Assessment of scintigraphic and thermographic changes after focused extracorporeal shock wave therapy on the origin of the suspensory ligament and the fourth metatarsal bone in horses without lameness

Simone K. Ringer, Dr med vet; Christoph J. Lischer, PD, Dr med vet; Gottlieb Ueltschi, Prof Dr med vet

Objective—To monitor the effect of focused extracorporeal shock wave therapy (ESWT) on bone and bone-tendon junction of horses without lameness by use of nuclear scintigraphy and thermography.

Animals—6 warmblood horses without lameness.

Procedure—The origin of the suspensory ligament at the metacarpus (OSL-MC) and the fourth metatarsal bone were treated at 2 time points (days 0 and 16) with 2,000 shocks applied by a focused ESWT device at an energy flux density of 0.15 mJ/mm^2. One forelimb and 1 hind limb were treated, and the contralateral limbs served as controls. To document the effect of focused ESWT, nuclear scintigraphy was performed on days -1, 3, 16 (before second ESWT), and 19. Thermography was performed on days -1, 0 (1 hour after first ESWT), 1, 3, 8, 16 (twice; before and 1 hour after second ESWT), and 19. On days 3, 16 (first scans), and 19, thermography was performed before scintigraphy.

Results—Scintigraphically, significant variations in radiopharmaceutical activity at the OSL-MC were detected in treatment and control limbs. No significant differences, however, in mean temperature or radiopharmaceutical activity could be detected by use of thermography or nuclear scintigraphy, respectively, between the treatment and control limbs at any time point in response to ESWT.

Conclusions and Clinical Relevance—After 2 treatments of focused ESWT, no physiologic effect on the studied structures could be demonstrated by use of nuclear scintigraphy or thermography. Results of this study indicate that at currently used ESWT settings, no damage to the bone or bone-tendon junction should occur. (*Am J Vet Res* 2005;66:1836–1842)

Extracorporeal shock wave therapy (ESWT) has been used successfully in human medicine for many years as a noninvasive technique for the fragmentation of uroliths so that they can be eliminated through the urinary tract.[1] Extracorporeal shock wave therapy has also been used to fragment gallstones[2] and sialoliths.[3] During lithotripsy, part of the applied extracorporeal shock wave energy reaches the pelvis. As a result of this, studies about the effects of ESWT on bone structure have become necessary.

Results of early investigations of ESWT on intact bone structures revealed an osteogenic effect on the femur and pelvis of rabbits and Beagles.[a] Results of further in vivo studies revealed a positive effect on fracture healing in rats, sheep, and dogs[4-6] and healing of hypertrophic nonunion fractures in dogs.[7] Although the mechanism of action remains unknown, Valchanou and Michailov[8] reported successful treatment of delayed healing or nonunion fractures in humans. Other investigators later confirmed their findings.[9,10] Shock waves are also routinely applied to treat common orthopaedic conditions in humans, including epicondylitis humeri radialis (tennis elbow), epicondylitis humeri ulnaris (golfer's elbow), plantar fasciitis (heel spurs), and tendinosis calcarea.[11]

The applications in human orthopaedics point toward 2 major groups of indications: first, the stimulation of bone formation and second, treatment of insertional desmitis and tendonitis. On the basis of satisfactory results in human medicine, shock wave technology is being used for the treatment of equine musculoskeletal diseases. Clinically, multiple investigators have observed the potential benefits of ESWT in treating horses with chronic proximal suspensory desmitis.[12-14,b-f] To date, only a few experimental studies have documented the effect of ESWT on equine bone. Most investigations have been focused on morphologic changes. Several weeks after ESWT of the equine metatarsus or metacarpus, an osteogenic stimulation was observed in 1 study,[15] but no evidence of microfractures or changes in material properties was observed after ESWT of ex vivo equine bone in 2 other studies.[16,17] In contrast, results of another study[18] revealed small but substantial effects on bone microcracks after application of a high number of shock waves (9,000 shock waves/treatment) to the distal aspect of equine cadaver limbs.

Microcrack accumulation impairs the mechanical properties of bone by reducing its elastic modulus.[19] Creation of microcracks during ESWT may increase the risk of fracture. Extracorporeal shock wave therapy is frequently used for the treatment of sport horses. However, the creation of microcracks as a result of ESWT may be a risk for fractures in horses that are in training during or soon after treatment.

The purpose of the study reported here was to monitor the effect of focused ESWT on bone and bone-

Received July 14, 2004.
Accepted December 6, 2004.
From the Equine Hospital, VETSUISSE Faculty, University of Zurich, Winterthurerstrasse 260, 8057 Zürich, Switzerland (Ringer, Lischer); and Division of Radiology, Department of Clinical Veterinary Medicine, VETSUISSE Faculty, University of Berne, Länggassstrasse 124, 3001 Berne, Switzerland (Ueltschi).
Supported by High Medical Technologies AG, Lengwil, Switzerland.
Address correspondence to Dr. Lischer.

