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Effect of two months whole body vibration on hoof growth rate in the horse: A pilot study

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ABSTRACT

Hoof problems are commonly seen in veterinary practice and manipulation of hoof growth rate can be practical and beneficial for that matter. The purpose of this research was to evaluate the effect of whole body vibration (WBV) on hoof growth rate of front feet in the horse. The study was an experimental, single subject, repeated measure design, with all horses serving as control and treatment. Ten horses were subject to WBV, 30 min, twice daily, five days a week, for 60 days in addition to their regular exercise routine. Hoof growth was measured from the reference hairline down to a horizontal groove in both front feet at 30-day (monthly) intervals starting 30 days before the start of treatment (WBV) up until 60 days post cessation of the treatment (WBV). The data analysis was carried out, by applying several paired *t*-tests to the mean 30-day hoof growth before, during, and after treatment (WBV). A significant mean increase in hoof growth was seen after 30 days WBV ($p < 0.001$) as well as after 60 days WBV ($p = 0.001$) with the increase occurring mainly during the first 30 days of WBV. No prolonged effect on hoof growth rate was seen after cessation of WBV. These results indicate that whole body vibration can be used as a non-invasive, safe and non labor-intensive therapeutic modality to accelerate hoof growth in the horse.

1. Introduction

The digit and more specific the hoof is one of the most important structures related to soundness in the horse. This is likely due to the ability of the hoof to attenuate impact vibrations transmitted at ground contact (Dyhre-Poulsen et al., 1994; Willemen et al., 1999). Hoof growth, quality and function as such become important factors as they often affect the usefulness of the horse. Manipulation of hoof growth can also have practical implications for farriers and veterinarians in terms of growing out lesions, producing sufficient horn to properly trim and balance the foot or nailing in to (Curtis, 2006).

Hoof growth is influenced by several factors. These include but are not limited to season (Frackowiak and Komosa, 2006; Lewis et al., 2014), age (Reilly et al., 1998; Curtis et al., 2014), gender (Frackowiak and Komosa, 2006), breed (Curtis, 2006), metabolic rate (Huntington and Pollitt, 2005), trimming and shoeing (Glade and Salzman, 1985) and nutrition (Butler and Hintz, 1977; Reilly et al., 1998). Average hoof growth for these reasons has a wide range but for a mature horse is around 0.19–0.28 mm/day or 5.7–8.4 mm/month (Glade and Salzman, 1985; Lockard and Reinertson, 1986; Pollitt, 1990). Most research has focused on the effects of nutrition on hoof growth and quality, with adequate caloric intake (Butler and Hintz, 1977) and biotin supplementation (Reilly et al., 1998) being important factors for proper hoof growth, just to mention a few. As most horses receive already a well balanced diet with adequate levels of nutrients to support proper hoof growth and quality, other means to further increase hoof growth would be helpful for those hoofs affected by factors beyond our control such as season, age, gender and breed. Whole body vibration (WBV) is a therapeutic modality in which low frequency vibration is delivered to the entire body. Whole body vibration claims to increase hoof growth in the horse but to the best of the authors' knowledge, no studies have been published so far to support those claims. Whole body vibration has proven to be safe for use in the horse and capable of inducing thermographic changes in the distal limbs and muscles (Tingbo M, unpublished data, 2005). Human research indicates that WBV is capable of increasing skin blood flow (Lohman et al., 2007) and studies in mice show that WBV is capable of improving angiogenesis (Weinheimer-Haus et al., 2014) and wound healing (Weinheimer-Haus et al., 2014).

Based on these data, WBV may have a potential benefit on the hoof. The aim of this study was to explore the effect of WBV on hoof growth rate. We hypothesized that adding WBV, five days a week, to a horse regular exercise regime will cause an increase in dorsal hoof wall

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growth compared to control over a 60-day (two month) period. Additionally the author was interested to see if the effect of WBV on hoof growth rate was sustained post cessation of WBV.

2. Materials and methods

2.1. Study design

The study was an experimental, single subject, repeated measure design. All horses served as control and treatment group. All participants were subjected to the treatment (i.e., WBV) and measurements taken at defined times to assess the effect of treatment.

