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Blood Volume, Lactate and Cortisol in Exercising Arabian Equitation Horses

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ABSTRACT. The present study was designed to assess the indicators of performance capabilities of horses which undergo daily controlled bouts of submaximal exercise. Pure bred Arabian horses ($n=14$, 449 kg) were worked 4 hours per day at the walk, trot and canter, 5 days a week. The standard exercise test consisted of a 15 min warm up and two 250 m gallops. The horses were galloped at a heart rate measured and held at 180 bpm (V_{180}) and timed over the last 100 m of the second gallop. Circulating blood volume was estimated with an Evans blue dye dilution technique. Hematocrit increased from 32% to 43% during exercise, but returned to pre-exercise levels within 15 min. Blood volumes averaged 43.1 l (0.097 l kg^{-1}). When regressed against V_{180}, mass specific blood volume was a relatively poor indicator of performance ($r^2=0.52$). Blood lactates increased from 1.1 mmol l^{-1} to 5.1 mmol l^{-1}, but within 15 min had decreased to 2.3 mmol l^{-1}. Cortisol averaged 75 ng ml^{-1} and increased with exercise to 108 ng ml^{-1}. Blood volume results indicate that despite daily workouts, Arabian equitation horses are only modestly fit compared to other values in the literature.

Key words. Standardized exercise test; fitness; performance evaluation

INTRODUCTION

How well a horse performs in competition is one means of assessing that animal's value. The success of this performance then provides a major impetus for studies on performance evaluation. Exercise performance represents the cumulative efforts and complex interplay of many physiological systems. The enhancement of performance requires developement of neural, skeletal, muscular, respiratory, endocrine and cardiovascular systems. Many of these physiological functions can be measured and thus provide insight into the mechanisms of adaptation to exercise.[18]

Many methods are used to assess the acute and chronic adaptation of the horse to exercise. Maximal oxygen consumption integrates all physiological components to deliver and utilize oxygen during exercise and there is a strong correlation between physical working capacity and the ability to consume oxygen.[6] Blood biochemistries[21] and muscle biopsies[9] provide information on more specific systems. Heart rate (HR), oxygen consumption and blood volume measurement are used to estimate the functional capacity of the cardiovascular system.[14,16,22] The purpose of the present study was to assess indicators of exercise capacity of Arabian equitation horses which undergo daily, controlled bouts of submaximal exercise. This study is unusual in that it uses Arabians, for which there are few comparative data. Additionally it uses animals which undergo substantial periods of exercise but at submaximal rates. Blood volume, blood lactate and cortisol levels were measured under controlled exercise testing.

MATERIALS AND METHODS

Animals. All horses were pure bred adult Arabians from an equitation center. These horses were worked in equitation classes (Sept.–June) approximately 4 hours per day, 5 days per week at the walk, trot and canter. Fourteen horses (9 geldings and 5 mares) ranging in age from 5 to 20 years (average 11.7±1.3), and weighing an average of 449±10 kg (range 393–511) were used in this study.

Standard Exercise Test (SET) Horses were trained for the experimental protocol by performing the SET during November, 3 times prior to the test. All test measurements were then conducted during December 1988. On experimental days, horses were weighed in the early p.m. and at this time a pre-exercise blood sample (PRE) of 30 ml was taken and placed into an iced, heparinized test tube. A catheter (Abbocath®, 16 g×12.5 cm) was placed aseptically into the left jugular vein and secured with suture. The horses were saddled within 30 min and walked (5 min) to the track, which consisted of a graded dirt oval, 2 furlongs in distance. An EQB heart rate monitor (Equine Biomechanics & Exercise Physiology, Inc., Unionville, PA) was installed, the horse mounted and exercised another 5 min at the walk. The remaining warm up consisted of 10 min of walk (5 min), trot (4 min, HR 110–115 bpm) and canter (1 min, HR 145–150 bpm). At this time the horse was galloped 250 m, in a counter clockwise direction, at HR of 180–184 bpm. The last 100 m of this 250 m gallop had two sets of posts located exactly 100 m apart. An electronic timer (Hewlett Packard) utilizing microswitches and 25 g wire was used to time the movement between the posts. The gallop was repeated once immediately following the first gallop. The second attempt was used to calculate velocity. Those horses that did not stay at HR of 180–184 for the second gallop were retested approximately 3 days later. No horse was tested more than twice. The same rider was used for all experiments. During the period of this study there was little variation in track conditions, due to the lack of rain and consistent daytime average temperatures of 21.0°±0.8°C.

