Pferdeheilkunde 27 (2011) 6 (November/Dezember) 706-710

The potential role of training programmes in reducing injuries

P. René van Weeren

Department of Equine Sciences, Faculty of Veterinary Medicine, Utrecht University, the Netherlands

Summary

Horses have always been used because of the huge potential of their musculoskeletal system and associated locomotor performance. Consequently, disorders of the musculoskeletal system rank first in causes of wastage. Within these musculoskeletal disorders problems related to articular cartilage and (flexor) tendons are of special importance, because of the notorious bad healing capacity of these tissues in mature individuals. There is increasing evidence for an important role of exercise in the juvenile phase in the conditioning of tissues and hence physical capacities and injury resistance of the horse (as in humans), including articular cartilage and (to a lesser extent) tendons. It is likely, therefore, that husbandry systems that limit the possibility to exercise at young age are detrimental for the development of a strong, injury-resistant musculoskeletal system whereas promoting physical exercise at young age can be expected to have a protective effect and hence may be an effective way to prevent musculoskeletal injury later in life.

Keywords: training / horse / injury / risk / joint cartilage

Die mögliche Rolle von Trainingsprogrammen zur Verringerung von Verletzungen

Pferde wurden aufgrund ihres immensen Vermögens des Bewegungsapparates immer genutzt. Dieses Vermögen ist mit einer lokomotorischen Leistungsfähigkeit assoziiert. Somit stellen Erkrankungen des Bewegungsapparates die Hauptursache für die Ausscheidung aus dem Sport dar. Im Rahmen dieser Erkrankungen sind Läsionen des Gelenkknorpels und der Beugesehnen von besonderer Wichtigkeit, da diese Gewebe beim adulten Tier eine schlechte Heilungskapazität besitzen. Es gibt zunehmend Anhaltspunkte, dass die Bewegung des Jungtieres eine wichtige Rolle bei der Konditionierung der Gewebe spielt und somit auch für die physikalische Kapazität und die Verletzungsresistenz einschließlich für den Gelenkknorpel und in geringerem Maße für die Sehnen der Pferde(ähnlich dem Menschen) verantwortlich ist. Es ist somit wahrscheinlich, dass Haltungsbedingungen, welche die Möglichkeit der Bewegung im jungen Alter begrenzen für die Entwikklung eines starken Verletzungs- resistenten Bewegungsapparates schädlich sind, wogegen erwartet werden kann, dass das Fördern von Bewegung im jungen Alter eine protektive Wirkung besitzt und somit die Möglichkeit besteht Verletzungen des Bewegungsapparates zu einem späteren Lebenszeitpunkt zu verhindern

Schlüsselwörter: Training / Pferd / Verletzung / Risiko / Gelenk / Knorpel

Introduction

Unlike almost all other domesticated species, the horse was domesticated for its athletic potential and the species has served mankind for millennia in warfare, transport and agriculture thanks to its sheer power, speed, agility and stamina (*Dunlop* and *Williams* 1996). The role of the horse in society has changed dramatically over the past 60 or 70 years, but also in its present-day use as a sports and leisure animal those same characteristics decide whether the horse will be successful or not. It may not be surprising, therefore, that injuries of the musculoskeletal system are by far most important in terms of wastage in equine athletes. This applies to the racing industry (*Rossdale* et al. 1984, *Williams* et al. 2001), but equally to other equestrian disciplines, such as dressage, show jumping, eventing and endurance (*Sloet* et al. 2010). The most important affected tissues are articular cartilage, tendons and bone (the latter tissue more in the racing industry than in other equestrian disciplines). Both articular cartilage and tendon are known to have extremely limited regenerative capacity in mature individuals, which makes severe lesions of these tissues often career-ending in performance horses.

There are no historical epidemiological data on the horse and even modern epidemiological studies are scarce and focussing almost invariably on racehorses, but the impression exists that musculoskeletal disorders have certainly not decreased in prevalence in recent times. This may have to do with the fact that the exigencies of modern top-level equestrian sports may be even tougher than those for former uses of the horse. However, there may be another factor too which is the way many horses are kept in today's strongly urbanised world where space is a rare and expensive commodity. Many horses, whose ancestors have evolved as animals free-roaming the vast steppes and plains of the Eurasian and North American continents, are now during most of the day confined to stables, or at the best to relatively small enclosures. The differences between domesticated horses and feral horses may be substantial. *Hampson* et al. (2010) observed that Australian wild horses (including new-born foals) travel on average 16 km per day (range 8-28), which is much more than the daily exercise of the average domesticated horse. The wish to have "early foals" (i.e. foals born as close as possible to their administrative birth date, which is January 1st in the Northern hemisphere and August 1st in the Southern) results in most parts of the temperate zones in stall confinement for young foals as well, because of harsh climatic conditions outside.

