

The effect of year and season of birth, sex, sire, and breeder on ossification of the distal epiphyseal cartilage of the radial bone in Thoroughbred horses

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Abstract: The aim of this study was to evaluate the effect of specific factors on ossification of the distal epiphyseal cartilage of the radial bone in Thoroughbred horses. The study was carried out on 452 Thoroughbred horses, two years old, that were under race training. X-ray tests were conducted and interpreted every month starting at the 18th month of life and continuing until ossification of the distal epiphyseal cartilage of the radial bone occurred. In the statistical model, the year of birth, sex, birth season, sire, and breeder were treated as constant effects. Horses that were born in the spring season were characterized by a shorter time until the closure of the distal radial epiphyseal cartilage in comparison to horses born in the winter season; the difference between these times was found to be highly significant. Furthermore, it was shown that the ossification time of cartilage was also significantly influenced by the year of birth, the sire, and the breeder. Knowledge and monitoring of factors affecting the rate of somatic maturity in Thoroughbred horses can be useful in breeding and veterinary practices. This fact, in conjunction with the analysis of somatotrophic processes, will provide a basis for improving the feeding, training, and management system of Thoroughbred horses as well as aiding in the early diagnosis, treatment, or prevention of various diseases associated with intensive growth in the early period of life.

Key words: Thoroughbred, ossification, epiphyseal cartilage

Introduction

In every organism, the period of growth is an important time in preparing for special forms of usability. This stage is extremely important in the case of Thoroughbred horses, which mature early and start to race at the age of 2 years. A variety of limb injuries have been observed to occur with alarming frequency as a result of such early usability. Unfortunately, financial motivation is the most common reason for beginning training so early. Therefore, it seems necessary to evaluate the optimal time to initiate training in intensive exercise in order to avoid negatively affecting the condition of the animal.

Based on a number of previous studies, many of which concerned pediatrics, it has been stated that calendar age is not sufficient enough to indicate the end of the somatic maturation process. Instead, it is also necessary to take into consideration skeletal age, which is evaluated in terms of the ossification of the epiphyseal cartilages, by conducting an X-ray test of the forelimb. Over the years, many studies focusing on the evaluation of somatic maturity in horses have confirmed that skeletal age is highly correlated with somatic maturity, but it is not clearly known which cartilage should be taken into consideration in order to evaluate the end of maturation. Despite the fact that results obtained by many authors differ slightly,

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the ossification sequence is the same (1-6). First, the proximal epiphyseal cartilages of the second and third phalanges are ossified, then the distal epiphyseal cartilages of the metacarpal and metatarsal bones followed by the distal epiphyseal cartilages of the humeral bone and tuber calcanei, and then, in turn, the distal epiphyseal cartilages of the femur, radius, and tibia bones. The final stage of ossification takes place in the distal epiphyseal cartilages of the iliac tuber and ischiadic tuber.

A kind of regularity is shown in the ossification of epiphyseal cartilages: in bones located further from the axial skeleton, ossification occurs earlier (7). Considering the limited accessibility of upper parts of limbs to epiphyseal cartilages, X-ray tests are routinely performed on the distal epiphyseal cartilage of the radial bone, which ossifies around the 20th month of life according to Empel et al. (8). For this reason, combined with the ease of X-ray test realization and the interpretation of X-ray pictures, the epiphyseal cartilage of the radial bone inferior apex seems to be the best indicator of the proper term of horse skeletal maturation. Because the age at which the epiphyseal cartilage of the radial bone inferior apex ossifies can vary quite widely in Thoroughbred horses, occurring between 20 and 32 months of life (7-9), breeders have tried to identify the factors that could influence this process. An awareness of these factors could be useful in evaluating the optimal time to initiate intensive training. It can also help to reliably decide when to eliminate horses that disappoint their owners with bad results caused by later maturation, as these decisions are often too rushed.

The present study shows the close relationship between growth rate, the time of ossification of the epiphyseal cartilages, and the frequency of developing orthopedic disorders (DOD) or angular limb deformities, which are responsible for enormous losses in the racing industry (10-14). A better knowledge of factors affecting the somatotrophic processes of horses could therefore help to minimize the costs associated with treating and curing such disorders and deformities.

