Limb loading activity of adult horses confined to box stalls in an equine hospital barn

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Objective—To determine a range of limb loading activity for healthy adult horses confined to box stalls in an equine veterinary teaching hospital and determine the effects of hospital environmental factors on load rates and daily limb loading patterns.

Animals—6 mature healthy horses of various ages, breeds, and sexes, and 1 horse with a repaired metatarsal fracture.

Procedure—Step monitors were placed on 2 limbs of adult horses confined to box stalls. Relocation steps and weight shifts were recorded, as loading events, for 24 hours. Influence of forelimb versus hind limb and environmental factors on load rate (loading events per hour) were assessed with repeated-measures ANOVA.

Results—Loading activity was greater for the forelimb than the hind limb and was greater during the day than the night. Loading activity differences were not associated with daytime environmental factors.

Conclusions and Clinical Relevance—Horses with normal locomotor activity appear to have higher load rates for forelimbs compared with hind limbs and higher load rates during the day compared with night. Knowledge of influence of environmental factors and mechanical restraint on limb loading activity may be useful in management of horses with musculoskeletal disorders. This information may also be used for in vitro simulation of in vivo loading of limbs during cyclic biomechanical investigations.(*Am J Vet Res* 2000;61:234–237)

Healthy adult horses confined to a box stall intermittently walk in the stall and shift weight from one limb to the other while standing.[1] Normal locomotion varies with each horse but usually can be distinguished from abnormal locomotor activity. Abnormal locomotor activity may consist of excessive locomotor activities, including stereotypies such as stall walking and weaving,[1] or locomotor deficits, including prolonged recumbency, which may be observed in horses with musculoskeletal or neurologic disorders. Stereotypic locomotor behaviors likely result in greater frequency of limb loading during the day, whereas locomotor deficits induce a lower frequency of loading. For horses with musculoskeletal injuries, these abnormal locomotor behaviors may inhibit healing or promote secondary problems such as laminitis or flexural deformities.

Our interest in limb loading activity stems from a need to reproduce in vivo repetitive loading in vitro for evaluation of bone fracture fixation implants. Bone implant composite structures must withstand repetitive loading, including the number of strides that a horse takes and the number of weight shifts from 1 limb to the contralateral limb that take place during the time necessary for fracture healing. In addition, management of horses with fractures, using methods that modify stride frequency, could prolong bone-implant life.

The purposes of the study reported here were to determine a range of limb loading activity for healthy adult horses confined to box stalls in an equine hospital and to determine the effects of hospital environmental factors on load rates (number of loading events per hour).

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Materials and Methods

A self-contained step activity monitor[a] (6.5 × 5.0 × 1.5 cm; 65 g) developed for research on human gait activity was used in the study. Loading of human limbs has been monitored by continuously counting steps and regularly recording subtotals in short, adjustable time intervals. Memory in the device allows, for example, steps to be recorded at 1-minute intervals for 11.2 days or at 2.5-minute intervals for 28 days. An optical link to a computer is used to program the device and to download the data. Motion and acceleration are detected when a step is taken or weight is shifted. Human steps can be detected for a wide variety of gait styles, ranging from a slow shuffle to a fast run. The accuracy for human subjects typically exceeds 99% for normal walking.[2]

Horses—Six mature healthy horses (1 Warmblood, 2 Thoroughbreds, 1 Quarter Horse, 1 Warmblood/Thoroughbred crossbreed, and 1 Arabian/Quarter Horse crossbreed; 4 to 14 years old; 3 mares, 2 geldings, 1 stallion; approx 450 to 500 kg) were confined to box stalls, and limb loading activity was monitored for 24 hours. Horses were considered sound for pleasure riding. Horses were housed in paddocks (n = 5) or stalls (1) and with (4) or without (2) other horses before the study began, at the California Center for Equine Health and Performance at the University of California at Davis, which is characteristic of a breeding or boarding stable environment. Horses were assessed as being easily tractable in their original environment. For the 4-day period of the study, horses were housed at the Veterinary Medical Teaching Hospital in paddocks (6 × 6 m) and moved into box stalls in the hospital barn 1 to 4 hours before instrumentation and monitoring. For the 24-hour monitoring period, horses were confined to a box stall (3.7 × 3.7 m) bedded with wood shavings and exposed to the typical routine of the hospital barn (representing the environment of noncritical care patients). Interaction between study horses and horses occupying adjacent stalls was permitted.