Physiological measurements Blood samples were taken pre-, immediately post-exercise (within 30 seconds), and 15 min post-exercise from the right jugular into lithium heparin vacuum tubes. One ml of blood was immediately pipetted into ice cold trichloroacetic acid (10% w/v) for lactate determination. All samples were placed on ice until centrifugation. Plasma samples were transferred and stored at −70°C for cortisol measurements. Lactates were measured enzymatically in triplicate using a diagnostic kit (Sigma Chemical, St. Louis, Mo., no. 826). Cortisol was measured in duplicate on plasma samples using a RIA (Diagnostic Products Inc, San Juan Capistrano, CA) validated for horses. Plasma volumes were measured by dye dilution techniques using plasma extracted on cellulose.[12] An Evans blue dye (1%, w/v, in saline) was injected via the left jugular catheter immediately pre-exercise. Sixty ml of saline was used to clear the catheter of residual dye. Blood volume was calculated using packed cell volumes (PCV) determined from samples collected immediately post-exercise.

Statistical analysis Differences between pre-, immediately post- and 15 min post-exercise were compared by ANOVA using repeated measures. Post hoc differences were identified with the Student–Newman–Keuls test with a significance set at 0.05. Comparison of velocity and blood volume were done by simple linear regression. All data are presented as mean ± SE.

RESULTS

Plasma volumes 15 min post-exercise averaged 24.0±1.0 l (range 17.4 to 30.1). For comparative purposes[15] plasma volumes 15 min post are used, rather than collecting additional samples and extrapolating back to 0 min post-exercise.

Exercise significantly increased hematocrit (Fig. 1). While PCV increased 32% with exercise, this value had returned to pre-exercise levels within 15 min of the final gallop. Using hematocrits immediately post-exer-

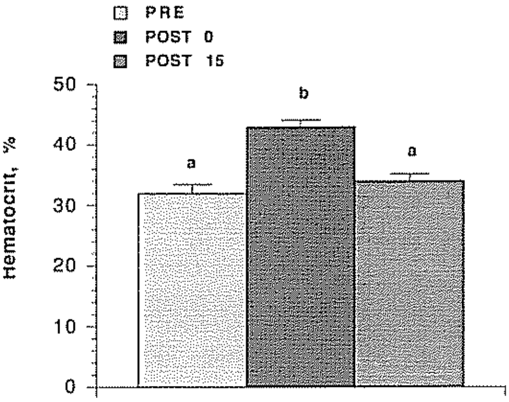

Fig 1 Hematocrit (%) pre-exercise (PRE), immediately post-exercise (POST 0) and 15 min post-exercise (POST 15). Significant differences indicated by different superscript letters. Bars indicate + SE.

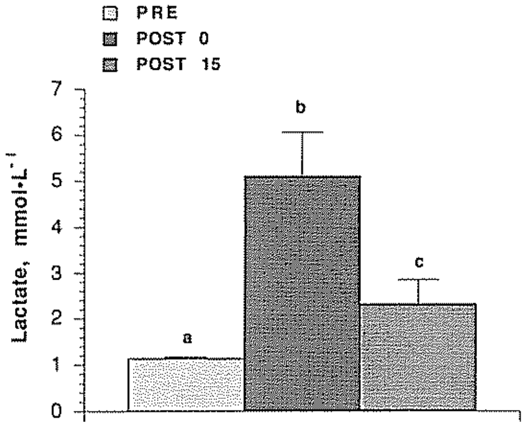

Fig 3. Whole blood lactate (mmol l^{-1}) pre-exercise (PRE), immediately post-exercise (POST 0) and 15 min post-exercise (POST 15). Significant differences indicated by different superscript letters. Bars indicate + SE.

cise, estimated circulating blood volumes averaged 43.1 ± 1.8 l. Since blood volume scales with body mass,[15] for comparisons it is important to calculate blood volume per body mass. For this study, mean mass specific blood volume was 0.097 ± 0.004 l kg^{-1}.

Velocities at V_{180} for the 100 m, averaged 10.7 m s^{-1} ±0.2 (range of 8.1–12.1). There was a significant positive correlation between velocity and mass specific blood volume (Fig. 2) as defined by the equation $y = 28.1x + 7.96$ where y = gallop speed in m s^{-1} and x = (blood volume)/(body mass) in l kg^{-1} ($r = 0.72$, $p < 0.05$).

Blood lactates increased over 5-fold from 1.14 ± 0.04 mmol l^{-1} pre-exercise to 5.11 ± 0.96 mmol l^{-1} immediately post-exercise (Fig. 3). The levels dropped significantly to 2.32 ± 0.53 mmol l^{-1} within 15 min but were still above pre-exercise concentrations.

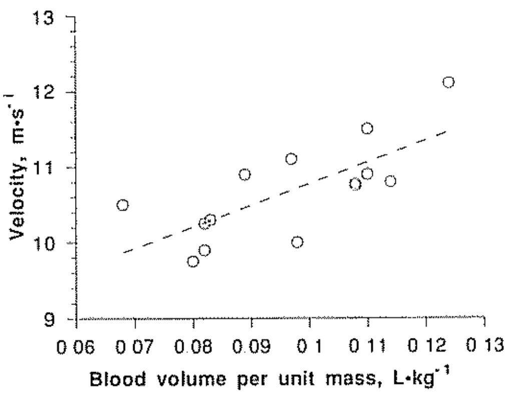

Fig 2 Velocity at a heart rate of 180 bpm in m s^{-1} as a function of mass specific blood volume. Line represents linear regression.

