Morphologic Evaluation of Rotated Tibiotarsal Bones in Immature Ostriches (Struthio camelus)

Gayle Hahulski, DVM, Denis J. Marcellin-Little, DEDV, and Michael K. Stoskopf, DVM, PhD

Abstract: The presence of potential morphologic anomalies associated with tibiotarsal rotation was determined in 10 ostrich chicks. Seven of the 10 chicks displayed various degrees of unilateral tibiotarsal rotation, whereas 3 were unaffected. Pelvic limb musculature and joint anatomy were similar between affected and control limbs. External rotation of clinically affected tibiotarsal bones (n = 7) ranged between 25 and 75° (median, 53°), whereas that of clinically normal bones (n = 13) ranged between 0 and 17° (median, 8°). The tibiotarsal nutrient foramen, in the midshaft, was more caudal in clinically affected limbs than in normal limbs (P = .002) and its displacement was correlated with the amount of tibiotarsal rotation (P < .001, r = .709). The distal aspect of the nutrient foramen was more cranial in clinically affected limbs than in normal limbs (P = .01). The cortical thickness and diaphyseal trabecular patterns of affected and control tibiotarsi were identical. The distal tibiotarsal physis of all birds had an atypical conformation, with transverse and longitudinal portions. Abnormal growth of the longitudinal portion of that physis might contribute to the development of tibiotarsal rotation. However, the caudal displacement of the nutrient foramen suggests that the deformity originates in the proximal portion of the bone.

Key words: rotational deformity, tibiotarsal bone, anatomy, ratite, ostrich, Struthio camelus

Introduction

A recent clinical interest in ostriches (Struthio camelus), emus (Dromaius novaehollandiae), and rheas (Rhea americana) has been fueled by a rapidly developing industry based mainly on the potential of ratites as an alternative food source and, less importantly, on hide, plumage, and oil markets. After a rapid initial growth influenced by speculation, the industry settled. However, efforts continue to bring ostrich meat to market. Pelvic limb deformities are a common problem in captive-reared ratite chicks (Fig. 1). Specifically, external tibiotarsal rotation affects a large enough population of ostrich chicks to result in an observable decrease in productivity for meat producers. A similar deformity is present in chickens and turkeys. This deformity is characterized by an external rotation of the tibiotarsus without concurrent bone angulation or tendon subluxation. Tibiotarsal rotation develops during a period of rapid growth, from 2 to 10 weeks of age, in both chickens and ostriches and progresses rapidly, resulting in birds that are unable to ambulate. Several causes have been proposed for tibiotarsal rotation, including nutritional deficiencies, insufficient or excessive exercise, inappropriate pen design, various environmental factors, defects in bone mineralization, and high growth rates. The impact of tibiotarsal rotation on the ostrich industry warrants further investigation.

We hypothesized that specific morphologic anomalies within the tibiotarsal bone contribute to the development of tibiotarsal rotation. Also, identifying morphologic differences between affected and unaffected (control) bones could help in understanding the pathogenesis of tibiotarsal rotation. In this study, we focused on defining relative size of the pelvic limb musculature; the morphology and points of origin and insertion of tendons and ligaments; the length, angulation, and rotation of the tibiotarsal bone; the location of the nutrient foramen; the thickness of the diaphyseal cortex; and the
conformation of the distal physis of affected and normal tibiotarsi of ostrich chicks.

**Materials and Methods**

Tibiotarsal bones from 10 ostrich chicks were included in the study. Specimens were donated by Rollins Animal Disease Diagnostic Laboratory, Raleigh, NC, USA, and by seven ostrich breeders. The bones were collected from chicks that ranged from 3 to 9 weeks of age; seven of these chicks exhibited varying degrees of unilateral tibiotarsal rotation, and three chicks were clinically normal. The seven affected chicks were euthanatized because of the poor prognosis associated with their deformities. Of the three unaffected chicks, the cause of death was unknown for two and was proventricular impaction for the third. The seven rotated tibiotarsi from the affected chicks were compared with the 13 clinically normal tibiotarsi, which included the normal tibiotarsi of affected birds (7) and both tibiotarsi of each of the three clinically normal chicks (6).

The pelvic limb musculature and the stiffe and tarsal joints were evaluated in clinically rotated and normal limbs by gross examination and dissection. Muscle circumference was evaluated with a tape measure. Muscle weight was not determined because it was likely altered during the delay between death and dissection. The dimensions, origins, and insertions of the intrinsic muscles of the pelvic limbs were evaluated. The joints were evaluated for color and consistency of synovial fluid; thickness and color of the joint capsule; and location, size, color, and consistency of the collateral ligaments, cruciate ligaments, and intratrochlear tendons. The points of entry of the nutrient vessels to the joints were also determined.

