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Bone Development and Leg Problem Incidence in Four Strains of Turkeys

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Abstract: Leg problems have become an increasingly prevalent issue in the turkey industry. The objective of this experiment was to evaluate leg bone development and growth and the incidence of leg problems in different strains of turkeys. Males from 4 Aviagen genetic lines, (A, B, C and D) were obtained and raised in 48 floor pens. Leg health issues were classified at 16 and 33 d and 15 and 18 wk of age. Weights and morphological measurements of the femur, tibia and tarsus-metatarsus were recorded at hatch and every two wk from two birds per strain and in poults with twisted legs at 16 d. At 20 wk bone mineral density (BMD) and content (BMC) of leg bones were obtained using DEXA. Weekly data were fitted to Gompertz equations and allometric ratios were calculated to assess bone development. Strain A turkeys had higher BW and femur weight at hatch than strain D toms. Strain A toms also had higher allometric growth ratios for all leg bones between 1 to 8 wk of age and lower tibia and femur BMD at 20 wk than strain D toms. At 16 d strain A turkeys had the highest incidence of twisted legs and strain A and C toms had higher incidences of crooked toes than strain D turkeys at 15 and 18 wk. Higher growth rates early in life may result in weaker bones that result in turkeys being more susceptible to developing leg problems. In summary, bone development patterns, BMD and incidence of leg problems vary in genetic lines of turkeys.

Key words: Turkeys, bone development, allometric growth

INTRODUCTION

In the past few decades, consumption of turkey meat has increased. Between 1980 and 1998 in the European Union alone, demand for turkey products increased by 300% (Brenoe and Kolstad, 2000). This dramatic boost in consumption has caused companies to develop breeding and management programs that select for poultry with greater BW gain and breast size (Lilburn and Nestor, 1991). These programs have resulted in fast growing poultry that have radically different body conformations and a greater incidence of leg problems. The effects of a faster growth rate and changed body conformation on different aspects of turkey development have been studied (Abourachid, 1991, 1993; Lilburn and Nestor, 1991; Corr *et al*., 2003; Mench, 2004). Abourachid (1991, 1993) found that birds with morphological modifications induced by selection have different mechanics of standing. Specifically, turkeys with pectoral hypertrophy have increased stresses on the pelvic muscles and a change in the position of the center of gravity. Corr *et al*. (2003) also found that rapid BW gain increases demands on the immature skeleton, potentially effecting walking ability while Lilburn and Nestor (1991) reported a negative correlation between breast yield and relative weight of the total femur and total tibia. All of these findings indicate that rapid BW and breast muscle gain impact turkey leg bones and walking ability. However, a connection between rapid growth rate, leg bone development and the incidence of leg disorders has not been clearly established.

Turkey long bone development, including that of the tibia, femur and tarsus-metatarsus, begins during embryonic growth as primary ossification centers develop in cartilaginous skeletal forms (Simsa and Ornan, 2007). By 3 d of age, growth plates have developed between the metaphysis and epiphyses of long bones and they reach their final form by 7 d of age (Simsa and Ornan, 2007). Bone growth has been shown to reach its maximum rate at a relatively early age, while maximum muscle deposition occurs at a later time (Hurwitz *et al*., 1991). Therefore, early in life more bone development is taking place than muscle development. Rapid growth in the earlier stages of life, as is common in commercial turkeys, is more likely to affect bone than muscle growth. In general, it is thought that high BW and rapid growth place abnormal loads on developing bone that induce abnormal bone growth as well as cause the production of bone and supporting tissue that are of poor structural quality (Mench, 2004). Since growth rates differ among genetic lines of turkeys, it is probable that the growth rates will also have different impacts on leg bone growth. Therefore, the objective of this study was to evaluate leg bone development and growth and the incidence of leg problems in 4 genetic lines of turkeys.

MATERIALS AND METHODS

This study utilized 4 different genetic lines of turkeys, identified as A, B, C and D (Aviagen Turkeys, Lewisburg, WV). Strains A and B were two proprietary strains of Aviagen turkeys while strains C and D were 2

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commercial strains Nicholas 85 and Nicholas 88, respectively. Eggs were obtained from breeders that ranged from 32 to 59 wk of age depending on the strain. Eggs from strain A were stored for 9.5 to 14 d while strain B eggs were stored for an average of 8 or 21.5 d. Eggs from stains C and D were stored for an average of 10.5 and 11 d, respectively. These eggs were all incubated under standard conditions. To simulate industry conditions, poults were placed 24 h after hatch. Male poults (960 total, 240 per strain) were randomly placed in 48 floor pens (12 pens per strain) with 20 birds per pen.

Turkey husbandry: All bird handling procedures used were approved by the North Carolina State University Institutional Animal Care and Use Committee. All birds were raised according to typical management practices and all birds were fed the same high-fat nutrient-dense diets following nutritional recommendations from the primary breeder. All experimental diets were pelleted (80°C for 20 s conditioning). Feed was consumed *ad libitum* in crumble form from hatch to 6 wk of age and in whole 4 mm pellets thereafter until market age at 20 wk.

Data collection: At hatch, 28 poults (7 per strain) were euthanized via cervical dislocation and BW and residual yolk weights were obtained. Both legs were removed and the leg, thigh and drumstick were weighed. Legs bones were then removed and femur, tibia and tarsus-metatarsus weights and lengths were recorded. Tarsus-metatarsus thickness was also obtained. Relative asymmetry (RA) of each leg section and the weight of each leg section relative to BW without yolk were calculated. After hatch, 2 turkeys per strain were sampled on a biweekly basis until 20 wk of age. Legs were removed and measurements were taken as was done at hatch. Twisted legs were observed in toms at 11 d of age. Therefore, 27 toms with twisted legs were taken at 16 d and their leg bone characteristics were measured. The incidence of leg abnormalities was also recorded at 33 d and 15 and 18 wk while gaits were scored at 15 and 18 wk. At 20 wk, bone mineral content (BMC) and bone mineral density (BMD) were evaluated with dual-energy x-ray absorptiometry (DEXA).

