1997
Physeal closure

Developmental variation in lumbosacropelvic anatomy of Thoroughbred racehorses

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Objective—To describe the incidence and types of gross osseous developmental variations and ages of physeal closure in the caudal portion of the thoracic and lumbosacral spine and the pelvis in a sample of Thoroughbred racehorses.

Animals—Thoroughbred racehorses (n = 36) that died or were euthanatized at California racetracks between October 1993 and July 1994.

Procedure—Lumbosacropelvic specimens were collected, and all soft tissues were removed. The osseous specimens were visually examined.

Results—Only 22 (61%) specimens had the expected number of 6 lumbar and 5 sacral vertebrae. Eight (22%) specimens had thoracolumbar transitional vertebrae, and 13 (36%) had sacrocaudal transitional vertebrae. Articular process asymmetries were present at 1 or more vertebral segments in 30 (83%) specimens. Intertransverse joints (2 to 4 pairs/specimen) were bilaterally distributed in the caudal portion of the lumbar spine and the lumbosacral joint in 31 (86%) specimens. Five (14%) specimens had asymmetric distribution of the intertransverse joints. Intertransverse joint ankylosis was found in 10 (28%) specimens. Lumbosacral vertebral body physeal closure occurred between 4.9 and 6.7 years of age; pelvic physeal closure occurred between 5.2 and 5.8 years of age. Iliac crest and ischial arch epiphyseal formation was evaluated, using a grading system, and fusion to the underlying bone occurred at 7.2 years and 5.4 years of age, respectively.

Conclusions—Numerous vertebral anatomic variations were commonly found in a sample of Thoroughbred racehorses.

Clinical Relevance—Normal anatomic variations and ages of skeletal maturity need to be considered in clinical evaluation of the equine spine and pelvis for differentiation from pathologic findings. (*Am J Vet Res* 1997;58:1083–1091)

Spinal disorders and sacroiliac joint injuries have been identified as important causes of long-term poor performance in horses.[1-4] Equine back problems often limit athletic performance, but are frustrating clinical problems because of our inability to localize the inciting abnormality or factor(s) contributing to back soreness. The inability to accurately diagnose and treat signs of back pain and pelvic lameness in horses has minimized therapeutic effectiveness and recommendations for the management of affected horses are, at best, directed at empiric relief without means of addressing the primary mechanisms of injury.

Developmental variations in the morphology of thoracolumbar vertebral bodies, processes, and joints in horses are known to occur.[5-10] Radiographic and gross anatomic descriptions of physes in portions of the back and pelvis have been reported.[6,9,11-13] Incorporation of technologic improvements in diagnostic techniques (eg, ultrasonography, nuclear scintigraphy, computed tomography, and magnetic resonance imaging) will enhance visualization of vertebral and pelvic morphologic detail. Knowledge of normal spinal morphology and the incidence of vertebral anomalies is important for distinction of pathologic change from functional anatomic variations. The high incidence of signs of back pain and lumbosacral spinal lesions in performance horses led us to evaluate the osseous spinal and pelvic anatomy in Thoroughbred racehorses. The purpose of the study reported here was to describe the incidence and types of osseous developmental variations and physes of the caudal portion of the thoracic and lumbosacral spine and of the pelvis in a sample of Thoroughbred racehorses.

Materials and Methods

Specimens—A sample of Thoroughbred racehorses that died at a California racetrack between October 15, 1993 and July 31, 1994 and were necropsied through the Davis Branch of the California Veterinary Diagnostic Laboratory System (CVDLS) for the California Horse Racing Board Postmortem Program were studied. Age (2, 3, 4, 5, or ≥ 6 years), sex (female, sexually intact male, or gelding), body weight (≤ 479, 480 to 500, ≥ 501 kg), reason for euthanasia (spontaneous musculoskeletal injury or other) and activity at the time of injury or euthanasia (racing, training, or nonexercise related) were obtained from CVDLS records.

Specimen preparation—Lumbosacropelvic specimens were collected via bilateral coxofemoral disarticulation and vertebral column transection at: a level approximately 2 vertebral segments craniad to the psoas muscle complex (in the caudal thoracic vertebral region), and within the proximal third of the caudal vertebrae (hereafter referred to as the caudal portion of the thoracic and lumbosacral spine and pelvis). All soft tissues except ligaments were removed from the specimens by manual dissection and dissolution in a 0.5% potassium hydroxide solution at 43 C for 4 to 7 days. Specimens were rinsed in tap water, air dried for 2 to 3 days, then visually examined, using the following protocols.

Categorization of typical vertebral segments—Each vertebral segment was categorized morphologically as thoracic, lumbar, sacral, or caudal vertebra. Thoracic vertebrae were characterized by presence of bilateral, cylindrical, articulating ribs; lumbar vertebrae by bilateral, horizontally flat, nonarticulating transverse processes; sacral vertebrae by partial or complete intervertebral body or transverse process fusion and absence of fibrocartilaginous intervertebral disks; and caudal vertebrae by thick fibrocartilaginous intervertebral disks and rudimentary spinous and transverse processes.[6]

Vertebral segments are traditionally counted within spinal regions from a cranial reference point (eg, occiput, cervicothoracic junction, thoracolumbar junction), and the vertebrae of each spinal region are assigned numbers from

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the cranial reference point caudad (eg, T1, T2, T3). Modified reference systems (Fig 1) were used to allow designation of vertebral segments when the total number of vertebrae in a spinal region was unknown (eg, the thoracic region in this study) and to facilitate comparison of anatomically related or biomechanically relevant regions between specimens. The modified vertebral reference systems use caudal reference points, and the vertebrae of spinal regions are numbered craniad, with the segment number designated within parentheses (eg, T[1], T[2], T[3]).

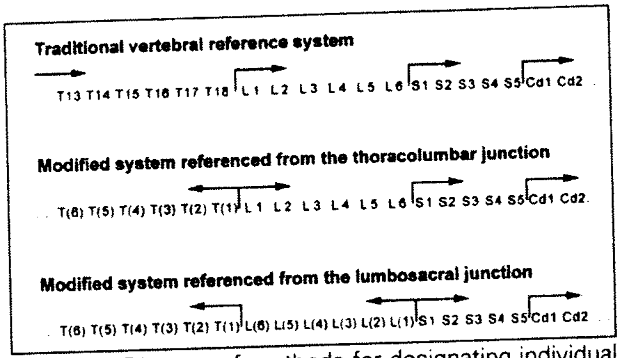

Figure 1—Diagram of methods for designating individual vertebral segments within specified spinal regions. Vertebrae counted from a cranial point of reference caudad are designated by abbreviation of the spinal region and the vertebral segment number (eg, L1, L2, L3). Vertebrae counted from a caudal point of reference craniad are designated by the vertebral segment number within parentheses (eg, L[1], L[2], L[3]).

