Journal of Equine Veterinary Science 71 (2018) 21–26

Contents lists available at ScienceDirect

Journal of Equine Veterinary Science

journal homepage: www.j-evs.com

Original Research

The Equine Hindlimb Proximal Suspensory Ligament: an Assessment of Health and Function by Means of Its Damping Harmonic Oscillator Properties, Measured Using an Acoustic Myography System: a New Modality Study

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ARTICLE INFO

Article history:
Received 3 August 2018
Received in revised form
12 September 2018
Accepted 13 September 2018
Available online 19 September 2018

Keywords:
CURO
Acoustic myography
Equine
Suspensory desmitis
Lameness

ABSTRACT

Enhanced, objective systems for evaluation of the proximal suspensory ligament are needed to hasten appropriate diagnosis and treatment of injury. This study compared the *in vivo* acoustic signals generated by healthy and injured hindlimb proximal suspensory ligaments (PSLs) in horses and determined if an acoustic myography (AMG) system was an acceptable tool to aid in diagnosis. Complete lameness evaluations were performed on 96 horses either with a history or suspicion of hindlimb lameness. Acoustic myography signals were acquired with the aid of a CURO from the hindlimbs after a moving evaluation and before additional procedures. For all horses with hindlimb lameness, diagnostic analgesia and appropriate imaging were performed to reach a causative diagnosis for the lameness. The signals obtained were analyzed by blinded evaluators *via* CURO algorithms and scored from 0 to 10 (poor to optimal). Eighty-five horses in total provided adequate diagnostic data. Of these, 15 (17.7%) horses were clinically sound, 48 (56.5%) horses had clinical evidence of PSL injury, 4 (4.7%) horses were recovering from prior PSL injuries, and 18 (21.1%) horses had another cause of hindlimb lameness. There was a significant difference ($P > .001$) in the CURO score between horses with evidence of PSL injury and all other groups. Correlations showed that PSLs were healthy with a score >5 (60% of SOUND horses; 87% of PSL-TREATED), had low-level injury at scores 2.5–4.5, and severe injuries at scores <2. It is concluded that AMG is a promising diagnostic tool to detect injuries of the proximal suspensory ligament in horses.
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1. Introduction

Injury to the proximal suspensory ligament (PSL) is common in most types of athletic horses and can account for up to 46% of all limb injuries [1–4]. This injury is likely more common than we know in the hindlimb, as diagnosis and imaging continues to be complex due to the intricate tarsal and metatarsal anatomy and concurrent pathologies that may exist [5–12]. A noninvasive, quick, and accurate means of assessing the health and functionality of the suspensory ligament could hasten diagnosis and treatment, hopefully reducing lay-up time and loss in the equine industry. Recent studies have evaluated ultrasound-based techniques in the assessment of tendon and ligament injury with application of elastography and acoustoelastography, which relates changes in echogenicity observed during deformation of a tendon from an

Animal welfare/ethical statement: The study was approved by the management and ownership of Virginia Equine Imaging and had informed consent of the owners. There was no ethical issue in this study because all the subjects were healthy. Moreover, the measuring equipment used complied with both CE and FCC regulations and was noninvasive in its nature. The study was carried out according to the guidelines laid out in the Helsinki Declaration (https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/) so as to protect owners names, gender, and other personal data.

Conflict of interest statement: A.P.H. is currently trying to commercialize the CURO system (CURO.diagnostics) and is establishing a company to cover the costs of future development. The CURO system was provided to Virginia Equine Imaging at no cost. Virginia Equine Imaging and its staff and doctors were not compensated for this study.

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https://doi.org/10.1016/j.jevs.2018.09.006
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unloaded to a loaded state to the mechanical properties of the tissue [13–15]. These techniques show promise for tracking improvements in tendon and ligament healing, but appear to have similar sensitivity to ultrasound alone for detecting the injury. Furthermore, these techniques often require sedation of the subject and cannot be performed during a moving evaluation.

Ligaments and tendons are generally known to be periodically vibrating elastic structures. Indeed, a recent *in vivo* study using ultrasound imaging has shown that tendon tissue undergoes a pattern of rapid lengthening and shortening during the stance phase of running [16]. Such a change has a clear benefit in terms of the return of elastic energy stored in the connective tissue structure to associated muscles, making such units largely free of metabolic costs [17]. However, these structures also act as damping harmonic oscillators, in much the same way that shock absorbers on vehicles reduce the vibrations associated with traveling over rough ground [18].

Acoustic myography (AMG) is a biomechanical method in that it evaluates tissues that generate pressure waves, for example, contracting muscle [19–21]. The AMG technique was originally designed to measure the pressure waves generated by voluntary muscle contractions and record them, using a flat piezoceramic sensor to convert pressure waves into microvolts. However, it has recently been discovered by the authors that these sensors can also be used to record the shock waves that are transmitted through the suspensory tissue after foot impact and as such monitor the ability of the suspensory system to act as a damping harmonic oscillator. Damping opposes the back and forth motion of a harmonic oscillator, and critical damping is defined as the condition in which the damping of an oscillator results in it returning as quickly as possible to its resting position [22]. The PSL acts as just such a harmonic oscillator, such that damage to the PSL consequently affects its ability to damp ground reaction forces, which can be seen in the recorded signal characteristics.