Statistical analysis: Data were analyzed in a completely randomized design with 4 treatments and 12 replicates per treatment. All percentage data were transformed to arc-sin prior to analysis. BW and bone weights were transformed to natural logarithm. The ANOVA function of SAS (Mixed Models Proc, 2004) was used to analyze the data and mean separation was done via Tukey's test. Gompertz growth curves were fitted by non-linear regression analysis in JMP 9.0 (SAS Institute, Cary, NC) to describe the growth of each bone and the entire turkey. The Gompertz function was best described by the following formula:

$$Wt = Wo * e^{(\frac{L}{K})*(1-e^{-Kt})}$$

where Wo is initial weight/length; L is the constant of acceleration; K is the constant of deceleration; t is age in d; Wt is weight/length at age t and t* is the age at maximum growth. The W_m or weight at maturity was estimated by the first derivative of the equation previously described. Allometric growth ratios (k) were calculated by linear regression analysis.

RESULTS

Bone development at hatch: At hatch strain A had a higher BW with and without yolk and a higher yolk % ($p<0.01$) than strains C and D with strain B being intermediate (Table 1). Strain C also had a lower BW with yolk ($p<0.01$) than strain B. At hatch strains A and B had heavier right and left legs ($p<0.05$) than strain C (Table 2). Turkeys from strain A also had heavier right and left thighs ($p\leq0.001$) than strains C and D as well as heavier drumsticks ($p<0.05$) than strain C. However, no differences ($p>0.05$) were found among strains in relative weight or RA of legs, thighs and drumsticks (Table 2). Similar to leg portion weights, strain A also had leg bone weights that were heavier than those of strains C and D (Table 3). Specifically, strain A had heavier tibias and tarsus-metatarsi ($p<0.05$) than strain C and heavier femurs than both strains C and D. Strain B tarsus-metatarsi were also heavier than those of strain C. However, relative weight and RA of leg bones did not differ ($p>0.05$) between the 4 strains (Table 3).
At hatch femurs of strain B turkeys were longer ($p\leq0.05$) than those of strain C toms with strains A and D being intermediate (Table 4). Tarsus-metatarsus length was greater ($p<0.01$) in strains A and B than in strain C. No differences in tibia length and tarsus-metatarsus width ($p>0.05$) were detected among strains. The RA of tarsus-metatarsus length was greater ($p<0.05$) in strain B than in strains C and D with strain A being intermediate. No other differences in RA of leg bone length or tarsus-metatarsus width were observed.

Leg and leg bone characteristics of poults with twisted legs: At 16 d the incidence of twisted legs in strains A, B, C and D was 5.12, 2.67, 5 and 0%, respectively (Table 5). Since no turkeys from strain D had twisted legs, only poults from strains A, B and C were sampled. Among the poults with twisted legs, several differences were found in body and leg characteristics (Table 6 to 8). Toms from stain A were heavier ($p<0.05$) than those from strain C with strain B turkeys being intermediate (Table 6). Relative weights of the right leg, thigh and drumstick were greater ($p<0.05$)

Table 1: BW, BW without yolk and residual yolk (%) at hatch

	Turkey strains					
Parameter	A	B	C	D	CV%	p-value
BW with yolk, g	61.69±2.1[a]	59.24±2.8[ab]	49.02±2.2[c]	50.50±2.1[bc]	11.3	0.000
BW without yolk, g	55.78±1.7[a]	53.97±2.4[ab]	46.30±1.9[b]	47.68±1.8[b]	10.4	0.002
Yolk, %	9.65±0.9[a]	8.61±1.2[ab]	5.25±1.0[b]	5.41±0.9[b]	20.1	0.004

[a-b]Means with different lowercase letter superscripts within a row differ significantly ($p \leq 0.05$)

Table 2: Weight, relative weight (g/100 g) and relative asymmetry (RA) of legs and leg portions in 4 strains of large white turkeys at hatch

		Turkey strains					
Weight		A	B	C	D	CV%	p-value
Absolute (g)							
Leg	Right	5.77±0.2[a]	5.69±0.3[a]	4.55±0.2[b]	4.94±0.2[ab]	13.2	0.004
	Left	5.77±0.2[a]	5.62±0.3[a]	4.59±0.2[b]	4.93±0.2[ab]	12.7	0.004
Thigh	Right	1.97±0.1[a]	1.83±0.1[ab]	1.49±0.1[b]	1.50±0.1[b]	14.6	0.001
	Left	1.94±0.1[a]	1.81±0.1[ab]	1.46±0.1[b]	1.50±0.1[b]	15.4	0.001
Drumstick	Right	1.99±0.1[a]	2.02±0.1[ab]	1.61±0.1[b]	1.73±0.1[ab]	14.9	0.018
	Left	2.00±0.1[a]	1.95±0.1[ab]	1.66±0.1[b]	1.76±0.1[ab]	12.6	0.020
Relative (%)							
Leg	Right	10.34±0.2	10.43±0.3	9.87±0.2	10.35±0.2	3.0	0.086
	Left	10.34±0.1	10.43±1.3	9.87±1.1	10.35±0.1	2.6	0.144
Thigh	Right	3.53±0.1	3.40±0.1	3.22±0.1	3.22±0.1	18.9	0.318
	Left	3.47±0.1	3.35±0.1	3.14±0.1	3.23±0.1	19.0	0.382
Drumstick	Right	3.47±0.8	3.35±0.8	3.14±0.8	3.23±0.8	19.6	0.636
	Left	3.60±0.1	3.63±0.1	3.57±0.1	3.77±0.1	19.3	0.699
RA[1]							
Leg		1.86±0.5	2.04±0.7	1.63±0.5	3.35±0.5	71.9	0.145
Thigh		5.93±1.1	3.92±1.6	3.57±1.3	5.90±1.2	72.2	0.433
Drumstick		4.56±1.5	3.60±2.0	6.65±1.6	4.91±1.6	91.0	0.670

