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To move or to perish: the importance of exercise during musculoskeletal development in the horse

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Summary

Horses have always been kept because of their locomotive capacities and the principal goal of horse breeding is to produce optimally performing equine athletes. However, wastage figures are relatively high and have a severe impact on both equine welfare and economic performance of the equine industry. Orthopaedic injuries are by far the most common cause of wastage in all equestrian activities. Some of the frequently affected musculoskeletal tissues, such as articular cartilage and (flexor) tendon, are known to have very limited regenerative capacity, which makes prevention a much more effective strategy than improvements of therapeutic interventions. A potential way to enhance prevention of musculoskeletal injury is to increase the resistance to injury of the tissues concerned by improving their biomechanical characteristics. There is increasing evidence that biomechanical loading (i.e. exercise) in the early juvenile phase plays a crucial role in the determination of biochemical and structural tissue characteristics of the musculoskeletal system and hence of biomechanical qualities. Several field trials have shown that withholding exercise will retard the normal development of the musculoskeletal system, creating a delay that cannot be made up for after a certain age because of the rapidly decreasing remodelling rate of collagen. To ensure an adequate conditioning of the musculoskeletal system, foals need to have an exercise load that is at least equivalent to what they would get when exercising freely at pasture. In more recent experiments, in which the effect of additional exercise to this basic workload was investigated, it was shown that even a relatively minor increase in workload could be effective in enhancing and accelerating the normal maturation process of musculoskeletal tissues. No adverse effects of extra early conditioning exercise have been observed thus far, but it is not yet clear whether there will be a long-term protective effect for musculoskeletal injury or not.

Keywords: foal, exercise, performance, musculoskeletal system, articular cartilage

Bewegen oder Untergehen - Über die Bedeutung der Bewegung während der muskuloskelettalen Entwicklung des Pferdes

Pferde wurden immer wegen ihrer Kapazität als Arbeitstier oder Sportkamerad gehalten, weswegen ihrer Bewegung und Gesundheit des muskuloskeletalen Apparates immer eine große Bedeutung zugemessen wird. Aus diesem Grund müsste das Ziel jeder Zucht sein, gesunde und talentierte Athleten zu produzieren. Die Wirklichkeit ist jedoch anders und Verluste in der Pferdeindustrie sind häufig und haben einen großen Einfluss nicht nur ökonomisch, sondern auch im Sinne des Tierschutzes der betroffenen Pferde. Dabei stehen die orthopädischen Erkrankungen an der Spitze, wobei Erkrankungen bei der Entwicklung einen großen Raum einnehmen. Knorpel und Sehnen haben eine sehr limitierte Regenerationsfähigkeit, womit der Prophylaxe solcher Erkrankungen eine umso größere Bedeutung zukommt. Vorbeugen ist hier viel besser als heilen. Eine Möglichkeit, Verletzungen des Bewegungsapparates zu vermeiden, ist die Resistenz der Gewebe gegen Verletzungen zu erhöhen, indem ihre biomechanischen Eigenschaften verbessert werden. So besteht eine große Evidenz, dass biomechanische Belastung (Training) in der frühen Jugendphase die biomechanische und biochemische Struktur und Komposition dieser Gewebe beeinflusst und letztlich ihre Qualität bestimmt. Feldstudien haben gezeigt, dass mangelndes Training von jungen Pferden die normale Entwicklung des Bewegungsapparates verlangsamt, wenn nicht sogar verhindert. Eine Verlangsamung der Entwicklung kann durch die schnelle Abnahme der Regenerationsfähigkeit von Kollagen im Knorpel und Sehnengewebe später nicht mehr unbedingt wettgemacht werden. Das Training muss in jedem Falle der biomechanischen Belastung entsprechen, welche ein Fohlen auf der Weide beim natürlichen Aufwachsen bekommen würde. In jüngeren Untersuchungen konnte gezeigt werden, dass sogar ein relativ mildes Training die Qualität des Bewegungsapparates von jungen Pferden verbessern kann und keine Erkrankungen hervorgerufen wurden. Noch unklar ist, ob die verbesserte Qualität der Gewebe nur temporär oder länger im Leben der Pferde bestehen bleibt. In der vorliegenden Übersicht werden alle diese Aspekte genauer beleuchtet.

