. From an athletic point of view, the stresses imposed are less than those that appear during a normal jump. This movement, therefore, helps effectively to develop certain actions such as engagement of the hindlimbs and dynamic elevation of the forehand. Jumping exercises, including placing an intermediary bar on the ground between two jumps (**17.1**), provide similar advantages to the bounce jump by pacing the movement and breaking down its actions and gestures.

There will be no repetition of the general biomechanics of jumping in this chapter. It will discuss only the features of the bounce jump or combined jumps, specifically during the intermediary loading phases. Effectively, the approach to the first jump and landing after the second differ little from the same phases over a similar single jump.

▲ **17.1** Intermediary phases of a combined jump. A bar on the ground between two medium height jumps serves to pace the movement, control the distances between landing and take-off of the jumps, break down the individual gestures and regulate the dynamics of muscular contractions.

The intermediary phase of the bounce jump is characterized by a suspension phase between the stance phase of the forelimbs and the stance phase of the hindlimbs. The features of this phase depend on the skill and athletic ability of the horse, as well as the height of the jump.

The speed at which the combination is approached dictates the duration of the suspension phase (**17.2**). The individual variations are very interesting to analyse. In fatigued or sluggish horses, the suspension phase may be absent, the placement of the hindlimbs taking place before the forelimbs leave the ground. In the active, responsive horse, lifting of the forelimbs and the forehand largely precedes landing of the hindlimbs. These observations highlight the importance of this exercise from an athletic perspective as it helps energize, stretch and tone the muscles involved in the movement in heavier horses.

To analyse the bounce jump, the biomechanics of the forehand, thoracolumbar vertebral column and the hindquarters will be discussed in this order.

Biomechanics of the forehand

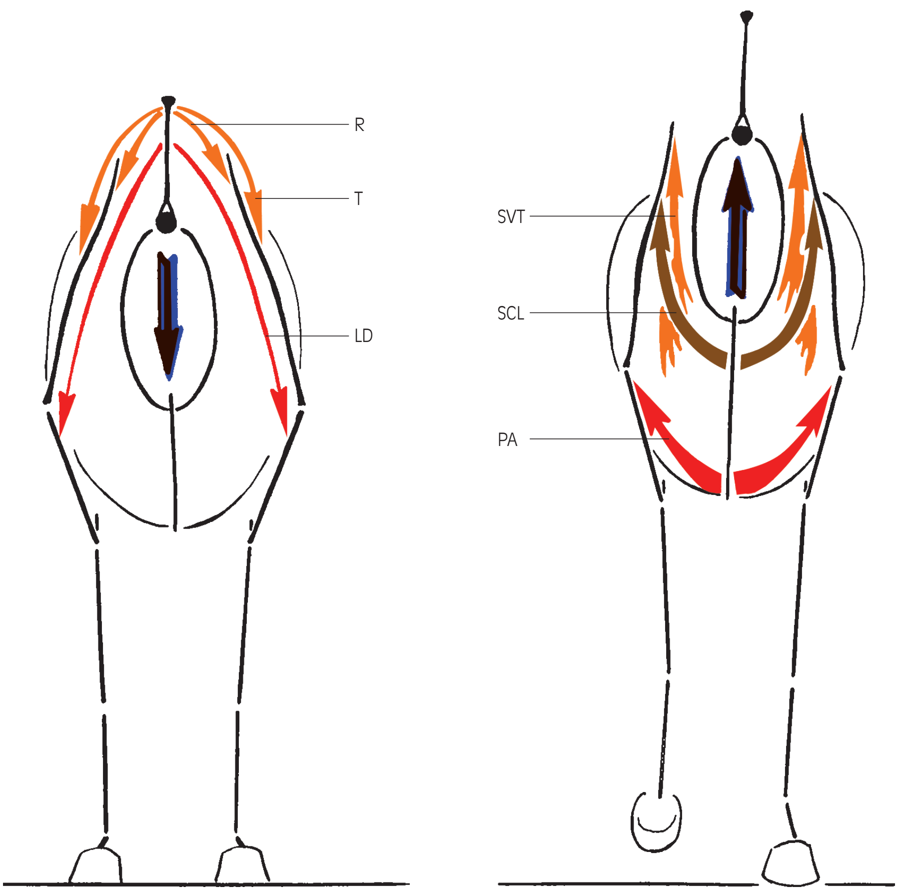
Between the two jumps in a bounce, the essential work of the horse consists of reversing the direction of vertical (downward then upward) movement of the body. During this movement, the neck and the forelimbs play a major role as they bring the forehand into a position that is favourable for taking on the second jump (**17.3**).