tendon junction of horses without lameness by use of nuclear scintigraphy and thermography. To assess treatment risks, we selected areas of possible clinical applications, such as the **fourth metatarsal bone (MTIV)** and the **origin of suspensory ligament at the metacarpus (OSL-MC)**. Treatment locations were chosen on the basis of therapeutic results reported after ESWT in horses with chronic proximal suspensory desmitis[12-14,b-f] and findings of stimulation of osteogenesis reported for intact[15,20,a] and healing bone.[4-7]

Materials and Methods

Animals—Six warmblood horses (2 mares, 3 geldings, and 1 stallion) with normal findings on physical and hematologic examinations were selected for the study. They had a mean age of 6.2 years (range, 3 to 8 years) and a mean body weight of 513 kg (range, 445 to 654 kg). Horses were kept on pasture and free from detectable lameness when moving at a trot in hand on a hard surface while being examined by 1 of the authors (SKR). Responses to flexion tests of all 4 limbs were negative. Anatomic locations where ESWT was applied were palpated carefully and examined radiographically and ultrasonographically to rule out any pathologic condition. For the duration of the study, horses were stalled (individual box stalls, 4 × 4 m) and hand walked for 30 minutes every day. The local ethical animal welfare committee approved the trial.

ESWT—Extracorporeal shock wave therapy was performed initially on day 0, and the same treatment was repeated on day 16. To obtain maximum skin contact and minimum loss of energy during ESWT, hair at the treatment site was clipped. Because differences in hair length cause important artifacts in thermography, all limbs were clipped up to the level of the radius and tibia. Ultrasound transmission gel[g] was applied before ESWT.

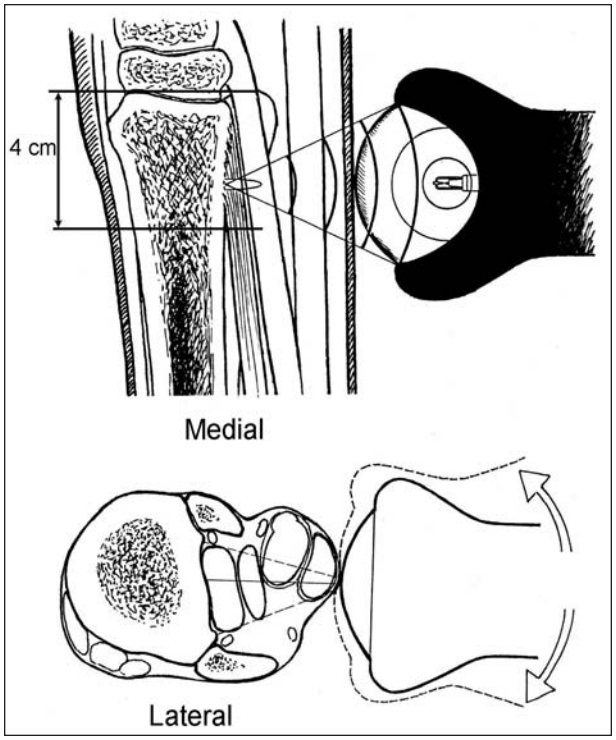

Figure 1—Illustration of the 35-mm probe placement for the treatment of the origin of the suspensory ligament at the metacarpus. Extracorporeal shock wave therapy was performed on a 4-cm area (longitudinal view [top panel]). To treat the whole area of the origin of the suspensory ligament between the second and fourth metacarpal bones, the angle of the probe was changed during the treatment (transverse view [bottom panel]; arrows). Notice the range of motion of the probe (dotted lines).

One hind limb and 1 forelimb were randomly selected for application of ESWT, and the opposite limbs served as the nontreated controls. Extracorporeal shock wave therapy was performed with the horse standing, sedated by IV administration of a combination of xylazine (0.4 mg/kg)[h] and levomethadone hydrochloride (0.05 mg/kg)[i] or of detomidine hydrochloride (0.01 mg/kg)[j] and butorphanol (0.012 mg/kg).[k] Horses were treated by an electrohydraulic shock wave generator.[l]

For ESWT of the 2 selected locations, 2,000 shock waves with an energy flux density of 0.15 mJ/mm^2 and a frequency of 240 Hz were applied. The same author (SKR) always applied the treatment. The probe was held in place with light pressure on the handpiece. Each treatment took 8.33 minutes. The OSL-MC was treated by use of a probe with a penetration depth of 35 mm (ie, 35-mm probe; **Figure 1**). On the basis of the measurements from the external surface of the limb and from radiographs, a 2-cm area that was equidistant from the proximal border of the MTIV and the apex of the lateral proximal sesamoid bone was treated with a probe with a penetration depth of 5 mm (ie, 5-mm probe). At -6 dB, the 5- and 35-mm probes had a maximal focal volume per treatment area of 6.6, 6.6, and 48.3 mm along the x-, y-, and z-axes, respectively.

Nuclear scintigraphy—Relative to ESWT (days 0 and 16), nuclear scintigraphy was performed on days –1, 3, 16 (before second ESWT), and 19. On days 3, 16 (first scans), and 19, scintigraphy was performed after thermography.