[a-b]Means with different lowercase letter superscripts within a row differ significantly ($p \leq 0.05$)

[1]Relative asymmetry between right and left traits, RA = (|R-L|/[(R+L)]/2)×100

Table 3: Weight, relative weight (g/100 g) and relative asymmetry (RA)[1] of leg bones in 4 strains of large white turkeys at hatch

		Turkey strains					
Weight		A	B	C	D	CV%	p-value
Absolute (g)							
Tibia	Right	0.59±0.0[a]	0.54±0.0[ab]	0.47±0.0[b]	0.54±0.0[ab]	14.7	0.013
	Left	0.57±0.0[a]	0.56±0.0[a]	0.45±0.0[b]	0.49±0.0[ab]	13.0	0.006
Femur	Right	0.34±0.0[a]	0.32±0.0[ab]	0.28±0.0[b]	0.28±0.0[b]	14.2	0.019
	Left	0.33±0.0[a]	0.33±0.0[ab]	0.28±0.0[b]	0.27±0.0[b]	13.2	0.008
Tarsus-metatarsus	Right	1.67±0.1[a]	1.66±0.1[a]	1.36±0.1[b]	1.50±0.1[ab]	11.0	0.003
	Left	1.66±0.0[a]	1.66±0.1[a]	1.37±0.1[c]	1.50±0.0[b]	11.4	0.010
Relative bone (%)							
Tibia	Right	1.07±0.0	1.02±0.1	1.01±0.0	1.07±0.0	20.0	0.641
	Left	1.03±0.0	1.05±0.0	0.98±0.0	1.07±0.0	19.8	0.708
Femur	Right	0.62±0.0	0.60±0.0	0.61±0.0	0.61±0.0	19.7	0.508
	Left	0.61±0.0	0.62±0.0	0.61±0.0	0.60±0.0	19.4	0.445
Tarsus-metatarsus	Right	3.01±0.1	3.10±0.1	2.93±0.1	3.16±0.1	2.8	0.059
	Left	2.98±0.1	3.09±0.1	2.97±0.1	3.16±0.1	3.0	0.106
RA[1]							
Tibia		7.99±1.9	4.98±2.5	6.67±2.0	6.07±2.0	89.9	0.925
Femur		4.21±1.4	7.12±1.9	5.82±1.4	5.12±1.4	78.3	0.649
Tarsus-metatarsus		2.20±0.5	1.74±0.7	2.06±0.6	1.38±0.5	86.6	0.723

[a-b]Means with different lowercase letter superscripts within a row differ significantly ($p \leq 0.05$)

[1]Relative asymmetry between right and left traits, RA = (|R-L|/[(R+L)]/2)×100

in strain B than in strain A; however, no differences ($p>0.05$) were detected in relative weights of the left leg, thigh and drumstick. Furthermore, weight and RA of weight of leg sections were not different ($p>0.05$) between strains.

No differences ($p>0.05$) were observed in leg bone weights of poults with twisted legs at 16 d (Table 7). Contrarily, both tibias, right femur and right tarsus-metatarsus relative weight were greater ($p<0.05$) in strain B than in strain A. Strain B turkeys also had greater tibia weight RA ($p<0.05$) than strain C toms. No other differences were detected between strains in RA of leg bone weights. Furthermore, there were no differences ($p>0.05$) in leg bone length or RA of leg bone length and width among the genetic lines studied (Table 8). However, the width of the left tarsus-metatarsus was smaller ($p<0.05$) in strain C toms than in strain B toms with strain A turkeys being intermediate.

Table 4: Length (mm) and relative asymmetry (RA) of leg bones and width of shanks (mm) in 4 strains of large white turkeys at hatch

		Turkey strains					
Parameter		A	B	C	D	CV%	p-value
Bone length (mm)							
Tibia	Right	37.91±0.8	37.18±0.8	35.97±0.8	36.97±0.8	6.3	0.326
	Left	38.10±0.8	36.37±1.1	35.77±0.8	37.44±0.9	6.6	0.243
Femur	Right	25.54±0.9^{ab}	28.38±1.2^{a}	24.06±0.9^{b}	24.72±0.9^{ab}	10.3	0.047
	Left	25.42±0.8^{ab}	28.15±1.1^{a}	24.06±0.9^{b}	24.80±0.8^{ab}	9.8	0.051
Shank[1]	Right	32.18±0.4^{a}	32.51±0.6^{a}	29.91±0.5^{b}	31.04±0.4^{ab}	4.2	0.003
	Left	31.43±0.4^{a}	32.56±0.5^{a}	29.72±0.4^{b}	31.21±0.4^{ab}	3.8	0.002
Shank[1] width (mm)	Right	2.99±0.1	2.82±0.2	2.96±0.1	3.13±0.1	11.6	0.432
	Left	2.97±0.1	2.89±0.2	2.84±0.1	3.11±0.1	0.1	0.459
RA[2]							
Tibia		1.13±0.3	0.80±0.4	0.72±0.3	0.93±0.3	87.3	0.747
Femur		0.90±0.3	1.34±0.3	1.03±0.3	1.05±0.3	97.1	0.895
Shank[1]	Length	2.80±0.9^{ab}	5.48±1.2^{a}	1.23±0.9^{b}	1.32±0.9^{b}	112.2	0.038
	Width	2.85±1.1	3.62±1.5	4.35±1.1	4.84±1.1	83.1	0.611