At landing following the first jump, dropping of the neck is limited in order to minimize the load on the forehand in the following sequence. Shock absorption by the forelimbs is therefore increased and the thoracic girdle muscles (serratus and pectoralis) are highly activated.

During this down and up movement (the transition from a downward to an upward vertical position), contraction of the dorsal cervical, serratus and pectoral muscles, along with contraction of the intrinsic muscles of the limb, suddenly changes from eccentric contraction (lengthening) to concentric contraction (shortening). It is this rapid change in contraction that switches the orientation of the forehand and initiates lifting in front of the second jump (**17.4, 17.5**). This action recruits three muscle groups:

▲ **17.2** Suspension phase of a bounce jump during training (**right**) and during a cross-country event (**left**). During training, the speed of the jump is deliberately slower. The suspension phase between take-off of the forelimbs and ground contact of the hindlimbs is short. In this competing event horse (**left**), the forelimbs start to lift and tuck, while the hindlimbs have not even made ground contact. In both horses, thoracolumbar flexion is substantial.

◀ **17.3** Loading of the forelimbs and elevation of the forehand in front of the second jump. Lifting and elevation of the trunk are due to tonic concentric contraction of the serratus and pectoral muscles.

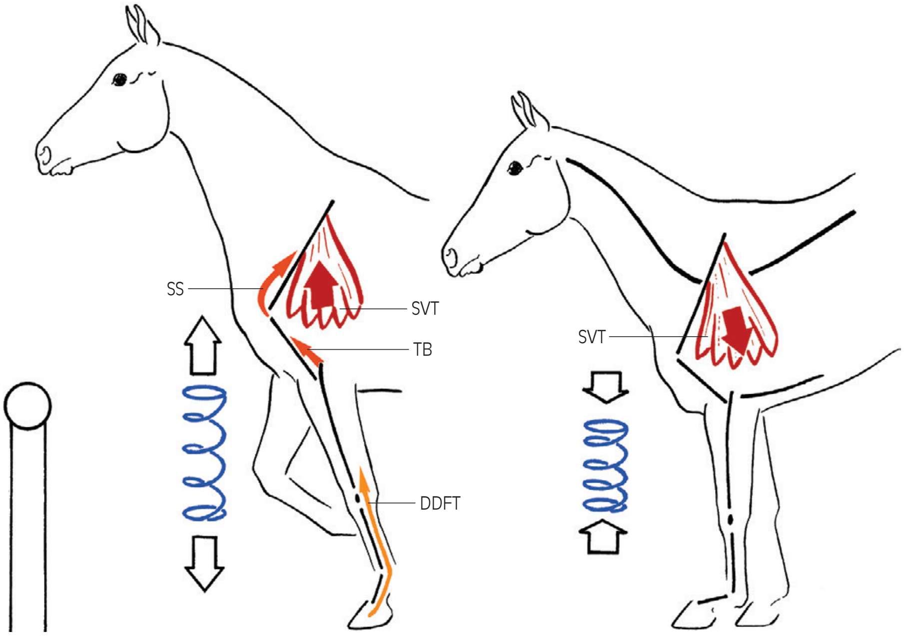


◀ **17.4** Muscular actions involved with loading and lifting of the forehand by the forelimbs in front of the second jump. During loading (**left**), the drop of the trunk is assisted by concentric contraction of the latissimus dorsi, trapezius and rhomboideus muscles. The muscles contributing to propulsion lengthen, preparing for dynamic upward movement of the forehand at take-off. Lifting of the forehand (**right**) is possible because of concentric contraction of the serratus and pectoral muscles. LD, latissimus dorsi muscle; T, trapezius muscle; R, rhomboideus muscle; SVT, serratus ventralis thoracis muscle; SCL, subclavius muscle; PA, pectoralis ascendens muscle.

