VETERINARY SPORTS MEDICINE AND PHYSICAL REHABILITATION

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Henry Steven Adair and Andris J. Kaneps
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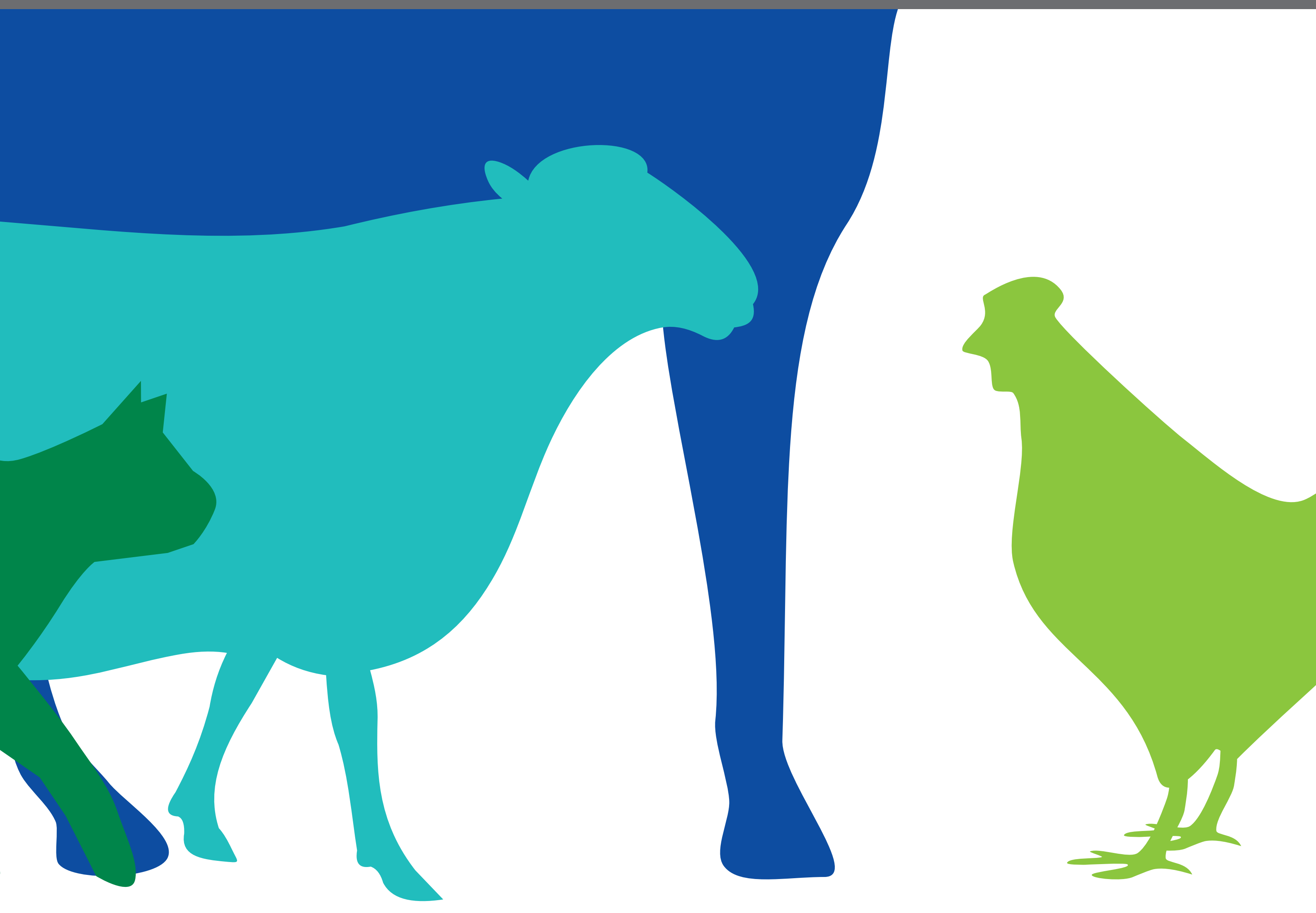

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VETERINARY SPORTS MEDICINE AND PHYSICAL REHABILITATION

Topic Editors:
Michael Jaffe, Mississippi State University, United States
David Levine, University of Tennessee at Chattanooga, United States
Denis J. Marcellin-Little, University of California, Davis, United States
Henry Steven Adair, The University of Tennessee, Knoxville, United States
Andris J. Kaneps, Kaneps Equine Sports Medicine and Surgery, United States

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EDITORIAL
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Editorial: Veterinary Sports Medicine and Physical Rehabilitation

David Levine[1]*, *Henry Steven Adair*[2], *Denis J. Marcellin-Little*[3], *Michael Jaffe*[4] and *Andris J. Kaneps*[5]

[1] Department of Physical Therapy, University of Tennessee at Chattanooga, Chattanooga, TN, United States, [2] Department of Large Animal Clinical Sciences, The University of Tennessee, Knoxville, Knoxville, TN, United States, [3] Department of Surgical and Radiological Sciences, University of California, Davis, Davis, CA, United States, [4] Department of Clinical Sciences, College of Veterinary Medicine, Mississippi State University, Starkville, MS, United States, [5] Kaneps Equine Sports Medicine and Surgery, Beverly, MA, United States

Keywords: rehabilitation, physical therapy, sports medicine, orthopedics, neurology

Editorial on the Research Topic

Veterinary Sports Medicine and Physical Rehabilitation

There is a clear need and a strong interest on the part of the veterinary profession to learn more about sports medicine and physical rehabilitation following injury, surgery, and illness, and to optimize patient outcomes by incorporating physical rehabilitation into practice. Human sports medicine and rehabilitation is a well-established discipline whose positive benefits have been clearly documented and recognized in human health care. Historically, relatively little attention was given to veterinary patients afflicted with similar conditions. The techniques used in human sports medicine and physical therapy are being adapted for use in small animal and equine patients, and their effectiveness has been or is being studied. The growing interest in sports medicine and physical rehabilitation among veterinarians has led to the formation of a specialty College, the American College of Veterinary Sports Medicine and Rehabilitation in 2010 and a veterinary technician specialty, the Academy of Physical Rehabilitation Veterinary Technicians in 2017.

This Research Topic issue seeks to address the science of small animal and equine sports medicine and rehabilitation to help provide better understanding of assessment methods, treatment techniques, and interventions utilized. Forty authors contributed to the 10 articles published in this issue.

A number of outcome measures are used to assess dogs during rehabilitation. Goniometry being one of the most widely used methods. Formenton et al. examined normal joint angles and range of motion in French Bulldogs using the standard method first described and published in 2002 (1) to examine how this breed might differ from others previously examined. Fahie et al. also studied an outcome measure to help us obtain better information on gait in dogs. The system they studied on 66 dogs discusses a simple and reliable gait assessment method that can be implemented in clinical practice.

Another assessment method was detailed in a paper entitled Variables Affecting Thigh Girth Measurement and Observer Reliability in Dogs by McCarthy et al. Measurement of muscle girth to indirectly assess muscle mass has been used for document muscle atrophy in patients and the recovery of muscle mass in response to rehabilitation. This study evaluated the use of thigh girth measurement in dogs before and after surgery of the stifle joint and evaluated inter-rater reliability which was excellent when conditions were standardized.

Prosthetics has been an evolving field in canine rehabilitation, and socket prostheses have been a more viable treatment option for distal limb pathologies including amputation (2). Wendland et al. performed a multi-center study evaluating owner satisfaction with socket prosthesis use in dogs. The authors found that owners were very satisfied, despite the presence of a substantial complication rate.

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Edited and reviewed by:
Karine Portier,
Université de Lyon, France

****Correspondence:***
David Levine
david-levine@utc.edu

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Laser therapy is a popular treatment modality in canine rehabilitation and sports medicine and one of the conditions it is used for is wound healing. The optimal parameters including dosage for wound healing is unknown but studies such as the one by Wardlaw et al. provide guidance for future work. In this study, they found that daily application of laser therapy at 8 J/cm^2 hastened wound healing in Dachshunds that underwent thoracolumbar hemilaminectomies to manage intervertebral disc disease.

Therapeutic exercises are an essential part of rehabilitation and sports medicine and surface electromyography (sEMG) provides a way of objectively measuring muscle activity during exercise. A prospective trial by McLean et al. continues to build on the previous sEMG work in dogs (3, 4) and adds to our knowledge base. The objective of the study reported here was to analyze the mean and maximum muscle activation patterns of the vastus lateralis, biceps femoris, and gluteus medius during stance, walking, trotting, and specific therapeutic exercises in clinically sound, healthy dogs. These results may help clinicians to choose specific exercises to target specific muscles during conditioning, strengthening, and rehabilitation.

Two of the studies in this Research Topic issue focused on therapeutic ultrasound which has been used in rehabilitation and sports medicine for humans, dogs, and horses (5). The study on dogs investigated by Acevedo et al.. This prospective, crossover, experimental study concluded that the heating effects of therapeutic ultrasound increase the effectiveness of stretching connective tissues, but these effects are short lived. This is in agreement with the human literature. The equine study by Adair and Levine presented here continues work performed by Levine et al. (6) and Montgomery et al. (7) The main findings of the study is that use of therapeutic ultrasound with a 1.0 MHz US for 10 min in horse's epaxial muscles when clipped creates the greatest heat at 1.0 cm depth. The heat in tissues at a 5-cm depth is more than at a 3-cm depth.

Wilson et al., in the article titled International Survey Regarding the Use of Rehabilitation Modalities in Horses attempted to define which biologic, electrophysical, and other modalities are used in horses for injury or performance issues. To achieve this, the authors developed a questionnaire listing 38 modalities and distributed it to eight veterinary groups. Their findings indicate that a broad range of invasive and non-invasive modalities are used in equine patients to address a variety of rehabilitation and performance needs, and that personnel with varying levels of expertise are involved in their administration.

Riccio et al., in the article titled Two Multicenter Surveys on Equine Back-Pain 10 Years Apart endeavored to assess the evolution in the veterinarian approach to diagnose and treat back-pain over a 10 years period. To investigate this topic, two surveys were sent to equine veterinarians working in practice throughout Europe 10 years apart, in 2006 and 2016. The study provided insight into the current perception of clinicians working in different settings regarding horse back-pain but did not identify changes in veterinarians' approaches to the diagnosis and management of equine back pain over the last decade.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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International Survey Regarding the Use of Rehabilitation Modalities in Horses

Janine M. Wilson[1], Erica McKenzie[2]* and Katja Duesterdieck-Zellmer[2]

[1] Oregon Equine, Damascus, OR, United States, [2] Department of Clinical Sciences, Carlson College of Veterinary Medicine, Oregon State University, Corvallis, OR, United States

To define which biologic, electrophysical and other modalities are used in horses for injury or performance issues, a questionnaire regarding 38 modalities was distributed to eight veterinary groups. A total of 305 complete or partial responses were obtained from over 10 geographic regions; 75.4% from private equine practice or regional private equine referral hospitals, 14.1% from university teaching hospitals or satellite clinics, 8.2% from private mixed animal practice, and 2.3% from veterinary rehabilitation centers. The majority of respondents were located in the USA (60%), Europe (25.6%), and Canada (5.6%). Respondents reported working with athletic horses primarily in the disciplines of hunter-jumper (26.9%), dressage (16.0%), and pleasure riding (14.7%), followed by Western riding, track racing, and eventing. Warmbloods (39.7%) were the predominant breed presenting to respondents, followed by Thoroughbreds (20.3%) and Quarter Horses (17.3%) ahead of other breeds. All 38 modalities were used by respondents. The 10 most prominently utilized were controlled hand walking (97.3%), therapeutic shoeing (96.1%), ice (95.2%), compression bandaging (89.5%), platelet rich plasma (PRP; 86.5%), therapeutic exercises (84.3%), interleukin-1 receptor antagonist protein therapy (IRAP; 81.4%), stretching (83.3%), and cold water hydrotherapy (82.9%). Heat (77.6%), massage (69.0%), and acupuncture (68.3%) were also commonly utilized. The least prominently used modalities were hyperbaric oxygen therapy (9.4%), cytowave (8.3%), and radiofrequency (6.4%). Injectable modalities (IRAP, PRP, mesotherapy, stem cells) were almost solely administered by veterinarians; other modalities were variably applied by veterinarians, technicians, veterinary assistants, farriers, physical therapists, trainers, and other entities. A total of 33% of respondents reported working collaboratively with physical therapists on equine patients. Findings indicate that a broad range of invasive and non-invasive modalities are used in equine patients to address a variety of rehabilitation and performance needs, and that personnel with varying levels of expertise are involved in their administration. This suggests that further investigation to better define the delivery, efficacy and any negative effects of many of these modalities is important.

Keywords: sports medicine, tendon, ligament, performance, exercise, rehabilitation, survey

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Edited by:
Andris J. Kaneps, Kaneps Equine Sports Medicine and Surgery, United States

Reviewed by:
Sarah Elizabeth Taylor, University of Edinburgh, United Kingdom
Raphael Labens, Charles Sturt University, United States

***Correspondence:**
Erica McKenzie
erica.mckenzie@oregonstate.edu

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INTRODUCTION

In the last two decades, the practice of equine sports medicine and rehabilitation has progressively developed into a large and focused field of specialized equine practice (1–3). Reflecting this phenomenon is the growth of organized training programs, and the consolidation of expert practitioners into groups with objectives that include sharing of and furthering knowledge in this field. Relevant examples include the Equine Rehabilitation Certificate Program (CERP), established in 2004, which offers training in equine rehabilitation for veterinarians, veterinary technicians, physical therapists, and assistants, and students of these fields. The American College of Veterinary Sports Medicine and Rehabilitation (ACVSMR) was approved by the American Veterinary Medical Association in 2010 and currently comprises over 100 equine interest diplomates and veterinarians in residency training programs distributed across multiple countries. In addition, other national and international groups contain practitioners who utilize rehabilitation modalities in equine practice, including the International Society of Equine Locomotor Pathology (ISELP, established 2007) with over 600 members, and the American Association of Rehabilitation Veterinarians (AARV). Physical therapists have also displayed a burgeoning interest in animal rehabilitation, and both the Orthopedic Section of the American Physical Therapy Association and the World Confederation for Physical Therapy have established subgroups for physical therapists with interest and expertise in animal rehabilitation (4). Furthermore, in 2016 the American Veterinary Medical Association published a resolution for the incorporation of Complementary Alternative Veterinary Medicine into the veterinary curriculum, which encompasses commonly used rehabilitation modalities such as acupuncture and chiropractic treatment (5).

Accompanying this growing field of practice, a progressively numerous array of rehabilitation modalities and techniques are available for use by veterinarians, physiotherapists, and lay persons (1, 3, 6, 7). A frequent objective of the use of these modalities is to facilitate return to performance after injury. To be achieved successfully, this requires accurate diagnosis of the injured tissue, selection of appropriate modalities in treatment, and regular assessment of the healing response during therapy. Different modalities are utilized to variably assist with pain reduction, restoration of range of motion, and healing and strengthening of tissues to restore health and performance.

Rehabilitation modalities and techniques can be broadly divided into categories, including specific exercise activities, thermal modalities, electrophysical modalities, biologic modalities, and acupuncture, and mechanical soft tissue modalities. Other available modalities include mesotherapy, hyperbaric oxygen therapy, and therapeutic shoeing.

Controlled or targeted exercise is a common foundation for most equine rehabilitation programs (8). Controlled walking activity (in hand or automatic horse walker) is used to improve mobility and reduce swelling, assist in tissue repair by facilitating tendon fiber alignment, preventing restrictive adhesions and promoting a gradual return of cardiovascular fitness and bone strength (1). As healing progresses, more intensive exercise activities can be applied, which can include specific therapeutic limb and core exercises with or without the incorporation of resistance bands, taping, or limb stimulators; swimming, and treadmill exercise (aqua and land) to optimize strength, flexibility, and fitness.

Thermal therapy can include cooling modalities (cold-water circulation machine, cold-water hydrotherapy, ice) to reduce pain, decrease tissue swelling, and alter circulation (1). Heat can be applied to increase local circulation, muscle relaxation, and tissue extensibility (1).

Electrophysical modalities include shockwave (focused and radial), Transcutaneous Electrical Nerve Stimulation (TENS), Neuromuscular Electrical Stimulation (NMES), Pulsed Electromagnetic Field Therapy (PEFM), therapeutic ultrasound, cytowave, radiofrequency therapy, cold laser, and vibration therapy (7, 9). These modalities variably provide analgesia and reduce tissue edema, fibrous scar formation, and inflammatory mediators, and may counteract disuse atrophy (1, 6, 9). Shockwave therapy is proposed to increase tissue concentrations of angiogenic cytokines, growth factors, osteoblasts, and mesenchymal stem cells (1, 9).

Biologic modalities (PRP, IRAP/autologous conditioned serum, and stem cells) aim to repair damaged tissue, inhibit inflammatory cascades and encourage tissue regeneration (10). Mesotherapy also represents an injection-based technique that aids in localized pain reduction (11).

A variety of mechanical techniques can impact soft tissues and joints, including compression bandaging, massage, stretching, therapeutic exercises, taping, and chiropractic or joint mobilization (12, 13). These can be used to reduce pain and inflammation, enhance tissue repair, improve soft tissue extensibility and function, reduce muscle hypertonicity, and increase range of motion. Acupuncture aids in pain control, reduces edema, muscle spasm and scar tissue, and promotes vasodilation and neuronal regeneration (14).

Finally, therapeutic shoeing can help displace concussion, change the traction between the ground and the shoe, alter the flight phase of the stride, distribute force, move the center of pressure of the hoof, and change the movement of the distal interphalangeal joint (15).

Since clearly a wide array of rehabilitation modalities are available to current day practitioners, the objective of this study was to determine which modalities are commonly used in equine practice by surveying a number of national and international equine veterinary groups containing members practicing equine sports medicine and rehabilitation. Furthermore, it was intended to determine how modalities are applied in the management of performance, disease, or injury in athletic horses, and which operators are providing the modalities. Such information is valuable in determining which modalities would benefit most from rigorous assessments of their efficacy and risks, ultimately to improve the burgeoning practice of equine rehabilitation.

MATERIALS AND METHODS

An electronic questionnaire querying the use of 38 different rehabilitation modalities was distributed to veterinarians in eight national and international veterinary groups and associations[1]. The questionnaire link was distributed between August 2016 through January 2017 via email lists for diplomates of the American College of Veterinary Internal Medicine (ACVIM) and the ACVSMR. The announcement and link were also emailed to the equine client list of a shockwave company[2], and to the members of the International Show Horse Veterinary Association (ISHVA). The questionnaire link was published in the newsletters of the International Society of Equine Locomotor Pathology (ISELP) and the American Association of Equine Practitioners (AEEP). Additionally, the questionnaire link was posted on the websites of the British Equine Veterinary Association (BEVA) and the Australian Equine Veterinary Association (AEVA). Contacting the membership of the American College of Veterinary Surgeons (ACVS) *en masse* was unable to be accomplished due to their diplomate contact policies. Although an exact number of individuals receiving the questionnaire could not be documented, based on approximate sizes of the groups that were contacted, it is estimated that the questionnaire was distributed to more than 2,000 equine veterinarians. Each respondent was given a unique identifier to avoid duplication of answers. The project did not meet the definition of "human subject" under the Common Rule (45 CFR 46) and therefore did not require review by the ethics committee at Oregon State University that oversees research on humans.

Respondents were queried regarding their form of practice and their geographic location; the equine athletic disciplines and breeds they most commonly work with; and the specific rehabilitation modalities they employ from a list of 38 proffered modalities contained within the survey (**Table 1**). Additionally, respondents were queried regarding a list of eight broad conditions or situations that are commonly encountered in horses in which rehabilitation modalities might be considered important. These included tendon or ligament injury, injury to the neck or back, generalized muscle strain, application after fracture repair, arthroscopy, or colic surgery, and for addressing poor performance or for maintaining performance. Respondents were also queried regarding the personnel involved in administering the modalities in question, selecting from the options of licensed veterinarian, licensed veterinary technician, veterinary assistant, veterinary student, farrier, licensed physical therapist, layperson, and trainer/owner. Responses were collated and evaluated by topic (question). No statistical measures were undertaken.

TABLE 1 | Rehabilitation modalities listed in descending order of utilization by responding practitioners.