Loading events—A step monitor was attached to a forelimb and an ipsilateral hind limb (left, n = 3; right, n = 3) at the junction of the proximal and middle thirds of the third metacarpal or metatarsal bone. The cannon bone was wrapped with a light bandage consisting of 1 sheet cotton[b] and 1 brown gauze.[c] The monitor was strapped to the lateral aspect of the bandage **(Fig 1)**. A heavy wrap, consisting of 8 sheet cottons and 2 brown gauze, was applied over the monitor for protection. Contralateral limbs were wrapped in an identical manner except for the step monitor. The sensitivity of the monitor was set to record relocation of the limb (steps), complete shifting of weight from 1 limb to the contralateral limb (weight shifts), foot stomping, and pawing as loading events. For each horse, 2 observers (LAM, KC) counted loading events with a handheld tally counter[d] for 30 minutes. The number of loading events recorded by the step monitor were divided by the number of loading events recorded by hand to determine a level of confidence in the accuracy of the step monitor before recording. The step monitor then recorded the number of loading events at 30 second intervals during the next 24 hours. Load rates (number of load events per hour) were determined for each activity period. Statistical analyses were performed on load rates of 5 horses with normal locomotor activity. The limb loading pattern, which is the temporal representation of load rates throughout a 24-hour period, was also assessed for each horse.

Because of a limited number of step monitors available, only 2 or 3 horses were monitored on a given day. Because step monitors were available for use on the horses for a limited time, some horses were monitored on weekdays and some on weekends. The periods of activities, but not the activities, varied slightly between weekdays and weekends. This difference in timing of the activity did not appear to influence the effect that the activity had on load rates.

Figure 1—Photograph of step monitor placed over the third metatarsal bone for monitoring loading events.

The 24-hour period was categorized by 2 methods. The first method divided the period into day (5 AM to 5 PM) or night (5 PM to 5 AM) categories. The second method divided the day into smaller periods when specific activities were taking place in the hospital: barn crew cleaning and morning feeding (5 AM to 8 AM); treatments administered by students and clinical rounds (8 AM to 10:30 AM); evening feeding (4 PM to 5 PM weekdays; 3 PM to 4 PM weekends); and low-activity times (all other times with generally quieter activities).

Additionally, a 2-year-old Mustang, with a third metatarsal bone transverse fracture repaired with dynamic compression plates and a full limb cast 2 weeks previously, was instrumented with a step monitor on the fractured and contralateral hind limbs. He was confined to a sling but could voluntarily bear weight on all limbs during data collection.

Statistical analyses—Repeated-measures ANOVA were performed to determine the effect of end of horse (forelimb vs hind limb) on 24-hour load rate, the effects of day versus night and forelimb versus hind limb on load rate, the effects of daytime activities (barn crew activities, student/round activities, evening feeding, and remaining low activity periods), and end of horse on load rate. The data were log transformed to stabilize variances. The dependent variable was load rate (number of loading events per hour). The independent variables were considered as fixed effects. Values of $P < 0.05$ were considered significant.

Results

One horse (horse 6) had stereotypic or abnormal locomotor activity,[3] including excessive stomping of the forelimbs and hind limbs, wall kicking, and stall walking for the entire monitoring period. Step monitor counts for this horse were 93 and 86% of hand tallied counts for the left forelimb and left hind limb, respectively. For the remaining 5 horses that had normal locomotor activity, step monitor counts ranged from 100 to 133% (median, 102; mean ± SD, 108 ± 14%) of hand tallied values for forelimbs and 86 to 126% (median, 101; mean ± SD, 102 ± 16%) for hind limbs.

Horse 6 had higher load rates for all periods and activities than means and medians of the other 5 horses that had normal locomotor activities during the study **(Table 1)**. Load rates for this horse were not included in the final statistical analysis, because this horse displayed stereotypic locomotor behavior.[2] Statistical comparisons for end of horse (fore vs hind), day versus night, and day activity effects were performed on only the 5 horses that had normal locomotor activities during the study.

The 24-hour forelimb load rate was greater (21%) than the hind limb load rate ($P = 0.006$). Horses that had normal locomotor activities averaged 4,560 forelimb and 3,624 hind limb loading events per day. Forelimb load rates were also significantly higher than hind limb load rates when day versus night ($P = 0.007$) or 4 of the daily activities ($P = 0.033$) were taken into account **(Fig 2)**.