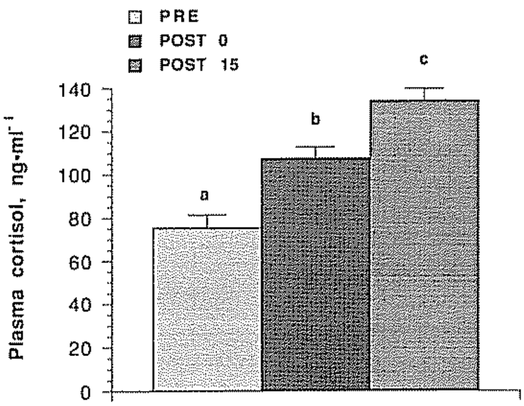

Fig 4 Plasma cortisol concentration (ng ml^{-1}) pre-exercise (PRE), immediately post-exercise (POST 0) and 15 min post-exercise (POST 15). Significant differences indicated by different superscript letters. Bars indicate + SE.

Cortisol was increased from 75.5±5.9 to 107.5±5.3 ng ml^{-1} with exercise. However, at 15 min post-exercise, values were significantly higher (134.3±5.4 ng ml^{-1}, Fig. 4).

DISCUSSION

Plasma volumes (53.4 ml kg^{-1}) in the Arabians are similar to those determined for a mixed group of Thoroughbred, trotters, saddle horses and North-Swedish horses,[15] but considerable variation exists. The amount of variation in total blood volume will be even greater in view of the spleen's role in red cell kinetics. The relative blood volume calculated for our equitation horses, 97.0 ml kg^{-1}, compares to 94.3 ml kg^{-1} in another study on Arabians[11] despite different techniques. Similar techniques (Evans dye) on several breeds provide ranges from 62.4–136.9 ml kg^{-1}.[15] While the blood volumes of the equitation horses are within normal limits, they fall well below those of an elite Arabian trained and conditioned for endurance.[5]

In calculating total blood volumes the importance of taking hematocrits immediately post-exercise is well demonstrated. In our horses, PCVs were elevated an average of 1.3-fold yet returned to pre-exercise levels within 15 min (Fig. 1).

In humans, maximal oxygen consumption is correlated with blood volume[4] and horses, animals with larger mass specific blood volumes, do have a higher capacity for submaximal exercise.[17] In this study performance, as assessed by the velocity to move 100 m at V_{180}, was significantly and positively correlated with mass specific blood volume (Fig. 2). However, the regression coefficient ($r=0.72$) indicates that mass specific blood volume is not a particularly powerful predictor of performance in our horses.

Another proposed indicator of performance capability is blood lactate, in that it provides information on anaerobic metabolism.[7] In our study, the relatively brief gallop produced a 5-fold change in blood lactates. This increase observed immediately after exercise is 20% that seen in Thoroughbreds[1] under conventional maximal workouts, but within the values observed in conditioned Quarterhorses undergoing a submaximal stress test.[13] The plethora of testing regimes leads to some of the profound differences in the reported values for blood lactate in the horse. Useful observations can still be made, one is the rapid recovery of lactate. Post-exercise lactate dropped by 50% (Fig. 3) within 15 min of recovery. This is noticeably more rapid than in either conditioned or unconditioned Quarterhorses. Data from other studies are consistent in that rate of lactate disappearance is increased in more fit horses.[1,13,20] Whether our observations reflect the capacity for lactate metabolism of Arabians or the mechanics of the SET itself, warrants further investigation.

Glucocorticoids affect metabolic pathways that provide fuel necessary for prolonged submaximal exercise and increase with strenuous (60% of $V_{O_2}max$) exercise in the horse.[23] Our horses demonstrated a 42% increase in cortisol during exercise and this trend continued increasing to 78% 15 min post-exercise. The magnitude of these increases, while similar to earlier results,[10] falls below those seen in horses undergoing heavier workloads.[3] However, these comparisons are in keeping with the observations that greater cortisol increases occur in more stressful situations.[8] The increase in cortisol post-exercise may be due, in part, to the patterns of disappearance of cortisol from the blood[19] in which there is a redistribution phase from the tissues back into the blood.

Results from this study provide additional perspectives on equine exercise physiology with special emphasis on Arabian equitation horses. While blood volumes of the horses were not particularly good indicators of performance, they were within other reported values. They did indicate that despite the daily bouts of extended submaximal exercise the horses appear only moderately fit. The results from the lactate and cortisol measurements establish that the SET in the present study was not particularly stressful. However, rates of lactate disappearance post-exercise appear relatively rapid and offer incentives for further investigation.