Schlüsselwörter: Fohlen, Bewegung, Leistung, Muskel, Slelett, Gelenkknorpel

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 just as important, which is the way many horses are kept in today's strongly urbanised world where space is a rare and an 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 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) results in most parts of the temperate zones in stall confinement for young foals as well, because of harsh climatic conditions outside.

There is growing insight that early events in an individual's life, which includes the pre-natal period, may have far-reaching consequences for both, mental and physical health later in life. This so-called DOHaD (developmental origins of health and disease) concept has been developed and has been most widely studied in man (*Gluckman* and *Hanson* 2006, *Silveira* et al. 2007), but no sensible reason can be given why the principle would not apply to animals. In fact, as will be shown later in this paper, there is convincing evidence from a number of recent studies that the concept applies to the horse as well, which would make some of the modern management practices pointed out above highly questionable.

This paper summarises the outcome of a series of recent studies that have investigated the effects of specific exercise regimens at early age on either the development of athletic capacities, or on the biochemical and biomechanical characteristics (hence indirectly on susceptibility for musculoskeletal injury) of key tissues of the musculoskeletal system.

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 than the first category, but still some work on the effects of early training on sports performance has been carried out in the horse.

The effect of early exercise on neuromuscular skills

In a study where a cohort of Warmblood foals was followed from foal age until the age of 5 years by means of repeated kinematical analysis of jumping performance, the so-called JUMPEX study (Fig. 1), *Santamaría* et al. (2004a) showed that several aspects of jumping technique that could be identified in free jumping foals at 6 months of age (*Santamaría* et al. 2002) were still recognisable at the age of 4 years, among them the peak vertical acceleration produced by the hind limbs, peak rate of change of effective energy produced by the hind limbs, vertical take-off velocity, vertical displacement of the centre of gravity during the airborne phase and duration of the airborne phase. It was concluded from this study that horses have individually different jumping patterns of which at

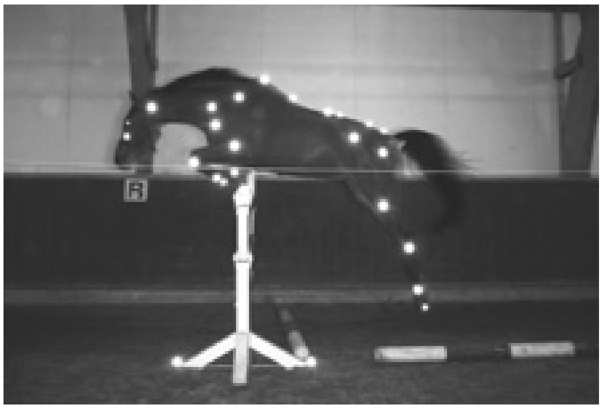

Fig. 1 Foal from the JUMPEX-trial equipped with retroflective skin markers jumping an obstacle.

least certain parts are inherent to a specific animal (*Santamaría* et al. 2004b). However, competitive performance in show jumping depends on more than technique alone, which is exemplified by the wide variety of techniques that can be observed in top-level show jumping competition. In an attempt to mimic the real-world situation as closely as possible, the cohort of horses used for the JUMPEX-trial (n=30) was engaged in a puissance competition at the age of 5 years and classified according to performance in good, bad and mediocre jumpers. There appeared to be consistent, statistically significant, differences in some kinematic variables (capacity to flex the forelimbs when over the obstacle, retroflexion of hind limbs) between the groups classified as good and bad. Retrospectively, these differences appeared to be present already at 6 months (*Bobbert* et al. 2005), indicating that these features that were related to good performance had predictive value already at foal age.