Daytime load rates were significantly ($P = 0.005$) greater than nighttime load rates when the end of the horse was taken into account (Fig 2). Load rate did not vary significantly ($P = 0.667$) between the daily activi-

Table 1—Mean (± SD) and median (range) of load rates (No. of loading events per hour) for 5 horses with normal locomotor activity and for 1 horse with stereotypic locomotor patterns

	Five horses with normal locomotor activity				One horse with stereotypic locomotor patterns	
	Forelimb		Hind limb			
Statistic	Mean ± SD	Median (range)	Mean ± SD	Median (range)	Forelimb	Hind limb
24-hour period	190 ± 184	93 (64–502)	151 ± 155	62 (52–412)	803	1,517
Day	230 ± 231	120 (79–672)	191 ± 193	81 (61–510)	478	727
Night	139 ± 139	74 (48–382)	107 ± 117	48 (39–314)	325	790
Barn crew	253 ± 224	195 (64–597)	216 ± 199	151 (47–510)	454	790
Students	272 ± 306	151 (49–799)	226 ± 275	105 (46–699)	480	825
Evening feeding	161 ± 165	69 (10–381)	178 ± 207	43 (7–459)	393	841
Low-level activities	234 ± 232	166 (36–613)	172 ± 169	109 (22–442)	817	885

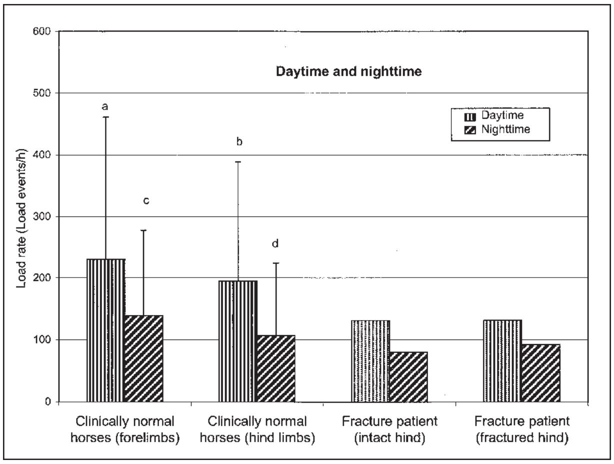

Figure 2—Comparison of mean (± SD) daytime and nighttime load rates for the forelimbs and hind limbs of 5 horses with normal locomotor activity and the load rate for the intact and fractured hind limbs of 1 horse confined to box stalls for a 24-hour period. [a,b,c,d]Bars with different superscripts are significantly ($P < 0.05$) different.

ties. Interactions between end of horse and day versus night load rates or between end of horse and daily activity load rates were not significant ($P = 0.263$ and 0.401, respectively).

Limb loading patterns for horses with normal locomotor activity had load rates that appeared to be random, with wide fluctuations in load rates during daytime hours. In general, the activity level was lower at night than during the daytime, and fluctuations in load rates were less extensive. These patterns were similar for the front and hind limbs of each horse. Limb loading patterns of the horse with the metatarsal fracture revealed load rates that appeared less random, with lower fluctuations. This horse also had a higher level of activity during the day. The activity patterns were similar for the fractured and intact hind limbs of this horse, except for one period near 1 AM when the fractured limb had a spike of activity much higher than that of the normal limb. A specific activity was not correlated to that time during the night in the hospital. The hind limb load rates of this horse were in the low end of the range for clinically normal horses (Fig 2).

Discussion

The step activity monitor was chosen for recording the limb loading activity of adult horses because of its ease of application and data collection, as well as the ability to set the sensitivity of the device to detect changes in weight-bearing and relocation steps. The simplicity of instrumentation allowed the horses to be free in the stalls without wires impeding their movement and without the need to attach a recording device to the horse that may have influenced behavior. The small size and weight of the step monitor allowed attachment to the distal aspect of the limb, resulting in high tolerance by the horses and no impediment to movement of the limb. The device proved to be resistant to trauma induced by abnormal or excessive activity (as observed in horse 6). The monitor was also useful when applied over a cast.