2.2. Horses

Through convenience sampling, ten mature horses (age 10.7 ± 4.3 years) were selected from an accessible population of 1651 horses owned by clients of "masked for review". Inclusion criteria were as follows: mature horse (≥5 years old), shod in regular steel shoes in all four feet, lameness not exceeding a lameness score of 4/5 on an AAEP scale (Stashak, 2002) and otherwise in good health, and signed informed client consent form before the start of the study. All horses were required to be housed in a stall (4 × 4 m) with daily turn out in a small paddock (8 × 16 m) and exercised six days a week. All horses in each group were trimmed and shod by the same farrier. Exercise consisted of a 30 to 45-minute under saddle training session tailored to their discipline and intended performance level except for two horses, which were laid up (Table 1). All horses were fed an oat/alfalfa (75/25) hay mix with a vitamin-mineral supplement and an additional pelleted feed (concentrate) depending on the needs (workload, body condition, metabolism) of each horse. None of the horses had access to fresh grass. As such, a specific type and duration of exercise, as well as diet, was not a prerequisite, but for participation in the study, farrier, rider, exercise regime and diet were required to remain the same from three months prior to the start of WBV and throughout the duration of the study for that individual horse.

Study subjects (Table 1) were involved in athletic activities (5 dressage horses [group A] and 5 eventer horses [group B]). Group A consisted of five Warmbloods, all gelding. Group B consisted of one Warmblood, two Irish sport horses and two Thoroughbreds of which four geldings and one mare. Horses in Group A were assessed from early October 2011 through early March 2012 (fall and winter). Horses in Group B were assessed from the end of April 2012 through end of September 2012 (spring and summer). Table 2 depicts the climate conditions and photoperiod during the two study periods.

Table 1
Characteristics of horses included in the study.

Horse id	Breed	Age (years)	Gender	Discipline	Exercise/ performance level	AAEP lameness score (0–5) (day 0)
A1	WB	9	G	Dressage	Third	3
A2	WB	15	G	Dressage	Second	1
A3	WB	19	G	Dressage	Second	2
A4	WB	8	G	Dressage	Laid up	3
B1	TB	8	M	Eventing	Training	1
B2	ISH	5	G	Eventing	Training	3
B3	ISH	10	G	Eventing	Training	1
B4	TB	8	G	Eventing	Training	1
B5	WB	10	G	Eventing	Laid up	4

WB – Warmblood, TB – Thoroughbred, ISH – Irish sport horse, G – Gelding, M – Mare. Second, Third, Training – performance/competition level for each discipline as defined by the United States Equestrian Federation. Laid up – stall rest with 15 min of hand walking.

2.3. Whole body vibration and exercise

All horses underwent WBV five days a week (Tuesday, Wednesday, Thursday, Saturday, Sunday), twice daily (morning and afternoon) for 30 min at a frequency of 40 Hz, amplitude of 0.8 mm and an acceleration of 4.9 m/s^2 (0.5 g) for a total of 60 days using a mobile linear (vertical) type vibration platform (Vitafloor VM0; Vitafloor USA Inc., Aromas, CA), producing an indirect vertical sinusoidal vibration applied to all four feet. This was added to their normal exercise routine as mentioned previously. As a safety measurement, all horses were lightly sedated with 0.006 to 0.01 mg/kg detomidine; Zoetis, Florham Park, NJ (Dormosedan) intravenously the first time they were introduced to the WBV platform. No sedation was needed after the introduction session. A hay net was provided while the horses were on the vibration platform to keep them occupied.

2.4. Hoof growth measurement of the dorsal hoof wall

A small horizontal groove was made in the dorsal hoof wall on midline with a hoof rasp, 2 cm below the distal hairline at the coronary band (reference hairline), of the left front and right front foot 30 days before the start of WBV in group A and B. Hoof growth was measured by the author ("Peninsula equine medical center, Menlo Park, California") in millimeters (mm) with a measurement tape from the reference hairline down to the groove at 30-day (monthly) intervals up until 60 days post cessation of WBV. Measurements were repeated 3 times for left front and right front hoof respectively. Measurements of both left front and right front hoof of each horse were pooled, with mean (average) 30-day hoof growth of both front hoofs shown in Table 3. Two horses were lost for post treatment follow-up. One horse (B1) moved out of the area and one horse (B3) was sold.