The aim of this study was to evaluate the effect of year and season of birth, sex, sire, and breeder on ossification of the distal epiphyseal cartilage of the radial bone in Thoroughbred horses.

Materials and methods

Material used in this study was collected from the Służewiec Horse Hospital at a horse racing track in Warsaw during December of 2007. The study was carried out on 452 Thoroughbred horses (202 colts, 250 fillies; 2 years old) that were under race training at the Warsaw Race Track between the years of 2000 and 2007. Horses were owned by 9 national studs and also by private breeders.

X-ray tests were conducted by a veterinarian using an Orange 8016 HF (54 kV, 1 mAs) X-ray apparatus. The resulting images were also interpreted by a veterinarian. For each subject, the first x-ray test was done at the age of 18 months, when training began. Tests were repeated every month until the ossification of the distal epiphyseal cartilage of the radial bone. Epiphyseal cartilage was classified as fully open when a radiolucent line was distinctly visible (Figure 1). Epiphyseal cartilage was classified as closing when the line was visible, but only intermittently (Figure



Figure 1. The distal epiphyseal cartilage of a radial bone classified as fully open (20th month of life).

2). Epiphyseal cartilage was classified as fully closed when the radiolucent line was not visible at all (Figure 3). In the first month in which the X-ray test of the A-P projection showed no visible light areas of the cartilage, the 15th day of that month was assumed as the moment of ossification (9).

Our statistical analysis of the effect of the chosen factors on the ossification of the epiphyseal cartilage was carried out using the GLM procedure (15). In the model, the year of birth, sex, birth season, sire, and breeder were treated as constant effects. The significance of these differences was evaluated using Tukey's test. Winter birth season was considered to be January, February, and March, while the spring season comprised April, May, and June. During the analysis of sire effect, only those stallions that produced more than 10 foals in the studied population were taken into consideration; similarly, during the analysis of breeder effect, our study only examined those who owned at least 10 horses.



Figure 2. The distal epiphyseal cartilage of a radial bone classified as closing (28th month of life).



Figure 3. The distal epiphyseal cartilage of a radial bone classified as totally closed (29th month of life).

Results

During the analysis of the stage of ossification of the distal epiphyseal cartilage of the radial bone according to the year of birth, it was shown that horses born in 2000 and in 2005 were characterized by the earliest time of ossification, at 781.8 and 784.2 days, respectively. For horses born in these 2 years, the time until ossification of the distal epiphyseal cartilage of the radial bone was significantly shorter than for those horses born in 1998, 2001, 2002, 2003, and 2004. Horses born in 2004 were characterized by the longest time until cartilage ossification, a figure that was also significantly different when compared to horses born in 1999 (795.0 days). Other statistical differences in the rate of ossification between horses born in different years are shown in Table 1.

During the analysis of the effect of birth season on the ossification of the distal epiphyseal cartilage of the radial bone of Thoroughbred horses (Table 2), it was observed that mares foaling in the spring season produced foals characterized by a very short

Table 1. The effect of year of birth on the ossification of the distal epiphyseal cartilage of the radial bone in Thoroughbred horses.

Factor	N	TODRE (days)	R (days)	
Year of birth	1998	65	804.00 ± 44.96 ^{ad}	717.00-912.00
	1999	66	794.98 ± 47.95 ^{ab}	681.00-891.00
	2000	62	781.84 ± 38.47 ^b	713.00-864.00
	2001	91	803.69 ± 38.66 ^{ad}	719.00-906.00
	2002	51	806.33 ± 48.01 ^{ad}	712.00-913.00
	2003	35	804.91 ± 60.19 ^{ad}	627.00-892.00
	2004	26	818.81 ± 37.08 ^{cd}	738.00-888.00
	2005	56	785.45 ± 45.85 ^b	690.00-904.00

N: number of horses, TODRE: time of ossification of the distal radial epiphysis (mean ± SD), R: range (min-max).

Average values marked by different letters differ significantly, $P \leq 0.05$.

Table 2. The effect of season of birth on the ossification of the distal epiphyseal cartilage of the radial bone in Thoroughbred horses.

Factor	N	TODRE (days)	R (days)	
Season of birth	Winter	331	810.30 ± 39.56 ^A	691.00-912.00
	Spring	121	766.11 ± 45.63 ^B	627.00-913.00

N: number of horses, TODRE: time of ossification of the distal radial epiphysis (mean ± SD), R: range (min-max).