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Scintigraphic Appearance of Dorsal Metacarpal and Metatarsal Stress Changes in Racing and Nonracing Horses

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ABSTRACT. The objective of this study was to examine the distribution and risk factors associated with dorsal metacarpal and metatarsal stress changes in horses examined scintigraphically for lameness problems. Subjects included 62 Standardbred racehorses (STB), 54 Thoroughbred racehorses (TB), and 54 nonracing horses (NR) which were presented for lameness examination between 1979 and 1988 and had all 4 limbs examined scintigraphically at the University of Illinois Veterinary Medicine Teaching Hospital. TB were 4.9 times more likely than NR to have at least one limb affected ($p<0.05$). STB were not at greater risk than NR. Forelimb changes were also more common in TB ($p<0.01$). All groups had some prevalence of increased uptake in the hindlimbs. Two and three year olds were more commonly affected among TB ($p<0.01$). Neither males, castrated males, nor females were at greater risk in any group.

Key words. Metacarpus; metatarsus; scintigraphy; stress fracture; horse.

INTRODUCTION

Horses are required to perform in a variety of athletic activities at varying levels of intensity, ranging from pleasure riding to racing. More intensive activities, such as Thoroughbred (TB), Standardbred (STB), and Quarter Horse (QH) racing, have been associated with a variety of stress-induced skeletal diseases such as dorsal metacarpal disease (bucked shins and cortical stress fractures),[5,17,18] sesamoid fractures[10] and carpal bone fractures.[13,21] Nuclear scintigraphy has been shown in horses to have a high sensitivity in the early detection of stress-induced lesions of the carpus,[6] tarsus,[2] metacarpus,[4,12] and tibia.[11,22] One previous report described the use of bone scintigraphy as an aid in the diagnosis of dorsal metacarpal disease in TB racehorses.[12]

The objective of this study was to determine the distribution and risk factors associated with metacarpal and metatarsal stress changes diagnosed by increased dorsal cortical ^{99m}Tc MDP uptake in the fore and hindlimbs of horses of various occupational groups.

MATERIALS AND METHODS

Inclusion criteria. The medical records of all horses examined scintigraphically for lameness at the University of Illinois Veterinary Medicine Teaching Hospital between 1979 and 1988, inclusive, were reviewed. Four hundred and forty-six STB, 66 TB, and 62 nonracing horses (NR) were presented for lameness examinations and had all limbs examined scintigraphically 2 to 3 hours after intravenous injection of ^{99m}Tc-methylenediphosphonate (MDP). A Pho/Gamma IV gamma camera (Siemens) was used between 1979 and 1985, and a Technicare 410 large field-of-view gamma camera was used subsequent to early 1985.

A random sample ($n = 70$) was drawn from 446 STB to allow more detailed comparisons of 3 occupational groups of approximately equal numbers. After re-examination of each horse's scintigraphs, some were excluded because the studies were incomplete or of inadequate quality. A total of 170 horses (54 TB, 62 STB, and 54 NR) were included in the study.

Age, breed, sex, and occupation were abstracted from each medical record. The presence of metacarpal and metatarsal physical abnormalities including localized palpable pain, heat, and swelling were recorded for each limb of each horse. Records of racing governing bodies were cross-referenced if needed for confirmation of signalment details. TB and STB groups included only horses which had recently raced or which were in active training and were soon to race at the time of the examinations. The NR group included horses in active training and currently being used for nonracing purposes such as pleasure, trail-riding, hunter/jumper showing, dressage, combined training, and western work (i.e. reining, roping, barrel racing). Breeds included in the NR group were TB (15 horses), QH (8), Arabian (7), American Saddlebred (5), crossbred (4), Trakehner (3), Missouri Fox Trotter (3), Lipizzaner (3), Tennessee Walking Horse (2), Appaloosa (1), Paint (1), Paso Fino (1), and Westphalian (1).

Scintigraphic criteria. The scintigraphic studies of 170 horses were reviewed by 2 investigators (J.H.F. and A.R.T.). The scintigraphs were reviewed in reverse chronological order (i.e. most recent first). Occupational groups were thus randomized in order and were not known to the investigators at the time of the scintigraphic review.

Only the metacarpal and metatarsal regions were re-examined on the scintigraphs. Each limb for each horse was classified according to the following grading criteria (Fig. 1):

Grade 1. Dorsal and palmar/plantar cortices equal and uniform in uptake and < proximal metacarpal/metatarsal uptake.

Grade 2. Dorsal cortical uptake uniformly and diffusely > palmar/plantar uptake but < proximal metacarpal/metatarsal uptake.

Grade 3. Dorsal cortical uptake uniformly and diffusely > palmar/plantar uptake and > proximal metacarpal/metatarsal uptake.

Grade 4. Dorsal cortical uptake nonuniform and/or nondiffuse (i.e. focal) and > palmar/plantar uptake.

Using this classification, Grade 1 corresponded with the normal metacarpus described by Koblick et al.[12] Grade 2 was similar to their "normal" mild training-induced change in younger TB. Grade 3 was equivalent to their "diffuse periostitis" (i.e. bucked shins) group, and Grade 4 was equivalent to their focal stress fracture-like lesions.