$^{a-b}$Means with different lowercase letter superscripts within a row differ significantly ($p \leq 0.05$)
[1]Tarsus-metatarsus with tendons and skin. [2]Relative asymmetry between right and left traits, RA = (|R-L|/[(R+L)]/2)×100

Table 5: Incidence of leg problems at 16 and 33 d in 4 strains of large white turkeys

		Turkey strains			
Incidence (%)	Age (d)	A	B	C	D
Incidence of twisted legs	16	5.12	2.67	5.00	0.00
Accumulative incidence of leg problems	33	10.82	14.35	14.59	5.70
Description of leg problems	33				
	Varus	0.00	0.48	0.54	1.04
	Valgus	2.06	3.35	3.78	2.59
	Twisted leg	6.19	3.83	5.95	0.52
	Crooked toes	2.58	6.22	4.32	1.04
	Slipped tendon	0.00	0.48	0.00	0.52

Table 6: BW and weight, relative weight and relative asymmetry (RA) of leg portions in 16-d-old poults with twisted legs

		Turkey strains					
Weight (g)		A	B	C	D[2]	CV%	p-value
BW (g)		565.00±20.0^{a}	487.50±31.9^{ab}	471.43±23.8^{b}	-	12.1	0.017
Leg	Right	56.00±2.5	56.46±4.0	51.66±3.0	-	14.6	0.493
	Left	59.18±2.4	52.67±3.7	52.37±2.8	-	13.5	0.152
Thigh	Right	20.30±0.9	20.06±1.5	18.34±1.1	-	15.2	0.409
	Left	21.91±0.9	18.56±1.5	19.74±1.1	-	14.2	0.128
Drumstick	Right	22.40±1.2	22.72±2.0	21.23±1.5	-	17.8	0.783
	Left	23.40±1.2	21.28±1.8	20.54±1.4	-	16.5	0.282
Relative (%)							
Leg	Right	9.91±0.27^{b}	11.68±0.43^{a}	10.96±0.32^{ab}	-	4.4	0.006
	Left	10.46±0.21	10.83±0.33	11.11±0.25	-	3.2	0.132
Thigh	Right	3.59±0.10^{b}	4.15±0.16^{a}	3.87±0.12^{ab}	-	4.3	0.028
	Left	3.88±0.10	3.78±0.16	4.19±0.12	-	4.0	0.112
Drumstick	Right	3.94±0.15^{b}	4.68±0.23^{a}	4.53±0.18^{ab}	-	5.7	0.019
	Left	4.12±0.12	4.38±0.19	4.36±0.14	-	4.5	0.325
RA[1]							
Leg		9.15±2.02	7.23±3.19	5.53±2.41	-	84.3	0.524
Thigh		12.6±2.35	7.88±3.72	8.67±2.81	-	71.7	0.442
Drumstick		11.76±2.57	6.78±4.06	7.36±3.07	-	86.9	0.443

$^{a-b}$Means with different lowercase letter superscripts within a row differ significantly ($p \leq 0.05$)
[1]Relative asymmetry between right and left traits, RA = (|R-L|/[(R+L)]/2)×100. [2]Samples were not collected for turkeys of this strain at this age

Incidence of leg abnormalities and gait scores: At 33 d the total incidence of all leg problems in strains A, B, C and D was 10.82, 14.35, 14.59 and 5.70%, respectively (Table 5). Of the 5 leg problems observed, no single abnormality was the most prevalent in all strains. For instance, the most common leg problem in strain D was valgus while the most common abnormality in strain B was crooked toes. Twisted legs was the most prevalent in strains A and C. In contrast, valgus was the most prevalent leg problem in all strains at both 15 and 18 wk of age (Table 9). At this time, strains A and C had a higher incidence of crooked toes ($p<0.05$) than strain D with strain B being intermediate. There was no difference ($p>0.05$) in gait scores among the genetic lines at 15 or 18 wk of age.

Gompertz equations and allometric growth ratios: Gompertz growth equations were used to describe changes in leg bone weight and length and turkey BW (Table 10 to 12). Strain A had the lowest Wo, W_m and t

Table 7: Weight, relative weight (g/100 g) and relative asymmetry (RA) [1] of leg bones in 16-d-old poults with twisted legs

		Turkey strains					
Weight		A	B	C	D[2]	CV%	p-value
Absolute (g)							
Tibia	Right	6.27±0.27	6.42±0.43	5.68±0.33	-	14.2	0.302
	Left	6.13±0.33	6.22±0.52	5.79±0.40	-	17.3	0.754
Femur	Right	3.49±0.14	3.51±0.22	3.17±0.17	-	12.9	0.311
	Left	3.68±0.15	3.26±0.24	3.32±0.18	-	13.9	0.225
Tarsus-metatarsus	Right	12.80±0.49	13.24±0.0.77	11.70±0.59	-	12.4	0.236
	Left	13.22±0.46	12.42±0.73	11.73±0.55	-	11.6	0.140
Relative (%)							
Tibia	Right	1.11±0.04^{b}	1.35±0.06^{a}	1.20±0.05^{ab}	-	5.7	0.028
	Left	1.07±0.04^{b}	1.25±0.07^{a}	1.24±0.05^{ab}	-	5.7	0.021
Femur	Right	0.62±0.02^{b}	0.73±0.04^{a}	0.67±0.03^{ab}	-	5.4	0.041
	Left	0.66±0.02	0.68±0.04	0.70±0.03	-	5.1	0.212
Tarsus-metatarsus	Right	2.27±0.88^{b}	2.78±0.14^{a}	2.47±0.10^{ab}	-	5.6	0.019
	Left	2.35±0.07	2.58±0.10	2.47±0.08	-	4.0	0.097
RA[1]							
Tibia		7.32±1.34^{ab}	10.60±2.12^{a}	3.40±1.60^{b}	-	63.8	0.038
Femur		8.35±1.97	7.30±3.12	5.50±2.36	-	86.7	0.657
Tarsus-metatarsus		7.83±1.71	6.45±2.70	3.40±2.04	-	88.7	0.273