Bandages were applied distal to the carpus and tarsus to the coronary band 12 to 18 hours prior to injection of the radiopharmaceutical to improve radiopharmaceutical uptake and to prevent contamination by urine. Each horse received a measured dose of 100 mCi (3,700 MBq) of technetium Tc 99m disodium oxidronate via an IV injection into the jugular vein 2.5 hours before the scan. For image acquisition, horses were anesthetized to decrease motion artifacts. Treatment and control limbs were imaged so that comparisons of radiopharmaceutical uptake could be made. Horses were placed in left lateral recumbency to perform scans of the right limbs and then turned to right lateral recumbency for scans of the left limbs. The gamma camera[m] was equipped with a general-purpose, low-energy collimator. Total number of counts was kept constant; 600,000 counts were taken on all images (256 × 256 matrix). No motion correction program was used because horses were examined under general anesthesia. The images obtained were a lateral, dorsal, and palmar view of each forelimb as well as a plantar and lateral view of the hind limbs.

Images were transferred to a workstation for processing and analysis by use of a nuclear medicine software program.[n] Activities of treatment and control limbs were compared. Quantitative image analysis was performed by use of a **region of interest (ROI)** method and a **profile (PRO)** analysis method. Radiopharmaceutical activity ratios of the studied regions to a reference area, which was unlikely to change, were calculated to determine whether changes in radiopharmaceutical uptake at a site reflected a real local change rather than a generalized phenomenon of the entire limb. The region of reference had to be in the same limb but at a distance from the ROI to avoid interference. The mid area of the third metacarpal bone and the region immediately distal to the mid area of the third metatarsal bone were chosen as reference sites in the forelimbs and hind limbs, respectively. For the lateral view of the hind limb, the reference area was cen-

tered in the middle of the proximal part of the third metatarsal bone because the distance to the ROI was not great enough if placed more distally.

The ROI was manually drawn at the OSL-MC and MTIV of the treatment and control limbs. The scaling of each image was adjusted to determine accurately the boundary of each ROI. The ROI and the regions of reference were always drawn by the same author (SKR) who was blinded to control and treatment limbs.

On the dorsal and palmar views of the forelimb, the ROI was centered over the OSL-MC on the third metacarpal bone, without including the second and fourth metacarpal bones. The reference area was centered on the middle of the third metacarpal bone, without including the medial and lateral cortex.

On the lateral view of the forelimb, the ROI was placed over the region of the OSL-MC that included 50% of the width of the third metacarpal bone. The reference regions were centered in the middle of the third metacarpal bone, without including the dorsal and palmar cortex.

In the hind limbs, the ROI was placed over the MTIV, covering a length of 4 cm that was equidistant from the proximal border of the MTIV and the apex of the lateral proximal sesamoid bone. The reference areas were centered on the third metatarsal bone as described. The dorsal and plantar and the lateral and medial cortices of the third metatarsal bone were not included on the lateral and plantar views, respectively. The mean count per pixel was recorded. Radiopharmaceutical activity ratios of the ROI to the corresponding region of reference on each view were calculated (ROI/reference area).

Profile analysis consisted of evaluation of horizontal slices of a fixed height (5 pixels) at the treatment and reference sites. The location of the slices was the same as for the ROI method. A software program[n] was used to calculate a graphic representation of the counts per pixel, which were a profile of the radioactivity of the slice. Profile analysis was limited to a width of 10 pixels centered in the areas of interest (ie, treatment and reference). As in the ROI method, radiopharmaceutical activity ratios of the region of reference to the site of treatment were calculated. Integral counts were used for the creation of the ratios.

Thermography—Relative to ESWT (days 0 and 16), thermography was performed on days –1, 0 (1 hour after first ESWT), 1, 3, 8, 16 (twice; before and 1 hour after second ESWT), and 19. On days 3, 16 (first scans), and 19, thermography was performed before scintigraphy.

Thermographic scans were performed in a draft-free area with low light and a temperature of approximately 20°C. An acclimation period of 10 minutes was provided before the scans. Thermograms were obtained by use of a thermal imaging camera[o] with a distance of 2 meters between the camera and the limb. Scans of the dorsal and lateral views of the distal portion of the forelimbs and plantar and lateral views of the distal portion of the hind limbs were performed. Images were downloaded to a flash memory card and viewed and analyzed on a laptop computer[p] by use of a software program.[q] Thermographic scans were evaluated by use of the ROI method in a similar way as described for scintigraphic images. However, instead of manually drawn regions, mean temperatures of rectangular areas placed over the studied and reference regions were analyzed. Reference regions for thermographic evaluation were the distal portion of the third metacarpal bone or third metatarsal bone of the forelimbs or hind limbs, respectively. Mean temperatures of the areas were recorded, and mean temperature ratios of the studied areas to the reference regions were calculated.

Table 1—Mean ± SD scintigraphic radiopharmaceutical activity ratios as obtained by the region of interest (ROI) method for treatment and control limbs at different times in relation to the first (day 0) and second (day 16) extracorporeal shock wave therapy (ESWT).