Statistical analysis. Age and sex distribution within each occupational group were determined. Distribution of each grade of increased scintigraphic uptake was determined for each limb within each occupational group.

Grades 3 and 4 were combined for the analysis of risk factors in this study because the numbers of horses in each grade were small and because the goal was the identification of differences in distribution and risk for abnormally increased uptake, defined as grades 3 and 4 by Koblick et al.[12] Sensitivity and specificity of Grade 3 and 4 scintigraphic changes were calculated to assess their value as a diagnostic test for physical abnormalities.[14] Physical abnormalities were selected for comparison because they are the traditional means for clinically diagnosing dorsal metacarpal disease. Sensitivity was calculated as the proportion of physically abnormal metacarpal/metatarsal bones which had Grade 3 or 4 changes. Specificity was calculated as the proportion of physically normal bones which were graded 1 or 2 scintigraphically.

For further analysis, horses were grouped as having: (*a*) a Grade 3 or 4 scan in one or more limbs; (*b*) a Grade 3 or 4 scan in one or both forelimbs; and/or (*c*) a Grade 3 or 4 scan in one or both hindlimbs. For any horse

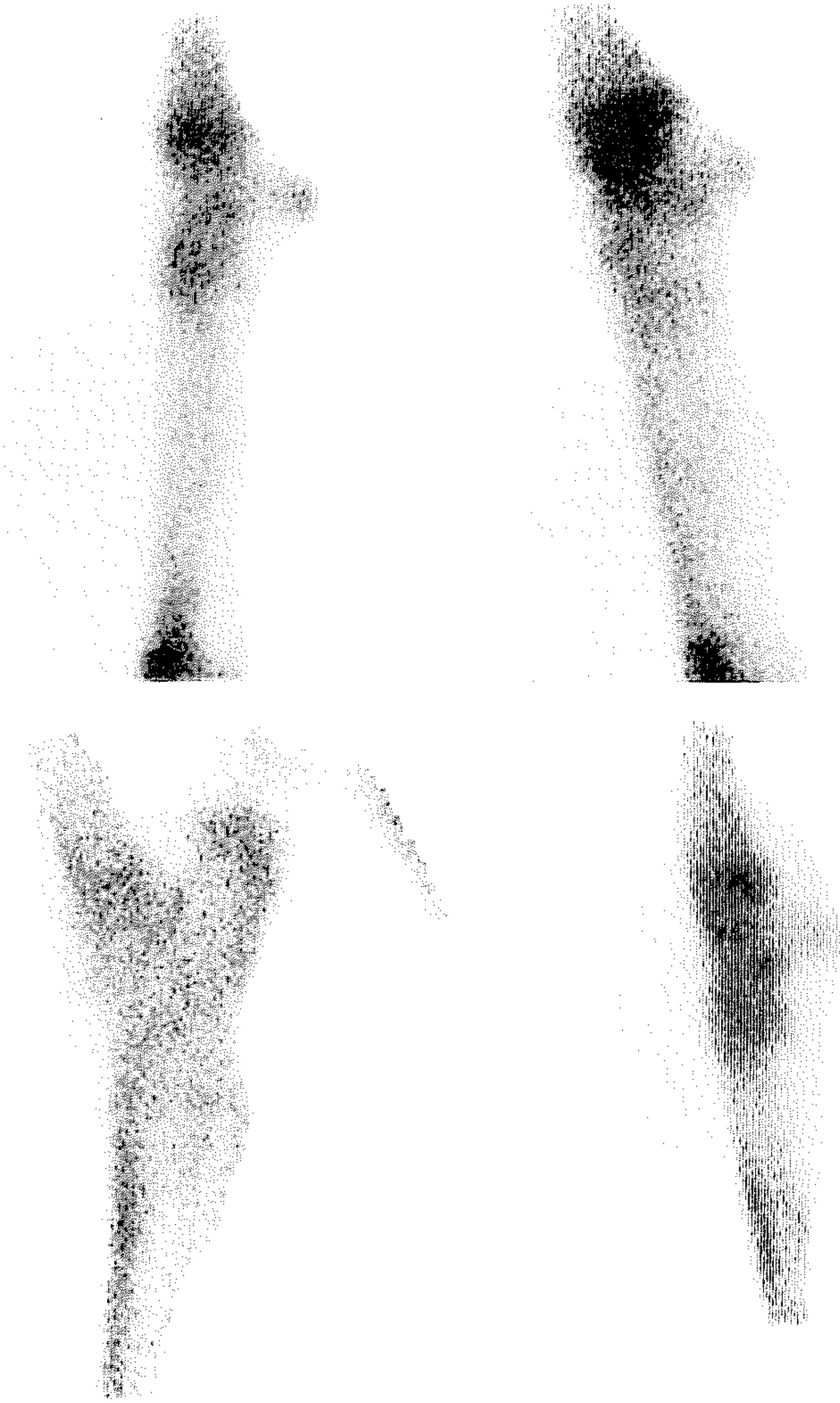

Table 1. *Age and sex distribution of horses by occupational groups*

	Thoroughbred		Standardbred		Nonracing	
	n	%	*n*	%	*n*	%
2–3 years old	37	68.5	36	58.1	6	11.1
>3 years old	17	31.5	26	41.9	48	88.9
Males	10	18.5	9	14.5	7	13.0
Castrated males	20	37.0	25	40.3	32	59.2
Females	24	44.5	28	45.2	15	27.8