Modality	Proportion of respondents that use each modality (%)	Total number of responses for each modality
Controlled hand walking	97.3	258
Therapeutic shoeing	96.1	257
Ice	95.2	248
Compression bandaging	89.5	247
Platelet rich plasma	86.5	251
Therapeutic exercises	84.3	242
Stretching	83.3	239
Cold water hydrotherapy	82.9	228
IRAP	81.4	247
Heat	77.6	232
Chiropractic	72.8	243
Shockwave therapy - focused	72.4	243
Range of motion therapy	71.9	235
Massage	69.0	232
Acupuncture	68.3	243
Stem cells—mesenchymal	62.7	233
Automatic horse walker	56.7	238
Mesotherapy	56.4	236
Cold water circulation machine	48.5	231
Pessoa® lunging system	46.2	225
Treadmill—land	39.9	218
Vibration therapy	39.6	220
Class 4 cold laser	39.2	227
Therapeutic ultrasound	39.0	223
Treadmill—aqua	39.0	223
Stem cells—adipose	36.6	216
Class 3 or less cold laser	34.3	219
Kinesio taping®	33.0	218
Neuromuscular electrical stimulation (NMES)	31.8	217
Swimming	30.4	217
Transcutaneous electrical nerve stimulation (TENS)	29.2	216
Shockwave therapy—radial	28.6	217
Equiband™	27.4	215
Pulsed electromagnetic field therapy (PEMF)	22.9	214
Saltwater spa	21.1	213
Hyperbaric oxygen chamber	9.4	203
Cytowave	8.3	206
Radiofrequency therapy	6.4	203

RESULTS

A total of 305 complete ($n = 175$) or partial ($n = 130$) survey responses were obtained from over 10 geographic regions. Partial responses represented those in which not every question in the survey was answered. A total of 75.4% of surveys were submitted from private equine practice or regional private equine referral hospitals, 14.1% from university teaching hospitals or satellite clinics, 8.2% from private mixed animal practice, and 2.3% from veterinary rehabilitation centers. The majority of respondents were

[1]Survey monkey—Surveymonkey.com, Portland, Oregon.
[2]PulseVet—https://www.pulsevet.com/

located in the USA (60%), Europe (25.6%), and Canada (5.6%), followed by Australia/South Pacific (3.6%), Middle East (2.0%), and Central America (1%); the remaining few respondents were located in South America, Africa, Asia, and the Caribbean.

Respondents reported by percentage, the proportion of horses of specific breeds that presented to them annually (**Figure 1**), and the specific athletic disciplines the horses they worked with participated in (**Figure 2**). In regard to the proportion of specific equine breeds that respondents ($n = 267$) interacted with, Warmbloods figured most prominently, followed by Thoroughbreds and Quarter horses, with lesser proportions of Arabians, Standardbreds, ponies, Draft horses, and other breeds (**Figure 1**). Respondents ($n = 243$) were most commonly treating horses associated with the disciplines of hunter-jumper, dressage, pleasure riding, Western riding, track racing, and eventing (**Figure 2**). A smaller proportion of respondents also worked with horses in trotting or pacing, endurance, driving, and other disciplines (**Figure 2**).

Of the 38 rehabilitation modalities that were presented to respondents, the most prominently utilized (those that were used by the highest proportion of respondents regardless of conditions treated) included controlled hand walking, therapeutic shoeing, and ice, which were used by more than 90% of respondents (**Table 1**). Compression bandaging, PRP, specific therapeutic exercises, interleukin-1 receptor antagonist protein therapy (IRAP), stretching, and cold water hydrotherapy were used by more than 80% of respondents (**Table 1**). The remaining modalities were utilized by between 6 and 78% of respondents, with hyperbaric oxygen chamber (9.4%), cytowave (8.3%), and radiofrequency (6.4%) representing the least selected modalities (**Table 1**).

In regard to acupuncture and soft tissue modalities (including chiropractic, stretching, range of motion, and massage; **Table 2**), chiropractic was most often applied to horses for maintenance of performance or addressing poor performance, followed by injuries of the neck or back and generalized muscle strain. Acupuncture, massage, and stretching were similarly most commonly applied to these same four situations, though stretching was more commonly applied for tendon and ligament injuries than for poor performance (**Table 2**). Range of motion therapy was equivalently applied most often for tendon and ligament injuries and injuries of the neck or back, and also for generalized muscle strain. Compression bandaging was typically applied to tendon and ligament injuries and after arthroscopy (**Table 2**).

In regard to electrophysical modalities, laser, therapeutic ultrasound, and focused shockwave were predominantly applied to tendon and ligament injuries, though injuries of the neck and back, and generalized muscle strain also represented commonly treated conditions (**Table 3**). Radial shockwave was most often applied to neck and back injuries and tendon or ligament injuries, while NMES, TENS, and PEMF were applied most often to neck and back injuries and for generalized muscle strain (**Table 3**).

Biologic modalities, including stem cells (adipose and mesenchymal), PRP, and IRAP were overwhelmingly directed at the treatment of tendon and ligament injury, though they were also frequently used following arthroscopic surgery, with IRAP divided equivalently between these situations (**Table 4**). Mesotherapy was largely applied to injuries of the back and neck, and to generalized muscle strain (**Table 4**).

Therapeutic shoeing was used by a large number of respondents ($n = 210$) primarily for the purpose of addressing tendon and ligament injury (92.4% of responses) but also for maintenance of performance (50.5% of responses) ahead of other specified uses (range 0–25%). Vibration therapy was also used for these two conditions (65.8 and 57.9% of 76 responses, respectively) as well as for generalized muscle strain (54.0%) ahead of other specified uses (range 13.2–47.4%). Kinesiotaping® was utilized equivalently (72.4% of 58 responses) for both neck and back injury and generalized muscle strain, and less often for all other specified conditions (range 13.8–51.7%). Few respondents ($n = 16$) utilized hyperbaric oxygen chambers, however, of those, half applied it for tendon and ligament injury, and one quarter used it after colic surgery.

Cold thermal modalities (cold water hydrotherapy, cold water circulation machine, saltwater spa, and ice) were commonly applied to tendon and ligament injury, generalized muscle strain and to maintain performance, whereas heat was most often applied to generalized muscle strain, followed by neck or back injury and tendon and ligament injury.

Exercise based modalities (walking, therapeutic exercises, Pessoa® lunging system, treadmill, swimming, and Equiband™) were variably applied in all medical scenarios, particularly in tendon and ligament injury, and neck or back injury.

Regarding the administration of modalities, respondents were asked to indicate which personnel provided each of the 38 different modalities. Responding veterinarians indicated that they were the personnel providing injection based modalities in most cases, including stem cells (mesenchymal: 99.1% of $n = 112$ selections in this category; adipose: 100%, $n = 59$), PRP (98.3%, $n = 175$), IRAP (97.5%, $n = 161$), and mesotherapy (95.4%, $n = 105$). Veterinarians were also the most frequent administrators of acupuncture (88.5%, $n = 148$) and chiropractic (69.8%, $n = 162$). Veterinarians were the most common personnel to apply shockwave therapy (focused: 65.4%, $n = 202$; radial: 62.5%, $n = 59$), and therapeutic ultrasound (31.9%, $n = 138$), followed by licensed veterinary technicians (17.3, 16.7, and 20.3% for the three modalities, respectively). Veterinarians were also the main providers of class 4 laser (47.2%, $n = 123$), followed by veterinary technicians (25.2%) or veterinary assistants (18.7%), with limited provision of this modality by other types of personnel. Class 3 or less laser was provided by veterinary technicians (17.1%, $n = 105$ total responses), owners or trainers (15.2%), and veterinary assistants (14.3%) behind veterinarians (36.2%). Veterinarians less often, but as the most frequent personnel, administered NMES (54.3%, $n = 70$), kinesiotaping® (52.7%, $n = 74$), TENS (43.2%, $n = 88$), and hyperbaric oxygen (40.9%, $n = 22$), as well as compression bandaging (31.5%, $n = 378$) and PEMF (23.8%, $n = 63$).

Farriers were the personnel most likely to provide therapeutic shoeing (82.7%, $n = 226$) followed by veterinarians (14.2%), and farriers rarely administered any

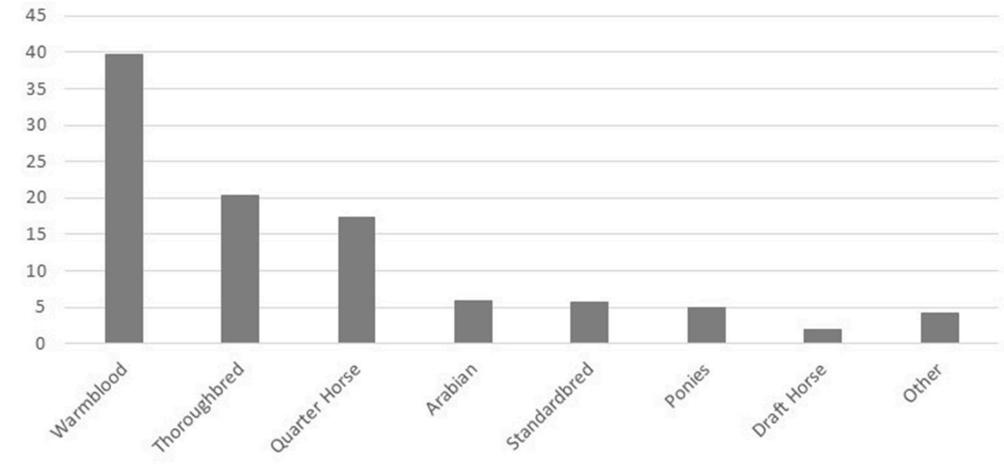

FIGURE 1 | Proportion (%) of horses of various breeds presenting to responding practitioners.

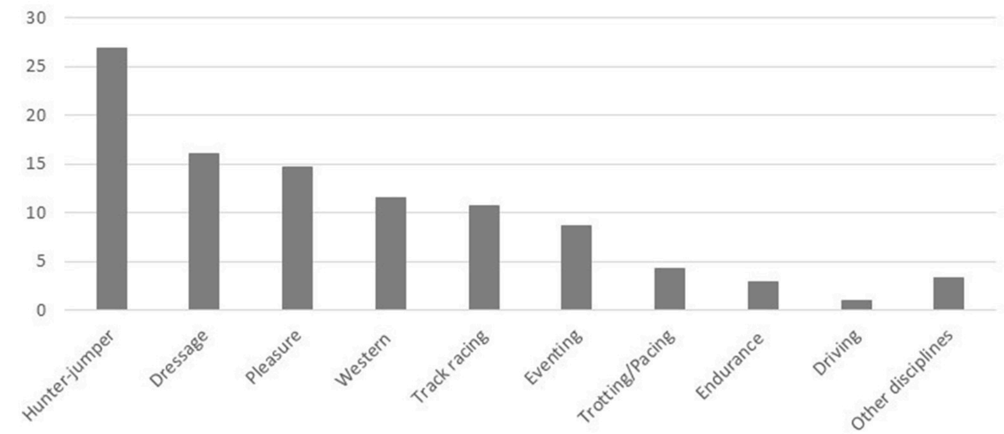

FIGURE 2 | Proportion (%) of horses in various athletic disciplines presenting to responding practitioners.

other modality. Licensed physical therapists were common providers of massage (26.1%, $n = 180$), chiropractic (17.9%, $n = 162$), kinesiotaping® (16.2%, $n = 74$), NMES (14.3%, $n = 70$), and TENS (12.5%, $n = 88$). Veterinary students were common providers of thermal modalities and walking.

Lay people were common providers of walking (in-hand or automatic walker), massage, swimming, treadmill (land and aqua), vibration therapy, cold water modalities, and PEMF. Lay people also reportedly provided some chiropractic therapy (8.0%). Trainers and owners similarly administered most of these modalities, and more commonly than lay people were also reported to administer or use the Pessoa® system (55.5%, of $n = 128$ total selections), Equiband™ (37.0%, $n = 73$), heat (33.7%, $n = 294$), ice (31.5%, $n = 429$), stretching (31.1%, $n = 360$), cold water hydrotherapy (30.3%, $n = 330$), compression bandaging (22%, $n = 378$), and therapeutic ultrasound (16.0%, $n = 138$).

DISCUSSION

A large array of non-invasive and invasive modalities are utilized in the treatment or management of a wide range of disorders affecting equine athletes in many disciplines. The findings from this survey confirm that a range of rehabilitation modalities are commonly implemented for a variety of conditions in athletic horses, and, according to responding veterinarians in this survey, many of these modalities are administered by personnel with a wide range of experience and expertise.

The most commonly utilized modalities, selected by more than three-quarters of respondents, are considered relatively innocuous, and included controlled hand walking, thermal modalities (ice, cold water hydrotherapy, and heat), compression bandaging, therapeutic exercises, and stretching. These modalities have the advantages of being relatively inexpensive, and can be applied by personnel with relatively basic levels of expertise or experience. Nonetheless, they can

TABLE 2 | Utilization of acupuncture and mechanical soft tissue modalities by practitioners for 8 different medical scenarios.

Acupuncture & soft tissue modalities	Compression bandaging (%)	Stretching (%)	Chiropractic (%)	Acupuncture (%)	Range of motion (%)	Massage (%)
Tendon or ligament injury	91.4	54.8	17.8	27.2	66.2	33.6
Neck or back injury	4.8	74.4	72.0	74.2	66.9	71.8
Generalized muscle strain	19.3	81.6	66.9	83.7	63.3	90.1
Post fracture repair	41.2	20.8	5.7	10.2	39.6	12.2
Post arthroscopy	50.3	25.0	8.9	11.6	46.0	12.2
Post colic surgery	11.8	14.9	10.2	38.1	10.1	9.9
Poor performance	8.0	49.4	77.7	67.4	36.7	55.0
Maintain performance	25.7	66.7	81.5	75.5	52.5	69.5
Other (not specified)	16.6	16.1	17.8	23.8	15.8	14.5
Total responses per modality	187	168	157	147	139	131

TABLE 3 | Utilization of electrophysical modalities by practitioners for 8 different medical scenarios.

Electrophysical modalities	Shockwave (focused) (%)	Class 4 laser (%)	Therapeutic ultrasound (%)	≤Class 3 laser (%)	Shockwave (radial) (%)	NMES (%)	TENS (%)	PEMF (%)
Tendon or ligament injury	95.4	96.3	93.2	86.4	66.7	25.0	42.9	59.5
Neck or back injury	71.7	60.5	54.1	53.0	72.2	69.2	77.6	67.6
Generalized muscle strain	35.5	65.4	51.4	62.1	38.9	59.6	63.3	62.2
Post fracture repair	10.5	25.9	9.5	13.6	1.9	7.7	10.2	35.1
Post arthroscopy	6.6	27.2	6.8	16.7	3.7	3.9	8.2	35.1
Post colic surgery	0.0	18.5	5.4	6.1	0.0	5.8	10.2	10.8
Poor performance	15.8	27.2	12.2	25.8	20.4	28.9	18.4	27.0
Maintain performance	30.3	28.4	24.3	27.3	29.6	30.8	34.7	43.2
Other (not specified)	19.7	16.1	12.2	16.7	9.3	23.1	30.6	18.9
Total responses per modality	152	81	74	66	54	52	49	37

NB cytowave and radiofrequency omitted due to minimal number of responses.

be time consuming, and present some risk if inappropriately applied or inadequately supervised. Veterinarians have a crucial role in educating personnel involved in these activities, and in helping establish organized and progressive rehabilitation programs which incorporate appropriate modalities for the condition being addressed.

Therapeutic shoeing was the second most commonly selected modality in the survey, and veterinarians indicated that this modality was extremely likely to be provided by farriers. Given the importance of therapeutic shoeing as a modality, particularly in horses with laminitis or other challenging foot, ligament or tendon conditions, collaborative efforts between veterinarians, and farriers are critical. Attention to fostering this relationship must be emphasized in the curricula for both professions (16, 17).

The administration of PRP and IRAP were also among the most commonly used modalities, with over 80% of responding veterinarians indicating their use. In a previous very large survey of medical joint modalities used by practitioners in 2009, ∼54% of veterinarians indicated that they used IRAP products (18). It is possible that the higher affirmative response in the current survey might reflect increasing use of this modality, a higher percentage of specialist practitioners in the current survey population, recent development of a potentially more efficacious version (IRAP II), or the equine disciplines or expectations of the clients the respondents work with (18, 19). In the previously mentioned study, English performance horse veterinarians were reported to be more likely to use IRAP than either show horse or racehorse veterinarians, though it was not clear if this related to different pathologies encountered in the different disciplines (18). In the current study, IRAP was directed equivalently toward tendon and ligament injury, and after arthroscopy, both of which are indicated uses at this time (20, 21).

Tendon injuries in particular may also be treated with PRP, however, the utilization of PRP is complicated by critical issues such as methods of preparation and platelet activation, with a large array of commercial systems to select from (22, 23). Since PRP is one of the most commonly utilized modalities by sports medicine practitioners it is critical that they have a thorough understanding of the advantages and limitations of the available

TABLE 4 | Utilization of biologic and injectable modalities by practitioners for 8 different medical scenarios.

Biologic and injectable modalities	PRP (%)	IRAP (%)	Stem cells (mesenchymal) (%)	Mesotherapy(%)	Stem cells (adipose) (%)
Tendon or ligament injury	98.9	54.0	98.3	1.8	95.1
Neck or back injury	13.0	18.6	11.9	87.4	16.4
Generalized muscle strain	1.6	3.1	1.7	57.7	1.6
Post fracture repair	6.0	6.8	10.2	1.8	6.6
Post arthroscopy	24.3	55.3	41.5	0.9	34.4
Post colic surgery	0.0	0.0	0.0	1.8	0.0
Poor performance	5.4	8.7	2.5	31.5	3.3
Maintain performance	12.4	32.3	4.2	33.3	4.9
Other (not specified)	10.8	30.4	14.4	10.8	21.3
Total responses per modality	185	161	118	111	61

systems to optimize the likelihood of a positive outcome in their patients.

Manual modalities (chiropractic, massage, range of motion) and acupuncture were commonly utilized modalities in this survey. Chiropractic, massage and acupuncture all commonly fall under the practice of licensed veterinarians, though this requirement can vary between states and countries (24). Reflecting this phenomenon, acupuncture was reportedly typically provided by licensed veterinarians in this survey, and the majority of chiropractic was administered by veterinarians or physical therapists. Physical therapists were reported to be the most common providers of massage. A total of 33% of veterinarians responding to the survey indicated that they consult with physical therapists certified in veterinary rehabilitation, supporting the concept that this is a growing and important collaborative relationship within the practice of equine sports medicine (4). Responding veterinarians indicated that lay people also provided some chiropractic (8%) as well as massage (19.4%). Practice of these techniques by laypeople is becoming more frequent, and has been a source of conflict, because it can potentially create risk to patients through iatrogenic injury, particularly if administration of sedative drugs by unlicensed personnel occurs (24). Furthermore, chiropractic and acupuncture were both commonly utilized for the treatment of poor performance in this survey, and when not performed by a veterinarian, the opportunity to identify specific disease conditions creating performance issues is substantially reduced. Veterinarians should ensure that owners and trainers understand the legal boundaries for specific activities, and should consider establishing collaborative supervisory relationships to facilitate delivery of modalities that they themselves may not provide. Incorporation of appropriate training in alternative modalities into the professional curriculum as recently proposed also enhances the probability of new graduates entering practice with a solid understanding of how to manage specific modalities (5, 25). Furthermore, ensuring that veterinary students and veterinarians in training programs receive adequate practical training in relevant modalities is critical. The results of the current survey suggest that veterinary students were most likely to be involved in delivery of very basic modalities including walking and thermal modalities. Increased emphasis on including rehabilitative and alternative modalities in the professional curriculum will hopefully also translate to more practical training opportunities in more advanced modalities prior to graduation.

The selection of modalities by practitioners in this survey was likely strongly influenced by a range of factors, including cost, convenience, access, and personal capabilities and bias. Some modalities require expensive equipment or are labor intensive, requiring additional personnel to support their administration. Others require substantial training and experience, such as acupuncture and chiropractic. Access and regulation is another influencing variable, which has most recently impacted stem cell therapy in the USA. The Food and Drug Administration (FDA) has classified stem cells as a "new animal drug" therefore requiring FDA approval prior to use for treatment purposes or in live animal research[3] Furthermore, certain modalities, such as shockwave, may be banned from some competitive events for a specified period of time ahead of competition. Ideally, the selection of modalities should primarily be driven by known or proven efficacy, which in itself is a dynamic characteristic since techniques and equipment evolve, improve, or are disproved (7, 26–28). The personal preferences of respondents for specific modalities represented in this survey may also be a source of bias in the data since one of the contact lists utilized was the client list of a shockwave company.

In conclusion, the survey findings indicate that a wide range of rehabilitation modalities are commonly utilized in athletic horses for a variety of reasons, and are administered by a variety of personnel. Additional investigations better defining the utility and efficacy of most of these modalities is indicated, particularly those that are utilized the most frequently or which are associated with considerable expense or the risk of adverse effects on equine patients.

[3]Guidance for Industry. Cell-Based Products for Animal Use. June 2015 https://www.fda.gov/downloads/AnimalVeterinary/GuidanceComplianceEnforcement/GuidanceforIndustry/UCM405679.pdf.

ETHICS STATEMENT

Data was collected via means of electronic survey where respondents were provided complete anonymity and could not be identified by the investigators or others. The project did not meet the definition of "human subject" under the Common Rule (45 CFR 46) and therefore did not require review by the ethics committee at Oregon State University that oversees research on humans.

AUTHOR CONTRIBUTIONS

JW and EM were responsible for study design and data collection. JW, EM, and KD-Z contributed to data assessment and manuscript preparation.