		Metacarpal views			Metatarsal views	
Day	Limb	Dorsal	Palmar	Lateral	Plantar	Lateral
–1	Treatment	1.047 ± 0.171	0.893 ± 0.127	1.342 ± 0.481	1.081 ± 0.221	1.060 ± 0.191
	Control	1.087 ± 0.282	0.996 ± 0.116	1.265 ± 0.519	1.066 ± 0.148	1.155 ± 0.092
3	Treatment	1.184 ± 0.173	1.033 ± 0.103	1.412 ± 0.236	1.165 ± 0.116	1.145 ± 0.128
	Control	1.216 ± 0.177	1.073 ± 0.101	1.435 ± 0.333	1.154 ± 0.140	1.253 ± 0.145
16	Treatment	1.377 ± 0.190*	1.200 ± 0.235*	1.532 ± 0.316	0.982 ± 0.112	1.054 ± 0.174
	Control	1.495 ± 0.183	1.163 ± 0.197	1.500 ± 0.336	1.037 ± 0.138	1.138 ± 0.143
19	Treatment	1.281 ± 0.376†	1.026 ± 0.156†	1.342 ± 0.263	1.121 ± 0.134	1.201 ± 0.243
	Control	1.048 ± 0.052	1.038 ± 0.102	1.251 ± 0.275	1.097 ± 0.129	1.194 ± 0.252

*Significant increase in bone activity, compared with the day before the first ESWT (day –1). †Significant decrease in bone activity, compared with before the second ESWT (day 16).

Table 2—Mean ± SD scintigraphic radiopharmaceutical activity ratios as obtained by the profile (PRO) analysis method for treatment and control limbs at different times in relation to the first (day 0) and second (day 16) ESWT.

		Metacarpal views			Metatarsal views	
Day	Limb	Dorsal	Palmar	Lateral	Plantar	Lateral
–1	Treatment	0.991 ± 0.236	0.920 ± 0.130	1.036 ± 0.340	0.839 ± 0.134	0.714 ± 0.075
	Control	0.989 ± 0.242	0.977 ± 0.219	0.942 ± 0.291	0.780 ± 0.057	0.718 ± 0.128
3	Treatment	1.171 ± 0.186	1.109 ± 0.124	1.114 ± 0.313	0.802 ± 0.089	0.755 ± 0.123
	Control	1.089 ± 0.124	1.057 ± 0.120	1.003 ± 0.111	0.873 ± 0.074	0.771 ± 0.086
16	Treatment	1.366 ± 0.274*	1.296 ± 0.237*	1.096 ± 0.219	0.747 ± 0.056	0.660 ± 0.075
	Control	1.417 ± 0.307	1.289 ± 0.199	1.084 ± 0.220	0.753 ± 0.112	0.662 ± 0.107
19	Treatment	1.053 ± 0.197†	1.011 ± 0.185†	0.997 ± 0.206	0.835 ± 0.174	0.772 ± 0.181
	Control	1.020 ± 0.068	1.029 ± 0.137	0.989 ± 0.175	0.816 ± 0.141	0.824 ± 0.220

See Table 1 for key.

Table 3—Mean ± SD temperature ratios as obtained by thermography for treatment and control limbs at different times in relation to the first (day 0) and second (day 16) ESWT.

		Metacarpal views		Metatarsal views	
Day	**Limb**	**Dorsal**	**Lateral**	**Plantar**	**Lateral**
–1	Treatment	1.017 ± 0.048	1.050 ± 0.067	1.031 ± 0.058	1.178 ± 0.113
	Control	1.008 ± 0.087	1.046 ± 0.079	1.024 ± 0.057	1.136 ± 0.189
0 (1 hour after ESWT)	Treatment	1.111 ± 0.302	1.100 ± 0.200	1.013 ± 0.010	1.170 ± 0.169
	Control	1.008 ± 0.084	1.041 ± 0.078	0.967 ± 0.047	1.044 ± 0.081
1	Treatment	0.995 ± 0.041	1.068 ± 0.089	1.002 ± 0.063	1.141 ± 0.095
	Control	1.112 ± 0.305	1.156 ± 0.288	1.046 ± 0.108	1.145 ± 0.178
3	Treatment	0.979 ± 0.043	0.986 ± 0.035	0.997 ± 0.041	1.043 ± 0.079
	Control	0.963 ± 0.080	0.995 ± 0.031	1.007 ± 0.067	1.029 ± 0.072
8	Treatment	1.108 ± 0.243	1.148 ± 0.209	1.007 ± 0.031	1.157 ± 0.129
	Control	1.111 ± 0.272	1.114 ± 0.207	1.019 ± 0.096	1.194 ± 0.229
16 (before ESWT)	Treatment	0.964 ± 0.024	1.003 ± 0.038	1.008 ± 0.016	1.053 ± 0.053
	Control	0.986 ± 0.019	0.991 ± 0.056	1.006 ± 0.011	1.027 ± 0.028
16 (1 hour after ESWT)	Treatment	0.970 ± 0.048	1.004 ± 0.016	0.989 ± 0.060	1.155 ± 0.106
	Control	0.983 ± 0.045	1.011 ± 0.061	1.007 ± 0.029	1.092 ± 0.069
19	Treatment	1.003 ± 0.018	1.024 ± 0.022	1.014 ± 0.024	1.082 ± 0.038
	Control	0.989 ± 0.019	1.005 ± 0.023	0.999 ± 0.012	1.072 ± 0.030

Table 4—Correlation coefficients between evaluation methods for analysis by use of scintigraphic ROI, scintigraphic PRO, and thermography.