2.5. Statistical analysis

The data analysis was carried out, by applying several paired *t*-tests to the data of Table 2. All calculations were performed using IBM SPSS version 22.0; IBM, Armonk, NY. All tests are performed two-tailed which means that the mentioned *p*-values are two-sided probabilities. Also, as some measurements are missing, the number of samples (N) differs from test to test. Confidence intervals for the estimation of mean differences are calculated at the 95% level.

3. Results

3.1. Effect on hoof growth rate during treatment (WBV)

A first paired *t*-test was performed in order to compare the average 30-day hoof growth (mm) for the first 30 days of WBV (mean = 8.65; SD = 1.383) with the average 30-day hoof growth (mm) before the start of treatment (mean = 6.53; SD = 1.080). In that case all data from the 10 horses are available. The *t*-test shows a strongly significant mean increase in hoof growth after 30 days of WBV ($t = 7.82$; $df = 9$; two-tailed $p < 0.001$). Hence it is very unlikely that the mean increase of hoof growth is accidentally. With almost certainty the increase is due to the applied treatment (WBV). The 95% confidence interval for the increase of mean hoof growth is 1.5 to 2.7 mm/30 days (month) (Fig. 1).

From a similar analysis with respect to the second 30 days of WBV, however, it follows that there is still an increase in hoof growth (mean = 7.3; SD = 1.053; N = 9), but the difference with respect to the period before the treatment started is no longer significant ($t = 1.66$; $df = 8$; two-tailed $p = 0.1$). The 95% confidence interval for the mean hoof growth this time does not exclude the possibility of no increase or even a slight decrease (−0.3 to 1.8 mm/30 days (month)). So it is not proven that continuation of WBV after the first 30 days is still effective (Fig. 1). Moreover, the decrease of the mean hoof growth during the second 30 days of WBV with respect to the first 30 days of WBV is close

Table 2
Climate conditions and photoperiod during the two study periods.

	30 days before start of WBV	First 30 days of WBV	Second 30 days of WBV	First 30 days after cessation of WBV	Second 30 days after cessation of WBV
Group A					
Temperature (°C)	18.3	11.1	5	10.7	8.9
Precipitation (cm)	1.6	2.3	0.1	14.3	2.6
Photoperiod (hr:min:s)	10:55:16	9:59:28	9:39:14	10:06:34	11:06:28
Group B					
Temperature (°C)	18.1	20.2	21	22	19.2
Precipitation (cm)	0.3	0.1	0	0	0
Photoperiod (hr:min:s)	14:00:30	14:37:18	14:32:00	13:47:28	12:43:08

°C - average 30-day (monthly) temperature in Celsius, cm - total 30-day (monthly) rainfall in centimeter, hr:min:s – average daily daylight time for each 30-day period expressed in hours, minutes and seconds. Source: www.usclimatedata.com and www.timebie.com.

Table 3
Mean (average) 30-day (monthly) hoof growth of the front feet for each horse before, during and after treatment (whole body vibration) expressed in millimeters (mm).

Horse	30 days before the start of WBV	First 30 days of WBV	Second 30 days of WBV	First 60 days of WBV	First 60 days after cessation WBV
A1	7.9	10.7	7.4	8.9	6.8
A2	6.1	7.9	5.9	6.8	6.4
A3	7.4	9.5	8.6	9.2	6
A4	7.4	10.9	7	8.7	6.8
A5	5.3	8.4	5.6	6.8	4.2
B1	4.3	6.4	7.9	7.3	
B2	6.7	7.9	8.6	8.3	7.1
B3	6.3	8.7			
B4	6.9	7.7	7	7.3	6.4
B5	7	8.4	7.6	7.9	7