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frontiers in Veterinary Science

ORIGINAL RESEARCH
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Two Multicenter Surveys on Equine Back-Pain 10 Years a Part

Barbara Riccio[1], **Claudia Fraschetto**[2], **Justine Villanueva**[2], **Federica Cantatore**[3] **and Andrea Bertuglia**[2]*

[1] Private Practitioner, Turin, Italy, [2] Department of Veterinary Science, University of Turin, Grugliasco, Italy, [3] Pool House Equine Clinic, Lichfield, United Kingdom

Despite back-pain being a common cause of poor performance in sport horses, a tailored diagnostic workflow and a consolidated therapeutic approach are currently lacking in equine medicine. The aim of the study was to assess the evolution in the veterinarian approach to diagnose and treat back-pain over a 10 years period. To investigate this topic, two surveys were addressed to equine veterinarians working in practice throughout Europe 10 years apart (2006 and 2016). The answers were organized in an Excel dataset and analyzed. There were 47 respondents in 2006 and 168 in 2016, from 8 European Countries. The main reasons for examining horses with back-pain were poor performance (76%), behavioral issues (68%), and lameness (50%). When assessing back pain, 97% of respondents applied careful digital pressure over paravertebral muscles, 90% of them used digital back mobilization, and 69% was detecting areas of localized heat. The use of diagnostic analgesia to confirm the source of pain was rarely employed. Radiography and ultrasonography were the most frequent diagnostic imaging modalities used to investigate the causes of back-pain in both surveys. Obtaining a definitive diagnosis in horses with back-pain is considered challenging due to the reduced accessibility of the area and the variability in the pain manifestations. Corticosteroids injections were used for local treatments by 80% of respondents in 2006 and 92% in 2016. Recently, ultrasonography has been extensively used during the injections of the vertebral articular facets and sacroiliac joints region. The use of complementary therapies was restricted to a low percentage of respondents in the first survey (20%) but it increased over the decade. In 2016, a wider percentage of respondents considered osteopathy (40%), kinesiotherapy (29%), and acupuncture (22%) when treating back disorders compared to 2006. The structural differences of the two surveys did not enable a direct data comparison. Based on the results of this surveys, however, veterinarians should be sensitized to the back-pain problems and seek to integrate findings from clinical research studies in their daily practice.

Keywords: back-pain, multicentric survey, sports medicine, veterinarians' opinion, equine spine

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***Correspondence:**
Andrea Bertuglia
andrea.bertuglia@unito.it

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INTRODUCTION

Back-pain is a common health problem in the equine population. It can cause chronic pain, limiting performance, and impair ability to work, which constitutes a common concern for veterinarians working with performance horses. Recently, the growing interest on equine back-pain has been demonstrated by the number of educational events have been organized and the increasing number of scientific manuscripts on the topic (1–4). In absence of randomized clinical trials and systematic reviews of literature, there is still a perception of poor general consensus as to the clinical modalities and therapeutic routes to manage back-pain. Indeed, the authors have no knowledge of studies reporting current approach of veterinarians to back-pain and the exact influence of scientific researches on equine daily practice is not known. Therefore equine practices to treat back-pain could be determined more by empirical preference than scientific evidence, with marked geographical disparity.

The first aim of this study was to assess the current approach of practitioners to back-pain in horses. Therefore, a first survey conducted in 2006 and a second survey-based investigation realized in 2016 were analyzed. These two surveys resumed the general point of view of a cohort of veterinarians based in Europe on equine back-pain and the strategies to investigate and manage this condition. The second purpose of this work was to analyse the change of the clinicians' approach to equine back-pain over 10 years.

MATERIALS AND METHODS

The Ethical Committee of the University of Turin approved the studies (Protocol Number 214499).

Questionnaire Composition

Two cross-sectional surveys were performed. The preliminary survey was conducted in 2006, containing 10 multiple-choice questions organized in a progressive order. The second survey was designed in 2016, sending a link for a web-based survey by email (Surveymonkey.com, Portland, Oregon). Additional questions were added in the 2016 questionnaire including 16 questions in total. In both cases, questions were translated into three different languages (English, French, and Italian) in order to reduce possible misunderstanding due to text interpretation.

In the first part of the survey, questions were focused on the veterinary surgeon's personal and professional information, including nationality, breed and use of the horses most commonly treated. The second questionnaire was anonymous and therefore it is impossible to know if responders to the first survey participated to the second one as well. Respondents' background was investigated to evaluate their experience as clinicians. Further questions were focused on diagnostic methods adopted and therapies preferred to treat horses with back-pain, including specific questions to evaluate the perceived efficacy of these diagnostic and therapeutic modalities. The questions related to the clinical examination, diagnostic techniques and treatment modalities required short answers such a simple "yes" or "no" and to indicate the frequency of use in case of positive answer. Otherwise, when the clinical value of specific behavior was investigated, a categorical scores system was employed with the following choices: no clinical value, poor clinical value, moderate clinical value, good clinical value, and excellent clinical value. The remaining questions required a multiple-choice closed answer; however free reply such as "other options" was always possible.

Data Collection and Analysis

In the 2006 survey, invitations to participate to the study were posted directly by the principal investigators using a personal e-mail. The enrolment process was performed by direct selection of well-recognized equine specialists, working in referral veterinary hospitals in some European countries (France, Italy, United Kingdom, Suisse, Spain, Germany). For the 2016 survey, the potential target group required was wider. Therefore, the questionnaire was mailed to the secretary office of equine practitioners' national associations in France, Italy, Germany, United Kingdom, Ireland, Belgium, Denmark, Sweden and Suisse. A link referred directly to the online questionnaire was present in the e-mail. A cover letter with the investigator's contact information and the explanation of the study purposes was included. All equine veterinarians associated to their national society received the invitation to participate to this current study. If a secretary office of national association of equine practitioners was not present (Croatia), personal invitations were directly sent to equine practitioners working in referral centers in such countries. Incomplete responses, incomplete surveys and duplicate (surveys from veterinarians working in the same equine clinic/hospital) were excluded from the analysis. The answers were organized in an excel dataset and analyzed using a descriptive statistical method. Summaries and percentage were calculated by the survey programme.

RESULTS

Excluding the incomplete surveys, 47 responses were received in 2006; whilst in 2016, 168 respondents could be included in the study.

Respondent's Characteristics and Study Caseload

In the 2006 survey, complete replies were received from 6 European countries (14 each from France and Italy, 6 from both England and Sweden, 4 from Spain, and 3 from Germany). In 2016, a larger cohort of European nationalities participated to the study: the majority of the answers came from France (61 replies), Italy (26 replies), Germany (20 replies), Switzerland (9 replies), Belgium (23 replies), Spain (17 replies), Ireland (7), Denmark, and Croatia (2 replies for each of the last 2 countries). We received only 1 reply from England.

Participants to the 2006 study were all clinicians working in referral equine hospital, whereas participants of the 2016 survey were clinicians working in second opinion referral centers (55%), first opinion practitioners (36%) and equine specialists working in University Teaching Hospital (9%). The 11% of the responders of the 2016 study have been working in practice for <5 years, 16% for a period ≥ 5 and <10 years, 39% for ≥ 10 and <20 years and 34% for more than 20 years.

In 2006's survey, show-jumpers, dressage and eventers were classified as "competition horses" and this group was the most represented (53% of the equine population), 18% were Standardbreds, 15% Thoroughbreds, while pleasure horses were represented in a smaller proportion (8%), 2% of the horses' population were respectively Quarter horses, Spanish Riding Horses and horses used for Endurance. Instead in the 2016 survey, the equine sport disciplines more commonly served by respondents were represented by show-jumping, followed by pleasure riding, dressage, and ponies horse riding. Less frequently served equine sport disciplines were western riding, endurance, standardbred racehorses racing, eventing, thoroughbred racehorses racing, Polo, Driving, and Spanish riding (**Table 1**).

In 2006, 42% of the interviewed veterinarians stated to perform 50–100 musculoskeletal investigations per month. In 2016, the average number of horses examined for orthopedics problems per months was reduced, in fact only 5% of respondents perform more than 50 investigation and the majority (40%) of the responders examined less than 20 horses per month. In both studies, back-disorder was recognized just in a minority of the orthopaedic cases, with a value between 0 and 20% of the examined cases by the 70% of respondents.

Clinical Tests to Detect Back-Pain in Horses

The digital pressure of paravertebral muscles and the behavioral response to back mobilization tests resulted the two most commonly tests to detect back-pain in horses adopted by veterinarians in both surveys (the above-mentioned tests were always performed respectively by 98–85% of respondents in 2006, and by 97–90% of respondents in 2016). Less commonly, palpation was employed in detecting local heat over the back (by 60% of 2006's survey respondents and by 69% of respondents in 2016). The numbers of tests routinely used by the survey's respondents in 2006 was greater than in 2016 (**Table 2**). In particular, 78% of respondents commonly used the surcingle test in 2006, however 38% of them did not employ this method in 2016. Diagnostic analgesia was occasionally performed during back work-up by the totality of the responders in 2006, but 38% of them did not include this procedure during back evaluation in 2016. The digital evaluation of local thickening of the supraspinous ligament and the ridden evaluation (always performed by the 65% and the 82% of respondents in the 2006 survey) were only occasionally performed in 2016 (by the 38% and the 70% of veterinarians).

Nevertheless, the range of the diagnostic tests performed in 2016 was extremely variable including rectal examination, oral examination, evaluation of the saddle's fit, and neurological examination. In particular, this latter showed an increase in its use compared to the 2006 survey. An osteopathic evaluation was mentioned multiple times as a part of the evaluation routinely performed to detect back-pain among the open answers given by respondents in 2016.

The clinical value attributed to the commonest clinical modalities was investigated in the 2016 survey. Physical examination of the thoracolumbar spine using the mobilization tests or the digital pressure over the epaxial muscles was considered as "excellent" or "good" method to evaluate the back region according to 89 and 81% of the respondents, respectively. The detection of areas of local heat was considered having "good"

TABLE 1 | Horses population characteristics examined by 2006 and 2016 survey respondents in clinical practice.

Horses population (2016)	Draft	Dressage	Endurance	Eventing	Pleasure horses	Polo	Ponies	Quarter horses	Show-Jumpers	Spanish riding	STBRs	*TBRs*
0–20%	163 (96)	112 (67)	139 (83)	148 (88)	91 (54)	163 (96)	129 (77)	134 (79)	52 (31)	163 (97)	139 (83)	146 (87)
20–50%	7 (4)	53 (31)	29 (17)	20 (12)	59 (35)	7 (4)	35 (21)	29 (18)	86 (51)	0 (0)	26 (15)	17 (10)
50–100%	0 (0)	3 (2)	0 (0)	0 (0)	18 (11)	0 (0)	3 (2)	5 (3)	30 (18)	5 (3)	3 (2)	5 (3)

Horses population (2006)	Competition horses (Dressage, Show-Jumpers, Eventing)	Endurance	Pleasure horses	Quarter horses	Spanish riding	STBRs	TBRs
Number (%)	25 (53)	1 (2)	4 (8)	1 (2)	1 (2)	8 (18)	7 (15)

STBRs, Standardbred racehorses; TBRs, Thoroughbred racehorses.

TABLE 2 | Clinical tests used by the 2006 and 2016 survey respondents in order to detect back-pain in horses.

Clinical tests	2016 Respondents *n* (%)			2006 Respondents *n* (%)		
	Always	Sometimes used	Never used	Always	Sometimes used	Never used
Back mobilization	**151 (90)**	12 (7)	5 (3)	**40 (85)**	7 (15)	0 (0)
Diagnostic analgesia	8 (5)	57 (34)	**102 (61)**	0 (0)	**47 (100)**	0 (0)
Evaluation of saddle	**76 (45)**	**82 (49**)	10 (6)	n.r.	n.r.	n.r.
Local heat areas	**116 (69)**	25 (15)	25 (15)	**28 (60)**	13 (27)	6 (13)
Local thickening of supraspinous ligament	40 (24)	**64 (38)**	**64 (38)**	**31 (65)**	12 (26)	4 (9)
Neurological examination	32 (19)	**118 (70)**	18 (11)	0 (0)	**47 (100)**	0 (0)
Oral examination	52 (31)	**89 (53)**	27 (16)	n.r.	n.r.	n.r.
Paraspinal muscles digital pressure	**163 (97)**	2 (1)	3 (2)	**46 (98)**	1 (2)	0 (0)
Rectal examination	13 (8)	**101 (60)**	54 (32)	10 (21)	**31 (66)**	6 (13)
Ridden exercise evaluation	10 (6)	**118 (70)**	40 (24)	**39 (82)**	8 (18)	0 (0)
Surcingle test	34 (20)	**71 (42)**	**64 (38)**	**41 (87)**	6 (13)	0 (0)

n.r., not required. Frequently reported percentage (>35%) are given on bold font.

to "moderate" clinical value for 33 and 29% of the respondents. According to 41% of the respondents, the rectal palpation of the pelvis had low sensitivity in detecting problems at the level of the axial skeleton. The clinical value given to diagnostic analgesia was contradictory: 27% of respondents considered it as reliable, whereas the 23% of respondents assigned no clinical value to it. All the other diagnostic tests were comprehensively considered having "low" to "moderate" value.

Signs Suggestive of Back-Pain

According to 2006's survey, clinical signs suggestive of back-pain in horses were unwillingness to work (96%), modification of the jumping technique and poor performance (89%), loss in gait amplitude (85%), and reluctance to turn during ridden exercise (81%). Less commonly, respondents mentioned subtle hindlimbs lameness (55%), modification in the trajectory during ridden exercise (53%), the presence of areas of focal heat (40%), and forelimbs lameness (21%). The presenting complaints for horses suffering from back-pain for the 2016 respondents were poor performances (76%) and non-specific problems (68%), such as behavioral issues, reluctance to jump, or difficulties with the farrier and lameness (50%). Paravertebral muscle atrophy, difficulty riding the horse, resistance, or difficulty in transition during ridden exercise, reluctance to jump, obvious discomfort and spasm of *longissimus dorsi* at palpation were also described. A bunny-hopping gait or the exhibition of bad attitude during work were considered clinical signs suggestive of pain at this level (**Table 3**).

TABLE 3 | Clinical signs considered by respondents in 2006 and 2016 suggestive of back-pain in horses.

Clinical signs	2016 Respondents *n* (%)	2006 Respondents *n* (%)
Aggressive behavior	134 (81)	n.r.
Bad attitude	102 (61)	n.r.
Bunny-hopping hindlimb gait	94 (56)	n.r
Difficulty during transition	121 (72)	n.r
Difficulty to curve	116 (69)	38 (81)
Difficulty to ride/Resists work	131 (78)	45 (96)
Drifting away during work	92 (55)	25 (53)
Local heat area	74 (44)	19 (40)
Loss of amplitude in the gaits	129 (77)	40 (85)
Modification of jumping style	138 (82)	42 (89)
Paravertebral muscle atrophy	133 (79)	n.r.
Poor hindlimbs impulsion	119 (71)	n.r.
Poor performances	124 (74)	42 (89)
Refuse to jump	113 (67)	n.r.
Spasm of longissimus dorsi at palpation	111 (66)	n.r.
Subtle hindlimb lameness	82 (49)	26 (55)
Unexplained forelimb lameness	67 (40)	10 (21)

n.r., not required.

Diagnostic Imaging Techniques

Results of both studies were similar, confirming that radiography and ultrasonography were the preferred modalities to image the axial skeleton.

In 2016, 45% of the respondents declared to use radiography during back work-up while 50% just occasionally. Ultrasonography was always included in the spinal evaluation by 25% of the clinicians while 70% of them used it occasionally. The majority of the respondents (70%) considered radiography "good" or "excellent", and 40% of respondents rated ultrasonography as a "good" technique. The use of scintigraphy was limited (only the 2% of respondents) although its clinical value was considered "excellent" according to 23% of respondents and "good" according to 41% of the responders. Thermography was rarely employed in clinical setting (88% of respondents has never used it) and 30% of respondents considered it as unreliable (**Table 4**).

Although these techniques were suitable to diagnose back-pain syndrome, veterinarians were rarely able to identify a primary pathology in this site. Primary back problems were

TABLE 4 | Frequencies of imaging modalities used to diagnose spinal pathologies by 2006 and 2016 survey respondents.

Imaging modalities	2016 Respondents *n* (%)			2006 Respondents *n* (%)		
	Always	Sometimes used	Never used	Always	Sometimes used	Never used
Radiology	**76 (45)**	**84 (50)**	8 (5)	**23 (49)**	**22 (47)**	7 (4)
Scintigraphy	3 (2)	**97 (58)**	**67 (40)**	15 (9)	**25 (53)**	**18 (38)**
Thermography	2 (1)	18 (11)	**148 (88)**	3 (2)	9 (19)	**37 (79)**
Ultrasonography	40 (24)	**118 (70)**	10 (6)	10 (21)	**30 (64)**	25 (15)

Frequently reported percentage (>35%) are given on bold font.

TABLE 5 | Primary back pathologies and corresponding frequencies identified in the case-load of horses with back-pain by 2016 survey respondents.

Primary back pathologies	0–10% of cases *n* (%)	10–20% of cases *n* (%)	20–40% of cases *n* (%)	40–60% of cases *n* (%)	60–80% of cases *n* (%)	>80% of cases *n* (%)
Kissing spine	7 (4)	44 (26)	49 (29)	42 (25)	25 (15)	2 (1)
Muscle strains	**83 (49)**	34 (20)	25 (15)	12 (7)	8 (5)	7 (4)
OA of the TL articular facets	29 (18)	34 (20)	57 (34)	22 (13)	24 (14)	2 (1)
Sacroiliac DJD	22 (13)	**74 (44)**	37 (22)	22 (13)	12 (7)	2 (1)
Sacroiliac ligament desmitis	32 (19)	**70 (41)**	27 (16)	27 (16)	13 (8)	0 (0)
Stress fractures back/pelvis	**139 (83)**	20 (12)	7 (4)	2 (1)	0 (0)	0 (0)
SL desmitis	47 (28)	**82 (49)**	23 (14)	10 (6)	3 (2)	2 (1)
Ventral spondylosis	**109 (65)**	40 (24)	15 (9)	2 (1)	2 (1)	0 (0)

OA, osteoarthritis; DJD, degenerative joint disease; TL, thoracolumbar; SL, supraspinous ligament. Frequently reported percentage (>35%) are given on bold font.

encountered in 50% of the cases in 2006 and in 46% in 2016; on the other hand back-pain syndrome was secondary to lameness in 49% of the cases in 2006 and 54% in 2016. The pathologies more commonly detected in 60–80% of the cases suffering from primary back-pain according with 2016 survey were kissing spine (15%) and osteoarthritis of the thoracolumbar articular facets (14%) (**Table 5**).

Therapeutic Modalities to Treat Back-Pain

In 2006 survey respondents had a favorable perception of intramuscular and intravenous drugs administrations (according to 55% of respondents). The ultrasound-guided (US-guided) techniques for administration of drugs in the sacroiliac region was judged fairly uncertain by 43% of respondents in 2006, and 40% of respondents had the same opinion for the US-guided medication performed at the level of the thoracolumbar articular facets and for mesotherapy. Likewise, the 32% of respondents ignored the effect of paravertebral injections.

In contrast, in the 2016 survey the systemic administration of drugs was employed routinely only in 2% of cases. The treatments commonly employed were mesotherapy, US-guided injection of thoracolumbar facets, the US-guided injection of the sacroiliac joint region and the injection of the dorsal spinous processes interspace (**Table 6**). During the considered decade, thoracolumbar facets injection and sacroiliac region injection under US-guidance were perceived having a superior efficacy compared to the same techniques performed blindly, and mesotherapy has been perceived to be effective by a large number of respondents (**Table 7**).

Drugs and Therapeutic Preparations

In both survey this section was divided in two parts consisting in drugs administered locally or systemically (**Table 8**). Corticosteroids were the drugs more commonly used among respondents for local treatment, followed by distillate of Sarracenia Purpurin, while anti-inflammatory non-steroid drugs (NSAIDS) were the commonest drugs administered using the general route (49%).

Respondents confirmed that local injection of corticosteroids was their first therapeutic choice treating back-pain, with a predilection for dexamethasone. Different molecules have been employed during the analyzed decade, in particularly local anesthetic drugs such lidocaine was frequently employed for mesotherapy (50% of respondents), Sarracenia purpurin (38% of respondents) for local analgesia, and bisphosphonates (19%). The NSAIDS were used less frequently in 2016 than in 2006 (24% of respondents), whereas 20% of respondents indicated to use central muscles relaxants, such tiocolchicoside and metocarbamol for general and for loco-regional route. There was no significant increase in the use of homeopathies

TABLE 6 | Therapeutic routes and corresponding frequencies to treat back disorders in horses by 2016 survey respondents.

Therapeutic modalities for drugs administration to treat back-pain in 2016 survey	0–10% of cases *n* (%)	10–20% of cases *n* (%)	20–40% of cases *n* (%)	40–60% of cases *n* (%)	60–80% of cases *n* (%)	80–90% of cases *n* (%)	90–100% of cases *n* (%)
IM or IV route	**70 (41)**	45 (27)	32 (19)	10 (6)	7 (4)	2 (1)	3 (2)
Medication between spinous processes	29 (17)	40 (24)	45 (27)	20 (12)	7 (4)	17 (10)	10 (6)
Mesotherapy	39 (23)	24 (14)	18 (11)	20 (12)	25 (15)	27 (16)	15 (9)
Paravertebral injection	30 (18)	42 (25)	30 (18)	34 (20)	15 (9)	15 (9)	2 (1)
Sacro-iliac joint injection	**84 (50)**	37 (22)	17 (10)	13 (8)	8 (5)	5 (3)	3 (2)
US-guided medication of the TL articular facets	**66 (39)**	22 (13)	25 (15)	20 (12)	8 (5)	15 (9)	12 (7)
US-guided sacro-iliac joint medication	52 (31)	34 (20)	27 (16)	25 (15)	7 (4)	13 (8)	10 (6)

IM, intramuscular; IV, intravenous; TL, thoracolumbar. Frequently reported percentage (>35%) are given in bold font.

