Changes in heart rate variability in horses during immersion in warm springwater

Tomohiro Kato, DVM; Hajime Ohmura, DVM, PhD; Atsushi Hiraga, DVM, PhD; Shinya Wada, DVM; Masayoshi Kuwahara, PhD; Hirokazu Tsubone, DVM, PhD

Objective—To determine the effects of immersion in warm springwater (38° to 40°C) on autonomic nervous activity in horses.

Animals—10 male Thoroughbreds.

Procedure—Electrocardiograms were recorded from horses for 15 minutes during a warm springwater bath after being recorded for 15 minutes during stall rest. Variations in heart rate (HR) were evaluated from the power spectrum in terms of low frequency (LF, 0.01 to 0.07 Hz) power and high frequency (HF, 0.07 to 0.6 Hz) power as indices of autonomic nervous activity.

Results—Mean (±SE) HR during stall rest and immersion in warm springwater was 31.1 ± 1.7 and 30.3 ± 1.0 beat/min, respectively. No significant difference was found between the HR recorded during stall rest and that recorded during immersion in warm springwater. The HF power significantly increased from 1,361 ± 466 milliseconds^2 during stall rest to 2,344 ± 720 milliseconds^2 during immersion in warm springwater. The LF power during stall rest and immersion in warm springwater was 3,847 ± 663 and 5,120 ± 1,094 milliseconds^2, respectively, and were not significantly different from each other. Similarly, the LF:HF ratio did not change during immersion in warm springwater. The frequency of second-degree atrioventricular block, which was observed in 2 horses, increased during immersion in warm springwater, compared with during stall rest.

Conclusions and Clinical Relevance—Increases in HF power indicates that the parasympathetic nervous activity in horses increases during immersion in warm springwater. Thus, immersion in warm springwater may provide a means of relaxation for horses. (*Am J Vet Res* 2003;64:1482–1485)

In general, it is thought that immersion in springwater has the influence of accelerating healing in instances of chronic disease. Although it is difficult to confirm it scientifically, it seems that the temperature and hydrostatic pressure of the water used for immersion are associated with acceleration of healing. The Joban Branch of Equine Research Institute of the Japan Racing Association was established in 1963 as a springwater recuperation center for racehorses needing prolonged rest and treatment for bone fractures, tendinitis, and other disorders of locomotion. The amenities at this center included a springwater sanatorium, swimming pool, a water treadmill, and track. Every year, 50 to 70 racehorses receive treatment and undergo rehabilitation at this facility, and most of them return to horse racing. The springwater treatment is intended to provide relaxation in addition to acceleration of healing.

There is considerable information on the effects of immersion in water in humans and dogs.[1-7] It has been shown that head-out immersion in thermoneutral water increases the stroke volume and cardiac output because the hydrostatic pressure induces a cephalad fluid shift.[1-7] It is thought that these physiologic changes influence an autonomic activity. Miwa et al[2] reported that cardiac sympathetic activity was suppressed and parasympathetic activity was enhanced during head-out immersion in humans. However, there is little information on the effects of immersion in warm springwater on the autonomic nervous activity in horses.

The purpose of the study reported here was to determine the effects of immersion in warm springwater (38° to 40°C) on the autonomic nervous activity in horses. We hypothesized that the parasympathetic nervous activity may be increased in horses during immersion in warm springwater as a result of relaxation. To confirm our hypothesis, the autonomic nervous activity was quantitatively evaluated by power spectral analysis of **heart rate (HR)** variability.

Materials and Methods

Horses—Experiments were performed on 10 male Thoroughbreds (mean [± SE] values, body weight of 494 ± 12 kg and 4.0 ± 0.3 years old) that had undergone > 3 weeks of warm springwater treatment. Horses had received treatments for bone fracture or tendinitis for at least 6 weeks (range, 6 to 48 weeks) and were given a warm springwater bath for 15 minutes every day for > 3 weeks. None of the horses was in acute pain or had any signs of being appreciably lame.