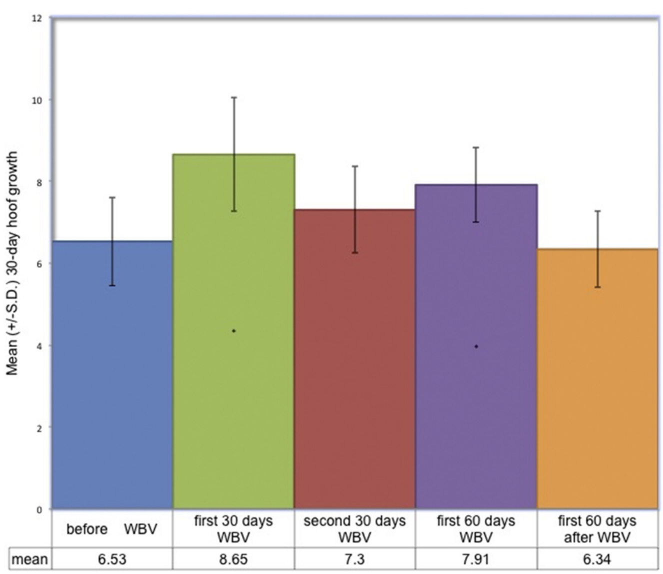

Fig. 1. Mean and standard deviation (S.D.) 30-day hoof growth before during and after whole body vibration (WBV). Asterisks indicate significant difference compared to before (blue) WBV ($p \leq 0.001$) and after (orange) WBV ($p \leq 0.002$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

to significant as can be demonstrated by another *t*-test ($t = -2.52$; $df = 8$; two-tailed $p = 0.05$). Nevertheless, there is still a statistically significant increase of the average 30-day (monthly) hoof growth (mean = 7.91; SD = 0.91; N = 9) over the total period of 60 days WBV ($t = 5.33$; $df = 8$; two-tailed $p = 0.001$) compared to the average 30-day hoof growth before the start of treatment. The 95% confidence interval for the increase of mean hoof growth over the whole treatment period is 0.8 to 1.9 mm/30 days (month) (Fig. 1).

3.2. *Effect on hoof growth rate during the first 60 days after cessation of treatment (WBV)*

It's also instructive to examine the average 30-day (monthly) hoof growth rate after cessation of WBV. To that purpose a first paired *t*-test was performed in order to compare the average 30-day hoof growth for the first 60 days after cessation of WBV (mean = 6.34; SD = 0.937; N = 8) with the average 30 days hoof growth before the start of WBV. Note that only 8 cases are available for this analysis. The t-test shows no statistically significant difference in the mean hoof growth ($t = -2.08$; $df = 7$; two-tailed $p = 0.08$), which is confirmed by the 95% confidence interval for the difference of mean growth (−1.1 to 0.1 mm/30 days (month)). A slight decrease with respect to the period before the treatment started is most likely but a zero difference also belongs to the possibilities. Hence it can be concluded that the effect of WBV has disappeared completely (Fig. 1).

On the other hand a comparison between the average 30-day hoof growth for the first 60 days after cessation of WBV and the average 30-day hoof growth during the 60 days of WBV demonstrates a statistically significant decrease of the 30-day (monthly) mean hoof growth ($t = -4.86$; $df = 7$; two-tailed $p = 0.002$). With respect to that period the 95% confidence interval for the loss in mean hoof growth resulting from the cessation of the therapy is −2.5 to −0.8 mm/30 days (month) (Fig. 1).

4. Discussion

4.1. *Hoof growth rate*

This study shows that WBV is capable of increasing dorsal hoof growth rate up to 41% in the front feet of horses. Although our hypothesis (whole body vibration is able to increase dorsal hoof growth compared to control over a 60-day period) proofs to be correct (0.8 to 1.9 mm/30 days), the increase in hoof growth appears to take place mainly during the first 30 days of the 60-day WBV protocol (1.5 to 2.7 mm for the first 30 days of WBV and −0.3 to 1.8 mm for the second 30 days of WBV compared to control). Although one could argue that the increase in hoof growth could be related to seasonal variations including temperature, precipitation, photoperiod, distance traveled and access to lush forage (Florence and McDonnell, 2006; Frackowiak and Komosa, 2006; Lewis et al., 2014) rather than WBV, this is unlikely looking at the study design and the data set provided in Table 2. Moreover, during the same study period other parameters (lameness grade and m. multifidus cross-sectional area) were assessed in these horse and a similar response pattern to WBV was seen (Halsberghe, 2017; Halsberghe et al., 2017), making it very unlikely that other factors beyond WBV were responsible for changes in all three parameters.

Sixty days after cessation (completion) of the WBV protocol, the effect seems to have disappeared completely, meaning there is no prolonged effect on hoof growth rate after cessation of the treatment (WBV). The average 30-day (monthly) hoof growth rate without WBV (before (mean = 6.53; SD = 1.080) and after (mean = 6.34; SD = 0.937)) in this study is in line with previous research data (5.7–8.4 mm/month) (Glade and Salzman, 1985; Lockard and Reinertson, 1986; Pollitt, 1990).