TABLE 7 | Perceived efficacy of different therapeutic modalities to treat back-pain in horses by 2006 and 2016 survey respondents.

Perceived efficacy of therapeutic modalities in 2016		None *n* (%)	Poor *n* (%)	Moderate *n* (%)	Good *n* (%)	Excellent *n* (%)
General administration of NSAIDs		39 (23)	**57 (34)**	**54 (32)**	17 (10)	2 (1)
General administration of tiludronate		49 (29)	34 (20)	**59 (35)**	84 (15)	2 (1)
General administration of steroids		30 (18)	**66 (39)**	**62 (37)**	10 (6)	0 (0)
IRAP		**79 (47)**	40 (24)	34 (20)	15 (9)	0 (0)
Medication between spinous process		12 (7)	27 (16)	49 (29)	**62 (37)**	17 (10)
Medication of sacro-iliac joint		38 (14)	34 (20)	44 (26)	**59 (35)**	8 (5)
Paravertebral medication of the TL articular facets		10 (6)	29 (17)	40 (24)	**60 (36)**	44 (16)
Paravertebral US-guided medication of the TL articular facets		5 (3)	10 (6)	32 (19)	**100 (59)**	20 (12)
US-guided medication of sacro-iliac joint		5 (3)	12 (7)	32 (19)	**97 (58)**	22 (13)
Mesotherapy		29 (17)	27 (16)	42 (25)	**54 (32)**	17 (10)
PRP		**92 (55)**	84 (15)	35 (21)	15 (9)	0 (0)
Perceived efficacy of therapeutic modalities in 2006	**Don't know *n* (%)**	**Poor response *n* (%)**	**Moderate response *n* (%)**	**Good response *n* (%)**	**Excellent response *n* (%)**	**Inconstant response *n* (%)**
IM or IV route	3 (6)	2 (4)	13 (27)	**26 (55)**	2 (4)	2 (4)
Mesotherapy	**19 (40)**	3 (6)	4 (9)	15 (32)	4 (9)	2 (4)
Paravertebral injection	30 (18)	42 (25)	30 (18)	34 (20)	15 (9)	15 (9)
Sacro-iliac joint medication	**20 (43)**	4 (8)	3 (7)	14 (30)	2 (4)	4 (8)
US-guided paravertebral medication	**19 (40)**	1 (2)	1 (2)	12 (25)	13 (28)	1 (3)
US-guided sacro-iliac joint medication	**23 (49)**	2 (4)	2 (4)	11 (23)	22 (17)	1 (3)

NSAIDs, non-steroids anti-inflammatory drugs; IRAP, interleukin-1 receptor antagonist protein; US, ultrasound; PRP, platelets rich plasma; TL, thoracolumbar. Frequently reported percentage (>35%) are given in bold font.
IM, intramuscular; IV, intravenous; US, ultrasound. Frequently reported percentage (>35%) are given in bold font.

(like Traumeel® and Zeel® injected locally), employed by the 13% of respondents in 2006 and by the 16% in 2016. The local use of vitamin-B and other preparations such as Interleukin 1-Receptor Antagonist Protein (IRAP®), Platelet-Rich Plasma (PRP), Hyaluronic Acid, sodium chloride 0.9%, Iodine, and Ozone were mentioned but not frequently used.

Based on the results of 2016 survey, the general perception is that drugs are more effective if administered locally rather than via the general route. Interestingly, the perceived therapeutic efficacy of corticosteroids, NSAIDS and bisphosphonates administered via general route was "poor" to "moderate" for 76, 66, and 55% of the respondents. Similarly, the perceived efficacy attributed to IRAP and PRP was "none" or "poor" according to 71 and 70% of respondents, respectively.

Complementary Therapies

In both 2006 and in 2016 surveys, a low percentage of respondents (<20%) prescribed complementary therapies

TABLE 8 | Classes of drugs administered to treat back-pain by 2006 and 2016 survey respondents.

Classes of drugs	2016		2006	
	General *n* (%)	Local *n* (%)	General *n* (%)	Local *n* (%)
Biological therapies (IRAP, PRP)	0 (0)	15 (9)	0 (0)	0 (0)
Local anesthetic	0 (0)	**84 (50)**	0 (0)	13 (28)
Central muscle relaxants	0 (0)	34 (20)	6 (13)	7 (15)
NSAIDs	40 (24)	0 (0)	**23 (49)**	0 (0)
Homeopathic	0 (0)	27 (16)	3 (7)	6 (13)
Sarracenia purpurin	0 (0)	**64 (38)**	1 (2)	**22 (47)**
Steroids	17 (10)	**138 (82)**	3 (6)	**38 (80)**
Tiludronate	34 (20)	0 (0)	3 (6)	0 (0)
Others	0 (0)	13 (8)	2 (4)	4 (8)

IRAP, interleukin-1 receptor antagonist protein; PRP, platelets rich plasma; NSAIDs, non-steroids anti-inflammatory drugs. Frequently reported percentage (>35%) are given in bold font.

to treat back-pain, however the use and efficacy perception of osteopathy were significantly increased during the last decade (**Figure 1**). The percentage of respondents considering osteopathy as an "excellent" technique treating back disorders increased from 0% in 2006 to 40% in 2016. Kinesiotherapy was considered "good' or "excellent" in a high proportion of responders (39%) as well. In the 2016 survey, the majority of respondents stated not to use the following therapeutic modalities: cryotherapy (71%), ozone therapy (75%), capacitive-resistive diathermy (68%), homeotherapy (45%), and phytotherapy (47%). Although extracorporeal shock waves therapy has never been used by the 37% of respondents, a considerable proportion (20%) considered it as "good" or "excellent." Similarly, acupuncture has never been employed by the 32% of respondents, but a large percentage of respondents considered its efficacy "good" or "excellent." Laser phototherapy has never been used by nearly half of the interviewed veterinarians (48%), however 12% of them considered it "good" or "excellent." Although water-treadmill has never been employed by the 41% of respondents for rehabilitative purposes, the general perception was positive by 52% of respondents. Finally, the 58% of respondents stated not to advise to use swimming pool for rehabilitation of back problems.

DISCUSSION

The current questionnaires are the first international surveys on back-pain management in sport horses. Two different multicentre surveys have been employed to collect veterinarians' opinions on equine back-pain syndrome over the last decade in a limited number of European countries. The restricted number of respondents from few Europeans countries does not allow giving a generalized portrait of the European trends in veterinary practice. Excellent feedback was obtained from French veterinarians in 2006 and in 2016, which likely created some degree of bias. Although just few countries were included in the investigations, the study is highly informative in light of the number of veterinary surgeons participating to it.

The major limitation is that the two surveys have been addressed to different groups of veterinarians, sampling different population of horses. Respondents represented a varied group of veterinarians with different experience, working in different clinical setting. It would have been interesting to restrict the interview to the same respondents to the previous survey to define the evolution in their approach over 10 years. However, the authors felt it would have been more appropriate to increase the number and the variability of the veterinary surgeons participating at the second study, including also veterinarians working in first opinion practices. Due to this major limitation, the second aim of the study was not achieved. Furthermore, in 2016 the casework of the interviewed veterinarians included a lower number of lameness investigations compared to 2006, when the majority of the enrolled clinicians were performing 50–100 investigation a month. This reflects a different caseload of horses sampled in our study; partly it could be the effect of the diffuse economic recession or the results of the sampling technique. Although a random method of selection of the study sample would have been more appropriate, it was impossible to select our sample in such way. The equine population considered in the surveys was not represented by a heterogeneous group of horses, with an highest prevalence for sport horses competing in equestrian disciplines and for a population of hospital attenders' competition horses; therefore, the results of the study cannot be generalized to the whole equine population.

Axial skeletal problems are one of most common injuries in horses performing equestrian disciplines (5, 6). The estimated prevalence of back problems in literature varies from 0.9 to 94% of the ridden horse population (7), depending on type and level of activity. The breed of horses served by the veterinary practice and the expertise of the operator evaluating back-pain could have influenced the extreme variability in this range, as demonstrated by a previous studies (5, 8, 9). Training intensity and the specific sport discipline may increase the risk of such specific injuries (5, 6, 10); however, the present study has not the purpose of drawing conclusions on the prevalence of back-pain syndrome in different equestrian specialties.

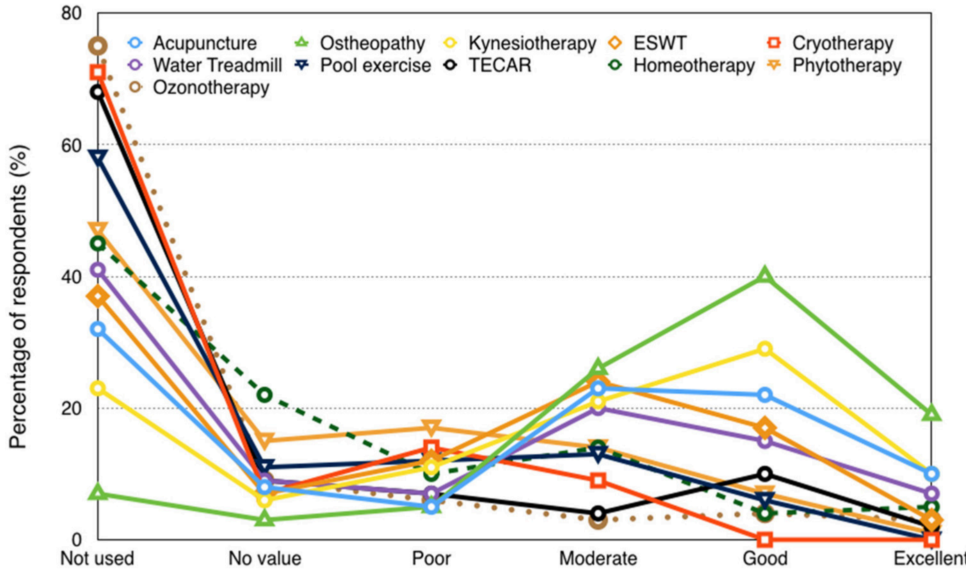

FIGURE 1 | Efficacy of the complementary therapies in treating horse's back disorders.

As reported in literature and confirmed in the current study, clinical signs of back-pain are various and poor specific (1–4, 8, 11). Usually clients of horses affected by the syndrome reported a reduction in performance and behavioral issues. Interestingly, this data reflects an increase attention to the horse's ethogram by the clients, in accordance with the current veterinary literature (12, 13). Respondents reported aggressive response to back manipulation and difficulty during ridden exercise/reluctance to work as the main hallmarks of back-pain in horse especially during ridden exercise. Nowadays, changes in behavior are considered one of the main manifestations of back-pain by equine specialists (1–4, 8, 9, 14). In spite of this fact, the veterinarians are still reluctant to correlate clinical signs of back-pain with a primary spinal pathology and back disorders were considered as main source of pain only in the minority of cases. The association between lameness and back problems in horses is frequently discussed among equine practitioners (1–4, 9, 14–18). Chronic subclinical lameness may have an impact on spinal biomechanics and kinematics (1–4, 14–16), and on the other hand lameness could be secondary to spinal dysfunction (14, 15). In the 2016 survey, our respondents reported that lameness was observed in <50% of the patients suffering from back-pain.

Atrophy of the paravertebral muscles is consistently related to back-pain in the opinion of veterinarians (according to 79% of respondents to the last survey) since it reflects a reduced function, providing information on the presence of pain and underlying lesions (19). The role of epaxial muscles in the spinal stabilization and stiffen has been analyzed in several studies in the last decade (2, 3, 20, 21) and secondary atrophy of *longissimus dorsi* and *multifidus* muscles has been described in horses suffering from pain localized to thoracolumbar region (9, 20, 22, 23). Therefore, in respondents' experience, the evaluation of the muscular system could be highly suggestive of spinal pathology. For the same reason, the subjective evaluation of the back flexibility and the subjective evaluation of animal response to digital pressure over the paraspinal muscles remained the clinical tests more commonly performed in practice, perceived as highly useful by veterinarians. However, the assessment of the response to these tests to date is still based on the subjective evaluation rather than on objectively algometric data, even in presence of multiple studies reporting the effectiveness of mechanical nociceptive thresholds (17, 24). The number of clinical tests used in 2016 was lower compared with 2006, suggesting that the veterinarians have selected more specific methods to detect back-pain over or that less time is dedicated to the static evaluation of the horse. The "surcingle test" and the diagnostic analgesia are currently rarely employed in practice. The "surcingle test" could be dangerous for both the horse and the operator in presence of severe back-pain (J. M. Denoix, personal communication) while diagnostic analgesia of the back has been previously criticized because the infiltration of local anesthetic could affect the spinal function even in clinically sound horses (25). On the other hand, clinicians are routinely employing several different methods for detecting back disorders, even though the clinical value attributed to them is poor to moderate.

Concerning diagnostic modalities, over the last decade radiography and ultrasonography became more popular investigating the back region and the general perception is that they are highly effective diagnostic methods. Radiography is considered useful in detecting osteoarticular lesions in the thoracolumbar region (3, 22) but it has limitations due to the superimposition of the pelvis (3, 23). For further investigation of the lumbar and pelvic region scintigraphy could be required (3, 22, 26). Nevertheless, its use is still limited due to financial constraints. Ultrasonography is routinely employed by practitioners in the diagnosis and treatment of back disorders (27–29), however in both surveys the employment of ultrasonography was lower than radiography. In first instance, veterinarians are probably accustomed to use radiography more often than ultrasonography to identify back lesions and, as consequence, they have possibly still less experience in the interpretation of ultrasound images compared with radiographs. Our data show that thermography is not routinely employed in equine practice, even if one clinical study reported that is a not invasive and auxiliary method to identify lesions in the thoracolumbar region (30). This result could be justified by the high variability of measurements due to the influence of environmental conditions (3, 31).

Although several therapeutic modalities are available, depending on the primary pathology and its severity (3, 19, 32–35), little objective information is present in literature on the current usage of different therapeutic modalities within equine practice. From the results of the last survey, it is possible to conclude that the veterinarians participating in our study preferred local medications, in contrast with what emerged in the previous questionnaire. Conclusions cannot be drawn due to the strong limitations of the study. However, the increased awareness of the advantages of local medications, together with the diffusion of US-guided techniques could explain this difference. In 2006, 40% of the respondents declared not to know the justification of US-guided injection of the sacroiliac region, facets joints and dorsal spinous processes whereas the majority of respondents routinely performed these procedures in 2016. The numerous studies evaluating the accuracy of US-guided injections in the axial and sacroiliac region compared to "blind techniques" could have helped the diffusion in clinical settings (34, 36–38). Although there is limited evidence of its effectiveness (32, 33), mesotherapy was perceived as a therapy with good efficacy between respondents to our last survey. The topical administration was the prevailing route for drugs administration in the 2016' survey because perceived as more effective. The two surveys confirmed that corticosteroids are the main drug family used by the interviewed veterinarians to treat back disorders. Interestingly, the use of a distillate of powdered of pitchered plant (Sarracenia purpurin) as an analgesic agent is still widespread, although its efficacy with regard to horses is not documented in literature (33). This data is surprising also considering the limited availability of the corresponding commercial preparations (Sarapin®, P-Block®) in most European countries and the counterproductive effect that could have in mesotherapy (32). Instead, the use of systemic NSAID in the treatment of spinal pathologies seemed to decrease over the last decade because the limited clinical value encountered in comparison to the 2006' questionnaire. Interestingly, the use of systemic bisphosphonates has tripled comparing data between our two questionnaires, even if the majority of veterinarians considered them of limited clinical value. Controlled clinical trials have been published on bisphosphonates' effect in back-pain over the last 10 years (33, 39) and this could have influenced the use by practitioners during such period. The results of our study can indicate a limited tendency to use biological therapies, homeopathies (Traumeel®, Zeel®), central muscle relaxant, and other preparations locally injected (Sodium Clorure, iodine, or ozone) by European horse clinicians. Further researches such as clinical trials are necessary to justify their use in horses before thinking a considerable diffusion in practice. Manual therapies have been applied to horses treating musculoskeletal diseases (7, 35, 40, 41). Osteopathic manipulations (21), kinesiotherapy and acupuncture (42) are perceived as good auxiliary treatments by our respondents. Despite the efficacy of extracorporeal shock wave therapy relieving deep muscular pain at the level of the back has been demonstrated (43) our study suggests its perceived efficacy by equine clinician is still moderate. A similar trend is registered for diathermy and ozonotherapy. The present study did not report surgical management of dorsal spinous processes impingement (44–47) despite three different studies from United Kingdom described encouraging results and therefore it effectiveness should perhaps be investigated in future (47–49). The limited number of respondents by United Kingdom could be the main reason of this discrepancy between our data and the literature.

In conclusion, the present study gives an insight into the current perception of different clinicians working in different settings regarding horse back-pain, but it was not able to highlights the change in the veterinarians approach in the diagnosis and management of this condition over the last decade. Equine practitioners are conscious of the limitations related to the clinical tests and imaging techniques available for detecting back disorders. Achieving the correct diagnosis is still challenging, because of the restricted accessibility of this area and the variability of the pain manifestations. As a consequence, the advised treatment is often empirical and focus to improve the comfort of the horse instead of treating the origin of the problem. A multimodal approach is often required to manage this condition. In the absence of an objective method to assess pain in practice and consolidated protocols to treat back-pain problems, this study could be considered just as a starting point. Futures studies should be designed in order to rigorously collect follow-up from veterinarians in order to verify whether the common perception on several treatments is actually confirmed in clinical setting. The value gained interviewing the treating veterinarians instead of the owners is that the physicians should be able to assess the improvement more objectively, without being influenced by the client satisfaction.

AUTHOR CONTRIBUTIONS

BR and AB conceived and designed the study. JV and AB contributed in an equal manner preparing surveys and to the acquisition of data. AB, BR, FC, and CF contributed to the interpretation of data. CF drafts the manuscript. BR, AB, and FC draft the paper and revising it critically for intellectual content.

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Variables Affecting Thigh Girth Measurement and Observer Reliability in Dogs

Daniel A. McCarthy[1], Darryl L. Millis[1]*, David Levine[2] and Joseph P. Weigel[1]

[1] Department of Small Animal Clinical Sciences, University of Tennessee College of Veterinary Medicine, Knoxville, TN, United States, [2] Department of Physical Therapy, The University of Tennessee at Chattanooga, Chattanooga, TN, United States

Objective: The purpose of the study reported here was to describe variables affecting thigh girth measurements preoperatively and 2 weeks after surgical stabilization of the stifle and to examine inter- and intra-observer reliability.

Animals: Ten hound-type dogs with experimental, unilateral, cranial cruciate ligament transection, and surgical stabilization.

Procedures: Dogs were placed in lateral recumbency for measurements of thigh circumference after the stifle was placed in flexed (F), estimated standing (S), and extended (E) positions. Measurements were made at 50 and 70% of thigh length (TL), with hair unclipped and then clipped prior to surgery, before and 2 weeks after cruciate ligament transection and stifle stabilization, and with and without sedation. A spring tension measuring tape was used to determine thigh girth that allowed a consistent amount of end-tension to be applied to the tape. All measurements were made by two blinded individuals in triplicate, data were recorded for each set of measurements and the mean of the three measurements for each condition was used for analysis.

Results: Thigh girth was significantly greater at the more proximal site of 50% TL (36.7 ± 2.6 cm) when compared to the 70% TL (31.7 ± 2.7 cm) ($P = 0.001$). Sedation did not significantly affect thigh girth at any stifle position at the 70% and 50% TL. Although there were no differences in thigh circumference between the flexion and standing positions at 50% TL (F 38.2 ± 2.8 cm, S 38.1 ± 2.9 cm) and 70% TL (F 33.6 ± 1.6 cm; S 33.6 ± 1.8 cm), full extension of the stifle resulted in significantly less thigh girth (50% TL 36.6 ± 2.6 cm, $P = 0.006$; 70% TL 31.7 ± 2.6 cm, $P = 0.006$). Significant decreases in thigh girth were seen after surgery in all limb positions at both measurement sites. The highest correlations between Observer 1 (OB1) and Observer 2 (OB2) with least differences in measurements were with the stifle in the extended position. Agreement between two observers using standard measuring technique was significant at both the 50% (OB1: 34.10 ± 2.93 cm, OB2: 34.08 ± 2.65 cm, $P = 0.007$, ICC = 0.984) and 70% (OB1: 29.89 ± 2.43 cm, OB2: 30.04 ± 2.30 cm, $P = 0.004$, ICC = 0.981) TL positions with the stifle placed in extended position.