Radiographs were evaluated for the presence of lesions of osteochondrosis (dyschondroplasia), such as areas of decreased radiolucency and retained cartilage. The degree of rotation of affected and clinically normal tibiotarsi was determined by evaluating radiographs (Fig. 2). A trigonometric method was designed to compare the transverse axis of the proximal and distal articular surfaces of each bone by using four spherical 2.3-mm-diameter lead pellets (95% lead-5% antimony pellets, West Coast
Figure 2. Radiographic determination of the tibiotarsal rotation in a 56-day-old male ostrich chick (specimen 10). Lead pellets (2.3-mm diameter) are placed on the medial and lateral aspects of the proximal and distal epiphyses. Craniocaudal (A, D) and mediolateral (B, E) radiographic projections of the proximal aspect of the tibiotarsal bone and a craniocaudal radiographic projection of the distal aspect of the tibiotarsal bone (C, F) are made. The distances separating the distal lead pellets on the radiographic projections are defined as $D_1$, $D_2$, and $D_3$, respectively. These values are used to trigonometrically calculate the degree of external rotation of the bone. In this bird, the left limb (A–C) is clinically...
Shot, Carson City, NV, USA) placed on the tibiotarsus as markers. The proximal markers were placed on the proximal articular surface of each tibiotarsus, forming a line oriented in a medial to lateral direction. The distal markers were placed on the center of each of the trochlear ridges of the condyle viewed in a mediolateral direction. Radiographs were made in three planes: a craniocaudal and a mediolateral view, based on the position of the proximal portion of the bone, and a craniocaudal view, based on the position of the distal portion of the bone (Fig. 2). Variations in marker distance were used to calculate the degree of rotation (D) by using the following formula:

\[ D = 0.5\arccos\left(\frac{D_1}{D_2}\right) + \arcsin\left(\frac{D_2}{D_3}\right) \]

where \( D_1 \) is the distance between the markers located on the medial and lateral condyles of the tibiotarsus in the first plane, \( D_2 \) is the distance between those markers in the second plane, and \( D_3 \) is the distance between the distal markers in the third plane (Fig. 2). The mediolateral and craniocaudal angulations of the tibiotarsal bones were measured.

The nutrient foramen, on the lateral aspect of the tibiotarsal diaphysis, was used as a marker for bone rotation. The location and direction of the nutrient foramen were determined from the mediolateral radiographic view. The location of the foramen was determined by dividing the distance between the foramen and the center of the bone by the radius of the bone (Fig. 2, inset). The orientations of the proximal and distal halves of the nutrient foramen were measured by comparing their direction with the direction of the longitudinal aspect of the bone (Fig. 2, inset).

Diaphyseal cortical thickness was evaluated radiographically in rotated and clinically normal tibiotarsi. Six 1-mm-thick cross sections selected throughout the diaphysis and distal metaphysis of normal and rotated tibiotarsi were cut with a Buehler Isomet Plus precision saw (Buehler, Lake Bluff, IL, USA). Contact microradiographs were made in a radiographic cabinet (90 seconds at 28 kilovolt peak [kVp]) (Faxitron Model 43855A, Hewlett-Packard, Rockville, MD, USA). The diaphyseal width in the craniocaudal and mediolateral directions and the cranial, caudal, medial, and lateral cortical thickness of six corresponding sections of the affected and unaffected diaphyses were measured by computer software (Adobe Photoshop 4.0, Adobe Systems, Mountain View, CA, USA).

The anatomic conformation of the distal tibiotarsal physis was also evaluated on radiographs (Fig. 2, inset). The condyles on the normal and affected tibiotarsi were cut longitudinally into 1-mm-thick sections with the Buehler saw. Contact microradiographs of these sections were made (Faxitron, 90 seconds at 28 KVp). The cortical thickness, trabecular patterns, and conformation of the affected and unaffected physes were compared by computer software (Adobe Photoshop 4.0). To confirm the shape of the tibiotarsal physes, the pelvic limbs of a clinically normal 35-day-old female ostrich were collected. The bones were boiled overnight to remove muscle and ligament attachments.