4.2. Mechanism(s) of action

The mechanism(s) of action responsible for the increased hoof growth due to WBV has not been researched. The exact mechanism(s) of hoof growth itself is also still unknown but the following structures seem to play a key role (Bowker, 2003): First of all, the corium, composed of micro-vessels, small nerve fibers and connective tissue, produces or supplies the nutritional products to be used by the basilar and other epidermal cells lining the basement membrane. Secondly, the basilar epidermal cells lining the basement membrane, capable of adapting to stress (load) by increasing its surface area through laminar bifurcation of its primary epidermal laminae and subsequently the number of horn forming cells (keratinocytes). When we look at these structures involved in hoof growth and adaptation, it is fair to say that increased blood supply, metabolic rate and cellular proliferation and differentiation are all potential mechanisms involved in hoof growth.

4.2.1. Increased blood supply

Increased blood supply is one potential mechanism behind the increase in hoof growth. One study in horses showed a 39% increase in hoof growth using a counter-irritant along the coronet band (Lockard and Reinertson, 1986). The author theorized that increased blood supply to the hoof was responsible for the increase in hoof growth (Lockard and Reinertson, 1986).

Whole body vibration is able to increase blood supply to the skin through increased blood flow secondary to vasodilation (Lohman et al., 2007) as well as angiogenesis (Weinheimer-Haus et al., 2014). Only few unpublished data are available regarding the effects of blood flow on horse's feet after WBV and this was assessed through the use of thermography. These studies reported a tendency for the temperature in feet to go down (Tingbo M, unpublished data, 2005; Oostveen H, unpublished data, 2013). This at first seems unexpected and contradictory to studies reported in humans, but this can be explained by the fact that the equine foot has a triple circulation (Bowker, 2011); one for thermoregulation, composed of arteriovenous anastomoses (AVAs) (Molyneux et al., 1994; Pollitt, 1991), one for nutrition composed of a capillary network (Pollitt, 2004), and one for shock absorption composed of micro-vessels, the latter is also called the hydraulic system (Bowker, 2011). As such a change in foot surface temperature, detected through the use of thermography, is most likely function of the AVAs circulation rather than the capillary and micro-vessel circulation (Mogg and Pollitt, 1992). As vasodilation of the AVAs leads to decreased capillary circulation (Pollitt, 1991), WBV induced vasoconstriction of the AVAs as a possible mechanism responsible for reduced foot surface temperature in the horse would secondary lead to an increase in capillary circulation to the hoof epidermis and indirectly have a positive effect on hoof growth rate.

Nevertheless, the fact that the increase in hoof growth takes place mainly during the first 30 days of WBV indicates that increased blood flow is most likely not completely responsible for increased hoof growth, otherwise it would be expected that the effect is sustained during the second part of the WBV protocol.

4.2.2. Metabolic rate

An overall increase in metabolic rate due to exercise has been suggested as one of the factors that can increase hoof growth (Huntington and Pollitt, 2005).

Whole body vibration is able to increase metabolic rate locally (Friesenbichler et al., 1985) and systemically (Bertucci et al., 2015; Rittweger et al., 2002) and this increase is further dependent on fitness level, frequency, amplitude and type of vibration platform, with higher increases seen in human patients with a lower fitness level (Gojanovic et al., 2014), as well as using higher frequencies (Rittweger et al., 2002), higher amplitudes (Rittweger et al., 2002) and side-alternating (rotational) platform types (Bertucci et al., 2015). The latter two variables are less likely to be applicable in the horse because of potential discomfort and compliance during the therapy.

The fact that Faramarzi et al. (2009) did not find a significant change in hoof wall growth in horses having mild exercise for 17 weeks compared to control group, indicates that a mild increase in systemic metabolic rate is not enough to accelerate hoof growth rate. Further research is needed in the horse to assess whether or not increased metabolic rate due to WBV is sufficiently increased to play a role in increased hoof growth.

4.2.3. Cell proliferation and differentiation

Whole body vibration is able to increase cell proliferation and differentiation (Edwards and Reilly, 2015; Kim et al., 2012) and as such may be a mechanism behind increased hoof growth secondary to increased proliferation and differentiation of the basilar epidermal cells lining the basement membrane. However little research is available on the effects of vibration on epidermal cells and keratinocytes specifically. The author could only find one paper that showed that WBV is able to modulate CD11b-cell type (which are mainly comprised of fibroblasts, endothelial cells and keratinocytes) in wound healing (Weinheimer-Haus et al., 2014).