The JUMPEX-trial alluded to above originally had two basic hypotheses. One was that jumping technique in adult show jumpers could to a certain degree be predicted from foal performance, which was proven true as pointed out above. The second hypothesis was that early training (at foal age) would improve neuromuscular function and lead to better performing show jumpers at the age of competition. To test this hypothesis, the entire cohort of horses was divided into two groups at the start of the experiment (age 6 months). One group was conventionally raised (at pasture or stabled according to the season) and the other group received additional training for jumping from age 6 months until age 3 years when all animals of both groups were broken in. After a rest period of 6 months at equal stabling conditions all animals went into an intensive one-year programme of specific training for show jumping at the age of 4 years, from which they emerged as 5-year-olds. Kinematical analyses were performed at ages 6 months, 4 years (i.e. after the period during which both groups had received different training regimens) and 5 years (i.e. after the common year of training for show jumping). It appeared that at the age of 4 years there were many significant differences in jumping technique between both groups. Horses that had been trained jumped much more efficiently and in a technically better way (*Santamaría* et al. 2005). However, at the age of 5 years these differences had disappeared completely. It was concluded that the (relatively light) training programme as applied in this study had apparently succeeded in accustoming the animals earlier to jumping, but not in changing their inherent capacities to jump, which in fact was the ultimate goal (*Santamaría* et al. 2005). It was also concluded that these results indicated that it is possible to manipulate jumping performance at stallion selection events, which are commonly organised by studbooks at the age of 3 or 4 years and at present often include judgment of free jumping technique. It should be taken as a caveat by these organisations, that animals that have been trained extensively at young age may perform better than animals that have not, but that these differences do not reflect differences in genetic potential (*Santamaría* et al. 2006).

The effect of early exercise on structure and function of musculoskeletal tissues

Whereas there is as yet little evidence that specific training at early age has a big impact on neuromuscular function (see above), there is now plenty of evidence that there is a big influence indeed on the biological characteristics of many musculoskeletal tissues.

The responsiveness of certain musculoskeletal tissues and especially bone to exercise, also in mature individuals, has been known for a long time. 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 (*Van Weeren* and *Brama* 2003, *van Weeren* 2005).

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. 1999a). They showed a significantly higher collagen content at the dorsal rim of the articular surface than in the central fovea. Numbers of crosslinks 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) (Fig. 2). 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 generated during activities such as standing, walking, trotting, cantering and jumping (*Brama* et al. 2001). From this study it became clear that there were huge differences in degree of loading throughout the joint. Whereas the central area is loaded during all activities, the dorsal rim is not always loaded but during the most strenuous exercise (Fig. 3). However, under those circumstances the load is almost double compared to the load in the central fovea. This means that there is a wide scale of differently loaded areas: from sites that are constantly, but relatively mildly loaded, to areas that are rarely, but very heavily loaded. In

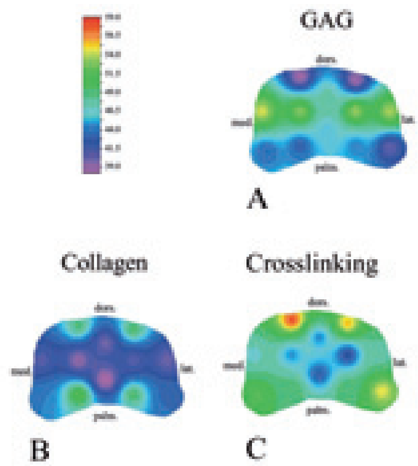

Fig. 2 Topographical patterns of measured biochemical parameters on the proximal articular surface of the proximal phalanx of the fetlock joint. dors.=dorsal; GAG=glycosaminoglycan; Cross-linking =hydroxylysylpyridinoline (HP) cross-links; lat.=lateral; med.=medial; palm.=palmar (Adapted from: *Brama P. A. J.* et al. (2000) Topographical mapping of biochemical properties of articular cartilage in the equine fetlock joint. Equine Vet. J. 32, 19-26