Statistical analysis was performed with statistical analysis software (SAS software, version 6.12, SAS Institute, Cary, NC, USA). A one-tailed t-test assuming that the variances were unequal was used to compare the amount of external rotation of the tibiotarsal bone in clinically normal and affected limbs. An independent two-sample t-test assuming that the variances were unequal was used to compare the locations of the tibiotarsal nutrient foramen of clinically affected and normal tibiotarsi. Correlation analysis was used to compare the correlation of external rotation and nutrient foramen displacement. An independent two-sample t-test assuming that the variances were equal was used to compare the directions of the proximal half of the nutrient foramen of clinically affected and normal tibiotarsi. A similar test was used to compare the direction of the distal half of the nutrient foramen. All limbs were considered as independent observations for these tests.

**Results**

On gross dissection of the pelvic limbs, no differences in muscle mass, color, origins, trajectory, or insertions were seen between clinically normal and rotated limbs. The left limb was involved in four of seven affected chicks. No abnormalities in the conformation, placement, or attachments of the cruciate ligament, collateral ligaments, and intratrochlear tendons were observed. No differenc-
Table 1. Signalment and morphology of normal and abnormal tibiotarsal bones in immature ostriches.

<table>
<thead>
<tr>
<th>Clinical status</th>
<th>Specimen</th>
<th>Limb</th>
<th>Age (d)</th>
<th>Sex</th>
<th>Length (mm)</th>
<th>Rotation (degrees)</th>
<th>Radius (mm)</th>
<th>Displacementa (mm)</th>
<th>Displacementb (%)</th>
<th>Direction of the foramen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotated (n = 7)</td>
<td>1</td>
<td>L</td>
<td>36</td>
<td>M</td>
<td>257</td>
<td>75</td>
<td>1.4</td>
<td>0.5</td>
<td>36</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>L</td>
<td>28</td>
<td>M</td>
<td>216</td>
<td>53</td>
<td>2.1</td>
<td>1.0</td>
<td>48</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>L</td>
<td>63</td>
<td>M</td>
<td>278</td>
<td>56</td>
<td>2.7</td>
<td>0.4</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>L</td>
<td>42</td>
<td>M</td>
<td>195</td>
<td>31</td>
<td>2.1</td>
<td>0.8</td>
<td>38</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>R</td>
<td>49</td>
<td>F</td>
<td>320</td>
<td>47</td>
<td>2.8</td>
<td>2.1</td>
<td>75</td>
<td>-6</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>R</td>
<td>56</td>
<td>F</td>
<td>271</td>
<td>25</td>
<td>2.6</td>
<td>0.9</td>
<td>35</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>R</td>
<td>56</td>
<td>M</td>
<td>276</td>
<td>66</td>
<td>2.8</td>
<td>1.7</td>
<td>61</td>
<td>-4</td>
</tr>
<tr>
<td>Median</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>38</td>
</tr>
<tr>
<td>Standard deviation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Normal (n = 13)</td>
<td>1</td>
<td>R</td>
<td>36</td>
<td>M</td>
<td>261</td>
<td>9</td>
<td>1.5</td>
<td>0.3</td>
<td>20</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>R</td>
<td>28</td>
<td>M</td>
<td>216</td>
<td>0</td>
<td>2.4</td>
<td>0.4</td>
<td>17</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>R</td>
<td>63</td>
<td>M</td>
<td>281</td>
<td>8</td>
<td>2.9</td>
<td>0.4</td>
<td>14</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>R</td>
<td>42</td>
<td>M</td>
<td>195</td>
<td>17</td>
<td>2.2</td>
<td>0.2</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>L</td>
<td>36</td>
<td>F</td>
<td>206</td>
<td>12</td>
<td>2.3</td>
<td>0.2</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>R</td>
<td>36</td>
<td>F</td>
<td>205</td>
<td>1</td>
<td>2.5</td>
<td>0.2</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>L</td>
<td>22</td>
<td>M</td>
<td>150</td>
<td>4</td>
<td>1.7</td>
<td>0.0</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>R</td>
<td>22</td>
<td>M</td>
<td>150</td>
<td>8</td>
<td>1.7</td>
<td>0.0</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>L</td>
<td>55</td>
<td>M</td>
<td>214</td>
<td>3</td>
<td>2.8</td>
<td>0.0</td>
<td>0</td>
<td>-6</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>R</td>
<td>55</td>
<td>M</td>
<td>214</td>
<td>3</td>
<td>2.8</td>
<td>0.2</td>
<td>7</td>
<td>-6</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>L</td>
<td>49</td>
<td>F</td>
<td>321</td>
<td>14</td>
<td>2.8</td>
<td>0.8</td>
<td>29</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>L</td>
<td>56</td>
<td>F</td>
<td>268</td>
<td>1</td>
<td>2.7</td>
<td>0.7</td>
<td>26</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>L</td>
<td>56</td>
<td>M</td>
<td>279</td>
<td>8</td>
<td>2.8</td>
<td>0.0</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>Median</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Standard deviation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

Proximal = proximal half of the nutrient foramen; Distal = distal half of the nutrient foramen; L = left; R = right; M = male; F = female.