$^{a-b}$Means with different lowercase letter superscripts within a row differ significantly ($p \leq 0.05$)
[1]Relative asymmetry between right and left traits, RA = (|R-L|/[(R+L)]/2)×100. [2]Samples were not collected for turkeys of this strain at this age

Table 8: Length (mm) and relative asymmetry (RA)[2] of leg bones and width of shanks (mm) in 16-d-old poults with twisted legs

		Turkey strains					
Parameter		A	B	C	D[3]	CV%	p-value
Length (mm)							
Tibia	Right	76.18±0.90	76.60±1.42	75.24±1.07	-	3.7	0.707
	Left	76.27±1.06	76.50±1.68	75.26±1.27	-	4.4	0.784
Femur	Right	50.84±0.59	50.24±0.94	49.28±0.71	-	3.7	0.266
	Left	50.47±0.60	50.95±0.95	49.24±0.72	-	3.8	0.300
Shank[1]	Right	62.68±0.73	61.98±1.16	62.19±0.87	-	3.7	0.848
	Left	63.51±0.77	61.07±1.21	62.16±0.92	-	3.9	0.226
Shank[1] width	Right	6.28±0.12	6.68±0.18	6.15±0.14	-	5.8	0.097
	Left	6.35±0.13^{ab}	6.86±0.21^{a}	6.10±0.16^{b}	-	6.6	0.033
RA[2]							
Tibia		0.92±0.23	0.33±0.37	0.97±0.28	-	89.2	0.339
Femur		1.15±0.18	1.43±0.28	1.24±0.21	-	45.6	0.714
Shank[1]	Length	1.84±0.29	1.48±0.46	1.03±0.35	-	61.4	0.229
	Width	2.99±0.71	3.43±1.12	2.19±0.85	-	80.1	0.643

$^{a-b}$Means with different lowercase letter superscripts within a row differ significantly ($p \leq 0.05$). [1]Tarsus-metatarsus with tendons and skin.
[2]Relative asymmetry between right and left traits, RA = (|R-L|/[(R+L)]/2)×100. [3]Samples were not collected for turkeys of this strain at this age

Table 9: Gait scores and leg abnormalities (%) at 15 and 18 wk in 4 strains of large white turkeys

Turkey strains	A	B	C	D	A	B	C	D
Age	15 wk				18 wk			
Crooked toes	9.96^{a}	6.24^{ab}	8.45^{a}	1.68^{b}	12.18^{a}	5.26^{ab}	9.58^{a}	1.53^{b}
Shaky leg	0.00	0.00	0.64	0.00	14.63	17.78	19.51	14.55
Varus	0.76	4.84	1.28	2.10	0.00	1.40	1.45	0.75
Valgus	49.32	43.29	42.73	46.48	75.93	61.36	75.13	77.68
Twisted legs	2.92	2.10	3.21	2.98	0.00	0.70	1.40	1.45
Gait scores (%)								
G0[1]	26.07	28.79	33.83	40.75	9.41	14.07	6.96	13.56
G1[1]	36.84	34.08	39.39	41.26	29.41	37.55	40.47	37.17
G2[1]	27.73	27.42	18.93	14.19	44.27	31.02	39.07	34.95
G3[1]	8.58	7.03	6.58	3.10	13.67	14.80	8.67	12.78
G4[1]	0.00	0.59	1.28	0.70	3.26	2.56	4.86	1.53
G5[1]	0.76	2.08	0.00	0.00	0.00	0.00	0.00	0.00

$^{a-b}$Means with different lowercase letter superscripts within a row differ significantly ($p \leq 0.05$). [1]PG0-5 = percentage of toms with gait scores 0 to 5

while strain D had the highest W_0, W_m and t for BW (Table 10). Strain A also had the highest L and K while strain D had the lowest L and K. Estimates for leg bone weight varied ($p>0.05$) among strains (Table 11). Strains B and C had the greatest and lowest initial weight for all leg bones, respectively. Turkeys from strain B also had the greatest mature weight for all leg bones. Strain A toms had the lowest tibia and femur mature weight while strain C toms had the lowest Wm for tarsus-metatarsus weight. In the tibia, strain A had the highest L and K values for weight while strain B had the lowest. For femur weight, strain D had the greatest acceleration

Table 10: Estimates of Gompetz equation parameters for BW of 4 strains of large white turkeys

	Turkey strains				
Parameters	A	B	C	D	Average
W_o[1]	72.8940	228.8002	254.8527	336.9313	223.3696
ApproxSE[2] W	92.2227	99.4839	104.0090	190.5116	121.5568
L[3]	0.1342	0.0873	0.0777	0.0681	0.0918
ApproxSE[2] L	0.0484	0.0145	0.0129	0.1723	0.0620
K[4]	0.0225	0.0171	0.0152	0.0138	0.0171
ApproxSE[2] K	0.0038	0.0017	0.0017	0.0025	0.0024
W_m[5]	28641	37769	42821	47152	39096
t[6]	79.5	95.4	107.7	115.9	99.7