Vertebral bodies—Each thoracolumbar vertebral body was evaluated for abnormal morphology (eg, hemivertebra or block vertebrae) and for having a prominent ventral crest.

Transitional

Categorization of transitional vertebrae—Transitional vertebrae, by definition, are located between 2 adjacent spinal regions and have characteristics of both adjacent spinal regions.[6,14,15] Thoracolumbar transitional vertebrae were evaluated for unilateral or bilateral morphologic alterations of the transverse processes and were categorized by their closest resemblance to adjacent thoracic or lumbar vertebrae. Transitional vertebrae with transverse process articulations were categorized as thoracic (ie, thoracoization of the first lumbar vertebra), and vertebrae with ankylosed or absent articulations were classified as lumbar (ie, lumbarization of the last thoracic vertebra). Vertebrae with a combination of articulating and nonarticulating transverse processes were categorized as thoracic if the processes were elongated and cylindrical (ie, typical of a thoracic costal process), and as lumbar if they were short and horizontally flat (ie, typical lumbar transverse process).

Lumbosacral transitional vertebrae were categorized by their closest resemblance to adjacent lumbar or sacral vertebrae. Vertebrae with modified transverse processes that had an articulation with the pelvis, fused vertebral bodies or transverse processes, or absent caudal intervertebral disk were categorized as sacral (ie, sacralization of the last lumbar vertebra). Transitional vertebral segments with individual transverse processes or the presence of a caudal intervertebral disk were categorized as lumbar (ie, lumbarization of the first sacral vertebra). Supernumerary caudal sacral segments were categorized as sacrocaudal transitional vertebrae owing to osseous fusion of the sacrum and first caudal vertebra (Cd1). ? ✱

Spinous processes—The L(2)-L(1) and L(1)-S1 dorsal interspinous spaces were each categorized as open or closed by relative orientation of the vertical axes of adjacent spinous processes. An open interspinous space had parallel or dorsally diverging processes, and a closed interspinous space had dorsally converging spinous processes (Fig 2).[3,10,16] ?

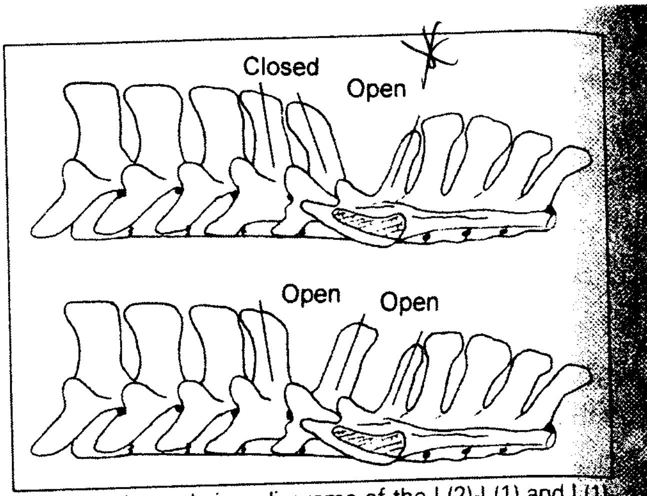

Figure 2—Lateral view diagrams of the L(2)-L(1) and L(1)-S1 interspinous space status of the lumbosacral part of the spine. Top—Closed L(2)-L(1) interspinous space and open L(1)-S1 interspinous space; bottom—Open L(2)-L(1) and L(1)-S1 interspinous spaces.

Articular processes—The articular processes and facets of the caudal portion of the thoracic and lumbosacral spine were evaluated for morphologic asymmetries in size, shape, and/or articular facet orientation.[10] Each individual articular process was compared with its contralateral articular process and with the cranial and caudal articular processes of adjacent vertebral segments. Articular process or facet asymmetry in size or shape was characterized by > 25% qualitative difference in size or shape (eg, unilaterally malformed articular process). Articular facet orientation was categorized by articular surfaces lying predominantly in either the dorsal or sagittal planes. Asymmetry in articular facet orientation (ie, tropism) was characterized by differences in facet orientation at an intervertebral articulation. The articular facets in the thoracolumbar region were examined for presence of unilateral or bilateral, vertically directed articular clefts.

Intertransverse joints of the lumbar spine and the lumbosacral junction—The vertebral location, laterality, and functional status (ie, diarthrodial or ankylosed) of intertransverse joints, specialized articulations between the transverse processes of adjacent caudal lumbar vertebrae or the last lumbar vertebra and the wing of the sacrum, were recorded.[6,17]

Physeal closure—The location and stage of closure of visible physes associated with vertebral and pelvic secondary ossification centers were recorded. Physeal closure was defined as ossification and replacement of the otherwise, externally visible cartilaginous physis. Physeal closure was classified as: open (ie, visibly complete cartilaginous separation of ossification centers); partial physeal closure, with the percentage of visibly absent cartilage noted; or complete physeal closure (ie, no visible cartilage between ossification centers). If similar physes within a specimen had various stages of physeal closure, the average closure status for that physeal location was recorded. The thoracolumbar vertebrae were examined for secondary ossification centers at the cranial and caudal vertebral body (ie, vertebral endplates), ventral crest, and dorsal spinous and transverse processes (Fig 3). The vertebral ventral crest is composed of cranial and caudal osseous projections from the ventral aspect of the respective caudal and cranial vertebral endplates. The osseous projections of the ventral crest extend axially in the midsagittal plane and, if fully developed, unite at the midbody of the vertebrae. A horizontally directed (ie, dorsal plane) physis lies between the ventral crest and the dorsally located vertebral body. The sacral vertebrae were examined for physes between the articular processes, transverse processes

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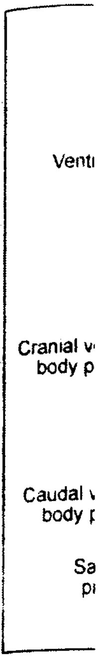

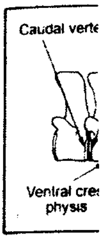

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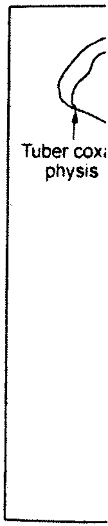