The influence of early exercise

In terms of conditioning, early exercise may have effects on either neuromuscular functioning, i.e. the co-ordination and technical execution of activities, or on the biological characteristics of musculoskeletal tissues, which can theoretically be broken down into biomechanics, extracellular matrix biochemistry and cellular performance. The biological characteristics have been researched more heavily and will be discussed here.

The responsiveness of certain musculoskeletal tissues and especially bone to exercise, also in mature individuals, has been known for long. Bone is not a homogeneous tissue with respect to biochemical composition and structure, but adapts to the amount and direction of the loads it is subjected to. This principle, known as Wolff's law, was discovered more than a century ago (*Wolff* 1892). The insight that this principle applies to more tissues than bone alone, is from a much more recent date.

Articular cartilage

In 1999 *Brama* et al. published a first report on site (and age) related differences in the biochemical characterisation of the collagen network at two sites of the proximal articular surface of the first phalanx (*Brama* et al. 1999). They showed a significantly higher collagen content at the dorsal rim of the articular surface than in the central fovea. Numbers of cross-links were higher too. In a more extensive study into the topographical heterogeneity of the same articular surface, in which 12 sites were sampled and proteoglycan content was determined as well, it was demonstrated that there was a distinct and consistent topographical variation for all parameters determined: water, DNA, glycosaminoglycans, collagen, hydroxylysylpyridinoline (HP) cross-links and degree of lysyl hydoxylation (*Brama* et al. 2000a). The findings corresponded neatly with the load distribution in the joint as determined using pressure-sensitive films in an in vitro setting and applying loads occurring during activities such as standing, walking, trotting, cantering and jumping (*Brama* et al. 2001), showing that in the mature individual there is normally a match between loading and tissue characteristics, i.e. between the resistance of the tissue and the demands placed upon it.

Little and *Ghosh* (1997) were the first to provide some evidence that these topographical differences in extracellular matrix composition may be not yet present at birth as they demonstrated that in neonatal ovine articular cartilage, in contrast to tissue from mature individuals, there was neither heterogeneity in proteoglycan biochemistry nor in chondrocyte metabolism. This brought them to the hypothesis that the regional chondrocyte phenotype of adult ovine cartilage resulted from factors imposed on the joint after birth, i.e. weight bearing and articulation. A first investigation to verify whether the situation in the horse was comparable to that in sheep showed that there were indeed no differences for all biochemical parameters of neonatal equine articular cartilage between the two sites that are most different in the mature animal (*Brama* et al. 2000b). This was true for all parameters that were investigated, including those related to collagen. Site-specific differences had developed at the age of 5 months for DNA, GAGs, collagen and lysyl hydroxylation, but were still absent for water and HP cross-linking at age 11 months. The picture became complete when these data were combined with data from older animals: the ratios between the two sites for these parameters became significantly different from zero in the age span of 1-4 years (*Brama* et al. 2002). It is interesting to note that most of the topographical heterogeneity takes shape in the first 5 months of life, which therefore seems to be a crucial period. Important evidence that loading (and hence exercise) plays a crucial role in this development came from a large-scale investigation into the influence of exercise on the development of the equine musculoskeletal system in general and on osteochondrosis in particular, the so-called EXOC study (*van Weeren* and *Barneveld* 1999). In this study 3 groups of foals were compared that had been reared under different exercise regimens from 0-5 months of age (box-rest only, box-rest with short bouts of high-intensity exercise and pasture exercise). At the age of 5 months, 24 (8 from each group) of the original 43 foals were euthanased and their musculoskeletal tissues were harvested for analysis. The remaining 19 foals were joined in a single group that underwent a moderate exercise regimen. These animals were sacrificed at the age of 11 months to see if any differences encountered at age 5 months persisted or not. The overall conclusion from the EXOC-study was that pasture exercise came by far out as best for an optimal conditioning of the musculoskeletal tissues. Box-rest led to a clear retardation of the normal maturation process (fig. 1), and the combination of box-rest with additional short bouts of high-intensity exercise appeared to have negative effects, among others on chondrocyte viability (*Barneveld* and *van Weeren* 1999, *van den Hoogen* et al. 1999).