with more than one Grade 3 or 4 limb, the higher grade of lesion was used for that horse.

Age, sex, and occupation were examined as risk factors for development of Grade 3 or 4 scintigraphic uptake. TB and STB were both compared to NR to test effects related to occupation. Racing TB were compared to nonracing TB ($n = 15$) to test effects of occupation within a single breed. Magnitude of risk was estimated using prevalence odds ratios (OR) and significance was calculated using Fisher's Exact tests.[3] The prevalence odds ratio measures the odds of having a lesion or disease in one group relative to another and is an estimate of risk in cross-sectional studies. An OR > 1 signifies increased risk while an OR < 1 means a factor is protective. Prevalence data can be used to measure the relative likelihood of lesions being present in animals, but not the likelihood of a given animal developing lesions. Stratum-specific and Cochran–Mantel–Haenszel (CMH) adjusted odds ratios were calculated to examine the effects of differences in age and sex composition of the population on odds ratios for occupation.[3] A p value <0.05 was considered significant.

Fig. 1. All scintigraphs of left limbs and oriented with dorsal aspect toward the left. Top left: Grade 1 scintigraph of 5 year old Arabian carpus and metacarpus. Top right: Grade 2 scintigraph of 3 year old racing Thoroughbred carpus and metacarpus. Bottom left: Grade 3 scintigraph of 4 year old racing Thoroughbred tarsus and proximal metatarsus. Note uniformly increased dorsal cortical uptake greater than plantar aspect and greater than proximal metatarsus. Bottom right: Grade 4 scintigraph of 3 year old Standardbred carpus and metacarpus. Note focal, nonuniform uptake on dorsal aspect of mid-metacarpal area.

RESULTS

Age and sex distribution of subjects within each occupational group are summarized in Table 1. Distribution of the various grades by limb and occupational group are presented in Table 2. The histories and clinical signs of horses with Grade 3 and 4 changes are summarized in Table 3. No horses with Grade 1 or 2 changes had clinical signs of metacarpal or metatarsal pain. Of the 13 asymptomatic horses with Grade 3 and 4 changes (Table 3), 8 had other joint injuries which may have affected weight-bearing. Grades 3 and 4 scans were 100% sensitive in documenting metacarpal/metatarsal changes in horses with clinically detectable localized pain. Grade 1 and 2 scans were 93.5% specific in detecting normal or mild stress changes in metacarpal/metatarsal bones which were clinically normal. Only 6.5% of the normal limbs were falsely identified as abnormal (i.e. false positives) based on having abnormally increased uptake (Grades 3 and 4) when they were not clinically abnormal at the time of admission to the Teaching Hospital.

Among STB and NR, there were no sig-

Table 2. *Distribution of metacarpal/metatarsal grades by occupational group*

Limb	Grades	Thoroughbred		Standardbred		Nonracing	
		n	%	*n*	%	*n*	%
RF	1	26	47.3	59	95.2	50	92.5
	2	6	11.2	1	1.6	3	5.6
	3	8	14.8	1	1.6	0	0
	4	15	27.7	1	1.6	1	1.8
LF	1	22	40.7	59	95.2	52	96.4
	2	10	18.5	0	0	0	0
	3	9	16.7	2	3.2	1	1.8
	4	13	24.1	1	1.6	1	1.8
RH	1	34	63.0	53	85.5	46	85.2
	2	12	22.2	8	12.9	6	11.2
	3	4	7.4	0	0	1	1.8
	4	4	7.4	1	1.6	1	1.8
LH	1	35	63.0	56	90.3	48	88.9
	2	10	18.4	4	6.5	3	5.6
	3	4	7.4	1	1.6	2	3.7
	4	6	11.2	1	1.6	1	1.8

nificant differences in the distribution of Grade 3 and 4 scans between younger (2–3 year olds) and older (>3 year olds) horses (Table 4). Younger TB were more likely to have Grade 3 and 4 scans than older TB, in at least one limb ($p<0.01$) and in the forelimbs ($p<0.01$). Neither males, castrated males, nor females were at greater risk overall or within individual occupational groups.