[1]W_o: Initial weight. [2]ApproxSE: Approximate standard error for each parameter. [3]L: Constant of acceleration.
[4]K: Constant of deceleration, [5]W_m: BW at the age of sexual maturity. [6]t: Age (d) at sexual maturity

Table 11: Estimates of Gompertz equation parameters for tibia, femur and tarsus-metatarsus weight in 4 strains of large white turkeys

	Turkey strains				
Parameters	A	B	C	D	Average
Tibia					
W_o[1]	0.2329	0.5802	0.1608	0.3739	0.3369
ApproxSE[2]	0.3633	0.6883	0.3142	0.4452	0.4528
L[3]	0.2632	0.1995	0.2604	0.2197	0.2357
ApproxSE[2]	0.0939	0.0672	0.1097	0.0647	0.0839
K[4]	0.0404	0.0347	0.0378	0.0364	0.0373
ApproxSE[2]	0.0049	0.0043	0.0055	0.0039	0.0047
W_m[5]	151.44	164.44	158.20	156.79	158
t[6]	46.3	50.3	51.1	49.5	49.3
Femur					
W_o[1]	0.3894	0.5515	0.2258	0.2388	0.3514
ApproxSE[2]	0.4279	0.5620	0.3877	0.2523	0.4075
L[3]	0.2063	0.1741	0.2119	0.2151	0.2019
ApproxSE[2]	0.0605	0.0513	0.0897	0.0555	0.0642
K[4]	0.0359	0.0322	0.0341	0.0350	0.0343
ApproxSE[2]	0.0039	0.0037	0.0054	0.0033	0.0041
W_m[5]	108.21	117.88	113.25	111.05	113
t[6]	48.5	52.3	53.6	51.9	51.6
Tarsus-metatarsus					
Wo[1]	7.7165	10.1340	5.0180	7.3531	7.5554
ApproxSE[2]	4.4941	5.4140	2.8520	3.7008	4.1152
L[3]	0.0745	0.0618	0.0882	0.0725	0.0742
ApproxSE[2]	0.0221	0.0188	0.0221	0.0188	0.0204
K[4]	0.0195	0.0168	0.0210	0.0187	0.0190
ApproxSE[2]	0.0034	0.0034	0.0029	0.0029	0.0032
W_m[5]	348.72	403.55	336.56	352.25	360.27
t[6]	68.5	78.0	68.5	72.3	71.8

[1]W_o: Initial weight.
[2]ApproxSE: Approximate standard error for each parameter.
[3]L: Constant of acceleration.
[4]K: constant of deceleration.
[5]W_m: Bone weight at the age of sexual maturity.
[6]t: Age (d) at sexual maturity

Table 12: Estimates of Gompertz equation parameters for tibia, femur and tarsus-metatarsus length in 4 strains of large white turkeys

	Turkey strains				
Parameters	A	B	C	D	Average
Tibia					
W_o[1]	33.2280	32.9244	33.5183	33.8887	33.3898
ApproxSE[2]	1.8120	2.3201	1.7810	1.6863	1.8998
L[3]	0.0688	0.0661	0.0640	0.0650	0.0660
ApproxSE[2]	0.0039	0.0045	0.0035	0.0033	0.0038
K[4]	0.0353	0.0331	0.0324	0.0332	0.0335
ApproxSE[2]	0.0013	0.0014	0.0012	0.0011	0.0012
W_m[5]	233.98	242.20	242.01	240.05	239.56
t[6]	19.0	20.8	21.1	20.2	20.3
Femur					
W_o[1]	24.5155	25.1105	22.8150	23.0005	23.8604
ApproxSE[2]	1.2016	1.4378	1.2762	1.0636	1.2448
L[3]	0.0616	0.0578	0.0627	0.0617	0.0609
ApproxSE[2]	0.0035	0.0037	0.0039	0.0031	0.0035
K[4]	0.0342	0.0319	0.0334	0.0331	0.0331
ApproxSE[2]	0.0013	0.0013	0.0014	0.0011	0.0013
W_m[5]	148.46	153.30	148.94	148.60	149.82
t[6]	17.2	18.6	18.8	18.9	18.4
Tarsus-metatarsus					
W_o[1]	28.6393	29.6346	28.0706	28.5598	28.7261
ApproxSE[2]	1.6976	1.7084	1.4809	1.3395	1.5566
L[3]	0.0683	0.0623	0.0649	0.0661	0.0654
ApproxSE[2]	0.0043	0.0037	0.0036	0.0033	0.0037
K[4]	0.0358	0.0327	0.0331	0.0345	0.0340
ApproxSE[2]	0.0015	0.0012	0.0012	0.0011	0.0013
W_m[5]	193.00	199.66	198.63	194.22	196.38
t[6]	18.1	19.8	20.3	18.9	19.2

[1]W_o: Initial length.
[2]ApproxSE: Approximate standard error.
[3]L: Constant of acceleration.
[4]K: Constant of deceleration.
[5]W_m: Length at the age of sexual maturity.
[6]t: Age (d) at sexual maturity

while strain A had the greatest deceleration and strain B had the lowest acceleration and deceleration. Strain B also had the lowest acceleration and deceleration in tarsus-metatarsus weight while strain C had the highest. All strains had peak weight gain in the tibia and femur between 46 and 54 d of age. Peak weight gain in the tarsus-metatarsus occurred between 69 and 78 d.

Peak growth in leg bone length occurred at a much earlier age than peak growth for leg bone weight (Table 12). For all leg bones and genetic lines, peak growth in length took place between 17 and 21 d of age. Stain A turkeys had the smallest length at maturity and the greatest deceleration for all leg bones. Strain B turkeys generally had the longest length at maturity and the lowest deceleration. Strain A had the greatest L for tibia and tarsus-metatarsus length while strain C had the greatest L in the femur. The lowest acceleration in the femur and tarsus-metatarsus was found in strain B toms while strain C toms had the lowest L in tibia length. Turkeys from strain B had the greatest initial length of the femur and tarsus-metatarsus but the lowest initial length of the tibia. Conversely, strain C had the lowest Wo in the femur and tarsus-metatarsus. The greatest Wo in the tibia was found in strain D toms.