Springwater immersion—The bathtub measured 2.0-m long × 0.8-m wide × 1.15-m deep. Each horse entered backwards from the approach slope into the bathtub and was restrained with a front bar. The temperature of the water, which was obtained from a natural hot spring, was maintained between 38° and 40°C. The water depth was maintained so the height was level with the olecranons. Horses also received a shower of warm springwater on their backs (**Fig 1**).

Electrocardiographic recordings—Electrocardiograms were recorded for 15 minutes with a base-apex lead and a

Received January 27, 2003.
Accepted June 2, 2003.

From the Joban Branch, Equine Research Institute, Japan Racing Association, 71 Uenohara, Joban shiratori-machi, Iwaki-shi, Fukushima 972-8325 Japan (Kato, Wada); Equine Science Division, Hidaka Training and Research Center, Japan Racing Association, 535-13 Aza-Nishicha, Urakawa-cho, Urakawa-gun, Hokkaido 057-0171 Japan (Ohmura, Hiraga); Department of Comparative Pathophysiology, Graduate School of Agricultural and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657 Japan (Kuwahara, Tsubone).
Address correspondence to Dr. Ohmura.

Holter-type electrocardiograph.[a] During the ECG recordings, horses rested in stalls. A Holter-type ECG recorder was attached to a cloth covering the horses. Horses were free to move within the stall without any restriction. Following the recording during stall rest, a 15-minute ECG recording of the horses was also obtained while they were in the warm springwater bath.

Data analysis—Electrocardiograms were analyzed by use of the ECG processor analyzing system[b] described previously.[8] The program first detected R waves and calculated the R-R interval tachogram as the raw HR variability in sequential order. Any noise that the computer detected as an R wave was eliminated manually, and any variability that lay outside 75% to 125% of the mean was eliminated. From this tachogram, data sets of 512 points were resampled at 200 milliseconds. The tachogram length was selected as that which constituted the best compromise between the need for a large time-series to achieve the greatest accuracy and the ease of short recording periods.[9] Each set of data was applied to the Hamming window and the fast Fourier transform to obtain the power spectrum of the fluctuation. **Low frequency (LF)** power was set at 0.01 to 0.07 Hz, and **high frequency (HF)** power at 0.07 to 0.60 Hz. Power spectrum analysis of HR variability in the HF power is generally thought to primarily reflect parasympathetic nervous functions.[9] However, both the sympathetic and parasympathetic nervous systems have been shown to contribute to the LF power.[9] The HR, LF power, HF power, and LF:HF ratio were obtained from each recording. These values were used as the indices of autonomic nervous functions. The results were expressed as mean (± SE) values. Comparisons were made by use of a paired *t* test. A value of $P < 0.05$ was considered significant.

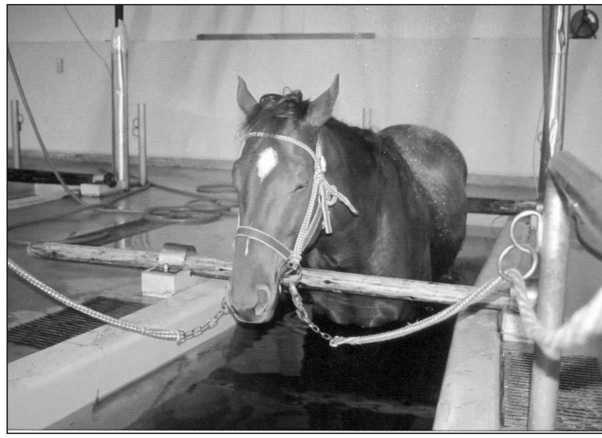

Figure 1—Photograph of a horse during immersion in a warm springwater bath. Notice that the water depth was maintained so the height was level with the olecranons. Horses also received a shower of warm springwater on their backs.

