

Functional Anatomy of the Equine Interphalangeal Joints

J.-M. Denoix, DVM, PhD

During locomotion, the interphalangeal joints undergo a variety of combined movements in the sagittal, frontal, and transverse planes, especially on uneven surfaces or during turns. Each movement induces specific stresses on the articular surfaces and ligaments. Asymmetric elevation of one quarter induces collateromotion and sliding on the same side and rotation on the opposite direction. With this knowledge, the biomechanical causes of every injury of the interphalangeal joint structures can be determined, and a rational corrective shoeing procedure can be established.

Author's address: Clinique Equine, U.P. Anatomie, U.M.R. INRA "Biomécanique du Cheval," Ecole Vétérinaire d'Alfort 7, avenue du Général de Gaulle F-94704, Maisons-Alfort Cedex, France. 1999 AAEP.

1. Introduction

The distal forelimb of the horse undergoes high stresses during locomotion, particularly during uneven foot bearing. The distal interphalangeal joint (DIPJ) is one of the most affected joints in the horse, the most influenced by hoof placement and orientation, and the most directly manipulated by hoof trimming and shoeing. The purpose of this study was to evaluate the extent and distribution of the contact articular surfaces within the interphalangeal joints under different circumstances of loading, limb attitude, and foot orientation, reproducing physiological stresses during natural gaits and jump and sport exercises. It was also to correlate experimental findings on isolated limbs and live horses with clinical applications and corrective shoeing.

2. Materials and Methods

A. Contact Articular Surfaces on Isolated Forelimbs

Forty-nine isolated thoracic limbs of adult horses and foals were used in the study. These limbs were sectioned at the mid-forearm to preserve the stay apparatus and especially the proximal insertion of the accessory ligament of the superficial digital flexor tendon (proximal check ligament).

For each test limb attitude (landing, support, or propulsion) and foot orientation (horizontal surface or surface that slopes down from medial to lateral or lateral to medial) were carefully chosen to reproduce one of the physiological circumstances of the horse weight-bearing limb during locomotion. The load was applied with a hydraulic workshop press and

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ranged between 200 and 1000 daN. As soon as the limb was positioned and loaded, lateromedial and dorsopalmar radiographs of the digit were taken and a colored solution of methyl violet (dilution 1%) was injected within the cavities of the distal and proximal interphalangeal as well as metacarpophalangeal joints, until distension of all synovial recesses was present. Then, an extensive lavage of the joints was performed to eliminate the excessive colored solution and protect the contact articular surfaces from coloration during the ultimate phases of the procedure. The latter included removal of the load and joint disarticulation under water. Then the synovial membrane, joint capsule, and ligaments were removed and, for the precise experimental conditions used, colored as well as noncolored articular surfaces of contact were identified and photographed. For each limb the size and situation of the contact articular surfaces were correlated to the conditions of loading, limb attitude, and foot orientation.

B. Radiographic Studies on Live Horses

On 15 live horses, radiographs of the digit were taken on weight-bearing forelimbs to evaluate joint spaces and bone orientation for different conditions of foot placement. Lateromedial projections were obtained under three circumstances: horizontal foot, elevated heels, and elevated toe. Dorsopalmar projections of the entire digit were performed under two circumstances: for bilateral weight bearing and for unilateral weight bearing, the opposite limb being held up.

On all radiographs, joint angulation and bone orientation were measured. On the dorsopalmar views the lateral and medial parts of each joint space were measured and compared between both weight-bearing positions. Interphalangeal rotation was assessed using the position of the extensor process of the distal phalanx (P3) and the imaging representation of the proximal phalanx (P1): when P1 underwent a lateral rotation, its medial border moved away from the film. Thus, because of the geometric magnification of the image due to the conic shape of the radiographic beam, an increased length of one border indicated a rotation of P1 on the opposite direction.