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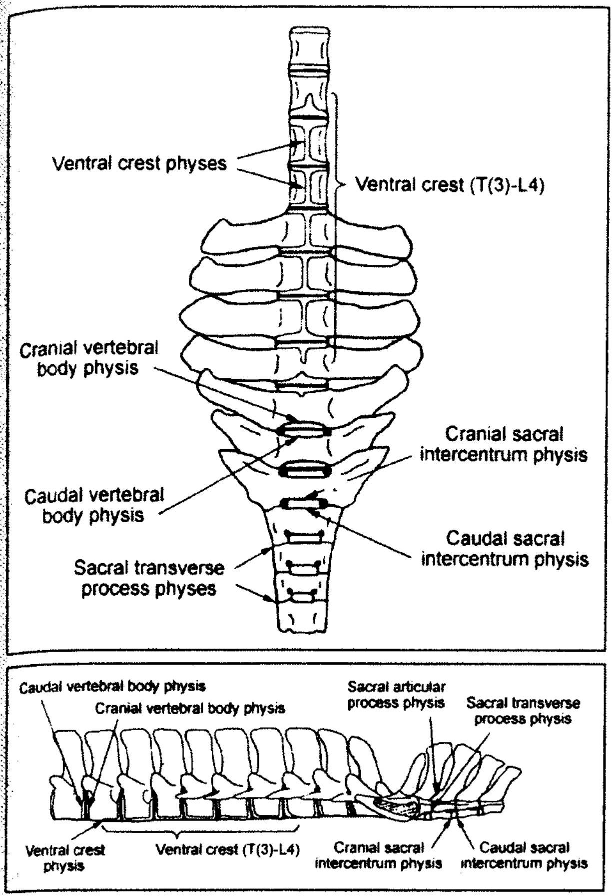

Figure 3—Diagram of the location of vertebral body and sacral physes. Top—ventral view; bottom—Lateral view.

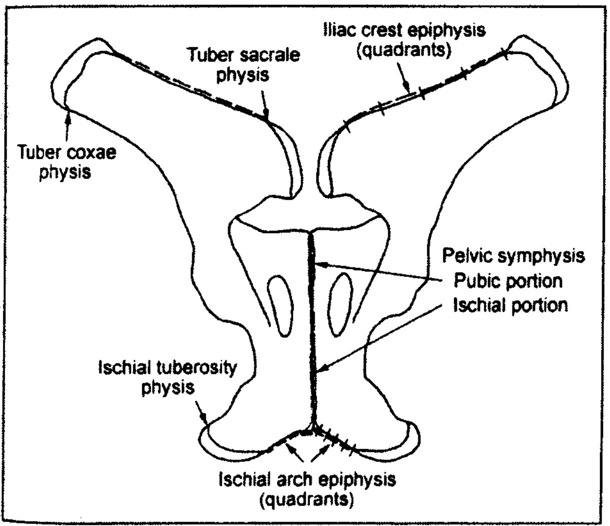

Figure 4—Dorsal view diagrams of the location of pelvic physes, and the iliac crest and ischial arch grading systems.

(ie, pars lateralis), and vertebral bodies at the cranial and caudal borders of the intercentrum (ie, ossified homolog of the fibrocartilaginous intervertebral disk and adjacent vertebral body endplates, Fig 3). Pelvic physeal evaluation included the tuber sacrale, tuber coxae, and ischial tuberosity physes (Fig 4). Pelvic symphyseal ossification was categorized similar to physeal closure. Evaluation of pelvic symphyseal ossification was based on ossification of the cranial pubic symphysis (not the caudal ischial symphysis).

A 0- to 5-point grading system was used for evaluating the formation of the iliac crest and ischial arch epiphyses, and subsequent fusion to the underlying bone (Fig 4). Specimens with no evidence of epiphyseal formation or ossification were graded 0. The length of the iliac crest and ischial arch was divided into 4 quadrants, and the number of quadrants that had ossified epiphyses (ie, epiphyseal formation) were recorded (grades 1–4). A grade 5 was recorded when the entire epiphysis formed and subsequently fused to the underlying ilium or ischium (ie, physeal closure). This is similar to the radiographic grading of iliac crest epiphyseal formation and closure in human beings (ie, Risser sign).[18]

Statistical analysis—A 2-tailed Fisher's exact test was used to evaluate the interrelation of categorical variables in all 2 × 2 contingency tables owing to expected values ≤ 5 within at least 1 cell. A χ^2 analysis was used for all categorical variables, with contingency tables larger than 2 × 2; however, expected values ≤ 5 occurred within at least 1 cell for these comparisons. A rank ANOVA was done to compare age versus vertebral or pelvic physeal closure status. Post-hoc comparisons of the mean ages in the various physeal closure status groups were done, using pairwise Mann Whitney tests. The level for significance was set at $P < 0.05$, and for statistical trends, was $P \leq 0.10$.

Results

Sample population—Intact lumbosacropelvic specimens were acquired from 36 Thoroughbred racehorses aged 2 to 9 years (mean [± SD], 4.5 ± 1.5 years) with 3 (8%) 2-year-old, 13 (36%) 3-year-old, 6 (17%) 4-year-old, 9 (25%) 5-year-old, and 5 (14%) ≥ 6-year-old horses. Horses included 12 females, 5 sexually intact males, and 19 geldings. Body weight (n = 18) ranged from 427 to 564 kg (496 ± 39 kg); 5 horses weighed ≤ 479 kg, weight of 6 was between 480 and 500 kg, and that of 7 was ≥ 501 kg. Statistical trends were detected between age and sex ($\chi^2_4 = 9.4$, $P = 0.052$) and between weight and sex ($\chi^2_2 = 5.9$, $P = 0.054$). Younger and lighter weight horses tended to be female. In addition, there was a significant association between age and weight ($\chi^2_8 = 15.8$, $P = 0.045$); older horses were heavier.

Musculoskeletal-related injuries were the cause of euthanasia in 29 (81%) horses, and included spontaneous bone fracture, muscle, tendon, and/or ligament injury (spontaneous musculoskeletal injury, 21 horses), trauma (6), and laminitis (2). Nonmusculoskeletal causes of death in the other 7 (19%) horses included gastric or cecal rupture (3), sudden collapse and death during race training (3), and encephalitis and pneumonia (1). The activity at the time of injury or euthanasia was racing (16), training (10), or nonexercise related (10). All 21 horses with a spontaneous musculoskeletal injury were either racing (12) or training (9) when injuries precipitating euthanasia were acquired, contributing to significant association between activity and the type of injury acquired (Fisher's exact test, $P = 0.001$).

Categorization of typical vertebral segments—The first 3 specimens collected for this study were entire vertebral columns that had 7 cervical, 16 or 17 thoracic, 6 lumbar, and 5 sacral segments. The remaining specimens (33/36) only included vertebrae caudal to the T(6) or T(5) thoracic vertebrae. This resulted in 22 specimens with T(6) present for evaluation and the other 14 specimens were evaluated from T(5) caudad. Only 61% of specimens had 6 lumbar

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and 5 sacral vertebrae (Table 1). A significant negative association was found between the number of lumbar and sacral vertebrae in a spinal column (Fisher's exact test, $P < 0.001$), with 89% of horses having a combined total of 11 lumbar and sacral vertebrae.

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Vertebral bodies—Vertebral body developmental anomalies, such as hemivertebrae or block vertebrae, were not found. A ventral crest observed on thoracolumbar vertebral bodies spanned from 4 to 8 vertebral segments (mean 5.5 ± 0.8 vertebral segments/specimen), with the cranial extent at T(3) or T(2) in 92% of specimens and the caudal extent at L3 or L4 in 97% of specimens.