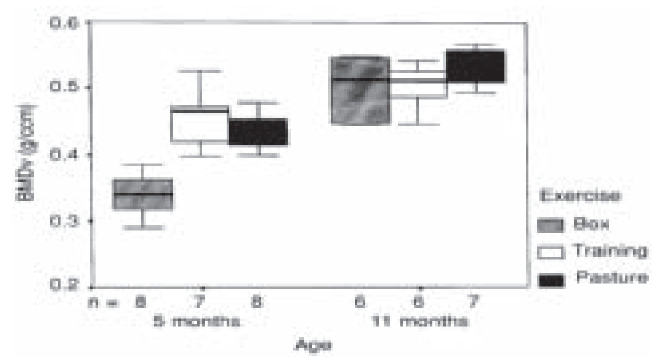

Fig. 1 The overall importance of early exercise is nicely illustrated by the response of bone. Bone mineral density development remained clearly and significantly behind in the foals from the EXOC experiment that were kept in box stalls for 24 hours per day, compared to foals that received either free (pasture) exercise, or foals that were kept in box stalls but received short bouts of high-intensity exercise. The common (light) exercise protocol the remaining 19 foals received was apparently sufficient to make the foals from he original box rest group to recover completely. At 11 months foals from all former exercise groups have comparable bone mineral density (right side of picture). BMDv: Bone mineral density by volume (in grams per cubic centimetre).

Building forth on the data from the EXOC-project that unequivocally showed the modulating influence of early exercise on musculoskeletal tissues (*van Weeren* et al. 2000), a new large experiment was set up by an international consortium with as major goal to investigate the possibility of strengthening the equine musculoskeletal system by conditioning it via an increase of the workload on top of the normal amount of exercise foals will have when moving freely at pasture (*McIlwraith* 2000). The so-called GEXA-trial was carried out in New Zealand and comprised two groups of Thoroughbred foals (*Rogers* et al. 2008a). The groups were raised under identical circumstances at pasture from birth until breaking in at 18 months, but one of the groups (CONDEX) were subjected to an additional exercise regimen that increased the total workload in comparison to the untrained group (PASTEX) with about 30%. Applying specific exercise regimens to young (suckling) foals may pose some technical problems (fig. 2).

Workload was measured using a specially developed Cumulative Workload Index (CWI) (*Rogers* and *Firth* 2004). It is important to note that no detrimental effects of the imposed exercise regimen could be noted (*Rogers* et al. 2008a,b). There was no exercise effect on proteoglycan content, indicating that the exercise level had not been strenuous and confirming the work by *Nugent* et al. (2004) and *Kawcak* et al.

Fig. 2 Specific training of young foals can only be done if the mare is exercised. It may be necessary to create specific conditions to achieve this. In the EXOC-trial mares and foals were chased between two helpers, in the GEXA-trial, mares and foals were exercised over a custom-built oval track between farmbikes

(2010) on full-thickness cartilage, but a detailed analysis of the various layers of the articular cartilage from the surface down to the calcified cartilage showed that there was an accelerating effect on normal development of cartilage. In the CONDEX animals, hydroxylysine, HP cross-links and pentosidine cross-links were all higher, all indicative of advancement of the normal process of functional adaptation (*van Weeren* et al. 2008). Other evidence for the difference in maturation rate came from ultrastructural studies. Polarised light microscopy techniques were used to investigate the spatial arrangement of the fibrils of the collagen network throughout the depth of the cartilage, measured as parallelism index (PI, a measure of the degree to which the collagen fibrils are aligned to each other) and orientation index (OI, a measure of the average angle of collagen fibrils with respect to the articular surface). Parallelism index was higher in CONDEX animals, again indicating advanced maturation (*Brama* et al. 2009).

With respect to the cellular component of the cartilage it was shown that the conditioned animals had higher viability scores for chondrocytes than the animals that had not received additional exercise (*Dykgraaf* et al. 2008).