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***Correspondence:**
Darryl L. Millis
dmillis@utk.edu

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Conclusion and Clinical Importance: Thigh girth measurement may be useful as an outcome measure when appropriate measuring technique is used. It is recommended that thigh girth be obtained at a distance of 70% thigh length, with the leg in an extended position while in lateral recumbency, and the dog relaxed or under sedation. Further studies should be performed in a variety of clinical situations.

Keywords: thigh circumference, muscle atrophy, muscle atrophy post-cranial cruciate ligament transection, dog thigh girth, measure thigh girth

INTRODUCTION

Muscle atrophy commonly occurs following injury and surgery (1, 2). Assessment and improvement of medical, surgical, and physical rehabilitation treatments for various conditions depend on accurate, inexpensive, and reliable methods of measuring outcome parameters. In human medicine, thigh girth has been used as a reliable functional outcome objective measurement to evaluate progress and recovery (1, 3–7). The quadriceps muscle group comprises a majority of the cranial thigh susceptible to atrophy, and the biceps femoris, semitendinosus, and semimembranosus muscles comprise the caudal thigh muscles susceptible to atrophy. Their location allows sufficient access to palpate, measure, and evaluate the muscles under the proper conditions.

The quadriceps muscle group is particularly prone to atrophy secondary to decreased limb function from musculoskeletal injury. In human patients with anterior cruciate ligament tears, there was no significant atrophy of any other muscle except the quadriceps muscle group during muscle measurements (1). The human quadriceps muscles of the anterior cruciate ligament-deficient limb were significantly weaker (average 25%) than those of the uninjured side; the total quadriceps, vastus lateralis, and vastus intermedius volume and cross-sectional area were significantly smaller in the anterior cruciate ligament-deficient limb (1). Therapy directed toward improving muscle strength and mass is likely to improve patient function and overall outcome.

Thigh girth measurements in humans have been considered both reliable and repeatable as long as a standardized measurement protocol is used (6, 7). A standard protocol is vital in decreasing observer variability. A recent study in dogs used a laser device to ensure precise location of landmarks to standardize the location of thigh girth measurement (8). Although these dogs were placed in relative standing angles, alterations in the flexion or extension angle of the stifle joint may have altered thigh girth, resulting in a low agreement of measurements between observers. More consistent positioning of the limb and joints may have improved agreement of measurements by different observers.

Thigh girth measurements have been used to assess progress following surgical management of cranial cruciate ligament repair and canine total knee arthroplasty and its use has been explored for other purposes (9–11). One study found that thigh circumference was statistically decreased compared to the unaffected contralateral limb in dogs 1 and 5 years after stifle stabilization surgery for naturally occurring cranial cruciate ligament disease (12).

A simple, repeatable method of determining thigh girth is necessary to assess changes in thigh girth as a non-invasive, clinically applicable method of estimating muscle mass. Although thigh girth measurement has been studied in veterinary patients, differences between observers have been problematic (8, 13). Standard technique and limb positioning may result in improved agreement among observers. In addition, measurement of thigh girth should be simple, inexpensive, reproducible, and relatively quick. Variables that may affect thigh girth include location of the measurement on the thigh, angle of limb in flexion or extension, whether the hair is clipped or not, determination of girth in awake or sedated dogs, and reproducibility between evaluators.

To the author's knowledge, no studies have evaluated the use of thigh girth measurement in dogs prior to and following surgery of the stifle under various positions and conditions. The purpose of the study reported here was to evaluate the effect of stifle joint position, clipping, sedation, and different evaluators on thigh girth measurements at two different locations before and 2 weeks after transection of a cranial cruciate ligament and immediate stabilization of the stifle. We hypothesized that extension of the stifle, measurement of the distal thigh, clipping the hair, and sedation of dogs would result in lower thigh girth as compared with flexion of the stifle, measurement of the proximal thigh, unclipped limbs, and non-sedated dogs. We also hypothesized there would be acceptable intra- and inter-observer repeatability when a standard measurement technique was used.

MATERIALS AND METHODS

Thigh girth was measured using 10 young, adult male and female mixed-breed hound-type dogs. All dogs were determined to be healthy on the basis of physical examinations, complete blood count (CBC), and serum chemistry profiles. The dogs were part of another study in which a unilateral cranial cruciate ligament was transected and the stifle immediately stabilized using an extracapsular technique. This study was carried out in accordance with the recommendations of University of Tennessee's Institutional Animal Care and Use Committee. The protocol was approved by the University of Tennessee's Institutional Animal Care and Use Committee prior to commencement.

FIGURE 1 | A Gulick II measuring tape was used to determine thigh girth. The tape was placed around the limb with a consistent amount of end-tension placed on the tissues minimizing differences in the amount of tension after the tape was pulled. The tape measure was pulled taut until one of the red balls was completely exposed (4 oz. of end tension).

A Gulick II measuring tape[1] was used to determine thigh girth. This instrument allowed the tape to be placed around the limb with a consistent amount of end-tension placed on the tissues, thereby, minimizing differences in the amount of tension after the tape was pulled taut. The tape measure was tensioned until one of the red balls was completely exposed (4 oz. [133.4 g] of end tension) (**Figure 1**). Care was taken to ensure that the tape did not slip distally during tensioning. Dogs were placed in lateral recumbency for measurements. All measurements were made by two individuals after a training period. Both evaluators practiced the technique, including palpation of anatomic landmarks, on at least 20 other dogs prior to study start.

To make the measurements, Observer 1 entered the room, measured thigh length and marked the site of interest. An assistant placed the limb in the position to be measured (full flexion, full extension or an estimated standing angle) while the observer placed the tape around the limb and pulled the tape until the desired amount of tension was reached. The observer held the tape in place without looking at the tape measure value while the assistant recorded the value. The measuring tape was then completely removed, and the limb was repositioned prior to placing the limb in the desired stifle angle to make the second and third measurements in the same fashion with minimal time lapse between each measurement. A total of 18 measurements were made for each observer. Following data collection, Observer 1 exited the room, Observer 2 entered the room and performed the measurements in a similar fashion. The means of each set of measurements (flexion, extension, and estimated standing angle) at both 50 and 70% thigh length were used for analysis.

Effect of Different Measuring Locations

Thigh length (TL) was determined by measuring from the proximal tip of the greater trochanter to the distal aspect of the lateral fabella (**Figure 2**). A surgical marking pen was used to mark points equal to 50 and 70% of the thigh length, as measured from the tip of the greater trochanter. Thigh girth was determined by placing the tape measure around the thigh at these points, ensuring the tape was perpendicular to the femur. To maintain blinding for OB2, OB1 made several marks to mask the actual site of measurement, and OB2 used a different color pen to make marks.

[1]Country Technology, Inc., Gays Mills, WI

FIGURE 2 | Thigh length (TL) was determined by measuring from the proximal tip of the greater trochanter to the distal aspect of the lateral fabella. A surgical marking pen was used to mark points equal to 50 and 70% of the thigh length, as measured from the tip of the greater trochanter.

Effect of Clipping

To determine the contribution of hair on thigh girth, measurements were made on limbs of awake dogs prior to clipping and after clipping prior to surgery with the stifle at an estimated standing angle.

Effect of Stifle Position

The effect of stifle position on thigh girth was determined by taking measurements with the stifle fully flexed, fully extended, and at an estimated functional standing angle. To estimate the standing angle, we attempted to create a floor surface by placing a hand under a paw, and placing the pelvic limb in the estimated standing angle with the tuber calcis and metatarsals placed perpendicular to the simulated floor surface. The hip was maintained in a functional standing angle (approximately 95–110°), and the tarsus was allowed to move passively while positioning the stifle.

Effect of Sedation

To determine the effects of sedation on muscle tension, measurements were made on dogs which were fully awake and after pre-medication with acepromazine[2] (0.11 mg/kg, intramuscular).

Effect of Surgery

Thigh girth was measured before transection of the cranial cruciate ligament and stifle stabilization and 2 weeks after surgery to determine the changes after surgery. No special exercise or rehabilitation protocol was instituted after surgery.

Intra-Observer and Inter-observer Variability

Intra-observer and inter-observer variability were evaluated using intra- and interclass correlation coefficients. To determine the intra-observer variability, the same observer performed three measurements for each stifle position, at the 50 and 70% thigh lengths. To determine inter-observer variability of thigh girth measurements, the same measurements were made by two independent evaluators (OB1 and OB2), who were unaware of the other investigator's findings.

Statistics

An *a priori* power analysis with a power of 0.80 and a P-value < 0.05 was performed using pilot data from three dogs to determine the number of subjects needed to detect differences between measurements collected by individual observers (intra-observer reliability) and different observers (inter-observer reliability). Analysis indicated that the sample size needed was three subjects for both intra- and inter-observer reliability.

Means of the three measurements were compared using paired t-test where appropriate. A repeated measures ANOVA was used to compare group means when more than two groups were being compared. If overall group differences were apparent, differences between groups were determined using the LSD procedure. The intraclass and interclass correlation coefficient (ICC) test was performed to compare the reliability and continuity between both inter- and intra-observer variability. The standard deviations of the individual measurements were all extremely small allowing us to average them for analyses. Statistical significance was established at $P < 0.05$.

RESULTS

A total of 1,200 measurements were performed by OB1 and OB2. Thigh girth was significantly greater at the more proximal 50% TL when compared to the 70% TL at all positions (**Table 1**). Although clipping the hair did not significantly affect thigh girth, mean thigh girth was 7 and 3 mm less in clipped limbs at the 50 and 70% TL locations, respectively, compared to the unclipped limbs (**Tables 2**, **3**, **Figure 3**). Position of the stifle joint also affected measurements. Although there was little difference between flexion of the stifle and placement of the limb in an estimated functional standing position, full extension of the stifle resulted in significantly less thigh girth (**Table 4**, **Figure 4**).

TABLE 1 | Comparison of thigh circumference (+/– SD) measured at 50% TL and 70% TL at three different stifle positions prior to sedation, clipping, and surgery.

	50% TL	70% TL	*P*-Value
Flexion	38.2+/−2.8	33.6+/−1.6	0.001
Standing	38.1+/−2.9	33.6+/−1.8	0.002
Extension	36.6 +/−2.6	31.7+/−2.7	0.001

All measurements are reported in centimeters.

Sedation had little effect on thigh girth in the standing and extended positions for both 50–70% thigh length sites (**Tables 2**, **3**). However, there was a trend for decreased thigh girth of sedated dogs with the limb in the flexed position ($P = 0.07$) (**Figures 5**, **6**).

Significant decreases in thigh girth were seen after surgery in all stifle positions at both measurement sites (**Figures 7**, **8**). The decreases ranged from 2.5 cm for the 70% thigh length with the limb extended to 3.8 cm for the 50% thigh length with the limb in a standing position (**Figures 7**, **8**).

Intraclass correlations were similar and highest with OB1 (0.993) and OB2 (0.994) for the thigh girth measurements made at 70% with the stifle in the extended position. Two observers using the standard measurement technique obtained similar results for thigh girth measurement. The highest interclass correlations (50% TL: ICC = 0.984, $P = 0.007$; 70% TL: ICC = 0.981, $P = 0.004$) between observers and the least differences between observers were for measurements made with the limb in the extended position (**Table 4**).

DISCUSSION

Thigh girth has long been an indirect method of assessing changes in muscle mass in people (14). Measurement of thigh girth is inexpensive, quick, and easily performed on clinical patients. Acceptable results depend on standard, repeatable methods of measuring thigh girth to obtain meaningful measurements. One factor in making reliable, repeatable measurements is the type of tape measure used. One study evaluating human thigh circumference measured by spring tape and optoelectronic volumetry revealed high reliability between the two methods (15). Another veterinary study compared the precision of four different types of tape measures used to measure dog thigh circumferences, and although significant differences were not found, the Gulick II tape measure had lower inter-observer and intra-observer variation (16). In the same study, thigh circumference measurements were made at an estimated half-way point and stifle position was not taken into account during measurements. These factors may have decreased consistency. It is important to use a flexible tape which easily

[2]Vet One, MWI Animal Health, Boise, ID

TABLE 2 | Different conditions affecting thigh circumference measurements (+/–SD) at 50% TL at three different stifle positions.

50% TL	Limb position pre-sx mean ± *SD*	Post-sx mean ± *SD*	Pre-clip mean ± *SD*	Post-clip mean ± *SD*	Pre-sedation mean ± *SD*	Post-sedation mean ± *SD*
Flexion	38.2+/−2.8	34.7+/−3 (*P* = 0.0001)	-	-	34.7 +/−3	33.4+/−2.4 (*P* = 0.07)
Standing	38.1+/−2.9	34.3+/−2.5 (*P* = 0.0001)	38.8+/−2.7	38.1 +/−3.1 (*P* = 0.27)	34.3+/−2.5	34+/−2.7 (*P* = 0.32)
Extension	36.6 +/−2.6	33.2+/−2.2 (*P* = 0.00004)	-	-	33.2+/−2.2	32.8+/−2.4 (*P* = 0.14)

Thigh girth was decreased at the stifle extension position relative to other stifle positions and in post-surgery flexion, extension, and estimated standing stifle positions. Pre-clip and post-clip measurements were only taken in the standing stifle position. All measurements are reported in centimeters.
sx, Surgery; SD, Standard Deviation.

TABLE 3 | Different conditions affecting thigh circumference measurements (+/– *SD*) at 70% TL at three different stifle positions.

70% TL	Limb position pre-sx mean ± *SD*	Post-sx mean ± *SD*	Pre-clip mean ± *SD*	Post-clip mean ± *SD*	Pre-sedation mean ± *SD*	Post-sedation mean ± *SD*
Flexion	33.6+/−1.6	31+/−2.1 (*P* = 0.00007)	-	-	31+/−2.1	29.8+/−1.9 (*P* = 0.07)
Standing	33.6+/−1.8	30.2+/−2.3 (*P* = 0.0002)	33.9 +/−2.6	33.6+/−1.8 (*P* = 0.27)	30.2 +/−2.3	30.1+/−2.4 (*P* = 0.42)
Extension	31.7+/−2.7 (*P* = 0.0001)	29.2+/−2 (*P* = 0.003)	-	-	29.1 +/−2	29.2+/−1.9 (*P* = 0.28)

Thigh girth was decreased at the stifle extension position relative to other stifle positions and in post-surgery flexion extension, and standing positions. Pre-clip and post-clip measurements were taken in the standing stifle position only.
sx, Surgery; SD, Standard Deviation.

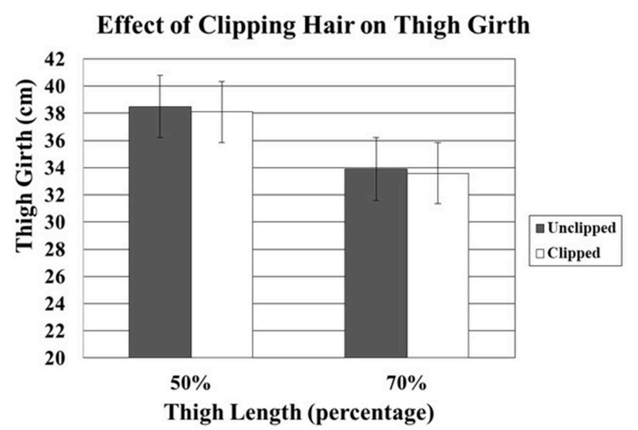

FIGURE 3 | Comparison of effect of unclipped and clipped hair at 50% and 70% thigh circumferences. Although clipping the hair did not significantly affect thigh girth, mean thigh girth was 7 and 3 mm less in clipped limbs at the 50% and 70% thigh length locations, respectively.

follows the contours of the limb, yet does not stretch. It is also critical to use strategies to minimize the differences in the amount of tension placed on the tape during serial measurements. A tape measure with a spring loaded tension gauge may also help to reduce variation between observers and is a reason why we used the Gulick II.

It is clear that thigh girth decreases distally along the femur. Muscles of the thigh are quite prominent proximally, and decrease in size distally. In particular, as the quadriceps muscles approach the stifle joint, they become musculotendinous structures, and finally become the patellar tendon near the stifle joint. We also found it technically easier to perform measurements at the 70% thigh length as compared with 50% because this site is distal to the flank fold.

Although there were no statistically significant differences in measurements before and after clipping hair, the average difference between clipped and unclipped measurements was 3 and 7 mm at the 70 and 50% thigh measurement locations, respectively. However, the difference may have been greater in dogs with longer hair than the short-haired hound dogs used in this study. Unclipped vs. clipped hair measurements were only made with the stifle at an estimated standing angle because of time constraints immediately prior to surgery. Despite the lack of statistically significant differences, we recommend that thigh girth be measured as consistently as possible, and that all serial measurements on an individual patient be made with the hair clipped short for ease of measurement if possible.

The degree of stifle flexion or extension may significantly affect measurement of thigh girth. Thigh girth measurements with the stifle fully extended were consistently less than those made with the stifle in a standing position or with the stifle flexed. Although there were no differences in the measurements made with the stifle in a flexed or standing position, we found that measurements with the stifle flexed are technically more difficult and require close attention to placing the measuring tape so that the tape does not slip down the leg. Placement of the limb in an estimated standing position requires knowledge of the standing angle of the joints in that particular patient with regards to breed, size and conformation. Estimated standing positions

TABLE 4 | Comparison of thigh girth at 50 and 70% thigh lengths with the limb in an extended, standing, and flexed angle.

Measurement position	OB1 mean ± *SD*	OB2 mean ± *SD*	ICC (Inter-rater class correlation with 95% CI)	ICC OB1 (Intra-rater class correlation with 95% CI)	ICC OB2 (Intra-rater class correlation with 95% CI)
70% Extended	29.89 ± 2.43	30.04 ± 2.30	0.981 (955.–0.992)	0.993 (0.975–0.995)	0.994 (0.978–0.996)
70% Standing	31.74 ± 2.61	32.08 ± 2.33	0.972 (0.944–0.986)	0.989 (0.974–0.996)	0.991 (0.974–0.996)
70% Flexed	31.43 ± 2.45	31.10 ± 2.38	0.973 (0.942–0.989)	0.987 (968.–0.994)	0.992 (0.984–0.996)
50% Extended	34.10 ± 2.93	34.08 ± 2.65	0.984 (966.–0.994)	0.986 (0.966–0.994)	0.984 (0.964–0.992)
50% Standing	35.38 ± 3.24	35.04 ± 2.71	0.963 (0.945–0.989)	0.966 (0.921–0.986)	0.979 (0.958–0.989)
50% Flexed	35.36 ± 3.35	35.01 ± 2.96	0.959 (0.932–0.978)	0.964 (0.931–0.986)	0.972 (0.952–0.982)

Highest inter- and intra-class correlations (ICC) between observers were found when the thigh girth was measured at the 50 and 70% with the stifle in an extended position. Measurements were made in centimeters. (SD, Standard Deviation; CI, Confidence Interval, $P < 0.01$ for all ICC values).

are somewhat subjective in a recumbent patient, however, fully extended positions may be more consistent. Placing the hind limb in an extended stifle position may have less variability and result in more consistent measurements of thigh girth. Measurements made in standing dogs in one study resulted in low agreement among investigators and may be due to the variations in the standing stifle angle and differences in muscle tension while standing (8). There is evidence from previous studies that maintaining the stifle in a standing position may result in unacceptable variability (8, 13). Subjectively, it seemed easier to measure thigh girth with the stifle fully extended by a handler, and with the dogs in lateral recumbency in our study.

Sedation resulted in a non-significant decrease in thigh girth. The differences were greatest at the 50% thigh length measurement, presumably because muscle mass is greater proximally and any changes in muscle tone would likely be accentuated in regions of greater muscle mass. Measurements at the 70% thigh length with the limb in either an extended or standing position differed by only 1 mm, on average, with and without sedation. The dogs used in this study were generally calm and tolerated restraint in lateral recumbency very well, similar to most, but not all, clinical patients. Sedation did not significantly affect measurements, suggesting that if the dog is reasonably calm, the additional relaxation provided by acepromazine did not appreciably affect the measurements. In a clinical setting, sedation may be necessary in certain situations, such as for an excited patient or to obtain radiographs, and thigh circumference measurements should be ideally obtained using a technique that is minimally affected by sedation. Acepromazine was the only sedative used in the study and other medications may produce different results (i.e., alpha-two agonist or benzodiazepines). However, our results suggest that if a dog is reasonably calm, sedation has minimal contribution to thigh circumference measurements. Although we cannot speculate how thigh circumference is affected by a dog that struggles and has tense muscles, our results suggest that thigh circumference measurements with the stifle in an extended position are similar in relaxed dogs and in dogs following sedation with acepromazine, and it is possible that measurements of tense dogs following sedation may give results that more closely reflect those obtained if the dogs were relaxed.