- The dorsal cervical muscles support and lift the cervicocephalic pendulum (neck and head). The sudden elevation of this region pulls on the forelimbs and shifts the centre of mass backwards. This lightens the forehand and facilitates the dropping of the hindquarters and landing of the hindlimbs.
- The thoracic girdles (serratus and pectoralis muscles) push the trunk of the horse powerfully upwards (**17.4**). These muscles are suddenly activated and are the primary agents responsible for reversing the orientation of the body. Along with the exercises involved in lowering of the neck, the bounce jump is a very dynamic and complementary exercise for the development of the above-mentioned muscles, which are critical in many sport exercises.
- The muscles of the forelimb must prolong the action of the thoracic muscular girdles. After having contributed to shock absorption through controlled joint closure, the shoulder and elbow joints open rapidly via tonic concentric contraction of the supraspinatus and triceps brachii muscles (**17.5**). This action is similar to that of a spring which, during compression, stores energy in order to open and lengthen efficiently. The caudal antebrachial muscles (superficial digital and deep digital flexors) contract rapidly to support the fetlock as it absorbs the forces accumulated during loading. This active concentric contraction also assists lifting of the fetlock at the end of propulsion, prior to the forelimbs leaving the ground (take-off) (**17.1, 17.5, 17.6**).

The main feature of this movement is the necessity for load absorption and propulsion to follow each other promptly. Eccentric contractions must therefore switch to concentric contractions without a significant transition period. This dynamic exercise therefore places stress on the muscles that support the forehand, as well as reinforcing equilibrium, agility and the reactive speed of the horse.

During this movement the cervicothoracic junction remains in extension, which assists in lightening of the forehand and lowering of the hindquarters to achieve ground contact (**17.6**). In particular, during the stance phase of the forelimbs this neck position results in the dorsal spinous processes of the thoracic vertebrae becoming closer. This can cause pain in horses that already have impinging dorsal spinous processes in the withers and back. Therefore, the bounce jump should be used with caution in horses that are sensitive to thoracic extension.



▲ **17.5** Support and lifting of the trunk by the forelimbs in the intermediary phase of the bounce jump. (**Right**) Lengthening (eccentric contraction) of the serratus ventralis thoracis muscle and closure of the joint angles of the forelimb. (**Left**) Concentric contraction of the serratus ventralis thoracis muscle and opening of the joint angles of the forelimb. SVT, serratus ventralis thoracis muscle; SS, supraspinatus muscle; TB, triceps brachii muscle; DDFT, deep digital flexor tendon.

▲ **17.6** Ground contact, stance phase and propulsion by the forelimbs in front of the second jump. (**Right**) The drop of the left fore fetlock results in lengthening of the flexor tendons and the suspensory apparatus. The elasticity of these structures assists with lifting of the fetlock (Left fore) in conjunction with synergistic concentric contraction of the serratus and pectoral muscles, which lift the forehand. (**Left**) Illustration of the suspension phase between the two jumps. Take-off of the forelimbs accentuates lifting of the forehand, while the hindlimbs are yet to make ground contact.

Biomechanics of the thoracolumbar spine

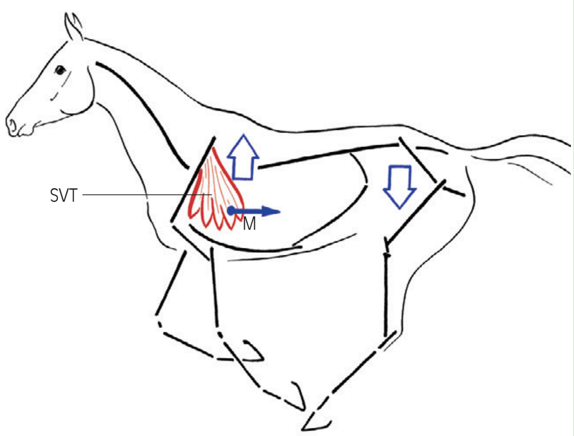
Landing after the first jump and propulsion at the second jump require significant engagement of the hindlimbs and a high degree of flexion of the thoracolumbar spine (**17.7**). These movements reach their maximal range during the suspension phase. The lumbosacral and thoracolumbar junctions are primarily responsible for the overall movement. Flexion is induced by contraction of the abdominal wall and iliopsoas muscles. This movement requires flexibility of the supraspinous ligament and the erector spinae muscle, which are significantly lengthened.