Tendons

Of the disorders of the musculoskeletal system tendon disorders rank first or second to articular cartilage problems, depending on breed or equestrian activity involved (*Rossdale* et al. 1985, *Todhunter* 1992). The effect of exercise on tendons depends on the type of tendon involved. *Woo* et al. (1982) showed in pigs that exercise led to an increase in cross-sectional area (CSA) in extensor tendons (which are so-called positional tendons that only transmit force between the muscle and the site of bony attachment), but not in flexor tendons (which are more elastic and also have an energy-storing function). There may be a good biological reason behind this: if the CSA of flexor tendons would increase considerably with unchanged material properties, this would imply an increase in stiffness and hence a decrease in elasticity. There are some indications, however, that the exercise level may affect the development of the flexor tendons too in the early juvenile period. In material from the EXOC-study cited above it was

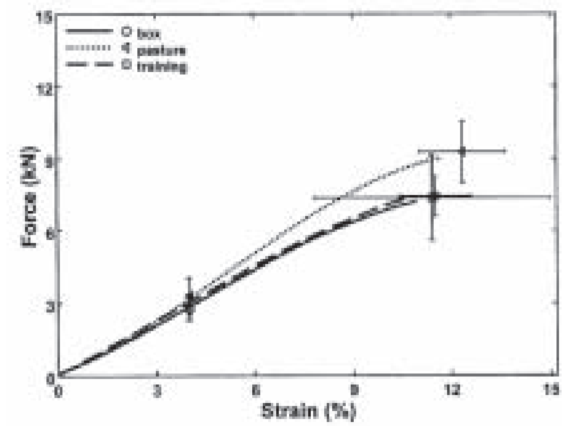

Fig. 3 Force-strain curves of the superficial digital flexor tendons of foals from the EXOC-experiment at age 5 months. Tendons were loaded until rupture. Tendons from the pasture-raised foals ruptured at a higher force than those from the foals that had been box-rested, or that had been box-rested in combination with bouts of short-term exercise. (From: *Cherdchutham* et al. 2001a).

shown that the pasture-exercised foals had a larger CSA of the superficial digital flexor tendon (SDFT) and the tendons ruptured at a higher load with less tissue stiffness than in the other two groups (*Cherdchutham* et al. 2001a) (fig. 3). There were also differences in collagen fibril diameter distribution (*Cherdchutham* et al. 2001b) and biochemical composition (*Cherdchutham* et al. 1999) between these groups of foals with higher cellularity and higher levels of polysulphated glycosaminoglycans (PSGAG) and hyaluronic acid (HA) in the pastured animals compared to the box-rested foals. Interestingly, in the foals that originated from the exercise groups and were joined in a single group to be euthanased at 11 months the differences in the abovementioned biochemical parameters between foals that had been box-rested respectively pastured during the first 5 months had disappeared. However, animals that had originally been subjected to the combination of box-rest and heavy exercise showed a significantly lower PSGAG/DNA ratio, which was interpreted as a negative long-term effect of that specific exercise regimen.
In a study (the JRA-study) in which Thoroughbred foals were

trained on a treadmill (in addition to a regimen of box-rest with limited access to pasture) and in which SDFT CSA was monitored ultrasonographically *Kasashima* et al. (2002) found significant differences in certain episodes only. SDFT CSA was larger in the exercised foals at around age 5 months, but there was no significant difference over the entire monitoring period. Biochemical parameters were not determined in that study.

In the GERA study that has been mentioned earlier (Rogers et al. 2008a,b) there was no difference in SDFT CSA between the trained CONDEX and the untrained (but pasture exercised) PASTEX animals after an experimental period lasting from age 3 weeks to age 18 months, although there was a trend (p=0.058) towards a larger CSA in the CONDEX group (*Moffat* et al. 2008).

Conclusion

In man there is increasing recognition of the importance of early exercise (USDHHS 1996), with even a clear effect of exercise during childhood on the risk of depression later in life (*Jacko* et al. 2011). Of the latter effect little is known in the horse, but in the equine species there is also ample evidence now that exercise in early life has a moulding influence on the extracellular matrix of articular cartilage and possibly also tendon. As articular cartilage in adult animals should have a composition that is matched to the loads it is subjected to and is known to have virtually no regenerative capacity, the first few months of life may be crucial to create a tissue with optimal biomechanical properties and hence maximal injury resistance. It has been shown that withholding of exercise during this early juvenile period will result in a retardation of the normal development that, in the case of the collagen matrix, cannot be compensated for and thus will lead to an inferior ECM. It is also known that a combination of inactivity with short bouts of heavy exercise has deleterious effects. Thus far free pasture exercise comes out best and it can now be said that there is compelling evidence to state that foals should always be raised in a way that they are subjected to a work-load that is at least equal to what they would be having if moving freely at pasture. Additional exercise to this basic workload will induce further changes in the speed of maturation of the ECM and in final biochemical make-up, but it is not clear yet whether this leads to a better injury resistance. It can be expected that in the future more research will be done on the effect of exercise at early age on musculoskeletal development. Specific exercise guidelines for optimal conditioning of the musculoskeletal system in the horse will emerge at some stage, making rearing and training of horses a little more into a science-based activity than the art that is entirely based on tradition and empiricism it is at present.