Categorization of transitional vertebrae—Eight (22%) specimens had thoracolumbar transitional vertebrae; 3 had lumbarization of the last thoracic vertebrae, and 5 had thoracoization of L1. Thoracic vertebrae with lumbarization had a unilateral, nonarticular, proximally flat rib and a contralateral morphologically normal rib (Fig 5A). Lumbar vertebrae with thoracoization had: a unilateral or bilateral, nonarticular, proximally flat rib (3 specimens, Fig 5B); or an articulated lumbar transverse process or short rib and a contralateral morphologically normal lumbar transverse process (2 specimens, Fig 5C). Lumbosacral transitional vertebrae were not found. Sacrocaudal transitional vertebrae were found in 13 (36%) horses, characterized by sacral fusion with Cd1, and thereby having 6 sacral segments. A statistical trend was observed between age and the number of sacral segments ($\chi^2_4 = 9.0$, $P = 0.061$). Older horses tended to have Cd1 fused with the sacrum.

Table 1—Distribution of the number of lumbar and sacral vertebrae in 36 Thoroughbred racehorses

Vertebrae		Lumbar (n) 5	Lumbar (n) 6	Totals
Sacral (n)	5	1 (3%)	22 [3] (61%)	23 (64%)
	6	10 (28%)	3 [2] (8%)	13 (36%)
Totals		11 (31%)	25 (69%)	36 (100%)

[] = No. of specimens with thoracoization of L1.

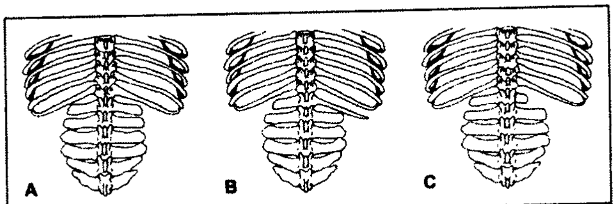

Figure 5—Dorsal view diagrams of thoracolumbar transitional vertebrae in specimens with 6 lumbar vertebrae. A—Lumbarization of the last thoracic vertebrae (T[1]) with a right horizontally flattened, nonarticular, costiform process; B—Thoracoization of the first lumbar vertebra (L1) with a right elongated, costiform, nonarticular transverse process; C—Thoracoization of the first lumbar vertebra (L1) with a right short, horizontally flattened, articulated transverse process.

Table 2—Distribution of the number of lumbar vertebrae and the L(2)-L(1) interspinous space status

Variable		Lumbar vertebrae (n) 5	Lumbar vertebrae (n) 6	Totals
L(2)-L(1) Interspinous space status	Closed	11 (31%)	12 (33%)	23 (64%)
	Open	0	13 (36%)	13 (36%)
Totals		11 (31%)	25 (69%)	36 (100%)

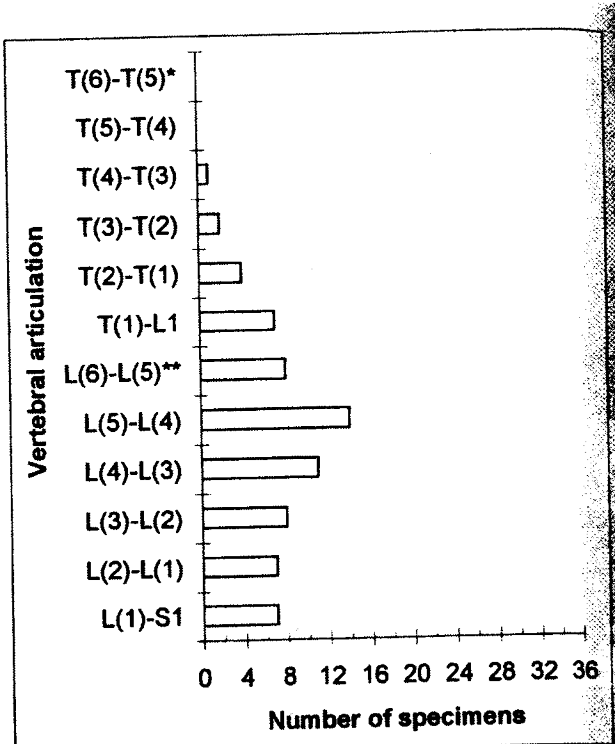

Figure 6—Vertebral distribution of articular process asymmetry in the caudal portion of the thoracic and lumbar spine. *Only 22 of 36 specimens had T(6) present for evaluation. **25 of 36 specimens had a total of 6 lumbar vertebrae.

Spinous processes—The status of the L(2)-L(1) dorsal interspinous space was significantly associated with the number of lumbar vertebrae (Fisher's exact test, $P = 0.003$, Table 2). A closed L(2)-L(1) interspinous space was found in all specimens with a total of 5 lumbar vertebrae.

Articular processes—Articular process size, shape, and/or articular facet orientation asymmetry was present at ≥ 1 vertebral segment in 30 (83%) specimens (Fig 6). A mean 1.9 ± 1.7 vertebral segments were affected per specimen. The number of vertebral segments with articular process asymmetries per specimen was 1 (36% of specimens), 2 (17%), 3 (14%), and 4 to 6 vertebral segments (17%). Articular process asymmetry was not found in 6 (17%) specimens.

The surfaces of the articular facets were evaluated in only 17 of the 36 specimens owing to incomplete joint capsule removal. Of the 17 specimens, 2 had no visible articular defects. The other 15 specimens had vertical articular clefts affecting only the cranial facets of vertebral segments in the T(3)-L(1) region of the spine (Fig 7). In the 17 specimens, a mean 4.2 ± 2.6 vertebral segments were affected. The number of vertebral segments with articular facet clefts per specimen was 2 (6% of specimens), 3 (11%), 4 (6%), 5 (6%), and 6 to 9 affected vertebral segments (14%).