During the warm-up for a jumping session involving bounce combinations, the muscles must be progressively activated by working in a lowered neck position and rein-back movements. The dynamic work associated with bounce or combined jumps will prolong, complement and reinforce the efficiency of movement of basic flat-work exercises.

Biomechanics of the hindlimbs

The hindlimbs are placed in a position that favours elevation of the forehand and flexion of the thoracolumbar spine. They first undergo vertical loading, with the momentum of horizontal movement reduced because of flexion of the joints controlled by eccentric contraction of the muscles and elasticity of the stay apparatus. Propulsion then takes place thanks to the stored energy and concentric contraction of the muscles to clear the following jump (**17.8, 17.9**).

Relative to the other regions (forehand and trunk), the work of the hindlimbs is not greatly increased during the bounce jump compared with the execution of a normal jump. The primary stresses imposed by the bounce jump are related to the marked engagement of the hindlimbs that occurs prior to landing (**17.6, 17.7**). These stresses are related to strong flexion of the hip by the iliopsoas muscles, which results in lengthening of the caudal femoral muscles. These actions also



▲ **17.7** Asynchronous movement of the forehand and hindquarters in the intermediate phase of the bounce jump. Lifting of the neck brings the centre of mass (M) backwards and assists placement of the hindlimbs at ground contact. Lifting of the forehand is the result of concentric contraction of the serratus muscles (SVT, serratus ventralis thoracis muscle) and the pectoral muscles. Collection of the horse assists lumbosacral and coxofemoral flexion, which is initiated by concentric contraction of the iliopsoas and abdominal muscles. Opening of the stifle promotes lengthening of the caudal femoral muscles.

▲ **17.8** Mid-stance phase (loading) and propulsion of the hindlimbs at the second jump. During the stance phase (**right**), the gluteal muscles work not only to extend the hip, but also to elevate the trunk. In the **left** image all the joint angles of the hindlimb are open. There is a dynamic extension of the upper limb joints (hip, stifle and hock) and lifting of the fetlocks by the elastic flexor tendons and suspensory apparatus.

▲ **17.9** Clearing the second jump. Good pace and regulation of the distance between jumps facilitate relaxed and coordinated movements.

take place in the rein-back and lowering of the neck exercises. Therefore, the two exercises are good preparatory exercises to warm up the horse for a bounce jump. Rein-back, lowering of the neck inducing slow activation of the muscles and stretching, and a bounce jump inducing dynamic activation of the muscles and joint movements are adequate complementary gymnastic exercises for developing the athletic capacity of the sport horse.

Summary

It is evident that the dynamic characteristics of the bounce jump make it an excellent complementary exercise to flat work, which has already been discussed from several different aspects.

From an athletic point of view, the bounce jump contributes very effectively to the preparation of the forehand during the approach, take-off and landing phases of jumping, while inflicting only moderate stresses on the limbs of the horse. Finally, repetition of these combinations facilitates coordination and synchronization of movements, which reinforce muscular tone and the pace of movements.

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BIOMECHANICS AND PHYSICAL TRAINING OF THE HORSE

Jean-Marie Denoix

Effective horse trainers strive to improve the performance of their horses while preserving the integrity of the musculoskeletal apparatus. **Biomechanics and Physical Training of the Horse** supplies an anatomical and functional overview of the topic, enabling trainers to optimize the different exercises their horses undergo during training and competition.

Following a brief description of the biomechanics of the muscles underlying equine movement, the book discusses the muscles of the forelimb, hindlimb, and neck and trunk. These fundamentals have direct bearing on the later chapters, which focus on training and the core exercises for a horse.

This text is illustrated throughout by the author's top-quality photographs, diagrams, and his own beautiful anatomical drawings. The book is of lasting value to all professionals and well-informed amateurs who work with horses: veterinarians, trainers and riders, researchers, physical therapists, and educators in equine courses.

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Jean-Marie Denoix is a worldwide authority on applied equine anatomy, biomechanics, imaging, and the clinical diagnosis of equine lameness. He is a horse rider, a qualified trotting driver, and an informed spectator of everything equestrian.

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