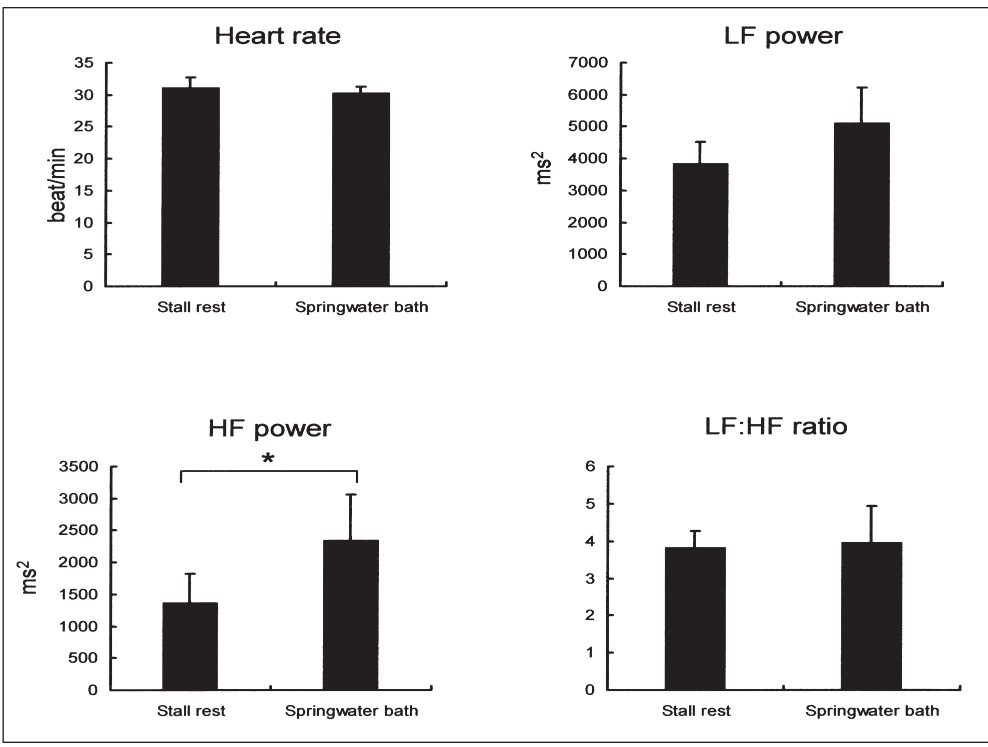

Figure 2—Heart rate (HR), low frequency (LF) power, high frequency (HF) power, and LF:HF ratio of horses during stall rest and during a warm springwater bath. *Significant ($P < 0.05$) difference between stall rest and warm springwater bath.

Results

All the horses remained calm during the warm springwater bath and did not have any sign of agitation or excessive movements despite being restrained in the bathtub. They appeared to be comfortable and relaxed during the warm springwater bath.

Second-degree atrioventricular block was observed in the ECG of 2 horses, both during stall rest and the warm springwater bath. The frequency of second-degree atrioventricular block was measured for 15-minute periods and was found to be higher during the immersion of the horses in warm springwater than during stall rest (45 and 17 vs 21 and 6 episodes of atrioventricular block/15 min, respectively). No arrhythmias were observed in any of the other horses.

The HR and the HR variability in the horses during stall rest and the warm springwater bath were evaluated (**Fig 2**). The mean (± SE) HR during stall rest and the warm springwater bath was 31.1 ± 1.7 and 30.3 ± 1.0 beat/min, respectively. Thus, no significant differences were found in HR between the 2 conditions. The HF power significantly increased from 1,361 ± 466 milliseconds^2 during stall rest to 2,344 ± 720 milliseconds^2 during the warm springwater bath. The LF power during stall rest and during the warm springwater bath was 3,847 ± 663 and 5,120 ± 1,094 milliseconds[2]. No significant differences were found in LF power between the 2 conditions. Similarly, the LF:HF ratio did not change during the warm springwater bath.

Discussion

The findings of our study reveal the effects of immersion in warm springwater on the autonomic nervous activity in horses. The HF power in the horses significantly increased during immersion in warm springwater, compared with that during stall rest, although the HR, LF power, and LF:HF ratio did not change significantly during immersion in warm springwater. In addition, the frequency of second-degree atrioventricular block increased during immersion in warm springwater, compared with during stall rest. These findings suggest that parasympathetic nervous activity increases during a warm springwater immersion bath, and that immersion in warm springwater may serve as an effective means of relaxation in horses.