References

Barneveld A. and *van Weeren P. R.* (1999) Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. Equine vet. J. 31, Suppl. 31, 112-119

Brama P. A. J., Holopainen J., van Weeren P. R., Helminen H. J. and *Hyttinen M. M.* (2009) Effect of loading on the organization of the collagen fibril network in juvenile equine cartilage. J. Orth. Res. 27, 1227-1234

Brama P. A., TeKoppele J. M., Bank R. A., Barneveld A. and *van Weeren P. R.* (2002) Development of biochemical heterogeneity of articular cartilage: influences of age and exercise. Equine vet. J. 34, 265-269

Brama P. A., Karssenberg D., Barneveld A. and *van Weeren P. R.* (2001) Contact areas and pressure distribution on the proximal articular surface of the proximal phalanx under sagittal plane loading. Equine vet. J. 33, 26-32

Brama P. A., Tekoppele J. M., Bank R. A., Karssenberg D., Barneveld A. and *van Weeren P. R.* (2000a) Topographical mapping of biochemical properties of articular cartilage in the equine fetlock joint. Equine vet. J. 32, 19-26

Brama P. A., Tekoppele J. M., Bank R. A., Barneveld A. and *van Weeren P. R.* (2000b) Functional adaptation of equine articular cartilage: the formation of regional biochemical characteristics up to age one year. Equine vet. J. 32, 217-221

Brama P. A., TeKoppele J. M., Bank R. A., van Weeren P. R. and *Barneveld A.* (1999) Influence of site and age on biochemical characteristics of the collagen network of equine articular cartilage. Am. J. Vet. Res. 60, 341-345

Cherdchutham W., Meershoek L. S., van Weeren P. R. and *Barneveld A.* (2001a) Effects of exercise on biomechanical properties of the superficial digital flexor tendon in foals. Am. J. Vet. Res. 62, 1859-1864

Cherdchutham W., Becker C. K., Spek E. R., Voorhout W. F. and *van Weeren P. R.* (2001b) Effects of exercise on the diameter of collagen fibrils in the central core and periphery of the superficial digital flexor tendon in foals. Am. J. Vet. Res. 62, 1563-1570

Cherdchutham W., Becker C., Smith R. K. W., Barneveld A. and *van Weeren P. R.* (1999) Age-related changes and effect of exercise on the molecular composition of immature equine superficial digital flexor tendon in foals. Equine Vet. J. 31, Suppl. 31, 86-94

Dunlop R. H. and *Williams D. J.* (1996) Veterinary Medicine. An illustrated history. St. Louis: Mosby

Dykgraaf S., Firth E. C., Rogers C. W. and *Kawcak C. E.* (2008) Effects of exercise on chondrocyte viability and subchondral bone sclerosis in the distal third metacarpal and metatarsal bones of young horses. Vet. J. 178, 53-61

Hampson B. A., de Laat M. A., Mills P. C. and *Pollitt C. C.* (2010) Distances travelled by feral horses in "outback" Australia. Equine vet. J. 42, Suppl. 38, 582-586

Jacko F. N., Pasco J. A., Williams L. J., Leslie E. R., Dodd S., Nicholson G. C., Kotowicz M. A. and *Berk M.* (2011) Lower levels of physical activity in childhood associated with adult depression. J. Sci. Med. Sport. 14, 222-226

Kasashima Y., Smith R. K., Birch H. L., Takahashi T, Kusano K. and *Goodship A. E.* (2002) Exercise-induced tendon hypertrophy: cross-sectional area changes during growth are influenced by exercise. Equine Vet. J. 34, Suppl. 34, 264-268

Kawcak C. E., McIlwraith C. W. and *Firth E. C.* (2010) Effects of early exercise on metacarpophalangeal joints in horses. Am. J. Vet. Res. 71, 405-411

Little C. B. and *Ghosh P.* (1997) Variation in proteoglycan metabolism by articular chondrocytes in different joint regions is determined by post-natal mechanical loading. Osteoarthr. Cart. 5, 49-62