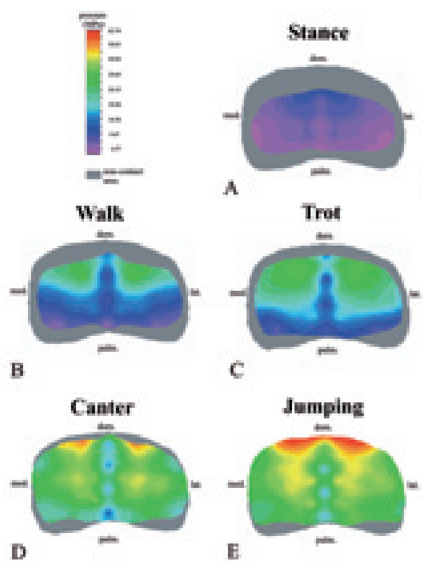

Fig. 3 Loading patterns (MPa) and contact areas on the proximal articular surface of the proximal phalanx of the fetlock joint under different loading conditions mimicking various physiological conditions. dors.=dorsal; lat.=lateral; med.=medial; MPa=megapascal; N=Newton; palm.=palmar; (From: Brama P. A. J. et al. (2001) Contact areas and pressure distribution on the proximal articular surface of the proximal phalanx under loading (in the sagittal plane). (Adapted from: Equine Vet. J. 33, 26-32)

the latter area collagen content is high, but glycosaminoglycan (GAG) content is low, in the more constantly loaded areas the situation is reverse. This pattern is consistent with findings in human intervertebral discs where *Scott* et al. (1994) demonstrated that increasing compressive loads corresponded with higher GAG-levels while higher collagen levels correlated with greater ranges of torsional and shearing strain. Cross-links are highest at the intermittently, but heavily loaded sites too, presumably in order to withstand the high forces that are generated. Cross-linking is higher medially than laterally, which is likely to be caused by the asymmetric loading in the living animal because of the central, and hence abaxial, position of the centre of gravity. In the in vitro drawbench experiment performed by *Brama* et al. (2001) this asymmetric loading was not taken into account. The degree of lysyl-hydroxylation largely mirrors collagen content and cross-linking and, thus, seems inversely related to biomechanical strength. This is in line with findings in bone, where elevated hydroxylysine levels in collagen type I were associated with lower biomechanical strength because of the inverse relationship of high lysyl hydroxylation with strength-providing pyrrole crosslinks (*Bailey* et al. 2004).

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. 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. To date, most work on the loading-related topographical heterogeneity of articular cartilage and the factors that influence the formation of it in the young individual has been done in the horse. 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 (*Barma* et al. 2002) (Fig. 4). 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.

With the pattern of topographical heterogeneity of the ECM of articular cartilage and its function elucidated, the question remained whether biomechanical loading, i.e. exercise, indeed plays a key role as is the case in bone and as was supposed by *Little* and *Ghosh* (1997). Important evidence 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

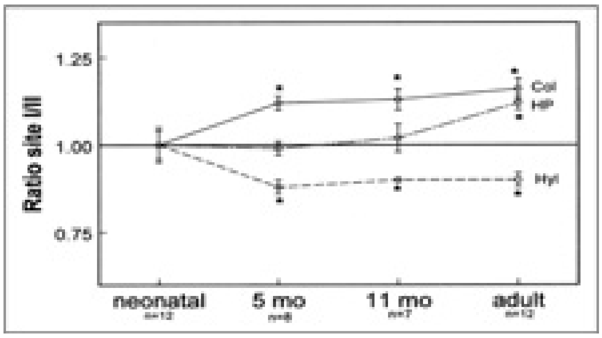

Fig. 4 The development of topographical heterogeneity between two differently loaded sites in the same joint (Site I = dorsal margin of proximal articular surface of first phalanx; Site II is central area of the same joint surface). For collagen content (Col) and hydroxylysine level (Hyl), the process of functional adaptation has largely taken place before age 5 months. For hydroxylysylpyridinoline cross-links (HP), developments start later.

the age of 11 months to see if any differences encountered at age 5 months persisted or not. With material from this study *Brama* et al. (1999b) showed that withholding of exercise (box-rest) led to a significantly lower GAG-content than in pastured foals. The difference disappeared, when normal exercise was given after the age of 5 months. They were not able to demonstrate changes in collagen parameters between the groups. However, in that study only one site (the central fovea) was examined. Detailed studies into the development of differences in biochemical composition between that area and the dorsal rim of the first phalanx in the same material made clear, that in the box-rested foals significant differences in total collagen content and degree of lysyl-hydroxylation had failed to develop at the age of 5 months (*Brama* et al. 2002). The most striking finding was, that these differences appeared to not develop either after the foals were subjected to a normal exercise regimen after the age of 5 months (Fig. 5). Apparently, cartilage metabolism had dropped too far to make up for lost ground by at that age (*van Weeren* and *Brama* 2001). The dramatic drop in cartilage metabolism was further substantiated by van den *Boom* et al. (2004), who demonstrated an exponential decline in the collagen degradation product hydroxyproline in synovial fluid from foals. 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, 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).