Allometric growth ratios illustrated that leg bones grow at different rates in relation to whole body growth at 1 to 8 and 10 to 20 wk of age (Table 13). From 1 to 8 wk, both femurs and tibias were growing faster than the rest of

Table 13: Allometric growth ratios and intercepts[1] of 4 strains of large white turkeys from 1 to 8 and 10 to 20 wk of age

			Tibia		Femur		Tarsus-metatarsus	
Age (wk)	Turkey strains		Right	Left	Right	Left	Right	Left
1 to 8	A	a[2]	-5.045±0.085	-5.117±0.055	-5.706±0.066	-5.740±0.076	-3.398±0.052	-3.429±0.059
		ln b[3]	1.092±0.014	1.104±0.009	1.122±0.011	1.124±0.013	0.949±0.009	0.954±0.010
		R^2	0.997	0.999	0.998	0.998	0.999	0.998
		a	-5.093±0.135	-4.988±0.104	-5.710±0.133	-5.661±0.110	-3.297±0.091	-3.317±0.107
	B	ln b	1.089±0.021	1.077±0.016	1.119±0.021	1.113±0.017	0.933±0.014	0.938±0.017
		R^2	0.995	0.997	0.996	0.997	0.997	0.996
		a	-4.977±0.079	-5.502±0.102	-5.585±0.107	-5.562±0.097	-3.339±0.038	-3.321±0.045
	C	ln b	1.083±0.014	1.083±0.017	1.102±0.018	1.099±0.017	0.938±0.006	0.937±0.008
		R^2	0.998	0.996	0.996	0.997	0.999	0.999
		a	-4.880±0.091	-4.862±0.063	-5.550±0.080	-5.577±0.072	-3.209±0.034	-3.210±0.039
	D	ln b	1.066±0.015	1.068±0.011	1.095±0.014	1.102±0.012	0.921±0.006	0.923±0.007
		R^2	0.997	0.999	0.998	0.998	0.999	0.999
9 to 20	A	a[2]	1.342±0.455	1.448±0.476	1.039±0.482	0.944±0.326	-0.588±0.634	-0.798±0.662
		ln b[3]	0.367±0.046	0.355±0.049	0.360±0.049	0.370±0.033	0.616±0.065	0.638±0.068
		R^2	0.756	0.728	0.729	0.861	0.820	0.817
	B	a	1.876±0.503	1.257±0.478	0.677±0.428	0.640±0.478	-0.851±0.635	-1.060±0.704
		ln b	0.316±0.051	0.377±0.049	0.400±0.043	0.404±0.049	0.642±0.065	0.665±0.072
		R^2	0.667	0.760	0.817	0.785	0.839	0.820
	C	a	1.014±0.854	0.916±0.814	0.028±-0.899	0.078±0.779	-1.025±0.530	-1.117±0.572
		ln b	0.401±0.088	0.411±0.084	0.463±0.093	0.460±0.081	0.659±0.055	0.669±0.059
		R^2	0.614	0.648	0.677	0.715	0.918	0.908
	D	a	1.476±0.500	1.633±0.603	0.876±0.414	0.898±0.464	-0.577±0.571	-0.841±0.421
		ln b	0.353±0.051	0.337±0.062	0.377±0.042	0.376±0.047	0.611±0.058	0.640±0.043
		R^2	0.705	0.600	0.799	0.759	0.846	0.917

[1]Following allometric growth equation was used as described by Huxley (1924): Y = aXb log Y = log a+b log X

[2]a: Allometric constant of intercept. [3]b: Allometric growth coefficient or slope

Table 14: Bone mineral density (BMD; mg/cm^2) and bone mineral content (BMC; g) measured with DEXA of 4 strains of large white turkeys at 20 wk of age

		Turkey strains					
Bones		A	B	C	D	CV%	p-value
BMD							
Tibia	Right	458.15±7.68^b	463.62±7.68^b	463.11±9.23^b	497.46±7.68^a	5.88	0.003
	Left	466.08±7.44^b	466.69±7.44^{ab}	471.00±8.94^{ab}	494.69±7.44^a	5.65	0.029
Femur	Right	462.85±8.17^b	471.31±8.17^{ab}	461.55±9.82^b	500.31±8.17^a	6.20	0.007
	Left	461.23±9.09^b	475.00±9.09^{ab}	467.33±10.92^b	508.31±9.09^a	6.84	0.004
Shank	Right	425.54±7.26^{ab}	409.77±7.26^b	404.44±8.73^b	446.00±7.26^a	6.19	0.002
	Left	425.77±7.71	415.00±7.71	398.89±9.27	430.62±7.71	6.63	0.059
BMC							
Femur	Right	20.02±0.52	20.85±0.52	19.72±0.62	21.14±0.52	9.11	0.237
	Left	20.11±0.54	21.07±0.54	19.93±0.64	21.29±0.54	9.34	0.244
Shank	Right	17.38±0.39	17.52±0.39	17.01±0.46	18.13±0.39	7.93	0.295
	Left	17.52±0.39	18.09±0.39	16.84±0.50	17.97±0.39	8.03	0.217
Tibia	Right	30.88±0.72	32.38±0.72	30.54±0.86	32.76±0.72	8.16	0.120
	Left	31.08±0.78	32.53±0.78	30.88±0.93	32.42±0.78	8.81	0.352

the body in all strains (ln b >1). In contrast, both tarsus-metatarsi were growing slower than the rest of the body (ln b <1). From 10 to 20 wk of age, all leg bones in all genetic lines were growing at rates that were slower than the body as a whole (ln b <1). All strain A leg bones were growing faster in relation to the body than all other strains within 1 to 8 wk while most strain D leg bones were growing the slowest. Between 10 and 20 wk, all strain C leg bones were growing the fastest in relation to the body when compared to the other strains. At this time, most strain D leg bones were growing the slowest.