* The nutrient foramen is on the lateral aspect of the bone. Its displacement is defined as the distance between the center of the bone on the mediolateral radiographic incidence and the center of the foramen (Fig. 2).

* Positive values correspond to a caudal displacement of the foramen.

* Positive values correspond to a distal and caudal direction for the foramen. Negative values correspond to a distal and cranial direction for the foramen.

es in joint capsule thickness, synovial fluid color or consistency, or arterial supply to the joints between affected and unaffected limbs were observed.

Tibiotarsal bone external rotation ranged from 25 to 75° (median, 53°) in clinically affected limbs and from 0 to 17° (median, 8°) in control limbs (Table 1). Clinically affected limbs were rotated more than clinically normal limbs (P < .001). A 10° varus angulation was present in the left limb of specimen 8 (clinically normal limb). Angulation was not identified in other bones. The length of affected bones did not differ from the length of control bones (Table 1). The location of the nutrient foramen was significantly (P = .002) more caudal (range, 15–75% caudal) in affected limbs than in control limbs (range, 0–29% caudal). External tibiotarsal rotation was correlated with caudal displacement of the nutrient foramen (P < .001, r = .709). The direction of the proximal half of the nutrient foramen was similar (P = .99) between affected and control limbs (median, 2° distal and cranial). The direction of the distal half of the nutrient foramen was more cranial (P = .011) in affected limbs (median, distal—4° cranial) than in control limbs (median, distal—0° cranial).

On radiographs, no lesions of osteochondrosis were seen. The cortical thickness and trabecular patterns of the diaphysis appeared similar between rotated and clinically normal tibiotarsi (Fig. 3). Slight differences in cortical thickness, secondary to the sectioning technique, made it difficult to accurately match corresponding transverse sections.

The distal tibiotarsal physis had an unexpected
Figure 3. Evaluation of cortical thickness and trabecular patterns of selected 1-mm cross sections, comparing rotated (left) and clinically normal (right) tibiotarsi of a 45-day-old female ostrich chick. The sections are arranged from proximal to distal (top to bottom). The cranial aspects of the sections are on top. The medial aspects are toward the center of the image. The distal physis is visible on the cranial aspect of the distal sections. Marker length = 10 mm.

appearance on radiographic evaluation and on cross sections of both the rotated and clinically normal tibiotarsi. The distal epiphysis was not confined to a two-dimensional plane as expected. It had a narrow portion that extended proximally on the axial cranial aspect of the bone. On the caudal aspect of the bone, the physis had a two-dimensional conformation similar to that in mammals. This conformation was clearly visible on the boiled specimens (Fig. 4).

Discussion

The evaluation of the morphology, etiology, and pathogenesis of rotational deformities in birds is important because of the high frequency of these deformities (6.3 and 10.3% of ostrich chicks in two studies), their severity, and their irreversible nature. Rotational deformities of the long bones of the pelvic limb, with or without concurrent angular deformities, are present in several species of birds including chickens, turkeys, guinea fowl, and psittacine birds. These deformities strongly resemble tibiotarsal rotation in ostriches. Rotational deformities have also been recognized in dogs. Rotation of the antebrachium may be present when abnormal physeal growth develops in one of two paired bones (eg, radius or ulna); however, rotation is thought to be secondary to the growth restrictions placed on the bone with the larger growth potential by the bone with the lower growth potential. These deformities may be caused by a disruption in endochondral ossification from trauma, dwarfism, hypertrophic osteodystrophy, multiple cartilaginous exostoses, or hyperparathyroidism. Rotation of the tibia associated with medial and lateral patellar luxation has been described in dogs. Medial patellar luxation is associated with hypoplasia of the medial femoral condyle, medial displacement of the tibial crest, and external rotation of the tibial shaft. Idiopathic tibial torsion also has been documented in children.