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

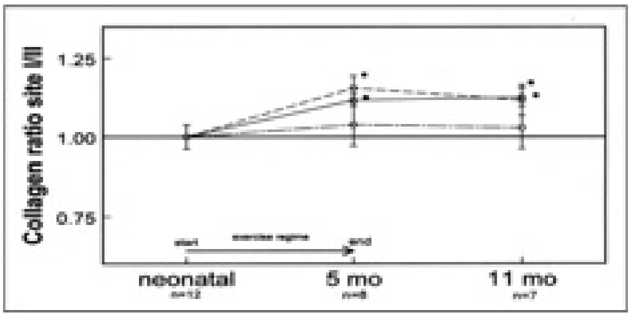

Fig. 5 Topographical heterogeneity in collagen between two differently loaded sites (Site I = dorsal margin of proximal articular surface of first phalanx; Site II is central area of the same joint surface) has been developed by age 5 months in two groups of foals that were exercised (—- and ____). This heterogeneity did not develop in a group of foals that was withheld exercise (_._._._.). When this latter group was given additional exercise after age 5 months, the retarded development was not caught up with, probably because of the already insufficient level of cartilage metabolism.

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 (Fig. 6) that increased the total workload in comparison to the untrained group (PASTEX) with about 30%. 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. (2010) on full-thickness cartilage, but a detailed analysis of

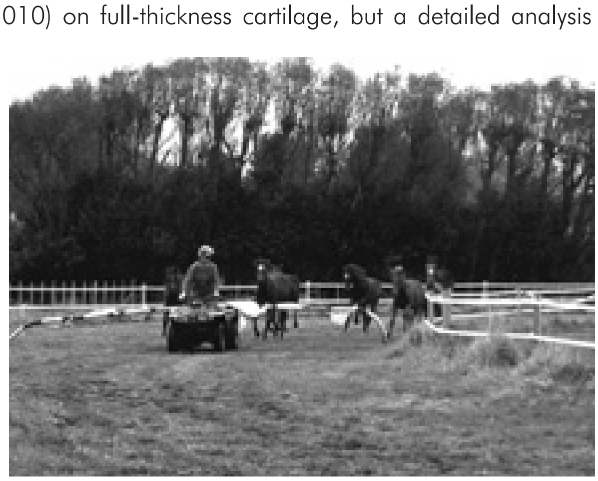

Fig. 6 Yearlings from the GEXA-trial being trained. The animals were driven around a custom-built track between two adapted farmbikes (the one in the front only visible in this picture).

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). Further, at 18 months old the normal physiological increase in collagen at the site located at the joint margin was less in CONDEX animals (*Brama* et al. 2009a). This was interpreted as a precocious cessation of collagen remodelling at this site due to advancement in time of the normal maturation process. 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. 2009b).

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).

From these studies it was concluded that loading is indeed the steering factor in the process that leadings to the formation of topographical differences in the biochemical make-up of the extracellular matrix (ECM) of articular cartilage and, hence, of biomechanical resistance. A crucial difference with bone is that, where bone retains its capacity to remodel throughout the entire lifespan of the animal, articular cartilage does not remodel anymore once maturity is reached and the process of moulding of the ECM according to the loading pattern is thus a once-in-a-lifetime process. In the foal this process takes for the major part place during the first 5-6 months of life with some activity remaining until an age of approximately 1½-2 years. This fact makes the early juvenile phase of the development of the horse into such an important period in terms of exercise management and indeed questions many modern management practices that imply restriction of free exercise in young foals.

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 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). 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 the age of 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

There is growing evidence 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 workload 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 as it is at present.

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