3. Results

A. Contact Articular Surfaces on Isolated Forelimbs

1. Sagittal Movements of Flexion and Extension

Under each experimental condition the contact involvement of the podotrochlear apparatus (distal sesamoid bone and associated structures) was established. During the first part of stance phase (from hoof contact to mid-stance phase) the DIPJ undergoes a passive movement of flexion.¹ This movement is associated with rotation of the distal condyle of the middle phalanx (P2) and sliding of its articular

surface dorsally on the glenoidal surface of P3 and distal sesamoid bone (DSB-navicular bone). In this limb attitude, because of the DIPJ flexion only the distal part of the DSB articular surface is in contact with the proximopalmar aspect of the distal condyle of P2. Moreover, the collateral (CSL) and impar distal sesamoidean (IDSL) ligaments are totally relaxed.¹

During the second part of the stance phase (from mid-stance to lift off) the DIPJ undergoes a movement of extension accompanied by sliding of the distal condyle of P2 palmarly on the articular surfaces of P3 and DSB. In this limb attitude, the articular surface of the DSB is in full contact with the distopalmar aspect of the distal condyle of P2.

2. Movements in the Frontal and Transverse Planes

During asymmetric bearing of the foot, a forced association of lateral or medial deviation and rotation movement was demonstrated within the interphalangeal (and metacarpophalangeal) joints (Fig. 1).

In the DIPJ, after elevation of the lateral quarter the joint space narrows laterally and opens medially, P3 slides on P2 towards the lateral side, and relative to P2, P3 rotates medially. The opposite movements occur when the medial side is elevated. Desmotomy of the CSL induced a DIPJ instability.

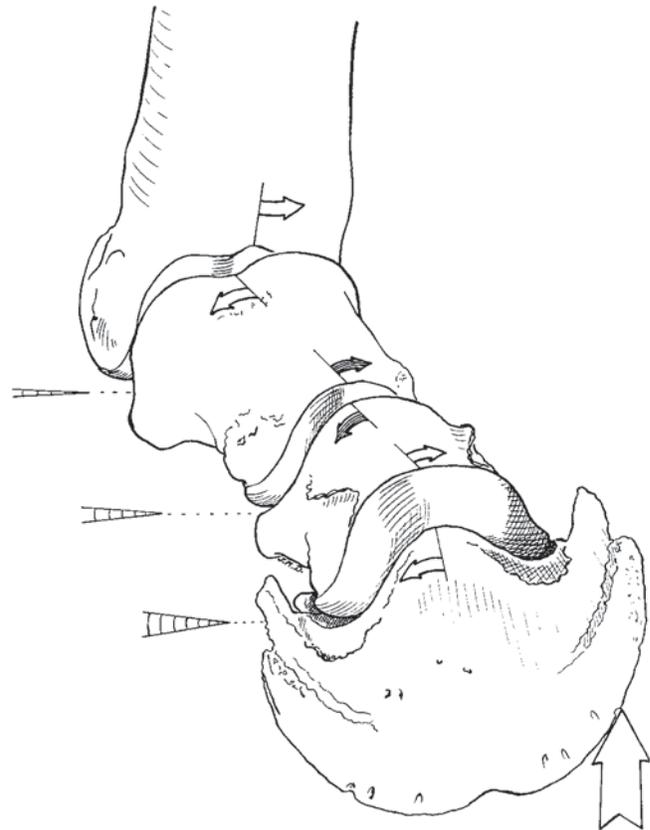


Fig. 1. Associated movements of rotation and collateromotion during asymmetric placement of the foot.

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B. Radiographic Studies on Live Horses

On live horses elevation of the heels induced flexion of the interphalangeal joints and limited extension of the metacarpophalangeal joint.^{1,2} The opposite movements appeared when the toe was elevated.

Compared with bilateral weight bearing on both frontlimbs, unilateral weight bearing on one limb induced on all horses: pinching of the interphalangeal joint spaces on the lateral side, medial rotation of both interphalangeal joints (medial rotation of the toe), and sliding of the distal articular surfaces on the lateral side (lateral sliding of the articular surface of P3 in relation to P2, and lateral sliding of the proximal articular surface of P2 in relation to P1).

4. Discussion and Applications

Analysis of the contact articular surfaces on the isolated forelimbs brought new data about the associated movements that take place within the interphalangeal joints during the stance phase. Basically, the DIPJ can move in three planes: sagittal plane (flexion and extension movements), frontal plane (lateromedial movements), and transverse plane (rotation and sliding).