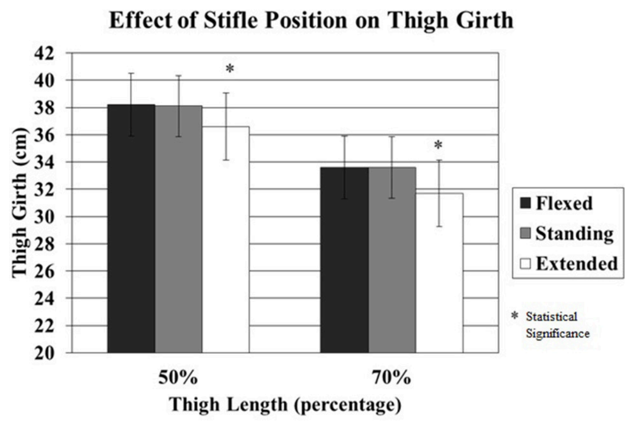

FIGURE 4 | The effect of stifle position on thigh girth measured at 50% and 70% thigh length when the stifle was flexed, standing, and extended. Although there was little difference between flexion of the stifle and placement of the limb in a functional standing position, full extension of the stifle resulted in significantly less thigh girth.

There was a significant decrease in thigh girth at both thigh length points for all limb positions 2 weeks after surgery. The changes in thigh girth are presumably due to muscle atrophy following surgery and are consistent with human studies measuring muscle mass post-surgery (1, 2). In this study, dogs did not use their affected limbs to an appreciable extent during the 2 weeks study period after surgery. Percent changes in thigh girth were similar at both limb length sites, although the absolute amount of change was greater at the 50% thigh length site, suggesting that areas with the greatest amount of muscle mass are

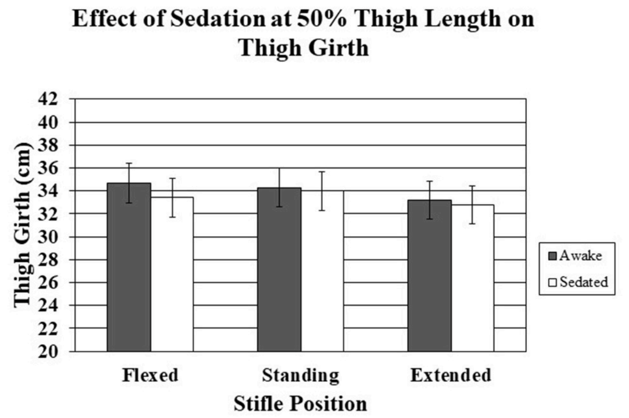

FIGURE 5 | The effect of sedation on thigh girth measured at 50% thigh length when the stifle was flexed, standing, and extended. There were no significant differences.

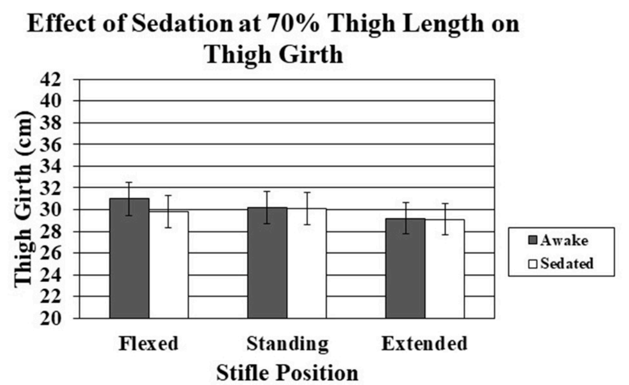

FIGURE 6 | The effect of sedation on thigh girth measured at 70% thigh length when the stifle was flexed, standing, and extended. There were no statistical significant differences between sedated and non-sedated dogs.

affected the most by muscle atrophy which has also been shown in human anterior cruciate ligament injuries (1). Although the limbs were not reclipped 2 weeks after surgery, the amount of hair regrowth was minimal during that time, and the magnitude of changes in thigh girth following surgery was much greater than that following clipping if the measurements are made with the stifle held in a consistent position and at a consistent thigh length. This suggests that the measuring techniques used in this study are sensitive enough to determine changes in thigh girth within 2 weeks of an event resulting in minimal weight-bearing. Future studies are necessary to examine the relationship between thigh girth and actual muscle mass to establish whether thigh girth is a reasonable method of assessing changes in muscle mass following injury and rehabilitation.

It is desirable to have a technique for measuring thigh girth that is repeatable between different observers so that reliable results may be obtained regardless of the observer. In this study, both investigators practiced measurements prior to the study start. With proper training and attention to detail,

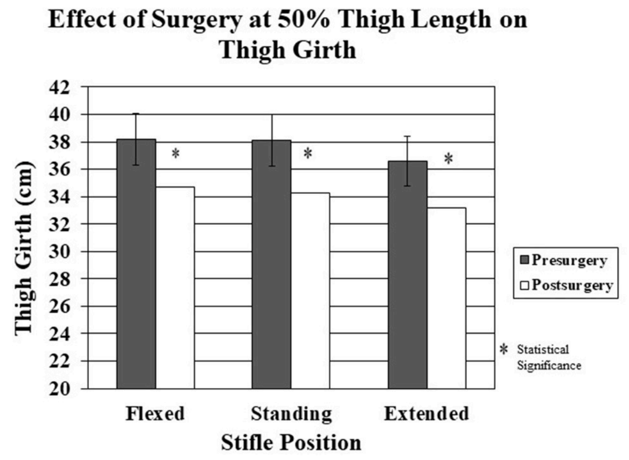

FIGURE 7 | The effect of surgery on thigh girth at 50% thigh length pre-surgery vs. post-surgery in the flexed, standing, and extended stifle positions. There was a significantly decreased thigh girth for all stifle positions post-surgery.

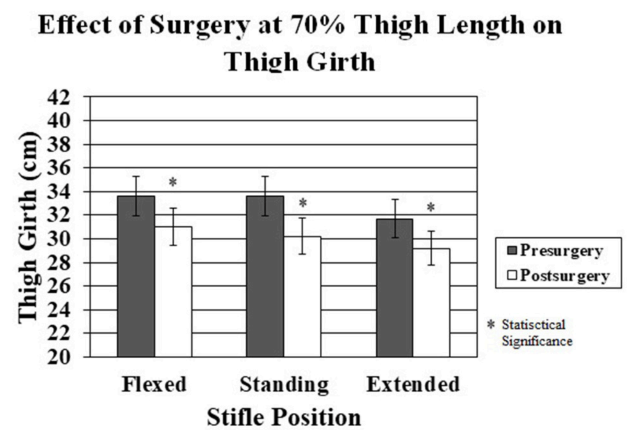

FIGURE 8 | The effect of surgery on thigh girth at 70% thigh length pre-surgery vs. post-surgery in the flexed, standing, and extended stifle positions. There was a significant decrease in thigh girth in all stifle positions post-surgery.

differences between investigators were relatively small. The difference between observers was 3.5% or less for each category assessed. The greatest differences were seen with the limb in the flexed and standing positions, suggesting that it was more difficult to obtain consistent measurements. Although the agreement between observers was slightly greater at the 50% thigh site, both observers subjectively felt that it was technically more difficult to properly obtain measurements at this site because of the presence of the flank skin in some dogs.

The authors performed the ICC to evaluate the repeatability of measuring thigh circumference. The ICC correlations indicated excellent agreement for both inter- and intra-observer variability (**Table 4**). Smith et al. found significant inter- and intra-observer variability when measuring thigh circumference midway between the hip and stifle in Labrador Retrievers (13). Similar findings were found by Bascuñán et al. in a two phase cadaveric and clinical study measuring thigh circumference at the 50% TL (8). This contrasts with our findings, where there was significant reliability between observers following training at both the 50 and 70% TL in the extended stifle position groups. We suspect that although TL location was taken into consideration for these previous studies, the degree of extension or flexion of the stifle joint may significantly affect thigh girth measurements. In addition, the thigh length measurements were made between two very distinct landmarks, the tip of the greater trochanter and the distal aspect of the lateral fabella. Others have measured from the greater trochanter to the lateral femoral condyle, which is less precise. We believe that less variation in measurement location should improve repeatability. While we acknowledge that marking the thigh length location would likely influence the repeatability of the triplicate measurements, measurement of the thigh length as described is quite repeatable in skeletally mature dogs. In fact, the thigh length measurements were within 3 mm between the preoperative and 2 weeks postoperative times. Our experience in determining thigh length in clinical patients is similar regarding measurements over several months.

It is unknown how slight variations in measurement technique may affect thigh circumference in clinical practice and we recommend adherence to techniques described here to obtain the most accurate results. It is also unknown if the results found in the study here could be extrapolated to other situations, such as making measurements in a standing position. In fact, it is our clinical experience that measurements made in a standing position are variable, as suggested by Bascuñán et al. (8) Finally, our findings should be further validated in dogs of different sizes and body type.

CONCLUSIONS

Determination of thigh girth may be useful as an outcome measure if appropriate measuring technique is used. Currently, we prefer performing measurements at the 70% thigh length, with the hair clipped, the limb held in an extended position and with the animal relaxed, but not necessarily sedated. Standardizing conditions can minimize intra- and inter-observer measurement differences between observations on an individual patient. It is also important that those performing thigh girth measurements practice their technique and compare results to assure consistency.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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ORIGINAL RESEARCH
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Pressure Mat Analysis of Walk and Trot Gait Characteristics in 66 Normal Small, Medium, Large, and Giant Breed Dogs

Maria A. Fahie[1]*, *Jonathan C. Cortez*[1,2], *Marc Ledesma*[3] and *Yuhua Su*[4]

[1] College of Veterinary Medicine, Western University of Health Sciences, Pomona, CA, United States, [2] VCA Yorba Regional Animal Hospital, Anaheim, CA, United States, [3] The Ohio State University, Columbus, OH, United States, [4] Dr. Su Statistics, Kaunakakai, HI, United States

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Australia

***Correspondence:**
Maria A. Fahie
mfahie@westernu.edu

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Objectives: To document temporospatial variables and gait symmetry measured by the GAITRite® system for normal, healthy dogs at the walk and trot with the leash side recorded.

Study Design: Observational, prospective, cohort study.

Sample Population: 66 healthy dogs of various common breeds with no evidence of lameness that were small (<10 kg), medium (10-<25 kg), large (25-<40 kg), or giant (≥40 kg).

Methods: Dogs walked and trotted at their preferred velocity on a pressure sensing walkway system. Video observation confirmed inclusion criteria were met for three valid trials at each gait for each dog. Coefficients of variance were used to summarize the data for analysis. Fore and hindlimb ratios were compared. Gait symmetry was assessed with the leash on the left and right side.

Results: Coefficients of variation for gait parameters ranged from 20 to 28% for all except velocity and hind reach. There was no statistically significant difference in differences in fore and hindlimb ratios for stance %, GLS, TPI, or step:stride ratio, across weight categories or between walk and trot. Less than 8% of normal dogs had a GLS score <90 (indicating lameness). Leash side did influence gait symmetry, since GLS, TPI, and step:stride all had statistically significant differences in means between leash side, irrelevant of the weight category or gait.

Conclusions and Clinical Relevance: This system allowed simple, reliable gait assessment and values reported may be considered normal reference ranges for temporospatial variables collected with this system within the weight ranges and gaits reported. Controlling leash side and patient size is recommended for therapeutic intervention studies.

Keywords: pressure mat, gait characteristics, dog, size, breed

INTRODUCTION

Quantitative gait analysis systems have become an invaluable tool in monitoring gait while comparing procedures and treatments (1). Pressure walkway systems used to measure temporospatial variables (TSV) have been shown to be simple and efficient in obtaining multiple gait cycles with little variability (2–10). Several published reports use such systems for objective assessment of gait in response to therapeutic interventions (11–15).

Established inclusion criteria for clinical studies are vital to achieving consistent, statistically significant results, however there is not a universally accepted method. The potential influence of controlling dog velocity during gait analysis is not resolved. Studies using the same pressure walkway system as this one controlled velocity by using a metronome the handler matched as they walked (16), or by setting inclusion criteria to a certain velocity range (5) or by simply allowing the dog gait velocity preference (6). Leash side may influence dogs to shift their weight away from the leash as reported in 5 small dogs (16). Breed conformation may also affect results (5).

The issue of calibration of pressure walkway systems was recently published (17). The system used in that and other studies assumes to calculate a force due to the pressure that is exerted on the paw (2, 4, 9, 17). The system used in the present study is initially calibrated at the manufacturer and since it does not use force as one of the measurements, repeated calibration is not necessary prior to each use. Parameters generated by the various walkway systems are quite different and cannot be compared for clinical research.

The purpose of this study is to document the parameters measured by the GAITRite® system for normal, healthy dogs of the various weight categories (<10 kg, 10-<25 kg, 25-<40 kg, ≥40 kg) at walk and trot. We hypothesized there might be differences in TSVs or gait symmetry among the dog sizes or based on leash side.

MATERIALS AND METHODS

Equipment

The walkway system (GAIT4 Dog® walkway, CIR Systems Inc., Sparta, NJ) used in this study was identical to prior reports (5, 16). The system consisted of a 5.8 × 0.6 m portable mat with 18,432 encapsulated sensors. The active dimensions of the mat were 4.9 × 0.6 m. A 1.25 × 0.85 m section of inactive mat was placed at each end of the walkway system to provide a transitional entrance and exit. The mat was calibrated by the manufacturer before purchase as previously described.[5] Digital video recording of each pass was made using a camera positioned at one end of the walkway system and used for visual gait assessment, scoring of the passes and footfall verification.

Abbreviations: CV, coefficient of variation; GLS, GAIT4 Dog® Lameness Score; HR, hind reach; LF, left front; LH, left hind; LL, leash on the left; LR, leash on the right; RF, right front; RH, right hind; TPI, total pressure index; TSV, temporospatial variables.

Inclusion Criteria

Healthy, adult, client-owned dogs of various breeds were enrolled in the study after approval by our institutional animal care and use committee. The dogs were acclimated to the boarding facility and accustomed to being walked on a leash. They all had normal body condition score (4–6/9) as determined visually by applying American Animal Hospital Association guidelines, and no history or presence of detectable orthopedic or neurologic abnormalities. No animals with a pacing gait were included. Dogs were grouped into categories by weight, defined as small (<10 kg), medium (10-<25 kg), large (25-<40 kg), and giant (≥40 kg). Dogs were measured according to previously published reports (5, 16) and walked by a trained handler (JC) with left or right leash side recorded. Walks were scored on a scale of 0–5 with 0 being a perfect pass with no head motion or leash pulling, 1 being a very slight leash pull at some point during the pass, 2 being a slight leash pull or slight head motion at the beginning or end of the walk, 3 being much leash pulling and head turning, 4 being stopping on the mat during the pass, and 5 being the disastrous walk where those patient motions are constant. Only walks scored 0–2 were included in the study.

Data Processing

Videos of each pass were reviewed by one author (MF) to ensure inclusion criteria were met. Three walk and three trot passes were selected for each dog with leash side recorded. The software program (GAITFour software version 4.9Wr, CIR Systems Inc., Sparta, NJ, United States) was used to determine measured parameters. Parameters analyzed included velocity, stance %, GAIT4 Dog® Lameness Score (GLS), Hind Reach (HR), Total Pressure Index (TPI), step:stride ratio and number of sensors activated. Velocity is obtained by dividing distance traveled by ambulation time and is expressed as centimeters per second. Stance percent is the percentage of stance time, the weight bearing portion of each gait cycle, compared to stride time, the time elapsed between the first contacts of two consecutive footfalls of the same foot. GLS is calculated considering weight distribution, based on observed to expected TPI by limb and established body type loading ratios (default 60:40) and should be approximately 100%. Hind Reach (HR) was measured along the line of progression, from the heel center of the hind paw to the heel center of the previous fore paw on the same side. A negative value of HR could result if the dog fails to bring the heel point of the hind paw forward of the previous fore paw. Total pressure index (TPI) was the sum of peak pressure values recorded from each activated sensor by a paw during mat contact. Expected TPI values were about 30 for each fore paw and 20 for each hind paw. Step:stride ratio was used to assess gait symmetry and was expected to be about 50% if the dog's gait was symmetric. The number of sensors activated was dependent on how much of the paw activates the sensors, independent of gait velocity. The overall coefficient of variation for stance %, GLS, TPI and step: stride ratio were calculated by dividing each SD by the mean, multiplying each by 100, then adding those values and dividing by the number of dogs.

Statistical Analysis

Several analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC) in order to achieve the goals of this study. The ratio between forelimbs (LF:RF) and the ratio between hindlimbs (LH:RH) of stance %, GLS, TPI, and step:stride were computed. Differences in the two ratios were then calculated for the forelimb parameters vs. the hindlimb parameters in different sized dogs, between walk and trot, and between handler and leash positions (left or right). Linear mixed-effects models (18, 19) were conducted for each parameter. No random effects were constructed. The compound symmetry covariance structure was used to model the dependence between observations for each dog. The predictors considered in the model include weight category (small, medium, large, giant), walk vs. trot, and handler (right vs. left). The F test was used to test if the effect of a predictor was statistically significant. A $p < 0.05$ indicated significance. Estimated marginal means were computed for the significant effects. Note that estimated marginal means (mean response for each factor, adjusted for any other variables in the model) are not the same as the arithmetic means (mean response for each factor, not adjusted for any other variables in the model). Quantile-quantile (QQ) plots of the scaled residuals (obtained after multiplying the raw residuals by Cholesky decomposition) (18, 20) were used to assess the multivariate normality assumption of the linear mixed-effects models. To further investigate Hind Reach, a 2-sample t-test was used to determine if there was a statistically significant difference in hind reach between limbs with no lameness (normal GLS of 100) vs. those with lameness (abnormal GLS 10% different from 100). The Cochran-Mantel-Haenszel (CMH) test (21) was used to determine if there was a relationship between limb and lameness, after controlling for walk/trot. Chi-square tests of independence were performed to determine if there was an association between lameness and limb, within each group of dogs (walk vs. trot). The CMH test was also used to determine if there was a relationship between weight category and step:stride ratio within 95% confidence, after controlling for limb. To determine if one gait (walk or trot) provided more consistent results in certain parameters (velocity, stance %, GLS, TPI, and step:stride) compared to walk, means, standard deviations and coefficient of variation (CV) were computed.

RESULTS

Eighty-three dogs were walked, 66 dogs were chosen based on the inclusion criteria. The 17 dogs excluded from the study did not have enough valid passes or data recorded to satisfy study inclusion criteria. There were 11 small (<10 kg), 25 medium (10–25 kg), 20 large (25–40 kg), and 10 giant (>40 kg) dogs. Small dogs included chihuahuas, small terriers, dachshund and mixed breeds. Medium dogs included medium terriers, schnauzers, spaniels, French bulldogs, and mixed breeds. Large dogs included boxers, pointers, bulldogs, large retrievers and mixed breeds. Giant dogs included Newfoundland, Great Dane, giant retrievers, and mixed breeds.

Symmetry

Tables 1, **2** summarize the mean ± SD for velocity, stance %, GLS, HR, TPI, step:stride for the 4 weight categories. **Table 3** documents overall coefficients of variation for velocity, stance%, GLS, HR, TPI, and step:stride at walk and trot. There was no statistically significant difference in differences in fore and hindlimb ratios for stance %, GLS, TPI, or step:stride ratio, across weight categories or between walk and trot. However, there was a statistically significant difference in differences in fore and hindlimb ratios for GLS, TPI, and step:stride ratio between the handler and leash on the right vs. the left side documented in **Table 4**.

Velocity

CV for velocity were consistent for walked and trotted dogs of any size.

Gait4 Dog® Lameness Score

In general, GLS scores should be about 100. The observation of gait by video assessment of the board-certified surgeon (MF) and handler (JC) did not reveal any signs of lameness. Despite that, of the 1528 observations of GLS scores, 122 (7.98%) were considered "lame" (GLS < 90). For walk, there was no association between limb and lameness ($p = 0.1103$). The percentage of lame limb was very close for each limb, 6% for LF, 7% for LH, 6% for RF, and 11% for RH. For trot, there was an association between limb and lameness ($p < 0.0001$). The percentage of lame limb was higher for the hindlimbs (16% for LH and 14% for RH) than for the fore limbs (2% for LF and 3% for RF).

Hind Reach

Mean HR for both hindlimbs was in general larger for walk than for trot across the 4 weight groups. Estimated marginal mean differences in HR between walk and trot were 1.80 (small), 5.86 (medium), 12.55 (large), and 15.28 (giant), with a statistically significant difference in HR between walk and trot in medium, large, and giant (all $p < 0.0001$) dogs but not small dogs. The difference in HR between walk and trot increased with the size of the dogs.

DISCUSSION

The present study reports normal gait characteristics across a variety of common breeds within multiple weight categories applicable to clinical patients. To the authors' knowledge, there are no other studies using this pressure walkway system reporting this variety of dog size and gait. Consistent data was able to be collected in healthy dogs of all sizes.

Symmetry

The degree of variation of gait symmetry considered normal has yet to be determined (21) but in the present study, symmetry was confirmed with the step:stride ratio values since 87–93% of values were within the 95% confidence interval of the expected value of 50. In general, TPI is expected to be about 30/30/20/20 for the LF/RF/LH/RH limbs, respectively. The fore

TABLE 1 | Data at the walk expressed as mean ± standard deviation.