Intertransverse joints of the lumbar spine and the lumbosacral junction—Intertransverse joints (either functional or ankylosed) in the caudal portion of the lumbar spine and the lumbosacral joint were bilaterally distributed in 31 (86%) specimens. Two sets of intertransverse joints were found at L(2)-S1 in 21 (58%)

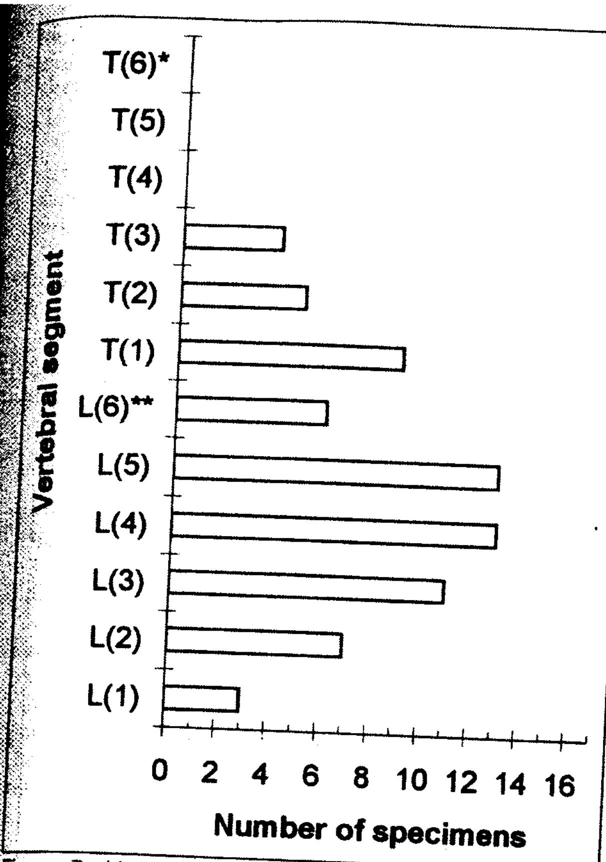

Figure 7—Vertebral distribution of cranial articular facet clefts in the caudal portion of the thoracic and lumbar spine (n = 17). *Only 10 of 17 specimens had T(6) present for evaluation; **12 of 17 specimens had a total of 6 lumbar vertebrae.

Table 3—Relation of age to physeal status of the thoracolumbar vertebral bodies, sacrum, and pelvis

Physes	Physeal status			
	Open	Partially closed	Closed	*P*-value
Vertebral				
Cranial vertebral body	2.5 ± 0.6^b (2.0 – 2.9) (n = 2)	3.4 ± 0.9^b (2.0 – 4.3) (n = 5)	4.9 ± 1.5^a (3.0 – 9.0) (n = 29)	0.007
Caudal vertebral body	3.4 ± 0.8^c (2.0 – 4.7) (n = 13)	4.4 ± 0.8^b (3.1 – 5.2) (n = 15)	6.7 ± 1.2^a (5.7 – 9.0) (n = 8)	< 0.001
Cranial sacral intercentrum*	3.2 ± 0.7^b (2.0 – 4.3) (n = 11)	4.5 ± 1.0^a (3.2 – 5.9) (n = 8)	5.4 ± 1.6^a (3.1 – 9.0) (n = 16)	< 0.001
Caudal sacral intercentrum*	NA NA (n = 0)	3.2 ± 0.8^b (2.0 – 4.3) (n = 10)	5.0 ± 1.5^a (3.1 – 9.0) (n = 25)	< 0.001
Sacral articular process*	4.1 ± 1.5^{a,b} (3.1 – 5.2) (n = 2)	3.7 ± 1.3^b (2.0 – 6.0) (n = 11)	4.9 ± 1.6^a (3.0 – 9.0) (n = 22)	0.085
Sacral transverse process*	3.1^a (3.1) (n = 1)	2.0^a (2.0) (n = 1)	4.6 ± 1.5^a (2.0 – 9.0) (n = 33)	0.121
Pelvic				
Tuber sacrale	3.6 ± 0.9^b (2.0 – 5.7) (n = 21)	5.7 ± 1.5^a (3.8 – 9.0) (n = 8)	5.8 ± 1.2^a (4.3 – 8.1) (n = 7)	< 0.001
Tuber coxae	3.1 ± 0.6^c (2.0 – 4.0) (n = 10)	4.4 ± 0.9^b (3.1 – 5.9) (n = 14)	5.8 ± 1.5^a (3.8 – 9.0) (n = 12)	< 0.001
Ischial tuberosity	3.1 ± 0.6^b (2.0 – 4.0) (n = 7)	3.7 ± 1.0^b (2.0 – 5.2) (n = 7)	5.2 ± 1.4^a (3.5 – 9.0) (n = 22)	< 0.001
Pelvic symphysis	3.6 ± 0.8^b (2.0 – 5.1) (n = 17)	4.7 ± 2.1^b (3.0 – 9.0) (n = 7)	5.7 ± 1.1^a (3.8 – 8.1) (n = 12)	< 0.001

*35 of 36 specimens evaluated.

NA = not applicable.

Different superscripts within rows indicate significant ($P < 0.05$) difference between means.

Data are expressed as mean (years) ± SD; range; No. of specimens.

specimens, 3 sets at L(3)-S1 in 9 (25%) specimens, and 4 sets at L(4)-S1 in 1 (3%) specimen. Five (14%) additional specimens had asymmetric distribution of intertransverse joints at L(3)-L(2), with 3 articulations at L(3)-S1 on 1 side and 2 at L(2)-S1 on the contralateral side. Three of the asymmetric articulations were in specimens with a total of 6 lumbar vertebrae, and 2 were in specimens with a total of 5 lumbar vertebrae. The overall size and width of the intertransverse joints were largest at the lumbosacral joint and decreased craniad in all specimens. Significant association was found between the number of lumbar vertebrae and the total number of intertransverse joints (Fisher's exact test, $P = 0.016$). Fifty-two percent (13/25) of spines with a total of 6 lumbar vertebrae versus 18% (2/11) of spines with a total of 5 lumbar vertebrae had intertransverse joints at 3 or more vertebral articulations.

Intertransverse joint ankylosis was found in 10 (28%) specimens. Ankylosis was detected at the L(2)-L(1) intertransverse joint in 9 specimens: unilaterally in 6 (17%) and bilaterally in 3 (8%). One additional specimen had unilateral intertransverse joint ankylosis at L(3)-L(2). Significant association was found between the number of intertransverse joints and intertransverse joint ankylosis (Fisher's exact test, $P = 0.014$). Specimens with fewer intertransverse joints had fewer intertransverse joints ankylosed. Ankylosed intertransverse joints were observed in 36% of horses with 6 lumbar vertebrae and in only 9% of specimens with a total of 5 lumbar vertebrae. However, significant association was not found between the number of lumbar vertebrae and intertransverse joint ankylosis (Fisher's exact test, $P = 0.128$). Also, association was not significant between age and intertransverse joint ankylosis ($\chi^2_4 = 2.6$, $P = 0.636$).

Physeal closure—Significant associations were found between age and vertebral body, sacral and pelvic physeal status, except for physes of the sacral articular processes and transverse processes (Table 3), and the iliac crest epiphysis (Table 4). The cranial vertebral body and caudal sacral intercentrum physes tended to close before the caudal vertebral physes and cranial sacral intercentrum physes. Within the sacral intercentrum, the medial portion of the physis closed before the lateral margins. Closure of the cranial and caudal portions of the ventral crest physis corresponded to closure times of the respective cranial and caudal vertebral body physes.