McIlwraith C. W. (2000) Global Equine Research Alliance to reduce musculoskeletal injury in the equine athlete. Equine Vet. Educ. 12, 260-262

Moffat P. A., Firth E. C., Rogers C. W., Smith R. K. W., Barneveld A., Goodship A. E., Kawcak C. E., McIlwraith C. W. and *van Weeren P. R.* (2008) The influence of exercise during growth on ultrasonographic parameters of the superficial digital flexor tendon of young Thoroughbred horses. Equine Vet. J. 40, 136-140

Nugent G. E., Law A. W., Wong E. G., Temple M. M., Bae W. C., Chen A. C., Kawcak C. E. and *Sah R. L.* (2004) Site- and exercise-related variation in structure and function of cartilage from equine distal metacarpal condyle. Osteoarthritis Cartilage 12, 826-833

Rogers C. W., Firth E. C., McIlwraith C. W., Barneveld A., Goodship A. E., Kawcak C. E., Smith R. K. and *van Weeren P. R.* (2008a) Evaluation of a new strategy to modulate skeletal development in Thoroughbred performance horses by imposing track-based exercise during growth. Equine vet. J. 40, 111-118

Rogers C. W., Firth E. C., McIlwraith C. W., Barneveld A., Goodship A. E., Kawcak C. E., Smith R. K. and *van Weeren P. R.* (2008b) Evaluation of a new strategy to modulate skeletal development in racehorses by imposing track-based exercise during growth: the effects on 2- and 3-year-old racing careers. Equine vet. J. 40, 119-127

Rogers C. W. and *Firth E. C.* (2004) Musculoskeletal responses of 2-year-old Thoroughbred horses to early training. 2. Measurement error and effect of training stage on the relationship between objective and subjective criteria of training workload. New Zeal. Vet. J. 52, 272-279

Rossdale P. D., Hopes R., Wingfield Digby N. J. and *Offord K.* (1985) Epidemiological study of wastage among racehorses 1982 and 1983. Vet. Rec. 116, 66-69

Sloet van Oldruitenborgh-Oosterbaan M. M., Genzel W. and *van Weeren P. R.* (2010) Factors influencing the career of Dutch sport horses. Equine Vet. J. 42, Suppl. 38, 28-32

*Todhunter R. J. (*1992) Synovial joint anatomy, biology, and pathobiology. In: Equine Surgery, Ed. Auer J.A., 1st ed. Philadelphia: Saunders, pp 844-866

United States Department of Health and Human Services. (1996) Physical activity and health: a report of the surgeon general. Atlanta, GA: Public Health Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion.

Van den Hoogen B. M., Van de Lest C. H. A., Van Weeren P. R., Van Golde L. M. G. and *Barneveld A.* (1999) Effect of exercise on the proteoglycan metabolism of articular cartilage in growing foals. Equine vet. J. 31, Suppl. 31, 62-66

Van Weeren P. R., Firth E. C., Brommer H., Hytinen M. M., Helminen H. J., Rogers C. W., DeGroot J. and *Brama P. A. J.* (2008) Early exercise advances the maturation of glycosaminoglycans and collagen in the extracellular matrix of articular cartilage in the horse. Equine vet. J. 40, 128-135

Van Weeren P. R., Brama P. A. J. and *Barneveld A.* (2000) Exercise at young age may influence the final quality of the equine musculoskeletal system. Proc. Am. Assoc. Equine Pract. 46, 29-35

Van Weeren P. R. and *Barneveld A.* (1999) Study design to evaluate the influence of exercise on the development of the equine musculoskeletal system of foals up to age 11 months. Equine Vet. J. 31, Suppl. 31, 4-8

Williams R. B., Harkins L. S., Hammond C. J. and *Wood J. L.* (2001) Racehorse injuries, clinical problems and fatalities recorded on British racecourses from flat racing and National Hunt racing during 1996, 1997 and 1998. Equine vet. J. 33, 478-486

Wolff J. (1892) Das Gesetz der Knochen. Berlin: Hirschwald

Woo S. L., Gomez M. A., Woo Y. K. and *Akeson W. H.* (1982) Mechanical properties of tendons and ligaments. II. The relationships of immobilization and exercise on tissue remodeling. Biorheology 19, 397-408

P. René van Weeren DVM PhD Dipl ECVS
Department of Equine Sciences
Faculty of Veterinary Medicine
Utrecht University
Yalelaan 112
3584 CM Utrecht
The Netherlands
r.vanweeren@uu.nl