	Metacarpal views			Metatarsal views	
Comparisons	**Dorsal**	**Palmar**	**Lateral**	**Plantar**	**Lateral**
ROI to PRO	0.763*	0.717*	0.706*	0.642*	0.427*
ROI to thermography	–0.251	NO	–0.330	0.127	–0.188
PRO to thermography	–0.225	NO	–1.96	0.103	–0.066

*Significant ($P < 0.05$) correlation between methods.
NO = Not obtained (palmar thermographic views of the metacarpus were not obtained).

Statistical analyses—Radiopharmaceutical activity and mean temperature ratios were analyzed over time by use of repeated-measures ANOVA[r] with treatment (ESWT or control) and time (day of study) as fixed effects. Values of $P < 0.05$ were considered significant. The Fisher protected least significant difference test and the Bonferroni-Dunn test were performed as post hoc tests with a significance level set at $P < 0.05$. Correlation analysis with the Pearson correlation test was used to compare scintigraphic results by use of the ROI method with that of PRO analysis as well as to compare findings on scintigraphy with those of thermography. Significance level for the correlation analysis was set at $P < 0.01$. Each view was analyzed separately for both scintigraphic analysis methods and for thermography.

Results

Scintigraphic ROI (**Table 1**) and PRO analysis (**Table 2**) data were obtained. No significant difference was found between the treatment and control limbs for any view at any time point. The influence of treatment (ie, first or second ESWT) on radiopharmaceutical activity ratios obtained from dorsal and palmar views of the forelimbs was significant. The radiopharmaceutical activity 16 days after the first ESWT was significantly increased, compared with activity on the day before the first ESWT. Additionally, a significant decrease in bone activity was observed 3 days after the second ESWT, compared with the radiopharmaceutical activity on day 16 before the second ESWT. No significant differences in radiopharmaceutical activity ratios at different time points were obtained from the lateral views of the forelimb and hind limb or from the plantar view of the hind limbs.

Thermographic data of 4 views (forelimb, dorsal and lateral views; hind limb, plantar and lateral views) were obtained (**Table 3**). No significant differences in mean temperature ratios were found between the control and treatment limbs at any time point.

Correlation data were obtained (**Table 4**). A significant positive correlation was found between the results of the 2 scintigraphic methods (ROI method and PRO analysis) for all views studied. No correlation was found between the results of scintigraphy and thermography.

Discussion

No significant difference in radiopharmaceutical activity or mean temperature between treatment and control limbs could be demonstrated by use of scintigraphy or thermography, respectively, after ESWT. Treatment had a significant effect on the radiopharmaceutical activity ratios of the OSL-MC obtained on the scintigraphic dorsal and palmar views but not on the lateral views. Changes in activity refer to an increase or decrease in the treatment region for control and treatment limbs. It does not refer to the entire limb because of the use of ratios. Changes in radiopharmaceutical activity indicate that a variation in local metabolism or blood flow in the region of the OSL-MC has occurred,

compared with that of the mid area of the metacarpus. A significant increase in radiopharmaceutical activity was found from before ESWT to 16 days after the first ESWT; a significant decrease in radiopharmaceutical activity was found 3 days after the second ESWT, compared with before the second ESWT on day 16. Radiopharmaceutical activity changes observed at the OSL-MC could be the result of normal variations in bone metabolism. It is unlikely, however, that the variations are the result of exercise because the horses were stalled and hand walked during the study period. Another possibility is that the local radiopharmaceutical activity changes are related to the mechanism of action of ESWT. The bilateral changes in bone activity after a unilateral treatment could be explained by a phenomenon found with acupuncture. Stimulation of acupuncture points can cause a stimulation of the same point on the contralateral limb.[21] However, from our results, we cannot determine which mechanism of action could lead to these bilateral changes in local bone activity after a unilateral ESWT treatment of the OSL-MC. No treatment effect was observed on the lateral views, probably as a result of superimposition of the second and fourth metacarpal bones with the suspensory ligament.

No significant treatment influence was observed at the MTIV, probably because the effect on bone-tendon junction is different from that on bone. Shock waves have their greatest impact when they meet an interface of differing acoustic impedance, where changes in tissue density are found that cause changes in impedance (eg, the interface between soft tissue and bone).[22]

Little information on the reliability of the quantitative scintigraphic evaluation methods exists. Therefore, we applied 2 methods that were available on the software program used in our study.[n] On the basis of the high positive correlation found between the results obtained with the 2 methods (ie, ROI method and PRO analysis), we consider both valuable methods for objective evaluation of scintigrams. In our experience, the ROI method is easier to perform and less time consuming. No correlation was found between the results of the scintigraphic methods and thermography. Thermography measures only superficial heat, whereas scintigraphy measures radiopharmaceutical activity of deeper structures. The correlation between the use of scintigraphy with that of thermography would have been different if scintigraphy had been performed during the soft tissue phase. Because artifacts are a frequent problem in the evaluation of thermograms, artifacts may have contributed to the lack of correlation between the use of scintigraphy and thermography. Another possibility is that the chosen quantitative method is not adequate for evaluation of thermograms.