Secondary ossification centers were not found in the dorsal spinous processes of the caudal portion of the thoracic or lumbar spine. A thick fibrocartilaginous cap was observed over the dorsal apex of the S2 through S5 spinous processes but was absent on all S1 apices. The fibrocartilaginous cap thinned peripherally as it became continuous laterally with the superficial and deep gluteal fascia and dorsal sacroiliac ligament. The tips of the lumbar transverse processes were capped by cartilage, but secondary ossification centers were not visible in any specimen.

The various pelvic physes closed between 5.2 and 5.8 years of age (Table 3). Within the pelvic symphysis,

Table 4—Relation of age to iliac crest and ischial arch epiphyseal formation and fusion to the underlying bone

Epiphyses	Epiphyseal status* Grade 0	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	*P*-value
Iliac crest	NA NA (n = 0)	3.5[a,b] (3.5) (n = 1)	4.0 ± 0.9[b] (2.9 - 5.2) (n = 12)	4.5 ± 1.1[a,b] (3.0 - 6.7) (n = 16)	5.5 ± 2.9[a,b] (2.0 - 9.0) (n = 4)	7.2 ± 1.2[a] (6.3 - 8.1) (n = 2)	0.101
Ischial arch	NA NA (n = 0)	3.5[a,b,c] (3.5) (n = 1)	3.7 ± 0.8[b,c] (2.9 - 5.2) (n = 6)	4.9 ± 0.3[a,b] (4.7 - 5.1) (n = 2)	3.3 ± 0.7[c] (2.0 - 4.2) (n = 7)	5.4 ± 1.5[a] (3.5 - 9.0) (n = 19)	< 0.001

See Table 3 for key.

Table 5—Approximated ranking of vertebral and pelvic physeal status on the basis of age

Physes / epiphyses	Age (y) (No. of specimens) 2 (n = 2)	2½ (n = 1)	3 (n = 5)	3½ (n = 8)	4 (n = 3)	4½ (n = 3)	5 (n = 6)	5½ (n = 3)	6 (n = 2)	6½ + (n = 3)
Vertebral										
Caudal sacral intercentrum	+/−	+/−	+/−	+/−	−	−	−	−	−	−
Cranial vertebral body	+	+	+/−	+/−	−	−	−	−	−	−
Sacral transverse process	+	+	+/−	+/−	−	−	−	−	−	−
Sacral articular process	+	+	+	+/−	+/−	−	−	−	−	−
Cranial sacral intercentrum	+	+	+	+	+/−	+/−	−	−	−	−
Caudal vertebral body	+	+	+	+	+/−	+/−	+/−	−	−	−
Pelvic										
Ischial tuberosity	+	+	+	+/−	+/−	−	−	−	−	−
Tuber coxae	+	+	+	+	+/−	+/−	−	−	−	−
Tuber sacrale	+	+	+	+	+	+/−	+/−	−	−	−
Pelvic symphysis	+	+	+	+	+	+/−	+/−	−	−	−
Ischial arch*	0	0	1	1	2	3	4	5	5	5
Iliac crest*	0	0	1	1	2	3	3	4	4	5

*0–5 grading system was used to categorize the iliac crest and ischial arch epiphyseal status.
(+) = Open physis; (+/−) = partially closed physis *or* a combination of open and closed physes present; (−) = closed physis.

the pubic symphyseal portion closed before the ischial symphysis, which often remained fibrocartilaginous and nonossified even in older specimens. A secondary ossification center located within the pubic symphysis was detected in several specimens. All specimens had evidence of iliac crest and ischial arch epiphyseal formation or fusion to the underlying bone (Table 4). The iliac crest and ischial arch epiphyses formed and began coalescing at approximately the same age, but the ischial arch epiphyses fused to the underlying bone at an earlier age (Table 5).

Discussion

Categorization of typical vertebral segments—Only 61% of our Thoroughbred racehorse specimens had 6 lumbar and 5 sacral vertebrae, the commonly accepted equine vertebral formula. Stecher and Goss found that most donkeys, wild asses, and Przewalski's horses had 5 lumbar vertebrae, but not 'shorter-backed' Arabians, as stated by other sources.[7,19-21] In this study, Thoroughbreds, a breed not characterized as 'short-backed', had variable numbers of lumbosacral vertebrae. Variations in the number of vertebrae within 1 spinal region are often compensated for by a reduction or increase in the number of vertebrae in an adjacent vertebral region. Stecher and Goss reported a tendency for the combined lumbosacral spine to contain 11 vertebrae and that specimens with fewer lumbar vertebrae often had more sacral vertebral segments.[7,19] A similar, significant inverse relation between the total number of lumbar and sacral vertebrae in the vertebral column of Thoroughbred racehorses was reflected by a tendency for these horses to have either 6 lumbar and 5 sacral, or 5 lumbar and 6 sacral vertebrae.

Vertebral bodies—The thoracolumbar vertebral body ventral crest corresponds to the region of tendinous insertion of the crura of the diaphragm. The ventral crest has been reported to be present on the last 3 to 4 thoracic vertebrae (T(4) or T(3)-T(1)) and the first 3 lumbar vertebrae (L1-L3).[6,17] These reported vertebral segments correspond to our findings of T(3)-T(2) to L3-L4 as the cranial and caudal limits of the ventral crest in most Thoroughbred racehorse specimens.

Categorization of transitional vertebrae—Alterations in vertebral morphology often affect the vertebral arches and transverse processes, but rarely the vertebral bodies.[6,22] Transitional vertebrae can have right-to-left asymmetry or altered cranial-to-caudal gradation in vertebral morphology.[23] Categorization of the thoracolumbar transitional vertebrae as thoracic or lumbar vertebrae was difficult owing to: large variations in the morphology of affected vertebrae, and examination of incomplete thoracic spines. The 22% prevalence of thoracolumbar transitional vertebrae in our Thoroughbred racehorses was higher than the 0.5% reported by Stecher.[7] Thoracolumbar transitional vertebrae are probably not clinically significant developmental variations.

Lumbosacral transitional vertebrae were not apparent in any of our specimens. Jeffcott reported sacralization of L6, characterized by ankylosis and malformation of L6 and the sacrum, in 2 horses with clinical signs of hind limb lameness and possible sacroiliac joint injury.[24] Both horses also had evidence of contralateral sacroiliac joint arthrosis or ankylosis. In dogs, lumbosacral transitional vertebrae have been associated with cauda equina syndrome and possible secondary degenerative joint disease, altered sacropelvic biomechanics, and hip dysplasia.[14,22,25] Similar compen satory musculoskeletal abnormalities might be expected in horses with appreciably malformed lumbosacral transitional vertebrae.