A. Sagittal Movements

During the weight bearing of the limb, the passive movement of flexion is limited by the tension of the deep digital flexor tendon (DDFT) palmarly, the dorsal digital extensor tendon (DDET) dorsally, and the dorsal part of the collateral ligament (CL) on each side. All these structures are important to maintain joint stability.^{1,2}

During the second part of the stance phase, as propulsive forces exerted on P2 are oriented palmaro-distally¹ and as the DDFT is taut, it is likely that the propulsion phase is accompanied by high pressure on the DSB.² It must be noticed that DIPJ extension is mainly induced by the tension of the DDFT, which contributes to elevate the fetlock (and is the more active *extensor* of the DIPJ). This movement

provokes tension within the podotrochlear apparatus (CSL and IDSL), the caudal part of the CL, and the distal digital annular ligament (DDAL). All these structures have a critical role to maintain joint stability during the propulsion phase.

B. Movements in the Frontal and Transverse Planes

These movements occur mainly during the stance phase and are totally passive as no muscles exist inducing them. They are spontaneously associated because of the oblique orientation of the articular surfaces of P3 and P2.

1. Frontal Plane (Lateral or Medial Displacement)

Asymmetric foot placement (quarters at different levels) induces lateral or medial displacement (combination of rotation and sliding) of P3 relative to P2, and P2 relative to P1. These movements are usually called "lateroflexion" or "abduction/adduction" movement, but the movement can be displayed medially, these movements do not correspond to a flexion, there is no abductor or adductor muscle inducing them, and they are symmetric relative to the sagittal plane. Thus, the author proposes the concept of *collateromotion* to describe these passive movements in the frontal plane (word made of "motion": movement, and "collateral": symmetrical relative to the sagittal plane). With this new concept, a lateromotion is a displacement of P3 in a lateral direction relative to P2 and a mediomotion is a displacement of P3 in a medial direction relative to P2. Collateromotion of the digital joints is a passive movement induced by asymmetric foot orientation.

2. Transverse Plane

Rotation and sliding in the transverse plane are totally passive and occur also during the stance phase during asymmetric placement of the hoof (lateral and medial quarter at different levels). When the lateral quarter is elevated, the lateral distal condyle of P2 slides palmarly on the oblique articular surface of P3 and this movement corre-

Table 1. Corrective Shoeing of DIPJ Injuries.

Structure Involved	Cause of Injury	Corrective Shoeing
Medial collateral ligament	Lateromotion	Wide medial branch
	Medial rotation	Narrow lateral branch
Lateral collateral ligament	Lateral sliding of P3	No lateral extension (wedge)
	Mediomotion	Wide lateral branch with lateral extension (wedge)
	Lateral rotation	Narrow medial branch
Symmetric: distal DDFT and/or DDAL	Medial sliding of P3	Egg bar shoe
	DIPJ hyperextension	Elevated heels + rolling toe or reverse shoe
Asymmetric: distal DDFT and/or DDAL	Long toe-low heels conformation	Similar to above + wide branch opposite to the injury side
	Similar to above + collateromotion on the injury side	Narrow branch on the injury side
IDSL	Rotation on the opposite side	Rolling shoe in dorsopalmar direction and lateromedial direction
Osteoarthritis (degenerative joint disease)	Secondary to ligament injuries	Shock absorbing device
	Joint instability	
	Degenerative process	

sponds to a medial rotation of P3. The opposite occurs when the medial side is elevated. Thus, rotation is automatically associated with collateromotion. Moreover, it is accompanied by a sliding (translation on the transverse plane) of P3 relative to P2 toward the side of elevation.

3. Movement Limits

The main structure that limits collateromotion and rotation is the collateral ligament opposite to the elevated quarter. Stability of the joint is also provided by the DDF, DDAL, and IDSL mainly on the side of the elevated quarter. These structures are highly stressed during asymmetric propulsion.

C. Lesions and Corrective Trimming and Shoeing

The precise nature of the interphalangeal joint movements must be considered for corrective shoeing of sound as well as lame horses. All the anatomical structures of the DIPJ are highly stressed during weight bearing and especially during the stance phase on uneven ground or asymmetric foot placement. An adequate trimming and shoeing program requires a precise diagnosis of each injured structure, mainly based on radiography and ultrasonogra-

phy (Table 1). Lateromedial and dorsopalmar radiographs proved to be of invaluable interest for the assessment of joint balance for adequate foot trimming.

5. Conclusion

This study demonstrates the interest of simple investigations on anatomical models to improve the knowledge of articular behavior in the horse. The qualitative results of this study present many applications in the field of orthopedic shoeing for foot, digital, and tendon injuries in pleasure, race, and sport horses.

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