Average values marked by different capital letters differ highly significantly, $P \leq 0.01$.

ossification time compared to foals born in the winter season. The average ossification time of distal epiphyseal cartilage of the radial bone in horses born in April, May, and June was 766.0 days, and this was significantly shorter than the time for horses born in January, February, and March (810.3 days).

The present study did not find any statistically significant influence of sex on the ossification of distal epiphyseal cartilage of the radial bone in Thoroughbred horses, even though the time of cartilage ossification in fillies was 5.7 days shorter than in colts (Table 3).

The earliest stage of ossification of the epiphyseal cartilage of the radial bone inferior apex was noted for foals sired by Professional (Table 4). The average age of somatic maturity for these horses was 770.0

days, significantly shorter than that of foals sired by Saphir, Winds of Light, and Duke Valentino (836.4, 821.8, and 817.9 days, respectively). The offspring of Alywar also demonstrated a comparatively early stage of cartilage ossification compared to foals from Saphir, Winds of Light, and Duke Valentino. The latest stage was observed in foals sired by Saphir, with an average age at cartilage ossification of 836.4 days; this was significantly longer than for foals sired by Special Power (791.7 days), Don Corleone (787.2 days), Jape (797.9 days), Royal Court (798.4 days), Who Knows (798.5 days), and In Camera (794.7 days).

Widzów Stud was shown to be the Thoroughbred horse breeding center that produced foals that reached somatic maturity in the shortest time (Table 5). The average time of cartilage ossification for horses bred

Table 3. The effect of sex on the ossification of the distal epiphyseal cartilage of the radial bone in Thoroughbred horses.

	Factor	N	TODRE (days)	R (days)
Sex	Fillies	250	796.16 ± 47.51	627.00-904.00
	Colts	202	801.32 ± 43.16	681.00-913.00

N: number of horses, TODRE: time of ossification of the distal radial epiphysis (mean ± SD), R: range (min-max).

Table 4. The effect of sire on the ossification of the distal epiphyseal cartilage of the radial bone in Thoroughbred horses.

	Factor	N	TODRE (days)	R (days)
Sire	Special Power	38	791.68 ± 43.40 ^{bcd}	707.00-867.00
	Saphir	12	836.42 ± 57.90 ^{ae}	721.00-901.00
	Jape	35	797.91 ± 37.88 ^{bcd}	712.00-884.00
	Royal Court	28	798.43 ± 41.17 ^{bcd}	723.00-904.00
	Enjoy Plan	22	806.64 ± 38.88 ^{abd}	731.00-863.00
	Don Corleone	35	787.20 ± 39.87 ^{bef}	681.00-839.00
	Who Knows	27	798.48 ± 48.16 ^{bcd}	730.00-912.00
	Alywar	12	779.33 ± 35.04 ^{bc}	733.00-833.00
	In Camera	11	794.73 ± 55.04 ^{bcd}	724.00-883.00
	Professional	10	770.00 ± 36.44 ^c	714.00-846.00
	Winds of Light	10	821.80 ± 39.25 ^{de}	767.00-891.00
	Duke Valentino	14	817.93 ± 42.44 ^{def}	776.00-913.00

N: number of horses, TODRE: time of ossification of the distal radial epiphysis (mean ± SD), R: range (min-max).
Average values marked by different letters differ significantly, $P \leq 0.05$.

Table 5. The effect of breeder on the ossification of the distal epiphyseal cartilage of the radial bone in Thoroughbred horses.

	Factor	N	TODRE (days)	R (days)
Breeder (stud)	Prywatne	230	797.69 ± 45.72	627.00-913.00
	Golejewko	38	801.03 ± 39.36	681.00-881.00
	Krasne	15	817.80 ± 41.17 ^a	747.00-891.00
	Kozienice	27	794.11 ± 45.07	707.00-870.00
	Stubno	24	806.96 ± 41.51	733.00-884.00
	Strzegom	16	786.13 ± 48.96	730.00-912.00
	Iwno	12	809.75 ± 46.4 ^a	746.00-900.00
	Jaroszkówka	36	812.42 ± 47.24 ^a	717.00-897.00
	Moszna	23	798.13 ± 42.10	729.00-868.00
	Widzów	20	770.45 ± 49.79 ^b	690.00-848.00