	<10 kg L *n* = 7	<10 kg R *n* = 26	10-<25 kg L *n* = 26	10-<25 kg R *n* = 49	25-<40 kg L *n* = 19	25-<40 kg R *n* = 41	>40 L *n* = 11	>40R *n* = 19
Velocity(cm/s)	75.3 ± 31.0	111.8 ± 55.2	124.4 ± 55.3	147.5 ± 70.9	131.3 ± 66.5	164.4 ± 66.7	107.2 ± 47.9	134.0 ± 65.4
Stance%LF	51.5 ± 21.3	72.1 ± 28.3	55.9 ± 15.7	51.8 ± 11.9	56.4 ± 14.2	56.0 ± 8.6	56.0 ± 19.9	58.4 ± 14.2
Stance%RF	52.2 ± 21.6	50.4 ± 11.5	53.7 ± 12.0	51.2 ± 11.8	55.4 ± 14.7	55.8 ± 8.6	56.6 ± 20.2	58.9 ± 14.0
Stance%LH	46.2 ± 20.1	42.9 ± 12.8	49.6 ± 12.1	47.4 ± 12.3	53.0 ± 14.2	52.7 ± 10.0	55.1 ± 19.6	54.4 ± 15.4
Stance%RH	45.4 ± 19.8	43.1 ± 12.2	49.4 ± 12.1	47.1 ± 12.1	53.0 ± 14.1	52.7 ± 9.9	55.1 ± 19.7	54.9 ± 14.9
GLS LF	89.3 ± 36.5	101.8 ± 16.9	89.9 ± 23.7	100.0 ± 12.0	96.6 ± 20.6	98.5 ± 6.0	82.9 ± 29.2	92.7 ± 19.2
GLS RF	90.8 ± 36.9	97.6 ± 16.6	98.9 ± 18.0	99.8 ± 12.3	95.3 ± 20.0	94.2 ± 5.7	87.5 ± 31.1	91.8 ± 19.1
GLS LH	79.8 ± 32.8	96.4 ± 17.9	94.6 ± 17.6	98.3 ± 13.5	95.4 ± 20.7	102.1 ± 9.0	94.5 ± 33.6	101.7 ± 21.4
GLS RH	87.9 ± 35.9	94.0 ± 17.5	96.5 ± 19.2	96.5 ± 12.4	97.4 ± 21.1	103.2 ± 8.7	100.8 ± 36.4	103.0 ± 21.5
HR LH	3.1 ± 8.8	0.8 ± 5.9	5.1 ± 7.4	5.0 ± 7.0	13.1 ± 11.4	14.3 ± 9.0	15.1 ± 33.6	15.1 ± 11.4
HR RH	2.7 ± 9.0	1.0 ± 5.8	5.5 ± 7.5	5.5 ± 7.6	13.2 ± 11.3	14.0 ± 8.6	15.9 ± 14.3	16.1 ± 11.6
TPI% LF	26.8 ± 10.9	30.6 ± 5.1	29.4 ± 5.3	30.0 ± 3.6	29.0 ± 6.2	29.5 ± 1.8	24.8 ± 8.8	27.8 ± 5.8
TPI% RF	27.3 ± 11.1	29.1 ± 5.2	29.6 ± 5.4	29.9 ± 3.7	28.6 ± 6.0	29.4 ± 1.7	26.2 ± 9.3	31.8 ± 23.3
TPI% LH	15.9 ± 6.5	19.3 ± 3.6	18.9 ± 3.5	19.7 ± 2.7	19.1 ± 4.2	20.4 ± 1.8	18.8 ± 6.7	20.3 ± 4.3
TPI% RH	17.6 ± 7.2	18.8 ± 3.5	19.3 ± 3.8	19.3 ± 2.5	19.5 ± 4.2	20.7 ± 1.7	19.7 ± 7.6	20.6 ± 4.3
Step:stride LF	43.3 ± 17.5	49.5 ± 7.7	44.7 ± 15.9	47.6 ± 10.4	36.9 ± 22.6	48.1 ± 10.3	44.3 ± 15.7	57.7 ± 40.0
Step:stride RF	44.1 ± 17.8	48.4 ± 7.3	48.3 ± 8.4	49.4 ± 5.6	47.8 ± 9.8	49.5 ± 1.5	45.5 ± 16.1	47.9 ± 9.8
Step:stride LH	44.0 ± 17.8	52.8 ± 7.4	51.2 ± 8.5	48.7 ± 5.7	48.1 ± 10.0	50.1 ± 4.1	44.0 ± 15.6	46.9 ± 9.9
Step:stride RH	43.3 ± 17.5	49.2 ± 8.1	48.6 ± 8.5	50.0 ± 5.8	48.0 ± 10.0	48.8 ± 3.8	45.7 ± 16.2	49.1 ± 10.4

L, Handler and leash on left; R, Handler and leash on right; n, number of data points; kg, kilograms; LF, left front; RF, right front; LH, left hind; RH, right hind; GLS, GAIT4Dog® Lameness Score; HR, hind reach; TPI, total pressure index.

and hindlimb ratios for stance %, GLS, TPI and step:stride were not significantly different for any size dog at the walk or trot. Leash side did influence gait symmetry, since GLS, TPI, and step:stride all had statistically significant differences in means between leash side, irrelevant of the weight category or gait.

Influence of Gait Velocity

In the present study, dogs were allowed velocity preference and both walk and trot were assessed for consistency. The variation in velocity was not consistently better for all sizes of dogs at either gait. Small breeds maintained a more consistent velocity at the walk, while giant breeds were more consistent trotting. Medium and large breeds were equally consistent at walk and trot. Since data collection is simple with this system, the most informative data for comparing interventions would include both gaits when testing small and giant breeds.

GAIT4 Dog® Lameness Score (GLS)

GLS is a unique parameter for this system software and to the author's knowledge is not reported prior. The author's subjective visual assessment of dog videos did not reveal lameness but almost 8% of them received a GLS score <90 on one limb, suggesting lameness. It is possible that the system was detecting subtle lameness in those dogs, which is one of its clinically applicable features. The variation could also have been related to the score of the pass, with a higher score indicating some head motion or slight leash pull during the pass, or leash side, if the dog was shifting weight away from the handler, as previously reported. (16) Dogs may also have a dominant forelimb, behavioral lateralization, or paw preference as reported by Schneider. (22) In that study, the Kong (KONG Company, Golden, CO) paw preference test (23) documented 63% of dogs demonstrated preferential paw usage, with about 34% left-pawed, 28% right-pawed, and 37% ambilateral. To the authors' knowledge, the potential effect of paw preference on gait analysis has not been tested, although if a patient is compared to itself in interventional studies, the effect should be inconsequential.

Hind Reach

The present study documented much variation in hind reach in all weight categories, although at walk the CV was lower than any other parameter. Various breeds have vastly different conformation and this parameter is dependent upon leg length and length of the body. Smaller dogs with shorter legs may have negative values for hind reach if they do not bring the heel point of their hind paw forward of their previous ipsilateral forepaw. Differences in fore and hindlimb muscling among breeds is likely also a contributing factor. Hind reach (HR) was accurate in the few limbs deemed lame by the GLS score, in that the HR was shorter than the contralateral hindlimb if the GLS score was <90. HR was also larger for walk than trot across all weight groups, which may be pertinent from the point of view of both postoperative rehabilitation monitoring and therapeutic intervention studies. Further studies of hind reach in specific breeds of dogs may elucidate patterns associated with certain conditions causing lameness.

TABLE 2 | Data at the trot expressed as mean ± standard deviation.

	<10 kg L $n = 18$	<10 kg R $n = 16$	10-<25 kg L $n = 36$	10-<25 kg R; $n = 36$	25-<40 kg L $n = 15$	25-<40 kg R; $n = 39$	>40 L $n = 8$	>40R $n = 12$
Velocity(cm/s)	127.7 ± 60.5	133.8 ± 65.4	165.1 ± 68.8	169.4 ± 65.8	228.8 ± 73.3	179.7 ± 70.3	209.2 ± 112.0	185.3 ± 73.9
Stance%LF	45.9 ± 13.4	45.1 ± 13.0	48.3 ± 12.3	48.1 ± 13.0	43.2 ± 12.3	51.5 ± 11.4	36.5 ± 19.3	51.2 ± 13.3
Stance%RF	45.6 ± 12.9	45.5 ± 12.3	47.5 ± 11.8	47.2 ± 11.8	4.50 ± 14.7	51.4 ± 11.8	36.0 ± 19.1	52.1 ± 13.3
Stance%LH	39.2 ± 12.7	36.0 ± 12.3	43.6 ± 12.9	42.0 ± 12.2	38.4 ± 11.5	47.4 ± 12.7	31.7 ± 16.9	47.2 ± 13.9
Stance%RH	48.9 ± 27.6	36.5 ± 12.5	43.0 ± 12.5	42.0 ± 12.2	38.1 ± 11.2	47.9 ± 12.6	32.5 ± 17.3	47.1 ± 13.5
GLS LF	102.1 ± 20.9	95.4 ± 23.3	100.6 ± 15.4	100.7 ± 15.3	93.8 ± 25.5	97.2 ± 12.8	77.5 ± 40.9	92.3 ± 19.7
GLS RF	99.3 ± 204	96.3 ± 23.3	99.5 ± 15.3	100.3 ± 15.7	95.8 ± 27.0	97.3 ± 13.0	77.2 ± 40.7	92.6 ± 19.7
GLS LH	91.3 ± 19.7	94.5 ± 23.8	95.7 ± 16.6	95.2 ± 17.8	94.6 ± 26.8	99.5 ± 14.7	83.6 ± 44.3	100.1 ± 21.7
GLS RH	88.4 ± 20.2	95.0 ± 24.0	94.9 ± 15.3	94.1 ± 16.3	90.6 ± 27.0	102.0 ± 15.2	85.1 ± 45.3	102.3 ± 22.5
HR LH	−2.1 ± 4.9	0.8 ± 6.3	3.4 ± 7.2	3.0 ± 5.5	8.0 ± 8.4	10.4 ± 9.9	4.4 ± 5.0	8.7 ± 12.9
HR RH	−1.7 ± 5.1	0.6 ± 6.1	3.6 ± 7.7	3.5 ± 5.9	7.1 ± 9.3	10.2 ± 9.6	5.3 ± 5.3	9.5 ± 13.7
TPI% LF	30.7 ± 6.3	28.6 ± 7.0	30.2 ± 4.6	30.2 ± 4.6	28.0 ± 7.6	29.2 ± 3.9	23.2 ± 12.2	27.7 ± 5.9
TPI% RF	29.9 ± 6.1	28.9 ± 7.0	29.8 ± 4.6	30.1 ± 4.7	28.7 ± 8.1	29.2 ± 3.9	23.1 ± 12.2	27.8 ± 5.9
TPI% LH	18.2 ± 3.9	18.9 ± 4.8	19.1 ± 3.3	19.0 ± 3.6	18.9 ± 5.4	19.9 ± 3.0	16.8 ± 8.9	20.0 ± 4.3
TPI% RH	17.7 ± 4.1	19.0 ± 4.8	19.0 ± 3.1	18.8 ± 3.3	18.1 ± 5.4	20.4 ± 3.0	17.0 ± 9.0	20.5 ± 4.5
Step:stride LF	48.8 ± 10.1	47.7 ± 10.7	49.2 ± 7.1	46.3 ± 13.1	47.3 ± 12.7	45.5 ± 14.9	41.1 ± 21.7	48.3 ± 10.1
Step:stride RF	47.9 ± 9.6	47.5 ± 10.7	53.8 ± 33.9	52.8 ± 35.5	46.2 ± 12.4	48.9 ± 6.0	38.8 ± 20.4	47.5 ± 10.0
Step:stride LH	47.6 ± 9.4	48.1 ± 10.8	49.4 ± 7.1	48.4 ± 6.9	52.9 ± 39.1	49.8 ± 6.3	40.4 ± 21.3	47.5 ± 10.1
Step:stride RH	49.2 ± 10.6	47.3 ± 10.6	48.5 ± 7.0	49.6 ± 7.1	44.0 ± 13.4	48.5 ± 6.2	39.4 ± 20.8	48.3 ± 10.3

L, Handler and leash on left; R, Handler and leash on right; n, number of data points; kg, kilograms; LF, left front; RF, right front; LH, left hind; RH, right hind; GLS, GAIT4Dog® Lameness Score; HR, hind reach; TPI, total pressure index.

TABLE 3 | Overall Coefficients of Variation (CV) at walk and trot.

Measure	Gait	CV %
Velocity (cm/s)	Walk	40.9
	Trot	37.9
Stance %	Walk	25.6
	Trot	28.6
GLS	Walk	20.4
	Trot	23.9
Hind Reach	Walk	173.9
	Trot	169.9
TPI %	Walk	21.0
	Trot	21.8
Step:stride	Walk	24.8
	Trot	25.7

GLS, GAIT4Dog® Lameness Score; TPI, Total Pressure Index.

TABLE 4 | Results of the mixed models.

Measure	Effect	DF1	DF2	F	*p*-value
Stance %	Weight	3	63	0.25	0.85
	Walk/trot	1	61	0.18	0.67
	Leash side	1	57	0.22	0.63
GLS	Weight category	3	63	0.32	0.81
	Walk/trot	1	61	0.25	0.61
	Leash side	1	57	6.37	0.01*
TPI	Weight category	3	63	0.44	0.72
	Walk/trot	1	61	0.61	0.43
	Leash side	1	57	6.12	0.01*
Step:stride	Weight	3	63	1.11	0.35
	Walk/trot	1	61	2.76	0.10
	Leash side	1	57	6.91	0.01*

DF1, Numerator degrees of freedom for the F-statistic; DF2, Denominator degrees of freedom for the F-statistic; GLS, GAIT4Dog® Lameness Score; TPI, Total Pressure Index.
** indicates significance at the 0.05 level.*

Comparison of Data With Prior Published Reports

There are 3 prior published reports of normal dogs that include parameter details for comparison to this study. The first detailed published study (5) of this system included Labrador retrievers weighing 17.7–35.5 kg. The present study weight categories fall between those numbers, although the symmetry ratios were similar to those reported in the present study for the two weight categories that fall into that weight range. The CVs for parameters in the present study were lower than a prior report (16) that included five small dogs and various handlers. Perhaps our increased sample size and consistent handler explain the variance reduction. Specifically, our TPI means were similar, however the hind reach means were quite different (present study: LH 1.65, RH 2.09, reference 15: −5.75 and −5.44, respectively). Kim et al. (4), used a different pressure walkway system, but also compared normal small and large dogs, and concluded that the mean stance phase duration of the hindlimbs was significantly shorter than the forelimbs in small dogs (4). Our results are similar, with a greater difference in stance % between fore and hindlimbs in small dogs compared to medium, large and giant dogs. However, data of this present study did not indicate overall TSV differences in the various sizes of dogs as the prior study concluded (4). The present study TPI was about LF 30, RF 30, LH 20, RH 20 for all sizes of dogs at both walk and trot. This differed from those of Carr et al. (10), who identified gait differences between Border Collies and Labrador Retrievers presumed related to their intended working purpose. It is also different from anticipated in a prior study (5) which suggested larger dogs with larger paws would activate more sensors and exert a greater TPI. The number of sensors activated in this study did increase with dog size but did not influence anticipated TPI values.

STUDY LIMITATIONS

Limitations of the present study include materials and methods details. A disadvantage intrinsic to use of a pressure sensing walkway and temporospatial gait analysis system includes the inability to measure forces in three dimensions, and thus only being able to quantitate a product of total ground reaction force. Theoretically, dogs could be exerting craniocaudal forces that would not be detected from a simple vertical pressure analysis, which could affect their limb kinematics. Data generated in this study are unique to this system. There are inherent problems with subjective gait assessment performed live and with video, however at least this study included only one observer for consistency, although increasing chances for bias. No dogs had radiographic evaluation to determine whether there was any underlying orthopedic disease. Dogs with GLS scores <90 were not further assessed with examination or radiographs to confirm a problem. This study grouped the dogs by weight, rather than breed, and since hind reach and possibly other parameters are affected by leg length compared to body length, results may have been affected by the inclusion of chondrodystrophic and brachycephalic breeds. The sample size for leash side data analysis was balanced with more values taken with the leash on the right side (238) compared with the left (140). Dogs well-trained to their handler on a certain side, more commonly the left, were more difficult to obtain low scoring, perfect walk/trot passes. This may have weakened the power of the statistical analysis.

CONCLUSIONS AND CLINICAL RELEVANCE

This system allowed simple, reliable gait assessment. We recommend controlling leash side and patient size for therapeutic intervention studies. The values presented in this study may be considered normal reference ranges for temporospatial variables (TSV) from this system within the weight ranges and gaits reported.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Western University of Health Sciences, College of Veterinary Medicine, Institutional Animal Care, and Use committee with written informed consent from all subjects. The approval number was R11/IACUC/009.

AUTHOR CONTRIBUTIONS

MF mentored JC and ML, who were veterinary students at the time of the data collection, in authoring the Morris Animal Foundation grant. They performed the data collection and wrote first drafts of the manuscript. Since their graduation MF has done all manuscript authoring/editing. YS did all of the statistical analysis and authored those sections of the manuscript.

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Laser Therapy for Incision Healing in 9 Dogs

Jennifer L. Wardlaw[1,2], Krista M. Gazzola[1], Amanda Wagoner[1], Erin Brinkman[1], Joey Burt[1], Ryan Butler[1], Julie M. Gunter[1] and Lucy H. Senter[3]*

[1] Department of Clinical Sciences, Animal Health Center, College of Veterinary Medicine, Mississippi State University, Starkville, MS, United States, [2] Gateway Veterinary Surgery, St. Louis, MO, United States, [3] Office of Research and Economic Development, Department of Clinical Sciences, College of Veterinary Medicine, Mississippi State University, Starkville, MS, United States

Laser therapy is becoming common place in veterinary medicine with little evidence proving efficacy or dosages. This study evaluated surgical wound healing in canines. Twelve Dachshunds underwent thoraco-lumbar hemilaminectomies for intervertebral disc disease (IVDD). Digital photographs were taken of their incisions within 24 h of surgery and 1, 3, 5, 7, and 21 days postoperatively. The first three dogs were used to create a standardized scar scale to score the other dogs' incision healing. The remaining 9 dogs were randomly assigned to either receive 8 J/cm^2 laser therapy once a day for 7 days or the non-laser treated control group. Incision healing was scored based on the scar scale from 0 to 5, with zero being a fresh incision and five being completely healed with scar contraction and hair growth. All scar scores significantly improved with increasing time from surgery (<0.001). Good agreement was achieved for inter-rater reliability ($p = 0.9$). Laser therapy increased the scar scale score, showed improved cosmetic healing, by day seven and continued to be significantly increased on day 21 compared to control dogs ($p < 0.001$). Daily application of laser therapy at 8J/cm2 hastened wound healing in Dachshunds that received thoracolumbar hemilaminectomies for IVDD. It also improved the cosmetic appearance.

Keywords: laser, wound healing, canine, scar scale, IVDD, incision, photobiomodulation

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***Correspondence:**
Jennifer L. Wardlaw
wardlaw@gatewayvetsurgery.com

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INTRODUCTION

Laser therapy is a novel rehabilitation technique being used in veterinary medicine for both rehabilitation and therapeutic purposes. Photobiomodulation (PBM) induced by laser therapy is the application of electromagnetic radiation within the near infrared spectrum and is aimed at stimulating healing or analgesia within the target tissue. Currently laser therapy is being advocated for a variety of conditions some of which include musculoskeletal pain, osteoarthritis, joint pain, and inflammation, neuropathic pain, otitis, dermatitis, chronic, or non-healing wounds and decubital ulcers (1–5).

There are three phases of wound healing; the inflammatory, proliferative and remodeling phases. The inflammatory phase is initiated at the time of injury and begins with hemostasis and formation of the platelet plug. Platelets release platelet-derived growth factor which attract neutrophils and more importantly macrophages. Macrophages attract fibroblasts and therefore commence the proliferative phase. Fibroblasts differentiate into myofibroblasts and cause tissue contraction. Tensile strength is increased by collagen reorganization and the eventual outcome is a wound that reaches 80% of the strength of uninjured tissue (6, 7). It has been shown in experimental studies that laser therapy reduces pain, positively influences inflammatory, proliferative, and maturation phases of wound healing and increases wound tensile strength (6, 8–10). However, most of these studies have been in laboratory animals and do not account for the difference in wound healing between species.

Despite the numerous accounts of the potential positive effects of laser therapy in various applications for both human and veterinary medicine, exact protocols for various conditions, and tissue healing do not exist. Recent studies in veterinary medicine show the potential benefit of wound healing using PBM induced by laser therapy, including accelerated wound healing in equine distal limb wounds using a wavelength of 635 nm and an energy output of 17 mW per diode for a power density of 5.1 J/cm2 (11). Another recent canine study has shown that surgery in combination with PBM decreases the time to ambulation in dogs with T3-L3 myelopathy secondary to intervertebral disk herniation using a wavelength of 810 nm and an energy output of 200 mW for a power density of 2–8 J/cm2 (4). Looking at other laser therapy reports in the literature wound healing protocols vary from 1 to 40 J/cm^2, consequently necessitating the continued need for controlled research studies in order to evaluate the efficacy of proposed protocols using specified power densities on specific target tissues for defined clinical indications (8, 12–17).