Sacrocaudal transitional vertebrae were not categorized in manner similar to that reported by Stecher and Goss.[5,7,19] Sacral vertebral segments were counted from the lumbosacral joint caudad to the last segment with partial or complete vertebral body fusion, regardless of lateral sacral foramina morphology. The sacrum, with fused caudal vertebra(e), functions as a unit and may have more sacropelvic biomechanical significance than a sacrum characterized by the extent of sacral foramina formation. The anomalous sacrocaudal vertebrae reported in the aforementioned study was 36% in all equine species combined and was 29% in domesticated horses. Similarly, 36% of our Thoroughbred specimens had sacrocaudal transitional vertebrae characterized by vertebral body fusion. Stecher and Goss suggested that sacrocaudal transitional vertebrae are attributable to congenital developmental anomalies rather than to acquired ankylosis or pathologic changes.[7,19] However, Sisson and Grossman reported that an elongated sacrum is often seen in aged horses owing to the first and sometimes second caudal vertebrae having fused with the sacrum.[6] This was supported in our sample of Thoroughbred racehorses by the trend of older aged specimens to have a larger number of sacral segments.

Spinous processes—Sisson and Grossman describe the spinous processes as varying greatly in size, shape, and orientation in different vertebrae and vertebral regions.[6] The T17-L6 spinous processes are angled dorsocranial and the S1-S5 spinous processes have a dorsocaudad inclination.[17] The divergent spinous processes of the lumbosacral junction produce a wide L(1)-S1 interspinous space, compared with the adjacent interspinous spaces.[5,10,16] However, 13 (36%) specimens with 6 lumbar vertebrae in our study had divergent spinous processes at L(2)-L(1) and L(1)-S1 interspinous spaces that produced an isolated L(1) spinous process spaced equally between the L(2) and S1 spinous processes. Variations in the L(2)-L(1)-S1 interspinous spaces may primarily affect muscular and ligamentous insertions and secondarily produce changes in spinal or pelvic biomechanics, overall performance, or potential morbidity.[10,26]

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Articular processes—Spinal mobility is related to the morphology (ie, size, shape, and orientation) and functional status of the vertebral articular facets.[5,10,21,26] The articular processes and facets vary greatly in size, shape, and orientation in different vertebrae and spinal regions.[6,17] Apart from these normal transitional changes between spinal regions, a large percentage (83%) of Thoroughbred racehorses had obvious asymmetries in the individual articular processes or facets. Boyd states that articular facet asymmetry is common in all species, and Morgan reported variable degrees of articular process malformations in almost all of the 145 canine vertebral columns evaluated.[22,27] The articular process changes were reported to usually occur unilaterally, as was observed in our Thoroughbred racehorse specimens. Most articular process shape and orientation asymmetries appeared to be developmental because they were unilateral and were not associated with obvious osseous lesions. However, it was difficult to determine whether the articular process size asymmetries were congenital or attributable to acquired osseous modeling in response to local biomechanical stresses.

Case studies of torticollis, scoliosis, and lordosis in horses indicate severe articular facet asymmetry or hypoplasia as the primary morphologic abnormality in affected spinal regions.[8,27-30] Several authors suggest that congenital articular process hypoplasia is caused by malpositioning or in utero postural restrictions.[8,28,29] Rooney evaluated about 50 fetuses and foals with scoliosis and suggested defective mesenchymal or cartilaginous models were the cause of the malformations.[8,28] Articular process and facet abnormalities in the thoracolumbar spine may induce asymmetries in spinal mobility with subsequent joint instability, muscle shortening, and bone modeling.[28] Abnormal cervical articular process development with altered articular processes have also been implicated in the pathogenesis of cervical vertebral stenotic myelopathy.[31-34]

The vertical articular facet clefts appeared to be developmental anomalies because they were surrounded by visibly normal cartilage and were not associated with articular process degenerative changes.

Intertransverse joints of the lumbar spine and the lumbosacral junction—It has been reported that rhinoceroses and all species of the genus *Equus* (ie, domestic horses, wild horses and asses, and prehistoric horses) have intertransverse joints in the caudal portion of the lumbar spine and the lumbosacral junction that provide spinal resistance to lateral bending and axial rotation.[5,10] Stecher found that intertransverse joints in horses were not present at birth but developed soon after.[5] Stecher suggested that the number of intertransverse joints seem to depend on the length (ie, number of vertebrae) of the lumbar spine. This observation was supported in Thoroughbred racehorses by the significant positive association between the number of lumbar vertebrae and intertransverse joints. Most of the lumbar intertransverse joints in Thoroughbred racehorses occurred in pairs, although 5 (14%) horses had asymmetric distribution of intertransverse joints at L(3)-L(2). Stecher reported that 22 (9%) spines from various equine species had asymmetric intertransverse joints.[5]

Smythe estimated that 50% of racehorses destroyed at the track had lumbar intertransverse joint ankylosis.[20] Townsend and Leach reported prevalence of either unilateral or bilateral intertransverse joint ankylosis to be 59% at L(2)-L(1) and 23% at L(3)-L(2) in routine submissions of 17 adult horses aged 3 to 23 years.[10] These findings of intertransverse joint ankylosis are higher than the prevalence of 25% at L(2)-L(1) and 3% at L(3)-L(2) in our sample of Thoroughbred racehorses. Stecher and Goss reported that ankylosis of the lumbar transverse processes may occur independent of intertransverse joint ankylosis.[5,19] This type of ankylosis was observed in 1 of our specimens. Thoroughbred racehorse findings also are compatible with other studies indicating that intertransverse fusion does not occur at the lumbosacral junction unless L6 is sacralized.[5,10,19,20,24]

Townsend et al[35] suggested that ankylosis of the intertransverse joints is not a substantial cause of back pain in horses. Stecher found that ankylosis of the equine lumbar intertransverse joints occasionally occurs before vertebral body physeal closure and considered ankylosis to be a developmental anomaly rather than a pathologic change.[5] This is consistent with our Thoroughbred racehorses where: age was not associated with intertransverse joint ankylosis; unilateral ankylosis was almost always accompanied by an apparently normal contralateral intertransverse joint; and joint ankylosis was not associated with any visible periarticular signs of degenerative joint disease. Stecher and Goss found ankylosed intertransverse joints only in domesticated equine species with 6 lumbar vertebrae and not in any wild equine species.[5,19] They reasoned that this was possibly attributable to the dependence of the wild equine species on fleetness of foot to escape predators and never having to bear weight on their backs.