N: number of horses, TODRE: time of ossification of the distal radial epiphysis (mean ± SD), R: range (min-max).
Average values marked by different letters differ significantly, $P \leq 0.05$.

in this center was 770.4 days, significantly shorter than for fillies and colts bred in Iwno Stud (809.7 days), Jaroszkówka Stud (812.4 days), and Krasne Stud (817.8 days). Horses bred in Krasne Stud were characterized by the longest time until ossification of the distal epiphyseal cartilage of the radial bone. Thoroughbred horses owned by different private breeders were characterized by an average cartilage ossification time of 797.7 days.

Discussion

Although many authors have written on the effects of the studied factors on the time of closure of the distal radial epiphyseal cartilage, their conclusions were ambiguous and the results were often contradictory.

In a study by Empel et al. (8), the average age of ossification of the distal epiphyseal cartilage of the radial bone in Thoroughbred horses was found to be shorter than has been shown in the present study, at an average of 793 days and with a range varying between 613 and 829 days. Ossification was observed significantly earlier in fillies than in colts and also for horses born later in the season compared to those born earlier in the year. A significant effect on the age of ossification was also seen in that study based on the breeder and year of birth (8). According to Vulcano et al. (9), the time of cartilage ossification in Brazilian Thoroughbred horses varied between 20.9 and 27.6 months and was shorter for fillies (701 days) in comparison to colts (748 days).

The highly significant effect of sex on the ossification of the distal epiphyseal cartilage of the radial bone was also shown by Buchmann de Godoy et al. (16) for Brasileiro de Hipismo horses. Among fillies, cartilage disappeared in an average of 2.33 months earlier than in colts. On the other hand, Goyal et al. (17) noted that the growth rate of long bones in limbs was higher for colts than fillies. Pasolini et al. (18) stated that in Standardbred horses, cartilage disappeared at the age of 28.2 months and sex did not influence this phenomenon. Gabel et al. (19) showed that the cartilage of this breed ossified about 1.6 months later and that breeding place did not influence this phenomenon. These authors did not note any significant differences between fillies, geldings, and

colts or between horses descended from the same sire or from both the same mother and the same sire. Łojek, however, observed that sire had a significant effect on the somatic development of young horses during the skeletally based analysis of the growth and maturation processes of Thoroughbred horses (20).

The significant effect of year of birth, breeder, or sire on the ossification time of the epiphyseal cartilage can be the result of many various local environmental conditions, in particular studs, and, connected to this, systems of feeding, training, management, and the use of different stallions for reproduction; these factors have been noted by Ellis and Lawrence (21), Glade and Belling (22), Łojek (20), and van Weeren et al. (23). The areas in which the horse studs were located all had a continental, transitional temperate climate and were characterized by a similar length of growth period (about 220 days) and a similar annual precipitation total of 550 mm. The management was also similar in these studs. The validity of potential differences in the factors mentioned above needs further investigation, but it seems that, with regard to observed differences, the greatest role could be played by genetic factors such as sire.

The significantly shorter time of cartilage ossification in horses born in the spring season shown in this study can be connected to the beginning of the pasture period. Foals born in this time, in contrast to those born in winter, are able to enjoy rich pastures, free movement, and sunlight. Under such conditions, vitamin D is produced in the skin. This vitamin affects the proper homeostasis of calcium and phosphorus in the organism (24,25). Access to a greater quantity of better fodder together with the peak lactation in foal mothers during the pasture season may be one reason for the higher growth rate and shorter time of epiphyseal cartilage ossification, a phenomenon that was confirmed by Mason and Bourke (3), Glade and Belling (22), Cymbaluk et al. (26), Pagan et al. (27), and Donabédian (13). Worse environmental conditions for foals born in the winter season, however, cause growth inhibition and the retardation of closure time for growth plates (21).

Empel et al. (8) showed that the parturition of most Thoroughbred foals takes place during the winter months in Poland. On the basis of the presented results, this tendency can be considered to be negative

since horses that skeletally mature later are more at risk for the contusions and injuries of an immature skeleton that are connected to intensive training or horses races. It has been shown (7) that the degree of skeletal maturity highly significantly influenced the degree of trauma experienced by the skeleton, muscles, tendons, and ligaments of Thoroughbred horses. The majority of injuries were observed in horses characterized by late ossification of the distal radial epiphysis, followed by those characterized by the earliest ossification; the fewest injuries were seen in those with a minor time of ossification.