Generally, horses in stalls have 2 main types of normal locomotor activity: walking and weight shifting. Walking around the stall consists of relocating the foot, whereas weight shifting consists of the horse alternatively shifting the weight of the forelimb or hind limb from 1 limb to the contralateral limb without relocating a hoof. Both types of activity result in loading or cycling of the bones and soft tissues of the limbs and were counted as loading events. Researchers have determined the mean number of steps taken by the forelimb of an adult horse confined to a stall as 4 steps/2 min[4] (2,880 steps/24 h or a step rate of 120 steps/h). The activity being monitored was defined as a relocation of the foot and did not include weight shifts. This 24-hour step rate (number of relocation steps per hour) was lower than the mean forelimb load rate in the study reported here (190 loading events/h), which also included weight shifting as a loading event but was within the range of forelimb 24-hour load rate (65 to 504 loading events/h; Table 1). A mean number of relocation steps or loading events for the hind limb of adult horses has not been reported. The 24-hour hind limb load rate we detected was lower than that for the forelimb. We determined that healthy adult horses with normal locomotor activity load their front limbs more often than their hind limbs and have higher limb loading activity during the daytime than the nighttime. Although the number of loading events measured in the forelimb and hind limb were significantly different, forelimb and hind limb loading patterns were similar. This information may be used for in vitro simulation of in vivo loading of limbs during cyclic biomechanical investigations and may be useful prognostically for clinical cases.

Differences in day and night periods included lack of specific scheduled activities and differences in amount of light in the hospital barn. Because horses were treated and monitored throughout the night, there was some artificial light in the hospital throughout the night period. However, the amount of light in the hospital was less at night than during daylight hours. Decreased human activity and decreased light during the night may have affected the load rate.

The specific activities scheduled during the day at this veterinary teaching hospital did not significantly influence load rate. Feeding times and quiet times in the hospital barn appeared to be associated with a lower load rate. It is possible that evaluation of a larger number of subjects would allow for detection of an activity effect on load rate for these 2 activities. Providing a hay bag for constant nibbling of feed may be beneficial for decreasing cycling of limbs for horses with musculoskeletal disorders. Decreasing human activity close to the horses may also result in decreased load rates and cycling of the limbs.

Horses that have abnormal locomotor activity may cycle the hind limb more often than the forelimb, and may cycle the limbs at a higher load rate than horses with normal locomotor activity (Table 1). Because locomotor behavior is likely important in influencing fatigue life of an implant and prognosis for fracture patients, these horses may be at an increased risk for implant failure and may be poor choices for fracture repair.

Implant failure is one complication that develops when equine fractures are treated with internal fixation.[5] However, environmental events, such as abnormal movements or an increased number of normal movements, that may contribute to these failures often remain unknown. Recognition of high activity periods of such horses and environmental influence of such activity may aid in decreasing the risk of fracture repair failure (eg, the fractured limb had an increase in load rate around 1 AM). If high activity were to be noticed consistently for several days, it may indicate a routine activity that is exciting the horse. Observation of the horse during critical times, with a video camera or a quiet human observer, may then be instituted. Patterns of loading activity as well as load rate for individual horses may also be beneficial in assessing the effect of a variety of surgical procedures, analgesics, joint medications, or behavioral drugs on locomotor activity.

The 24-hour load rate for the fractured and intact hind limbs were similar (Fig 2), indicating that during this period of postoperative recovery (2 weeks) the horse was comfortable using the stabilized limb. Even though this horse was confined to a sling, it was able to move around enough to have load rates in the low range of horses without sling confinement (Table 1).

Mean load rates for the forelimb and hind limb determined in this study can be used for in vitro simulation of cyclic loading of the limbs during biomechanical investigations. Biomechanical investigations of structures, including equine long bones, may involve application of a single force until failure of the structure develops (monotonic studies) or application of a force multiple times for a finite number of times (cyclic studies). Cyclic biomechanical studies represent typical loading of a structure during a certain period. To simulate in vivo cyclic loading of equine long bones accurately, knowledge of the number of times a bone or limb is cycled is important.

Horses with normal locomotor activity appear to be more active with their forelimbs than their hind limbs. Therefore, it would be inappropriate to use previously reported in vivo step rates for the forelimb[4] for in vitro simulation of the hind limb. Further knowledge of environmental influences and mechanical restraint influences on limb loading activity may be useful in managing horses with musculoskeletal disorders.

[a]Step Activity Monitor (SAM), Prosthetics Research Study Inc, Seattle, Wash.
[b]Sheet cotton, Union Wadding Co, Pawtuckett, RI.
[c]Brown gauze, Jorgensen Laboratories Inc, Loveland, Colo.
[d]Tally 1, General Binding Corp, Northbrook, Ill.

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