Nuclear scintigraphy is a sensitive method for assessment of early changes in bone metabolism.[23] The osteogenic effect described after ESWT is expected to result in local increase in blood flow and bone metabolism measurable with scintigraphy. Scintigraphy was performed 2.5 hours after radiopharmaceutical administration (bone phase). During bone phase, the bone-to-soft tissue contrast is highest, allowing an optimal judgment of bone activity. The bone is a dynamic tissue in constant state of remodeling. Hence, we calculated a ratio between the treatment region and a reference region to eliminate these physiologic changes, allowing comparison of different limbs at different times.

Thermography is a noninvasive technique that measures infrared emissions, producing a graphic representation of the surface temperature of the skin.[24,25] Infrared radiation is emitted proportional to the temperature.[26] Skin derives its heat from the local circulation and tissue metabolism, so the emitted infrared radiation is correlated to these 2 factors.[25] Because an increase in blood flow and tissue metabolism after ESWT is expected,[27] this technique should reveal effects of ESWT. To avoid artifacts, the images were performed in a controlled environment, as already described. After removing the bandages, an increase in heat was detected. This postbandaging increase in temperature was controlled by use of ratios and a control limb. Body temperatures of healthy horses (without lameness) are not constant over time; physiologic variations in body temperatures occur. Ratios were used in our study to eliminate physiologic variations of body temperature.

The mechanisms by which shock waves affect bone are minimally understood. It has been postulated that an osteogenetic response is induced by microfissures.[8] Results of an in vitro experiment[28] reveal the formation of bone chips and fractures after ESWT, but results of in vivo studies[4-7,15,a] do not support microfractures or microfissures as the mechanism of osteogenesis. Studies of the effect of ESWT on bone have been mostly limited to smaller laboratory species, primarily sheep, dogs, rabbits, and rodents. McClure et al[15] evaluated the effect of high-energy ESWT on the equine third metacarpal bone. In agreement with findings of earlier studies, they concluded that the primary mechanism for stimulation of osteogenesis is not the induction of microfractures. Therapeutic amounts of ESWT did not create microcracks in ex vivo shocked equine bone.[16,17]

The selected energy level is important. In a study[29] involving the application of shock waves on bones, it was determined that relatively low energy levels do not stimulate bone formation, whereas those that use a high energy level result in bone formation. Other studies[15,28] describe dose-dependent bone changes. It has also been reported that after penetrating 1 cm of bone, a shock wave energy reduction of 80% occurs.[a] On the basis of this, it is probable that high energies are necessary to induce osteogenesis of equine bone. McClure et al[15] did see more activated osteons in ESWT-treated limbs at 30 days after treatment, but they used energies as high as 0.89 mJ/mm^2. With our shock wave machine, we can generate energies only up to 0.15 mJ/mm^2; this is an energy level frequently described for the treatment of injuries in horses. The number of shock waves applied during each treatment is also important to consider; microcracks have been observed in vitro after 9,000 shocks.[18] Such a high number of shocks are usually not applied therapeutically in 1 treatment.

Increase in number of capillaries and dilatation of microvessels has been described 18 hours after low-

energy ESWT of skin wounds in pigs.[27] One possible effect of shock wave therapy is a neovascularization at the bone–soft tissue junction, as described in dogs after low-energy ESWT.[30] The regions studied by Wang et al[30] underwent prior surgery, so it is not clear if neovascularization occurred secondary to surgery or was induced by ESWT. In our study, maybe a scintigraphic study during the vascular or soft tissue phase would have revealed an increase in vascularization of the treatment region but it was impossible to have the horses in anesthesia during all 3 phases (ie, 4 to 5 hours of anesthesia).

The exact effect of shock waves is still unknown and may not be detectable by use of scintigraphy or thermography. Alterations in substance P release,[31] increase in nitric oxide, and release of cytokines such as tumor growth factor-β_1 as well as destruction of abnormal metaplastic tissue in horses with chronic proximal suspensory desmitis have been described after ESWT.[32] Extracorporeal shock wave therapy is reported to have analgesic and osteogenic properties; some authors postulate that only an analgetic effect of ESWT occurs.[11]

Ultrasonography could have been performed in our study after ESWT to see anatomic alterations. A controlled study[33] in horses that documents the effect of ESWT on healing of previously damaged suspensory ligament by use of ultrasonography has been conducted. Ultrasonographic and histologic examination after the treatment of smaller rabbit tendons with low-energy flux densities (0.08 mJ/mm^2) revealed no changes. Middle-energy flux densities (0.28 mJ/mm^2) revealed only a transient swelling of the tendon with a minor inflammatory reaction, but after high-energy flux densities (0.60 mJ/mm^2), formation of paratendinous fluid with a significant increase in the diameter of the tendon was described.[34] We would not expect sonographic changes in the large equine tendon with our ESWT settings.