Although this study did not observe the significant effect of gender on the time of cartilage ossification found by many other authors, a trend was noted, such that this time was shorter in fillies as compared to colts. This difference was probably due to the varying effects of sex hormones, primarily estrogens, which play a key role in the skeletal development of horses and particularly affect bone maturation and linear growth (28,29). Jackson et al. (30) also pointed to the importance of some bone turnover markers. According to these authors, lower concentrations of serum osteocalcin in the blood of fillies compared to

colts may be related to their earlier skeletal maturity.

We conclude that the horses that were born in the spring season were characterized by a shorter time of closure of the distal radial epiphyseal cartilage, which was highly significant in comparison to horses born in the winter season. It was shown that the ossification time of cartilage was also significantly influenced by the year of birth, the sire, and the breeder. Knowledge and monitoring of factors affecting the rate of somatic maturity achievement in Thoroughbred horses can be useful in breeding and veterinary practice. This fact, in conjunction with the analysis of somatotrophic processes, will help to provide a basis to improve the feeding, training, and management of Thoroughbred horses in addition to aiding the early diagnosis, treatment, or prevention of various diseases associated with intensive growth in the early period of life.

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References

1. Banks, W.C.: Radiography of the tuber calcis and its use in Thoroughbred training. *Acta Radiol. Suppl.*, 1972; 319: 71-72.
2. Koper, S., Sasimowski, E., Mucha, M., Pietrzak, S., Moś, L., Kolstrung, R.: Radiographic examinations of the calcis ossification process of Arab Koniks Turing skeleton maturation. *Ann. UMCS w Lublinie.*, 1986; EE., 15: 129-136 (in Polish with an abstract in English).
3. Mason, T.A., Bourke, J.M.: Closure of the distal radial epiphysis and its relationship to unsoundness in two year old Thoroughbreds. *Aust. Vet. J.*, 1973; 49: 221-228.
4. Pezzoli, G., Del Bue, M.: Evaluation of bone development in trotting horses and athletic activity. *Folia Vet. Lat.*, 1975; 5: 399-411 (in Italian with an abstract in English).
5. Fretz, P.B., Cymbaluk, N.F., Pharr, J.W.: Quantitative analysis of long-bone growth in the horse. *Am. J. Vet. Res.*, 1984; 45: 1602-1609.
6. Strand, E., Braathen, L.C., Hellsten, M.C., Huse-Olsen, L., Bjornsdottir, S.: Radiographic closure time of the appendicular growth plates in the Icelandic horse. *Acta Vet. Scand.*, 2007; 49: 19-26.
7. Dzierżęcka, M., Wasowski, A., Kobryń, H.: Time-span of the ossification of the distal radial epiphysis in Thoroughbred horses as a criterion of skeleton maturity. *Med. Weter.*, 2005; 61: 1190-1192 (in Polish with an abstract in English).
8. Empel, W., Łojek, J., Wąsowski, A.: The effect of the breeder, year and month of birth and sex on the skeletal maturation of Thoroughbred horses. *Ann. Warsaw Agricult. Univ. SGGW Anim. Sci.*, 1993; 29: 11-15.
9. Vulcano, L.C., Mamprim, M.J., Muniz, L.M., Moreira, A.F., Luna, S.P.: Radiographic study of distal radial physeal closure in thoroughbred horses. *Vet. Radiol. Ultrasound.*, 1997; 38: 352-354.
10. Leitch, M.: Musculoskeletal disorders in neonatal foals. *Vet. Clin. North Am. Equine Pract.*, 1985; 1: 189-207.
11. Jeffcott, L.B.: Osteochondrosis - an international problem for the horse industry. *J. Equine Vet. Sci.*, 1996; 16: 32-37.
12. Balfour, R.J., Boudrieau, R.J., Gores, B.R.: T-plate fixation of distal radial closing wedge osteotomies for treatment of angular limb deformities in 18 dogs. *Vet. Surg.*, 2000; 29: 207-217.