Research in horses has shown that the basilar epidermal cells lining the basement membrane are capable of adapting to stress (load) by increasing its surface area through laminar bifurcation of its primary epidermal laminae and subsequently the number of horn forming cells (keratinocytes) (Bowker, 2003). This could potentially explain the effect of WBV on hoof growth seen in this study. It is possible that WBV induced shear forces, increased the stress on the epidermal laminae in the foot, leading to proliferation and differentiation of the basilar epidermal cells and as such increased hoof growth. As vibration parameters were kept constant throughout the study, adaptation to this new stress could have taken place within 30 days, explaining a reduced response to WBV during the second 30 days of WBV.

4.3. Optimal vibration for hoof growth

The optimal vibration parameters, it is, frequency, amplitude, acceleration and duration, to achieve maximum hoof growth are unknown.

Transmissibility is not of a concern regarding hoof growth as the feet are in direct contact with the vibration platform, except when the horse is resting one particular leg more often. As we looked at hoof growth in the front feet, this most likely did not play a significant role, as horses tend to rest one of the hind legs rather than a front leg.

Resonance is important to consider because of its potential harmful effects (Rittweger, 2010). Resonance can occur at frequencies below 20 Hz in humans (Randall et al., 1997) and decreased digital blood flow "vibration white fingers" is seen with high frequency occupational vibrations using industrial tools that vibrate at skin resonance of 80-100 Hz (Lundstrom and Burstom, 1984). As such, it seems prudent not to use frequencies below 20 Hz and above 80 Hz.

The results of this study suggest that there may be a need for adjusting the vibration parameters over time, in an effort to prevent adaptation, if continues response is desired. Increasing the stress on the hoof capsule over time by increasing the intensity or acceleration of the vibration at specific time intervals could be a key factor to achieve a sustained increase in hoof growth during WBV.

4.4. Limitations

The study has several limitations. First of all we have a relative small group size (ten) and the precision with which data were measured could have been better. These two parameters will negatively affect the statistic power. Larger group size (twenty or more) and more accurate measurement as described by Florence and McDonnell (2006) would give more statistic power to the study.

Second, factors influencing hoof growth such as diet, exercise and season among horses were not well standardized. However as horses served as control as well as treatment, the inter-individual variability is less of a concern. This variability might actually play somewhat in our advantage as the study shows that WBV seems to be able to increase hoof growth independent off other variables that can affect hoof growth rate.

Third, the study did not assess the mechanism(s) behind an increase in hoof growth achieved in horses undergoing WBV.

5. Conclusion

Being able to increase hoof growth has practical application for growing out lesions faster and producing sufficient horn for proper farriery. Whole body vibration is a non-invasive, safe and non labor-intensive therapeutic modality, well tolerated by the horse that can be helpful for those conditions. Optimal WBV parameters need to be defined to achieve maximal hoof growth over longer periods of time.

It is clear that further research need to be done to define the mechanisms behind the effects of WBV on the hoof, as well as its potential applications in pathologies of the foot. However, this study provides some interesting information that makes it worthwhile to further explore the potential benefits of WBV on the foot.

Statement

This paper is original, has not been submitted or published elsewhere, and has the approval of all authors.

Ethical considerations

Prior to being enrolled in the study, owners completed an informed client consent form. A full physical and lameness exam was performed by the primary author (BTH) before the start of the study to assure the horses were in good physical health and that there were no contra-indications to participation in the study. As a safety measurement, all horses were lightly sedated with 3–5 mg detomidine (Dormosedan®) the first time they were introduced to the whole body vibration platform. No sedation was needed or used after the introductory session. All Horses were willing to walk and stand on the vibration platform and tolerated whole body vibration (WBV) well during subsequent treatment sessions; it is the horses were comfortable and relaxed during treatment. A physical and lameness exam was repeated at monthly intervals. No adverse effects were noticed throughout the study. All horses that entered in the study completed the study, except two horses for reasons not related to the treatment (WBV), it is one horse moved out of the area and one horse was sold.

Contribution

Study design, study execution, data acquisition and interpretation, preparation of the manuscript and final approval of the manuscript.

Declaration of interest

None.

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