Physeal closure—The primary ossification centers of the thoracolumbar vertebral bodies and neural arches (ie, neurocentral joint) fuse shortly after birth.[9] Sisson and Grossman describe secondary spinal ossification centers for the dorsal spinous process summits, transverse processes extremities, and vertebral body epiphyseal plates.[6] Newborn foals have radiographically well defined cranial and caudal thoracolumbar vertebral body epiphyses, and radiographic physeal closure has been reported to occur at 3 to 3.5 years of age.[9] Serial spinal radiographic views of 7 Thoroughbred horses in training were reported to have indicated vertebral endplate physeal closure at 2.5 years and complete closure by 3.2 years of age. Gross anatomic evaluation of our Thoroughbred racehorses revealed thoracolumbar vertebral endplate physeal closure between 4.9 and 6.7 years of age. The discrepancy in anatomic and radiographic physeal closure times may be related to the limitation of radiographic techniques for documentation of thin, irregularly shaped radiolucencies characteristic of vertebral physes.[36]

The caudal sacral intercentrum physes are comparable to the cranial thoracolumbar vertebral body physes, and the cranial sacral intercentrum physes are comparable to the caudal thoracolumbar vertebral body physes. This is supported by similar physeal closure times in our Thoroughbred racehorses. Sisson and Grossman describe overall sacral physeal closure proceeding craniad to caudad, with the transverse processes uniting before the medial sacral body physes.[6] Additionally, the sacral articular processes fused before closure of the sacral body physes in our Thoroughbred racehorses. Sacral body fusion was reported to occur at 3 years of age by Sisson and Grossman. However, our Thoroughbred racehorse sacral physes were often not closed until 4 to 5 years of age, as reported by Nickel et al.[17] Classification of the overall sacral physeal closure status was difficult in some locations owing to large variations in physeal closure. Incomplete fusion of the caudal-most sacral vertebrae (S4-S6) was common even in older Thoroughbred racehorses. This may explain the lack of association between age and physeal status of the sacral articular processes and the transverse processes.

The spinous processes of the caudal portion of the thoracic and lumbosacral spine did not contain secondary ossification centers as reported in the cranial thoracic (ie, withers) spinous processes.[12] However, the summits of the S2-S5 spinous processes were expanded (sometimes bifid) and covered with fibrocartilaginous caps. Anatomically, the summits of the S2-S5 spinous processes serve as strong attachment sites for the gluteal muscles, gluteal fascia, and the dorsal sacroiliac ligaments. The S1 spinous process must be short and narrow to prevent impingement at the sacropelvic junction and did not have a fibrocartilaginous cap in our Thoroughbred racehorses.

The age of physeal closure for the primary ossification centers of the equine pelvis (ie, fusion of the ilium, pubis, and ischium) has been reported to occur in gross specimens at 10 to 12 months and radiographically at 12 to 24 months of age.[6,13] Sisson and Grossman reported that the acetabular portion of the pubis fuses to the pelvis at 4.5 to 5 years of age.[6] Evidence of an open physis near the acetabular portion of the pubis was not found in any of our Thoroughbred racehorse specimens. Physeal closure of several secondary pelvic ossification centers has been observed radiographically between 2 and 9 years of age.[9] Jeffcott found radiographically that the centers of secondary ossification at the tuber coxae and ischial tuberosity are usually closed by 2 years of age.[9,11] This is earlier than findings in our Thoroughbred racehorses and in reports by Sisson and Grossman where they stated that the secondary ossification centers for the tuber coxae and ischial tuberosity fuse to the pelvis at 4.5 to 5 years of age.[6]

Various authors observed radiographically that the equine pelvic symphysis begins ossification after 2 years of age and is completely fused at 5 to 6 years, but may occasionally remain incompletely fused in horses 8 to 9 years of age.[9,11,13] These reported ages of pelvic symphysis union are consistent with findings in our Thoroughbred racehorses. Pelvic symphyseal closure begins craniad with ossification of a secondary ossification center located within the pubic symphysis.[6] Complete pubic symphyseal ossification occurs before fusion progresses caudad toward the ischial symphysis, which may remain fibrocartilaginous and nonossified in some older horses.

In the equine pelvis, the iliac crest epiphysis forms within the thoracolumbar fascial insertion site on the cranial margin of the wing of the ilium. The iliac crest epiphysis develops from intermittent ossification sites along the length of the iliac crest and from extensions of the tuber sacrale and tuber coxae epiphyses. The intermittent ossification sites of the iliac crest epiphysis subsequently coalesce and fuse to the underlying wing of the ilium, resulting in closure of the secondary ossification center. The equine iliac crest epiphysis appears to form and fuse to the wing of the ilium in a different progression than does human or canine iliac crest epiphyseal formation and fusion. In human beings, Risser sign grading was developed as a radiographic indicator of skeletal maturity by evaluation of iliac crest epiphyseal formation and fusion to the underlying ilial wing.[18] Radiographically, the iliac crest is divided into 4 quadrants and, as the ossified iliac crest epiphysis appears laterally and advances medially along the iliac crest, quadrant ossification is graded 1 through 4. Grade 5 is characterized by osseous union of the completely formed iliac crest epiphysis to the underlying wing of the ilium. Dogs, in contrast, have iliac crest epiphyseal formation and subsequent osseous union that begins caudad (medially) and proceeds craniad (laterally) along the ilial wing.[37-39] The radiographic status of the iliac crest in dogs is variable and has been reported to be an unreliable indicator of age or skeletal maturity.[37] A margin ally nonsignificant trend in the association between age and iliac crest epiphyseal status and no apparent direction of progressive iliac crest ossification or fusion to the underlying ilial wing was observed in Thoroughbred racehorses.

Osseous union of the iliac crest epiphysis to the underlying ilial wing was the last vertebral or pelvic physis to close in Thoroughbred racehorses. The iliac crest physis closes about a year after the neighboring tuber coxae and tuber sacrale physes close. Therefore, evaluation of the iliac crest epiphyseal status may be used as a crude indicator of skeletal maturity in Thoroughbred racehorses. However, large age variations occurred within each grade of iliac crest epiphyseal status that may have contributed to a nonsignificant association. Therefore, the overall vertebral or pelvic physeal closure status should be evaluated for a more accurate estimate of skeletal maturity in Thoroughbred racehorses.

Similar to the iliac crest epiphysis, the ischial arch epiphysis forms and fuses to the underlying ischium. The ischial arch epiphysis initially forms from the medial and lateral margins of the ischial arch as extensions of the ischial symphysis and ischial tuberosity epiphysis. Coalescence of the ischial arch epiphysis and fusion to the underlying ischium complete epiphyseal formation and closure. The ischial arch physis closes about a year after the neighboring ischial tuberosity physes close. The ischial arch epiphysis formation and ossification process is similar in dogs.[39]

In conclusion, numerous anatomic variations affecting the vertebral bodies and articulations and spinal processes were commonly found in a sample of Thoroughbred racehorses. A total of 5 lumbar vertebrae were found in a significant proportion of presumed 'long-backed' Thoroughbreds. Variations in the intertransverse joints and articular process asymmetry occurred to variable degrees in most of the horses, which may affect low back mobility. Thoracolumbar vertebral body physes closed at an older age than previously reported. A grading system for the iliac crest and ischial arch formation and fusion to the underlying bone may help quantify skeletal maturity in the pelvis of horses. Normal anatomic variations and age of skeletal maturity need to be considered in the clinical evaluation of the equine spine and pelvis for differentiation from pathologic findings.

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