Power spectrum analysis of HR variability has been shown to serve as an index of the relative magnitude of the autonomic nervous tone in dogs and humans.[9-11] We have established the power spectral analysis of HR variability as a method to assess the autonomic nervous functions in horses.[8] Power spectrum analysis of HR variability in the HF power is generally thought to primarily reflect parasympathetic nervous functions.[9] Alternatively, both the sympathetic and parasympathetic nervous systems have been shown to contribute to the LF power.[9] Therefore, the LF:HF ratio is considered an index of the cardiac sympathovagal balance. Moreover, we have recently applied power spectral analysis of HR variability to the evaluation of the influences of drugs in horses. Analysis of HR variability quantitatively reflected changes in the autonomic nervous activity, even when the HR did not change.[12,13] In the present study, this method accurately reflected the influence of a warm springwater bath on the autonomic nervous activity, even though the HR did not change significantly.

The LF:HF ratio has been suggested to be an index of the cardiac sympathovagal balance in humans.[9] By comparison, both LF power and HF power strongly reflect parasympathetic nervous activity in horses.[8,12] Therefore, we have to evaluate carefully the autonomic balance integrating LF, HF, and LF:HF ratio values together. The HF power significantly increased during immersion in warm springwater, compared with that during stall rest. Although no significant differences were found in LF power between the 2 conditions, the LF power during immersion was higher than that during stall rest. The LF:HF ratio did not change because the LF power and the HF power increased by similar magnitudes with immersion. We therefore conclude that the parasympathetic nervous activity increased in the horses during their immersion in warm springwater.

A few studies have previously described the effects of immersion in warm springwater on the circulatory system in horses. Richter et al[14] reported that the cardiac output and HR did not change significantly during hydropool recovery, compared with the changes observed during stall recovery from general anesthesia, although they also pointed out the limitations of the equipment used. The height of the water in the recovery pool used in their study was 4 to 6 cm over the withers. Hafford et al[3] reported that the HR decreased when the water level for immersion was increased in human subjects. We thought that the effect of the fluid shift from the limb veins following immersion in warm springwater might be only slight because the water level used in our study allowed immersion of approximately 10% of the body mass of the horse.[15] Additionally, Saeki[16] reported that parasympathetic nervous activity increased significantly during footbaths in human subjects. Therefore, we speculate that the increase in parasympathetic nervous activity may be a result of relaxation associated with immersion in warm springwater in horses.

McClintock et al[17] determined the optimal water temperature of floatation tanks in use for 21 days. They concluded that a water temperature of 36°C provided more patient comfort than that of 28°C and 32°C. Additionally, Sakurai et al[18] reported that the changes in the blood constituent of horses immersed in 37° to 40°C water were less than that in horses immersed in 40° to 43°C water or 43° to 45°C water. We used the same water temperature as Sakurai et al[18] because the water level used was the same as in our study. The increase in water temperature, which causes the increasing peripheral circulation, perspiration, and so on, has the possibility of increasing the sympathetic nervous activity. We speculate that sympathetic activity did not change because the LF:HF ratio did not change significantly during immersion in warm springwater in our study. However, further studies are needed to clarify the effects of water level and temperatures on the autonomic nervous activity and circulatory system in horses.

It was reported that respiratory tract disease was the most serious adverse effect of prolonged water immersion in a floatation tank.[17,19,20] Increasing extrathoracic pressure when horses are immersed up to the neck in water have been reported to result in changes in lung volumes and mechanics that may lead to pulmonary disease.[19] None of the horses examined in our study had any signs of respiratory tract disease. In our study, the water level was low, and the immersion period was only 15 minutes. Moreover, in our experience, we have never observed respiratory tract disease as a complication of a warm springwater bath in horses.

[a]SM-60, Fukuda Denshi Co Ltd, Tokyo, Japan.
[b]ECG processor analyzing system, Softron Co Ltd, Tokyo, Japan.