In summary, we were not able to demonstrate an effect on the treated limb, compared with the control limb, by use of thermography or nuclear scintigraphy. Indeed, previously damaged tissues may respond differently[16] because intensification of shock wave–associated pressure changes may occur, for example, at a fracture site through large changes in acoustic impedance. On the basis of our results, it is unlikely that focused ESWT with 2,000 shocks/treatment and an energy flux density of 0.15 mJ/mm^2 damages equine cortical bone or bone-tendon junction. Therefore, shock wave therapy can be used safely in horses. If bone stimulation after ESWT is intended, higher energy levels or larger number of shocks per treatment should be considered.

a. Graff J. *Die Wirkung hochenergetischer Stosswellen auf Knochen- und Weichteilgewebe*. Urologische Klinik, Ruhr-University Bochum, Bochum, Germany, 1989.
b. Boening KJ, Löffeld S, Weitkamp K. Contribution to extracorporeal shock wave treatment in equine orthopedics (abstr), in *Proceedings*. 6th Cong World Equine Vet Assoc 1999;9:555.
c. Brems R, Cartanjen B, Kaminski M. Extracorporeal shock wave therapy (abstr), in *Proceedings*. 6th Cong World Equine Vet Assoc 1999;9:229.
d. Crowe OC, Freeman S, Eliashar E, et al. Extracorporeal shockwave therapy for the treatment of hindlimb proximal suspensory desmitis (abstr), in *Proceedings*. 40th Congr Br Equine Vet Assoc 2001;197.
e. Siedler C. *Proximal suspensory desmitis in the horse: extracorporeal shock wave therapy compared to injections according to Dr. Müller-Wolfahrt*. Doctoral thesis, Universitätsklinik für Orthopädie bei Huf- und Klauentieren und Institut für Anatomie, Veterinärmedizinische Universität Wien, Vienna, 2002.
f. Boening KJ, Löffeld S, Weitkamp K, et al. Radial extracorporeal shock wave therapy for chronic insertion desmopathy of the equine suspensory ligament-a controlled study (abstr), in *Proceedings*. 4th Cong Int Soc Musculoskeletal Shockwave Ther 2001;12.
g. Aquasonic 100, Parker Laboratories Inc, Orange, NJ.
h. Xylazin Streuli, G Streuli & Co AG, Uznach, Switzerland.
i. L-Polamivet, VETERINARIA AG, Zürich, Switzerland.
j. Domosedan, Pfizer SA, Zürich, Switzerland.
k. Morphasol, provided by Dr. E. Gräub AG, Bern, Switzerland.
l. Equitron, HMT High Medical Technologies AG, Lengwil, Switzerland.
m. GE Millennium RPR, GE Medical Systems, Milwaukee, Wis.
n. Hermes, HERMES NUCLEAR DIAGNOSTICS, Stockholm, Sweden.
o. Therma CAM PM695, FLIR SYSTEMS ALTRONA vision AG, Zürich, Switzerland.
p. Notebook Evo N1020v, COMPAQ Computer Corp, Bern, Switzerland.
q. Irwin OLE 1.1, AGEMA Infrared Systems AB, Danderyd, Sweden.
r. StatView, version 5.0, SAS Institute Inc, Cary, NC.

References

1. Chaussy CH, Brendel W, Schmiedt E. Extracorporeally induced destruction of kidney stones by shock waves. *Lancet* 1980;2:1265–1268.
2. Sauerbruch T, Delius M, Paumgartner G, et al. Fragmentation of gallstones by extracorporeal shock waves. *N Engl J Med* 1986;314:818–822.
3. Iro H, Nitsche N, Schneider HT, et al. Extracorporeal shockwave lithotripsy of salivary gland stones. *Lancet* 1989;2:115.
4. Haupt G, Haupt A, Ekkernkamp A, et al. Influence of shock waves on fracture healing. *Urology* 1992;39:529–532.
5. Ekkernkamp A, Bosse A, Haupt G, et al. Effects of extracorporeal shock waves on standardized tibial fractures in sheep. In: Ittel TH, Sieberth HG, Matthiass HH, eds. *Aktuelle Aspekte der Osteologie*. Berlin: Springer-Verlag Inc, 1992;307–310.
6. Wang CJ, Huang HY, Chen HH, et al. Effect of shock wave therapy on acute fractures of the tibia: a study in a dog model. *Clin Orthop Relat Res* 2001;387:112–118.
7. Johannes EJ, Kaulesar Sukul DM, Matura E. High-energy shock waves for the treatment of nonunions: an experiment on dogs. *J Surg Res* 1994;57:246–252.
8. Valchanou VD, Michailov P. High energy shock waves in the treatment of delayed and nonunion of fractures. *Int Orthop* 1991;15:181–184.
9. Schleberger R, Senge T. Non-invasive treatment of long-bone pseudoarthrosis by shock waves (ESWL). *Arch Orthop Trauma Surg* 1992;111:224–227.
10. Vogel J, Rompe JD, Hopf C, et al. High-energy extracorporeal shock wave therapy (ESWT) for treatment of pseudarthrosis [German]. *Z Orthop Ihre Grenzgeb* 1997;135:145–149.
11. Haist J, von Keitz-Steeger D. Stosswellentherapie knochennaher Weichteilschmerzen- Ein neues Behandlungskonzept. In: Chaussy C, Eisenberger F, Jocham D, et al, eds. *Die Stosswelle-Forschung und Klinik*. Tubingen, Germany: Attempto Verlag, 1995;162–165.
12. Boening KJ, Löffeld S, Weitkamp K, et al. Radial extracorporeal shock wave therapy for chronic insertion desmopathy of the proximal suspensory ligament, in *Proceedings*. 46th Annu Meet Am Assoc Equine Pract 2000;203–207.
13. Crowe OM, Dyson SJ, Wright IM, et al. Treatment of chronic or recurrent proximal suspensory desmitis using radial pressure wave therapy in the horse. *Equine Vet J* 2004;36:313–316.