Odds ratios for the presence of abnormally increased dorsal cortical uptake in TB and STB relative to NR are summarized in Table 5. TB were 8.6 times more likely to have at least one limb affected than NR ($p<0.001$). Both the fore ($p<0.001$) and hindlimbs ($p<0.05$) were more likely to be affected in TB than in NR. There were no differences in risk for at least one affected limb, for forelimb changes, or for hindlimb changes when STB were compared to NR. When OR were adjusted for age effects (Table 5), TB remained at greater risk relative to NR for one

Table 3. *History and clinical signs of horses with Grade 3 and 4 metacarpal and metatarsal scintigraphic stress changes*

	Thoroughbred	Standardbred	Nonracing
Total number of horses	28	6	6
Localized pain	13	1	1
Previous history of localized pain	4	0	0
Decreased level of work immediately prior to admission	4	1	3
Asymptomatic	7	4	2

Table 4. *Odds ratios (OR) for metacarpal/metatarsal scintigraphic abnormalities (Grades 3 and 4) in young horses (2–3 years old) relative to older horses (> 3 years old)*

	Odds Ratios (OR)		
	Thoroughbred	Standardbred	Nonracing
RF abnormal	3.4	0.1	2.4
LF abnormal	3.1	1.5	1.4
RH abnormal	3.7	0.2	1.4
LH abnormal	2.1	3.8	1.0
One or more abnormal	6.0**	1.4	0.5
One or more fore abnormal	5.3**	0.7	1.0
One or more hind abnormal	2.8	1.5	1.0

** $p < 0.01$.

or more abnormal limb ($p < 0.05$) and forelimb abnormalities ($p < 0.01$).

The nonracing TB were all > 3 years old, and so only a comparison of older TB could be made to examine the effect of TB racing relative to nonracing. Older racing TB were not at greater risk for forelimb or hindlimb abnormalities relative to nonracing TB.

DISCUSSION

Scintigraphic detection of bone stress remodelling and fracture is a well established technique in human medicine.[15,16,24,27] Roub et al. stated that "since the delayed appearance of radiographic signs in other pathological conditions is well known, it should not be unexpected that radionuclide bone imaging can also demonstrate pathological changes associated with repetitive bone stress long before such evidence is visible on radiographs."[24] Stress fractures in man are believed to be part of a continuum of stress remodelling, not an isolated event like acute traumatic fracture.[24] The continuum progresses from bony remodelling to cortical fracture, with pain and positive radionuclide images preceding positive radiographs chronologically. Matin's extensive review of stress fractures in man followed the same concept and incorporated a "stage of injury" classification relating the extent of bone involved to the scintigraphic appearance,[16] similar to that employed by Koblik et al.[12] and in this study.

Table 5. *Odds ratios (OR) for metacarpal/metatarsal scintigraphic abnormalities (Grades 3 and 4) in racehorses relative to nonracing horses*

	Thoroughbred		Standardbred	
	OR	Age adjusted OR	OR	Age adjusted OR
RF abnormal	39.3***	27.7**	0.9	3.9
LF abnormal	17.9***	13.4**	0.9	1.3
RH abnormal	4.5*	3.4	0.4	0.9
LF abnormal	6.8*	3.6	0.6	0.3
1 or more abnormal limbs	8.6***	4.9*	0.9	0.9
1 or both forelimbs abnormal	17.0***	10.0**	1.2	1.5
1 or both hindlimbs abnormal	4.9*	4.0	0.9	0.9

p value for OR calculated using Fisher's exact test. Age adjusted OR and p value calculated by Cochran–Mantel–Haenszel method. Significance levels designated by * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Bone scintigraphy has previously been shown to be effective in the diagnosis of occult stress fractures in the horse.[6,11] The horses in this study were chosen because a higher prevalence of stress-induced changes was expected among lame horses relative to the general horse population. Selection of this high risk group allowed sufficient power to test for age, breed, sex, and occupational predilection. Additionally, the study of high risk patients allowed examination of the sensitivity and specificity of bone scintigraphy as an aid in the diagnosis of dorsal metacarpal/metatarsal disease. One previous study of dorsal metacarpal disease in TB has shown scintigraphy to be the only positive diagnostic finding in some cases of bucked shins.[12] A correlation between scintigraphic and radiographic changes was not examined in this study because the authors also believe scintigraphy to be the more sensitive indicator of the remodelling status of the metacarpus/metatarsus in the horse.[12,23]

In this study, bone scintigraphy was 100% sensitive in detecting abnormally increased uptake in metacarpal/metatarsal bones which were clinically abnormal. While there were some apparent false positives detected scintigraphically in clinically normal limbs, the data in Table 3 reveal that 75% of TB with Grade 3 or 4 scans had localized pain, a recent history of localized pain, or a decrease in work level immediately prior to admission. It is not uncommon for TB racehorses with early dorsal metacarpal disease to be unwilling to gallop normally at high speed and to be mildly shin sore immediately after such a workout, but then afterward to seem normal clinically until the next high speed workout 5 to 7 days later.[9,23] A rapid drop in workload immediately prior to admission may, therefore, have made the failure to detect localized pain in this hospital a false negative finding.