References

1. Miwa C, Sugiyama Y, Mano T, et al. Effects of aging on cardiovascular responses to gravity-related fluid shift in humans. *J Gerontol A Biol Sci Med Sci* 2000;55:M329–M335.
2. Miwa C, Sugiyama Y, Mano T, et al. Sympatho-vagal responses in humans to thermoneutral head-out water immersion. *Aviat Space Environ Med* 1997;68:1109–1114.
3. Hafford AA, Mohler JG, Harrison AC. Effects of water immersion on cardiac output of lean and fat male subjects at rest and during exercise. *Aviat Space Environ Med* 1991;62:123–127.
4. Yoshino H, Curran-Everett DC, Hong SK, et al. Altered heart rate-arterial pressure relation during head-out water immersion in conscious dog. *Am J Physiol* 1988;254: R595–R601.

5. Hajduczok G, Miki K, Hong SK, et al. Role of cardiac nerves in response to head-out water immersion in conscious dogs. *Am J Physiol* 1987;253:R242–R253.

6. Weston CF, O'Hare JP, Evans JM, et al. Haemodynamic changes in man during immersion in water at different temperatures. *Clin Sci* 1987;73:613–616.

7. O'Hare JP, Heywood A, Summerhayes C, et al. Observations on the effect of immersion in Bath spa water. *Br Med J* 1985; 291:1747–1751.

8. Kuwahara M, Hashimoto S, Ishii K, et al. Assessment of autonomic nervous function by power spectral analysis of heart rate variability in the horse. *J Auton Nerv Syst* 1996;60:43–48.

9. Pagani M, Lombardi F, Guzzetti S, et al. Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. *Circ Res* 1986; 59:178–193.

10. Akselrod S, Gordon D, Ubel FA, et al. Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. *Science* 1981;213:220–222.

11. Pomeranz B, Macaulay RJ, Caudill MA, et al. Assessment of autonomic function in humans by heart rate spectral analysis. *Am J Physiol* 1985;248:H151–H153.

12. Ohmura H, Hiraga A, Aida H, et al. Effects of repeated atropine injection on heart rate variability in Thoroughbred horses. *J Vet Med Sci* 2001;63:1359–1360.

13. Ohmura H, Hiraga A, Aida H, et al. Influence of quinidine and flecainide on autonomic nervous activity in Thoroughbred horses. *Vet Rec* 2003;152:114–116

14. Richter MC, Bayly WM, Keegan RD, et al. Cardiopulmonary function in horses during anesthetic recovery in a hydropool. *Am J Vet Res* 2001;62:1903–1910.

15. McClintock SA, Hutchins DR, Brownlow MA. Determination of weight reduction in horses in flotation tanks. *Equine Vet J* 1987; 19:70–71.

16. Saeki Y. The effect of foot-bath with or without the essential oil of lavender on the autonomic nervous system: a randomized trial. *Complement Ther Med* 2000;8:2–7.

17. McClintock SA, Hutchins DR, Brownlow MA. Studies on the optimal temperature of flotation tanks in the management of skeletal injuries in the horse. *Equine Vet J* 1986;18:458–461.

18. Sakurai N, Yamaoka S, Amada A, et al. Temperature of water and length of bathing in hot spring for horse. *Exp Rep Equine Health Lab* 1967;4:20–28.

19. McClintock SA, Hutchins DR, Laing EA, et al. Pulmonary changes associated with flotation techniques in the treatment of skeletal injuries in the horse. *Equine Vet J* 1986; 18:462–466.

20. Hutchins DR, McClintock SA, Brownlow MA. Use of flotation tanks for the treatment of seven cases of skeletal injury in horses. *Equine Vet J* 1987;19:73–77.

Correction: Identification of variations in SzP proteins of *Streptococcus equi* subspecies *zooepidemicus* and the relationship between protein variants and clinical signs of infection in horses

In the report, "Identification of variations in SzP proteins of *Streptococcus equi* subspecies *zooepidemicus* and the relationship between protein variants and clinical signs of infection in horses" (*AJVR*, Aug 2003, pp 976–981), Line 13 under the subheading "Bacterial strains" should read: "Prior to use, all isolates were reconfirmed as *S equi* subsp *zooepidemicus* on the basis of Gram stain reaction, production of B-hemolysis on sheep blood agar plates, a negative catalase reaction, presence of Lancefield group C antigen, and fermentation of lactose, maltose, and sorbitol but not trehalose."