14. Loffeld S, Boening KJ, Weitkamp K, et al. Radial extracorporeal shock wave therapy for horses with chronic insertion desmopathy of the proximal suspensory ligament—a controlled study. *Pferdeheilkunde* 2002;18:147–154.

15. McClure S, VanSickle D, White R. Extracorporeal shock wave therapy and the equine metacarpus/metatarsus, in *Proceedings*. Symp Extracorporeal Shock Wave Users Vet Med 2002;19–22.

16. Bathe AP, Collings A, Boyde A. Ex-vivo study into the microstructural effects of extracorporeal shock wave therapy on equine bone, in *Proceedings*. 11th Annu Meet Eur Coll Vet Surg 2002;165–170.

17. Pauwels FET, McClure SR, Amin V, et al. Effects of extracorporeal shock wave therapy and radial pressure wave therapy on elasticity and microstructure of equine cortical bone. *Am J Vet Res* 2004;65:207–212.

18. Da Costa Gomez TM, Radtke CL, Kalscheur VL, et al. Effect of focused and radial extracorporeal shock wave therapy on equine bone microdamage. *Vet Surg* 2004;33:49–55.

19. Burr DB, Turner CH, Naick P, et al. Does microdamage accumulation affect the mechanical properties of bone? *J Biomech* 1998;31:337–345.

20. Delius M, Draenert K, Al Diek Y, et al. Biological effects of shock waves: in vivo effect of high energy pulses on rabbit bone. *Ultrasound Med Biol* 1995;21:1219–1225.

21. Steiss JE. The neurophysiologic basis of acupuncture. In: Schoen AM, ed. *Veterinary acupuncture: ancient art to modern medicine*. 2nd ed. St Louis: Mosby Year Book Inc, 2001;27–46.

22. Ogden JA, Toth-Kischkat A, Schultheiss R. Principles of shock wave therapy. *Clin Orthop Relat Res* 2001;387:8–17.

23. Ueltschi G. Bone and joint imaging with Tc-99m labelled phosphates as a new diagnostic aid in veterinary orthopedics. *J Am Vet Radiol Soc* 1977;18:80–84.

24. Purohit RC, McCoy MD. Thermography in the diagnosis of inflammatory processes in the horse. *Am J Vet Res* 1980; 41:1167–1174.

25. Turner TA, Purohit RC, Fessler JF. Thermography: a review in equine medicine. *Compend Contin Educ Pract Vet* 1986;8:855–862.

26. Eddy AL, Van Hoogmoed LM, Snyder JR. The role of thermography in the management of equine lameness. *Vet J* 2001; 162:172–181.

27. Haupt G, Chvapil M. Effect of shock waves on the healing of partial-thickness wounds in piglets. *J Surg Res* 1990;49:45–48.

28. Kaulesar Sukul DM, Johannes EJ, Pierik EG, et al. The effect of high-energy shock waves focused on cortical bone: an in vitro study. *J Surg Res* 1993;54:46–51.

29. Delius M, Dranaert K, Dranaert Y, et al. Effect of extracorporeal shock waves on bone: a review of shock wave experiments and the mechanism of shock wave action. In: Siebert W, Buch M, eds. *Extracorporeal shock waves in orthopaedics*. Berlin: Springer-Verlag Inc, 1998;91–107.

30. Wang CJ, Huang HY, Pai CH. Shock wave-enhanced neovascularization at the tendon-bone junction: an experiment in dogs. *J Foot Ankle Surg* 2002;41:16–22.

31. Maier M, Averbeck B, Milz S, et al. Substance P and prostaglandin E-2 release after shock wave application to the rabbit femur. *Clin Orthop Relat Res* 2003;406:237–245.

32. McClure SM, VanSickle D, White MR. Effects of extracorporeal shock wave therapy on bone. *Vet Surg* 2004;33:40–48.

33. McClure S. In vivo evaluation of extracorporeal shock wave therapy for collagenase induced suspensory ligament desmitis in horses, in *Proceedings*. Symp Extracorporeal Shock Wave Users Vet Med 2002;23–24.

34. Rompe JD, Kirkpatrick CJ, Kullmer K, et al. Dose-related effects of shock waves on rabbit tendo Achillis. A sonographic and histological study. *J Bone Joint Surg Br* 1998;80B:546–552.