BMD and BMC at 20 wk: In general, leg bones from turkeys in strain D had greater BMD than those from other strains (Table 14). Specifically, strain D toms had greater tibia BMD ($p<0.05$) than strain A turkeys and greater femur BMD ($p<0.01$) than both strains A and C. Right tarsus-metatarsus BMD was greater ($p<0.01$) in strain D toms than strain B and C turkeys. Although differences were found in leg bone BMD, no differences ($p>0.05$) were detected in leg bone BMC among the strains studied.

DISCUSSION

At hatch differences were found between strains in BW with ($p<0.001$) and without yolk ($p<0.01$) as well as leg, thigh, drumstick, tibia, femur and tarsus-metatarsus weight ($p<0.01$) with no differences ($p>0.05$) in the relative weights of these body portions. This agrees somewhat with the report of Lilburn and Nestor (1991)

who found only a difference in BW between the genetic lines they studied. However, these authors did find differences in femur and tibia length and total tibia and femur weight by as early as 4 wk of age. In our data at hatch, strains A and B had ($p<0.01$) greater BW and leg bone and leg section weight than strains C and/or D. Strains A and B also had longer leg bone lengths than strain C; therefore, poults that may be growing faster at hatch are also likely to have longer leg bones at this age. While strain A turkeys with twisted legs continued to have greater BW than strain C poults with this leg disorder, trends in leg section and leg bone weight did not mirror those found at hatch. At 16 d, differences were detected in relative weights of leg sections and leg bones instead of the absolute weights and lengths of these body portions. In general, strain B tended to have greater relative weights than strain A. Similarly, differences due to turkey strain in leg bone morphometry have been previously reported by Taha and Farran (2009).

At 16 d, strains A and C had a greater incidence of twisted legs than strains B and D. At 33 d of age, this pattern was still present; however, in terms of the incidence of all leg problems, strains B and C had a greater prevalence of leg disorders than strains A and D. When the birds reached 15 and 18 wk of age, there was no significant difference in the incidence of twisted legs, but strain A and C poults did have a greater prevalence of crooked toes than strain D turkeys. This data indicated that not only did leg disorder incidence vary by turkey strain and the specific leg abnormality observed, but it also changed in all the strains studied as the turkeys aged.

Turkeys are reported to have diphasic growth behavior with early and late growth phases that is caused by different growth rates of various organs in the body (Hurwitz *et al*., 1991). Hurwitz *et al*. (1991) classified the growth rates of organs into 2 groups. The first group had rapid initial growth that leveled off at a later age while the second group had slow initial growth followed by rapid acceleration. Leg bone development, such as tibia weight and length, were placed in the first category while muscle tissue was placed in the second (Hurwitz *et al*., 1991). This agrees with Gerrard and Grant (2003) who reported that bones grow and develop before muscle. Our data complements this since allometric growth ratios for all strains studied in both tibias and femurs indicated that these bones were growing faster than the rest of the body from 1 to 8 wk of age but slower than the body from 10 to 20 wk. Furthermore, the age of maximum growth (t*) for leg bone length and weight (17.2 to 21.2 d and 46.3 to 78.0 d, respectively) was shorter than t* for BW (79.5 to 115.9 d). This agrees with the findings of Hurwitz *et al*. (1991), who also reported that the maximum growth for tibia length (24.0 d) occurred before that of tibia weight (54.4). These authors fitted BW data to a double-component Gompertz equation in order to account for the two growth phases turkeys experience. The maximum growth of BW for the second phase was calculated to be 100.3 d, which was much earlier than that of both tibia length and weight.

Between 1 and 8 wk, strain A turkeys had the highest allometric growth ratios while strain D toms had the lowest, indicating that the leg bones of strain A were growing more rapidly in relation to the body than those of strain D early in life. For leg bone length and weight and BW, strain A toms reached maximum growth at the lowest age of all strains. These findings indicate that strain A turkeys were likely growing at a faster rate at an early age than the other strains. At 16 d, twisted legs were more prevalent in strain A than strain D and at 15 and 18 wk, crooked toes were more common in strain A. Furthermore, strain A turkeys had lower BMD than strain D toms for nearly all leg bones, suggesting that strain A leg bones were weaker than those of strain D. This illustrates that rapid growth in the earlier stages of life may make turkeys more susceptible to certain leg problems, possibly by inducing rapid bone development and impairing bone mineralization and organic matrix formation that results in weaker bones. This is supported by Mench (2004) and Julian (2004) who reported that rapid growth likely causes the production of bone and supporting tissue, such as tendons, that are of poor structural quality. Corr *et al*. (2003) stated that slowing the rate of weight gain early in life should improve walking ability by allowing for skeletal growth instead of muscular development. Moreover, other studies have found that the incidence of certain leg problems can be decreased and skeletal health can be improved by decreasing growth rate early in life (Bennett *et al*., 2002; Bradshaw *et al*., 2002). In conclusion, differences were evident in bone development patterns, leg problem incidence and leg bone BMD in commercial genetic lines of turkeys. Strains with slower rates of growth and bone development tended to have lower incidences of leg problems and higher BMD. This information may be useful in developing a genetic selection program to reduce the prevalence of leg disorders in turkeys in commercial production.

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