This study focused on describing the tibiotarsal morphology of affected and clinically normal limbs of ostrich chicks. Most morphologic parameters in affected and control limbs were similar, including muscle size, joint capsule thickness, size and shape of intraarticular tendons and ligaments, bone length and angulation, diaphyseal cortical thickness, and morphology of the distal tibiotarsal physis. However, the external rotation of the tibiotarsus was greater, and the nutrient foramen was more caudal, in affected limbs than in normal limbs. These two features were correlated. Affected bones also had a nutrient foramen that coursed in a more cranial direction, distally. The displacement of the nutrient foramen is unlikely to be secondary to bone remodeling; rather, it was more likely caused by rotation of the bone proximal to the foramen (Fig. 5). This suggests that the external rotation present in
Figure 4. Clinically normal tibiotarsi of a 35-day-old female ostrich chick. The cranial (left) and medial (right) aspects of the normal tibiotarsal bone are shown. The soft tissues and articular cartilage have been removed. The longitudinal portion of the distal epiphysis is visible along the axial cranial aspect of the bone. The conformation of the caudal aspect of the physis is similar to that in mammals.

tibiotarsal bones of ostrich chicks originates in the proximal metaphyseal region. The cranial direction of the distal portion of the foramen suggests that a mild, compensatory internal rotation of the bone develops in the midshaft (Fig. 5). This study also identified a longitudinal component to the distal tibiotarsal epiphysis. Disruption in endochondral bone formation along one side of this vertical aspect could lead to a rotational deformity, because growth would proceed asymmetrically without a concurrent angular component to the deformity.

The cause of tibiotarsal rotation in birds is unknown. The disease is likely multifactorial. Eight chick-related and four farm-related factors influencing the incidence of tibiotarsal rotation in several Australian ostrich farms were recently identified. These factors include placement and padding of posts, width of night pen exits, water availability, calcium and phosphorus supplementation during the first 5 weeks of age, pen surface and length of night pen after 7 weeks of age, veterinary medication during the first 10 weeks after hatch, number of veterinary visits in the last 6 months, latitude of the farm, number of days with rain, and chick ownership. Additionally, vitamin D deficiency, biotin (vitamin H) deficiency, vitamin B-6 deficiency, food deprivation, a high amino acid to protein feed ratio, a low dietary calcium level, a high energy feed, high peak growth hormone concentration, and the mycotoxin fusarochromone have been linked to tibiotarsal rotation in chickens.
The pathogenesis of tibiotarsal rotation in ostriches remains unknown. The initiating factor in the rotational deformity of the tibiotarsal bone does not seem to be abnormal muscle or ligaments because no differences were present between these structures in rotated and control limbs. Rotation may have developed because of abnormal bone plasticity or because of physeal dysfunction. In the bones of large birds, extremely rapid longitudinal bone growth takes place early in life. A decrease in elastic modulus, resilience, and strength of the proximal tibiotarsal subchondral cancellous bone was found at 9 weeks of age in broilers. This rapidly forming bone may be mechanically weak and predisposed to vascular injuries. A soft subchondral bone is also present in rapidly growing long bones of large-breed dogs and is considered to be a significant factor in the pathogenesis of osteochondrosis. In birds, osteochondrosis (dyschondroplasia) also has been shown to cause abnormal bone development. In the ostrich chicks we examined, radiographic evidence of dyschondroplasia was not present in the rotated tibiotarsal bones, and changes in cortical morphology between clinically normal and rotated tibiotarsi were not observed. However, in ostrich chicks, abnormal plasticity of the rapidly forming tibiotarsus or the presence of mild lesions of dyschondroplasia may be responsible for tibiotarsal rotation.

The methods used in this study to evaluate the tibiotarsal physes had significant limitations. The morphologic evaluation was based on radiographs and included only one time period for each bird. The bone preparation methods precluded the use of histologic examination to evaluate the cellular morphology of the physes. Physeal structure and potential presence of dyschondroplasia would be better assessed by histologic methods rather than by radiographic evaluation. Growth patterns of normal and abnormal distal tibiotarsal physes also could be better assessed by using fluorescein bone markers to evaluate the involvement of the proximal and distal tibiotarsal physes in the development of tibiotarsal rotation. Biomechanical tests such as nondestructive static compression or vibrational testing could further evaluate bone strength and stiffness. These tests would significantly enhance our understanding of the pathogenesis of tibiotarsal rotation in ostriches.

Acknowledgments: This study was sponsored in part by a grant from the Burroughs Wellcome Fund and by the North Carolina Ostrich Breeders Association. We thank Marlina Dumasari Nasution for statistical assistance.

References