Thus AMG as a technique is capable of detecting pressure waves within a tissue, pressure waves that arise from an external source. In this particular study, the recordings were of the absorption of the ground reaction force (GRF) by the suspensory system, acting as a harmonic oscillator. The purpose of this study was to determine if AMG, using sensors placed over the skin on the plantaroproximal metatarsus, could accurately detect the damping function of the PSL during both walk and trot. It was hypothesized that the parameters recorded using AMG could be used to assess the degree of injury and functionality of the hindlimb PSL of horses.

2. Materials and Methods

All horses presenting for a second opinion or a referral in clinic lameness evaluation scheduled with Dr Allen at Virginia Equine Imaging over a period of 7 months were candidates for inclusion. Ninety-six horses were used for data collection. The population consisted of 69 (71.9%) geldings, 26 (27.1%) mares, and 1 stallion (1.0%), of which there were 71 (74.0%) warmbloods, 15 (15.6%) Thoroughbreds, 6 (6.2%) Thoroughbred crosses, 2 (2.1%) ponies, and 2 (2.1%) draft crosses. The average (mean ± standard deviation) mass was 533 ± 55 kg and age was 10 ± 3 years with ranges of 363–681 kg and 3–17 years, respectively.

All horses received complete physical and lameness evaluations. Any palpable abnormalities (thickening, swelling, etc.) were recorded. The horses were evaluated by experienced lameness clinicians (A.K.A. and J.C.C.) moving at the walk and trot on a straight line on a firm rubber surface, and walk, trot, and canter lunging on a 20-m circle to the left and right on a firm, crushed compacted bluestone surface. Horses with subtle lameness or complaints by riders of poor performance were also evaluated lunging with a weighted surcingle (27 kg) and ridden under saddle over a sand arena surface. Flexions of both distal forelimbs, upper hindlimbs, and distal hindlimbs were performed on the firm rubber surface. After completion of the baseline lameness evaluation, the CURO sensors were applied (Fig. 1) and recordings performed at the walk and trot over the firm rubber surface.

Over 3 to 5 minutes, four separate consecutive recordings at the walk on a 30-m straight line, followed by two recordings at a trot on the straight line, and two final recordings at the walk on the straight line were performed. The data were compiled in WAV format and any identifying or clinical information except for right or left hindlimb designation was removed. The data were analyzed by blinded evaluators (W.A., L.H.C., and A.P.H.). After completion of data collection, the lameness evaluations continued with diagnostic analgesia and imaging performed as dictated by results of the evaluation to reach a final diagnosis.

Based on the diagnosis obtained with evaluators unaware of final results of the CURO scores, the horses were assigned to one of the four groups: (1) horses with proximal suspensory ligament desmopathy or enthesopathy (PSL-INJURY n = 48, 56.5%); (2) horses with lameness that did not block to the proximal suspensory ligament (NON-PSL n = 18, 21.1%); (3) horses with no clinical or performance history of lameness (SOUND n = 15, 17.7%); and (4) sound horses currently recovered from PSL injury and in full work (PSL-TREATED n = 4, 4.7%). In this study, TREATED represents horses that received focused extracorporeal shock wave therapy for a predefined period and at set intervals or surgery (neurectomy of the deep branch of the lateral plantar nerve), in combination with carefully monitored exercise of gradually increasing duration and intensity as part of a successful rehabilitation program developed at Virginia Equine Imaging (for details contact Dr Kent Allen).

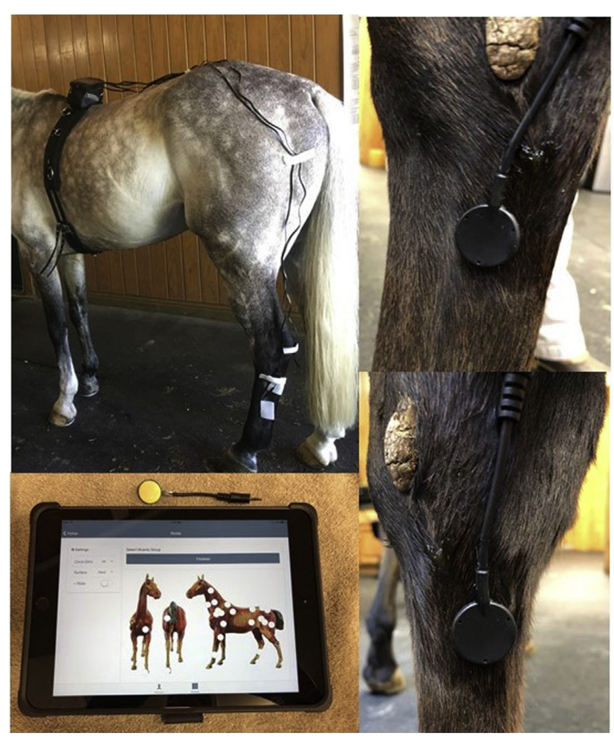

Fig. 1. CURO sensors, placement, rigging, and user interface.

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