Of the 13 asymptomatic Grade 3 and 4 horses (Table 3), 8 had other joint injuries which might have affected weight-bearing and thus might have resulted in increased metacarpal/metatarsal stress. However, longitudinal studies in man have routinely failed to document milder injuries or stress changes in the limb contralateral to the one with a stress fracture manifested by localized pain and a positive bone scan.[24] Additionally, as many as 40% of stress fractures have been detected scintigraphically before they were apparent clinically in longitudinal studies of army recruits.[27] Matheson and coworkers have stated that the use of scintigraphy to diagnose stress fractures allows detection "independent of clinical suspicion or radiographic changes that are known to vary significantly with time and with the specific bone involved."[15] It seems possible, therefore, that the asymptomatic horses with Grade 3 and 4 scans actually had occult dorsal metacarpal/metatarsal disease which was soon to be manifested clinically or which may already have been manifested but was poorly documented historically.

These data support previous reports in which TB were suspected to be at greater risk for the development of dorsal metacarpal disease.[23,25,26] Unlike previous reports, these data have also documented the presence of scintigraphic changes characteristic of dorsal metacarpal disease in STB and in NR performance horses. Finally, it is apparent that these remodelling changes can occasionally be seen scintigraphically in the metatarsus in horses in all 3 occupational groups studied.

Koblick et al. characterized the presence of dorsal cortical uptake, greater than the palmar cortex but not greater than the proximal metacarpus (i.e. this study's Grade 2), as being a normal training-induced change seen in 2 and 3 year old TB.[12] This study has shown this change not to be unique to racing TB nor to the forelimbs. It is the authors' opinion that the Grade 2 change may be a mild form of shin stress which may progress to Grades 3 and/or 4 if fast training is not curtailed, similar to the continuum described in man.[16,24] As such, Grade 2 may not be normal and may actually represent the earliest scintigraphically detectable form of dorsal metacarpal/metatarsal disease, in a continuum of metacarpal/metatarsal scintigraphic abnormalities from Grades 2 through 4.

Nunamaker et al. have described age-related biomechanical differences between TB and STB metacarpal bones based on calculations made from post mortem cross sectional area measurements.[19] Yearling TB metacarpal bones had lower minimum and maximum moments of inertia than did those of yearling STB. Nunamaker and co-workers have subsequently documented that older (>3 years of age) TB and STB metacarpal bones were similar in mechanical properties when the results of fully reversed cyclic bending of *in vitro* metacarpal preparations were compared.[20] Similarly, in the current study, there were no differences beween older racing and nonracing TB in the risk for dorsal metacarpal/metatarsal disease. In both studies, there was wider variation amongst TB subjects compared to STB. This wider variability in TB is probably a reflection of metacarpal changes incurred earlier in training. Nunamaker et al. concluded that "differences in training regimens between the two breeds may influence the incidence of disease."[20]

Two-beat gaits (i.e. trotting or pacing STB racing) do not result in single-limb weight-bearing as does the 3-beat TB gallop which results in one lead limb in the horse galloping heavily on the forehand. Additionally, the TB's hindlimb which is diagonal to the lead forelimb also bears weight singly and thus may contribute to the higher prevalence of increased uptake in TB hindlimbs compared to NR (Table 5). The STB's lower prevalence of abnormal changes in all 4 limbs compared to the TB is likely a result of STB trainers' regimes of long, slow jogging sessions of up to 5 to 6 miles followed by gradual introduction of faster speeds (i.e. "training down" in time).[1,7] Progressively faster workouts probably allow more gradual adaptation of the STB metacarpus to speed as opposed to the TB trainer's typical early introduction of speed before the horses have shown cardiopulmonary and metabolic adaptations to the slower portions of their training program.[8,9] The fact that the STB yearlings' metacarpi were significantly more developed prior to the onset of training in Nunamaker's first study may provide some additional explanation for the apparent resistance of younger STB to the development of bucked shins.[19]

The population chosen for this study represented lame horses from 3 occupational groups. Although these data apply specifically to clinically lame animals, comparisons of the same high risk subgroup in different occupations is often the first step in evaluating risk factors.[3] Additionally, it has been reported that as many as 70% of all racing TB develop clinically apparent dorsal metacarpal disease some time during their racing careers.[17,23] Thus, lame horses may represent a relatively large proportion of the general population. To confirm the preliminary data presented in this study, a prospective examination of horses, begun before training and repeated periodically throughout training, using standardized classification and quantification of training stress, clinical signs, and dorsal cortical metacarpal/metatarsal scintigraphic changes would be useful. Such a study would allow characterization of changes as they occurred and determination of the significance of Grade 2 changes. Similar prospective serial examinations of racing and nonracing 2 year old TB would provide a comparison of early training effects within a single breed. However, the expense, time, and owner/trainer commitment and compliance required in such studies make their feasibility questionable.

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