13. Donabédian, M., Fleurance, G., Perona, G., Robert, C., Lepage, O., Trillaud-Geyl, C., Leger, S., Ricard, A., Bergero, D., Martin-Rosset, W.: Effect of fast vs. moderate growth rate related to nutrient intake on developmental orthopaedic disease in the horse. *Anim. Res.*, 2006; 55: 471-486.
14. Lepeule, J., Bareille, N., Robert, C., Ezanno, P., Valette, J.P., Jacquet, S., Blanchard, G., Denoix, J.M., Seegers, H.: Association of growth, feeding practices and exercise conditions with the prevalence of Developmental Orthopaedic Disease in limbs of French foals at weaning. *Prev. Vet. Med.*, 2009; 89: 167-177.
15. SAS Institute, Inc. The SAS System for Windows. Release 8.2. Cary, NC, USA. 2001..
16. Buchmann de Godoy, C.L., Vulcano, L.C., Santos, F.A.M., Soares, J.C.M.: Distal radius physeal closure in the Brasileiro de Hipismo horse breed (BH). *Cienc. Rural Santa Maria*, 2004; 34: 1813-1815 (in Spanish with an abstract in English).
17. Goyal, H.O., MacCallum, F.J., Brown, M.P., Delack, J.B.: Growth rates at the extremities of limb bones in young horses. *Can. Vet. J.*, 1981; 22: 31-33.
18. Pasolini, M.P., Meomartino, L., Testa, A., Fatone, G., Potena, A., Rosa, G., di Lamagna, F.: Radiographic assessment of skeletal maturity in the racehorse: statistical validation and correlation with orthopaedic injuries in the Standardbred. *Ippologia*, 2007; 18: 15-19 (in Italian with an abstract in English).
19. Gabel, A., Spencer, C.P., Pipers, F.S.: A study of correlation of closure of the distal radial physis with performance and injury in the Standardbred. *J. Am. Vet. Med. Ass.*, 1977; 170: 188-194.
20. Łojek, J.: Effect of sire on the process of somatic development of Thoroughbred horses. *Ann. Warsaw Agricult. Univ. SGGW Anim. Sci.*, 1993; 29: 17-22.
21. Ellis, R.N., Lawrence, T.L.: Energy under-nutrition in the weanling filly foal. II. Effects on body conformation and epiphyseal plate closure in the fore-limb. *Br. Vet. J.*, 1978; 134: 321-332.
22. Glade, M.J., Belling, T.H.: Growth plate cartilage metabolism, morphology and biochemical composition in over- and underfed horses. *Growth*, 1984; 48: 473-482.
23. van Weeren, P.R., Firth, E.C., Brommer, B., Hyttinen, M.M., Helminen, A.E., Rogers, C.W., Degroot, J., Brama, P.A.: Early exercise advances the maturation of glycosaminoglycans and collagen in the extracellular matrix of articular cartilage in the horse. *Equine Vet. J.*, 2008; 40: 128-35.
24. Kawashima, H., Kurokawa, K.: Metabolism and sites of action of vitamin D in the kidney. *Kidney Int.*, 1986; 29: 98-107.
25. Maxwell, J.D.: Seasonal variation in vitamin D. *Proc. Nutr. Soc.*, 1994; 53: 533-543.
26. Cymbaluk, N.F., Christison, G.I., Leach, D.H.: Longitudinal growth analysis of horses following limited and ad libitum feeding. *Equine Vet. J.*, 1990; 22: 198-204.
27. Pagan, J.D., Jackson, S.G., Caddel, S.A.: Summary of growth rate in Thoroughbreds in Kentucky. *Pferdeheilkunde*, 1996; 12: 285-289.
28. Feuillan, P., Merke, D., Leschek, E.W., Cutler, G.B.: Use of aromatase inhibitors in precocious puberty. *Endocr. Relat. Cancer*, 1999; 6: 303-306.
29. Lemazurier, E., Toquet, M.P., Fortier, G., Séralini, G.E.: Sex steroids in serum of prepubertal male and female horses and correlation with bone characteristics. *Steroids*, 2002; 67: 361-369.
30. Jackson, B.F., Lonnell, C., Verheyen, K., Wood, J.L., Pfeiffert, D.U., Price, J.S.: Gender differences in bone turnover in 2-year-old Thoroughbreds. *Equine Vet. J.*, 2003; 35: 702-706.