This study attempts to objectively measure the ability of PBM induced by laser therapy to accelerate the healing time of surgically created wounds by using a previously described scar scale that corresponds with histopathology (18). This scar scale using photography has shown in numerous species that scar cosmetics is a consistent and sensitive indicator of histologic healing and is independent of the reviewer (3, 18–21). By using digital photographs, blinded to the reviewers, the present study evaluated healing while avoiding tissue sample collection. The goal of the study was to objectively evaluate the use of laser therapy as a treatment modality in canine intervertebral disc disease (IVDD) patients for surgical incisional healing.

MATERIALS AND METHODS

All procedures were approved by the Mississippi State University Institutional Animal Care and Use Committee and all treatment and control animal participants had documented informed client consent before enrollment in the study. The use of veterinarians to score the incision healing was approved by the Mississippi State University Institutional Review Board for the Protection of Human Subjects in Research.

Dachshund patients who present to College of Veterinary Medicine, Mississippi State University for a hemilaminectomy in the thoraco-lumbar region were included in this study. Dachshunds with a dapple colored coat, known systemic health issues, incisions closed with staples, or owners that did not consent were not included in the study. Dogs that had received previous back surgeries were also not included in the study population. Dogs that met the inclusion criteria had data collected with regards to signalment, weight, body condition score, coat color, location of disc herniation, surgical incision length, type of suture used, fat pad graft or gel foam usage, steroid administration, bladder medications, neurologic status at presentation, and at the time of discharge.

A 10 mega-pixel camera[1] was used to take digital photographs. Photographs were taken at an equal distance (15 cm), angle, setting and lighting on days 0, 1, 3, 5, and 7 and again at day 21 of all dogs, with day 0 being the day of surgery. All photographs were taken with the standardized distance from the incision, on the same exam table, with the same camera settings and 90° from the dogs' back, by one of two authors (KG or AW).

A clinical scar scale using digital photography was created as previously described (18).The first three dogs presented that met our inclusion criteria had digital photographs taken at days 0, 1, 3, 5, 7, and 21 using the standardized variables listed. These three dogs were used to create the scar scale from 0 to 5 with 0 being a fresh surgical incision (day 0 picture), a score of 1 with a fresh incision but no hemorrhage present (day 1 picture), a score of 2 had incision with some scabbing, swelling or bruising (day 2 picture), a score of 3 had visible healing with ongoing skin remodeling but resolving bruising or inflammation (day 5 picture), a score of 4 had healing progressing but a visible scar present (day 7 picture), and a score of five had a completely healed surgical incision with epithelialization, contraction and hair regrowth (day 21 picture) (**Figures 1A,B**).

The first three dogs enrolled in the study were selected and photographed to assure appropriate and expected healing without complication. After the initial three dogs were used to create the visually representative scar scale, the next qualifying dog was assigned to one of two treatment groups (laser or non-laser) using a coin flip. Subsequent dogs were then assigned every other to maintain similar treatment group sizes. Laser therapy dogs received 8 J/cm^2 daily for seven days, beginning on day 1 using a class 3B veterinary laser[2]. The laser was wiped clean before and after each patient with the Novus polish system cloth provided by the laser manufacturer. The incision and one additional probe head spot size (7.55 cm^2) around the entire incision (cranial, bilaterally the length of the incision, and caudal) were treated, except for over the laminectomy site. Total patient irradiation times varied due to varying lengths of incisions. The probe[3] was applied with contact, but no pressure, perpendicular to the skin at all times used. The manufacturer pre-programmed muscle/increase local circulation for acute, low pulse setting was used. This setting has a pulsatile setting at 8 Hz with a 90% on, 10% off emissions at 850 nm for laser diodes and 670 nm for LED and defaults at 4 J/cm^2. All treatment spots received 4 J/cm^2 in this described spot pattern, twice during each treatment totally 8 J/cm^2 treatment dosage. Digital photographs were taken at days 0, 1, 3, 5, 7, and 21. The non-laser group did not receive

Abbreviations: PBM, Photobiomodulation; IVDD, Intervertebral Disc Disease.

[1]Canon PowerShot SD1200 IS Digital ELPH, 10.0 megapixel. Canon U.S.A. Inc. Lake Success, NY 11042, USA.

[2]Vectra Genisys Transport Laser Model 2784. DJO, LLC Vista, CA 92083, USA.

[3]9 Diode Cluster Applicator, 1040 mW total power; (5) 850 nm Laser diodes at 200 mW each, with a spot size of 0.188 cm^2, and (4) 670 nm LED diodes at 10mW each, with a spot size of 0.64 cm^2 each. Total contact area 7.55 cm^2 with a power density of 0.138 W/cm^2 Hudson Aquatics, Angola IN 46703, USA.

A

B

FIGURE 1 | Examples of the scar scale images used for reviewer ranking of surgical incisions for both treatment groups. **(A)** This image was defined as a scar scale score of zero. **(B)** This image was defined as a scar scale score of five.

laser treatment, and had pictures taken at days 0, 1, 3, 5, 7, and 21. Upon completion of the study all pictures were randomly assigned a number, 1 through 125, using a computer generated[4], unsorted list. The scar scale dog photographs were arranged on white cork board and labeled as 0, 1, 2, 3, 4, or 5 to define the scar scale. The board represented a score of 0 (day 0), 1 (day 1), 2 (day 3), 3 (day 5), 4 (day 7), and spaced linearly until the day 21 photographs which represented a scar scale score of 5. The treatment group photos were arranged in ascending numerical order according to their randomly assigned image number.

Veterinary volunteers, not involved in the surgery, patient care, laser therapy, or photograph acquisition were recruited to score the images (JW, EB, JB, RB, JG, LS). All scoring sessions were performed privately, in the same room and during daylight hours. All volunteers were instructed to score the images using whole integers from 0 to 5 based on cosmetic healing by considering; incision oozing, bruising, crusting, inflammation, edema, granulation, epithelialization, contraction, and hair regrowth on the incision site. Each volunteer scored all the photographs once and did so in one sitting. Once all six evaluators had ranked the images, the author (JW) was then given the treatment group assignments from the co-investigators (KG, AW) to send for statistical analysis.

The tests for significance of sources of variation and inter-rater reliability were determined using covariant analysis performed with Statistical Analysis System's GLIMMIX program[5]. The clinical importance of statistically significant differences in treatments was assessed using confidence intervals (22). A *P*-value of <0.05 was considered to be significant. Free marginal Kappa values were used to assess inter-rater agreement.

RESULTS

This study was performed entirely at the Animal Health Center, College of Veterinary Medicine, Mississippi State University from September 2010 to May 2012. Twelve dogs met ouri inclusion criteria during this timeframe and were designated as three scar scale example dogs, five non-laser dogs, and four laser therapy dogs. Signalment, body condition score, incision length, lesion location, use of fat graft and/or gel foam, suture material used, steroid administration, and neurologic status at the time of surgery did not differ between laser therapy and non-laser dogs. All the laser therapy dogs were brown, whereas the non-laser group contained three black and two brown dogs. All dogs enrolled in the study appeared calm and comfortable for photography acquisition and laser therapy; therefore, were able to complete the study. All the dogs remained static in their neurologic status at the time of discharge or improved, none declined. Most of the dogs received steroids either at the time of surgery or before referral (67%). Some of the non-laser dogs ($n = 4$) and laser dogs ($n = 2$) received steroids. Steroid type, dosage, time of administration and frequency varied within the study population.

The first three dogs healed without incident, appeared uniformly cosmetic and were selected to make the scar scale score. Scar scale score of the study dogs was significantly associated with the day of the image ($p < 0.0001$), and whether laser therapy was used ($p < 0.001$), but not by reviewer ($p = 0.9$). The scar scale rankings were similar for all six veterinary reviewers which consisted of a dermatologist, radiologist, laboratory animal specialist, general practitioner and two surgeons (JG, EB, LS, JB, RB, JW). There were no differences between scar scale scores on days 0, 1, 3, or 5 between groups. There was a statistically significant improvement in scar scores on days 7 and 21 for laser therapy vs. non-laser dogs ($p < 0.0.1$). The mean scar score was significantly higher for the laser (95% CI = 3.21-4.12) than the non-laser (95% CI = 1.85-2.56) dogs at day 7. The mean scar score was significantly higher for the laser (95% CI = 4.52-5.03) than non-laser (95% CI = 3.25-4.21) dogs at day 21 (**Figures 2A–C**). Dogs on day 21 that received laser therapy had less variation in their score with an average score of 4.78 ± 0.54 vs. non-laser dogs average 3.73 ± 1.34 (**Figure 3**).

[4]Microsoft Office Excel 2007, Microsoft. Redmond, WA 98052, USA.

[5]SAS Institute. 2008. SAS/STAT Online 9.2 Users Guide. SAS Institute, Cary, NC 27512, USA.

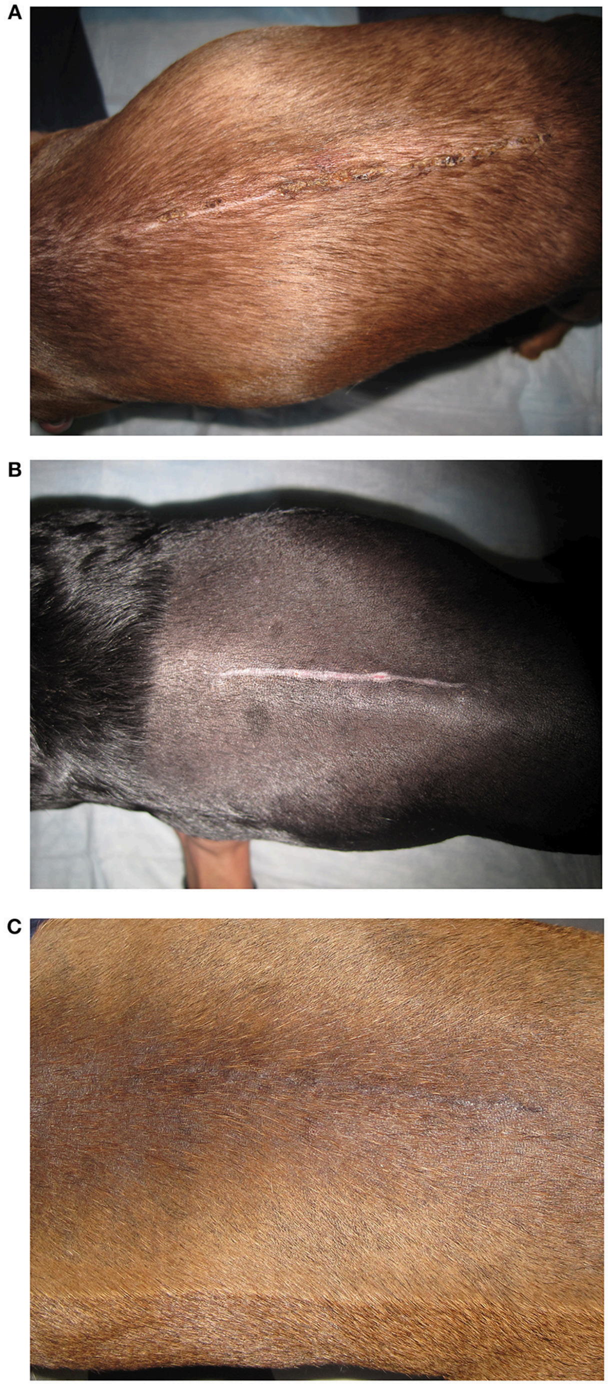

FIGURE 2 | Representative images of the two treatments groups at day 21. **(A)** A non-laser patient illustrating the continued presence of a scab over some of the incision's epithelium. **(B)** A non-laser patient with a wide scar area and one remaining pink area of granulation toward the right side of the incision. **(C)** A laser therapy patient showing a completely healed incision with contraction and hair regrowth around and on the incision.

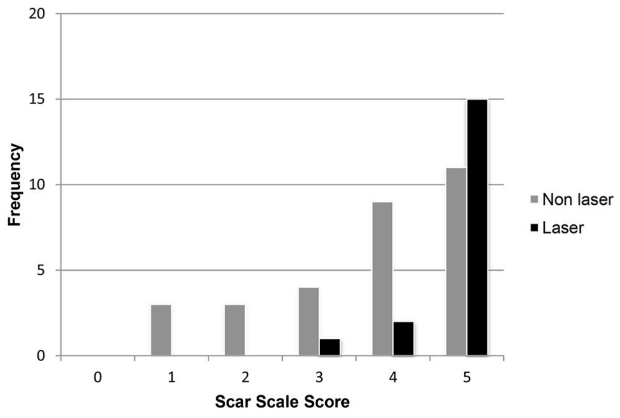

FIGURE 3 | Frequency histogram showing individual scar scale scores (n = 48) on day 21 for the low intensity laser therapy (n = 3) and non-laser treatments (n = 5) groups from the six veterinary reviewers.

Day 21 results were further compared for laser therapy and non-laser groups for eight patients using the six reviewers. One laser therapy dog did not return for the 21 day photograph. Dogs that received steroid treatment regardless of laser therapy had a clinically significant lower scar score (95% CI 3.41–4.25) vs. dogs that did not receive steroids (mean 5 ± 0.0) at day 21. The dogs that received steroids had a mean scar score that was higher for those that also received laser therapy (95% CI = 4.30-5.32) compared to the steroid administered dogs that were in the non-laser group (95% CI = 2.89-3.94) at day 21. But the two dogs that received steroids and laser therapy had a median score of 5 and a mean score of 4.8 at day 21. Dogs receiving steroids and did not receive laser treatments scored 1–3 points lower on the scar scale at day 21.

The average score by day 5 was a full point higher on the scar scale score for the laser group and continued to be one point higher on average through day 21. The standard deviation (SD) ranged from 0.85 to 1.6 for all scores except day 21 laser group which had a SD of only 0.35, indicating strong agreement between the reviewers (**Table 1**). Medians were equally elevated for the laser treated group starting at day 3 and continued until the end of the study. Median scores for the laser group at days 0, 1, 3, 5, 7, and 21 were 1, 2, 2.5, 3, 4, and 5 respectively. The median scar scores for the non-laser group at days 0, 1, 3, 5, 7, and 21 were 1, 2, 2, 2, 2.5, and 4, respectively. Overall there was a strong predictive value for scar scale score with laser therapy treatment in this study (**Figure 4**). Spearman's Correlation Coefficient was statistically significant for scar score and day for the reviewers ($r_s = 0.80$). Kappa values comparing inter-rater agreement are shown for each day (**Table 2**).

DISCUSSION

Laser therapy has been found to accelerate wound healing by possibly stimulating oxidative phosphorylation therefore reducing the inflammatory response and pain (6, 8–10). This study helps to further support the idea of PBM induced by laser therapy as a vital component to wound healing and rehabilitation by showing the improved outcome of laser therapy

TABLE 1 | The scar scores for the two treatments groups collected on each day.

Non-Laser					Laser				
Day	**Mean**	**SD**	**95% CI**	**Median**	**Day**	**Mean**	**SD**	**95% CI**	**Median**
0	2.12	1.64	1.48–2.76	1	0	1.45	1	1.01–1.89	1
1	2.24	1.17	1.78–2.7	2	1	1.85	1.35	1.26–2.44	2
3	1.92	1.12	1.48–2.36	2	3	2.45	1.1	1.97–2.93	2.5
5	1.72	0.94	1.35–2.09	2	5	3.1	1.29	2.53–3.67	3
7	2.25	0.85	1.88–2.62	2.5	7	3.65	1.14	3.15–4.15	4
21	3.84	1.28	3.34–4.34	4	21	4.87	0.35	4.69–5.04	5

Mean Confidence intervals (CI) had an alpha set at 0.05. Standard Deviation (sd) for the laser group at day 21 showed very strong agreement among reviewers.

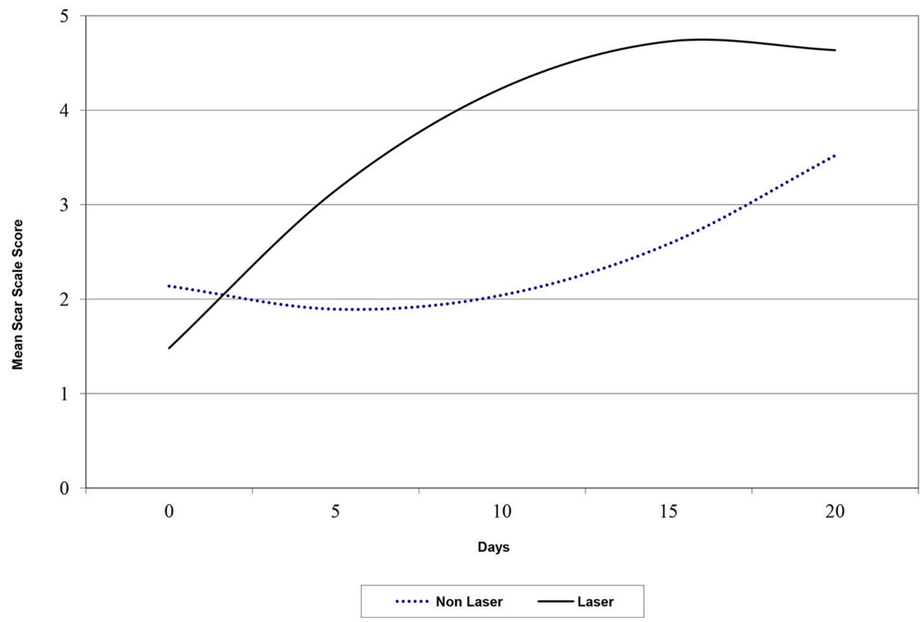

FIGURE 4 | A constant interval graph showing plotted predicted values of scare scale scores for laser treated and non-laser treated patients.

on the surgical incisions of dogs with IVDD that underwent a hemilaminectomy.

Five different specialty veterinarians and a general practitioner were recruited and given the same instructions on ranking the overall cosmetic appearance by looking at incision oozing, bruising, crusting, inflammation, edema, granulation, epithelialization, contraction, and hair regrowth on the incision site. Other studies have also evaluated the ability to assess wound healing without using histologic evidence and have found successful modalities, such as a clinical scar scale using digital photography, that are indicated in ante-mortem studies (3, 18, 21). The use of digital photography as a valid means to evaluate the efficacy of wound healing using specific treatment modalities is of particular value because it allows for gross patient evaluation and does not necessitate histologic confirmation (3, 21). This method of evaluation has been more specifically explored using porcine burn scars, human skin grafts and a more recent canine laser study (18, 23, 24). Such studies have confirmed the correlation between histologic characteristics of wound healing with visual assessment of clinical scar outcome. The information extrapolated from this study, and the Gammel et al. (23) study, proves that it is achievable to establish a reliable clinical scar scale using digital photography (23). This high level of correlation therefore indicates that this is a viable method to use when analyzing surgically created wounds treated with ancillary therapy such as PBM induced by laser therapy. We saw a large increase in inter-rater agreement after day 7, especially in the laser group at day 21 having excellent correlation between reviewers (kappa 0.79). While the variance in scar scores improved with healing, the variance in the scores for the laser group was lower throughout the study and had a higher numerical score on the scale throughout the study. This coupled with the excellent kappa value on day 21 demonstrated reference scars are a potentially reliable method to assess clinical healing on photographs. However, higher agreement was seen with increased familiarity with

TABLE 2 | Free Marginal Kappa for Inter-rater agreement of scar scores.

Day	Kappa coefficient		
	All cases	Laser cases	Non-laser cases
0	0.21	0.26	0.17
1	0.21	0.18	0.23
3	0.17	0.14	0.2
5	0.22	0.26	0.18
7	0.16	0.1	0.22
21	0.54	0.79	0.47

the scar scale score and repeated scoring of photographs (18). Wang et al. demonstrated an increase of correlation coefficients from 65% to over 80% with simply repeated ratings of the photographs. Perhaps, we would have had higher agreement earlier in the results with reviewers scoring the same images several times.

Steroid administration for IVDD patients continues to be a bone of contention among veterinarians. In this prospective study the type, dosage, and length of administration of steroids were not controlled so no conclusions could be drawn. It should also be noted perioperative high dose steroids are not thought to statistically effect wound healing, vs. chronic usage (25). Steroid usage over 10 days in humans can show 2 to 5 times wound complication rates, but varies with comorbidities, dose and surgery (25). We also avoided the laser beam directly over the hemilaminectomy site, due to unwarranted concerns of potential contraindication for laser therapy directly over the spinal cord. This potential concern has been refuted in the literature and has been shown to improve neurologic outcome (4). Combined with our results, these two studies suggest increased surgical healing in IVDD canines using 8 J/cm^2 daily for the first week after surgery.

Our study used a higher dosage than previously reported for a case report of a chronic canine wound (5 J/cm^2), for wound healing (5 J/cm^2), and for open wounds (1 J/cm^2) (12, 23, 26). It should also be noted that previous studies treated for 4 or 5 days, and this study did for 7 consecutive days (4, 12). An additional study did not have apparent benefits to PBM for therapy 3 times a week for 32 days of treatment using 1 J/cm^2 (26). This suggests that a higher dose and perhaps a more concentrated treatment schedule may be more successful for PBM. But since these papers were not performed in a parallel manner, it is unclear if our success in speeding wound healing would be seen with an altered protocol.

While every other day laser therapy, more or less J/cm^2 or less treatment days may alter the findings, canine epidermal keratinocytes showed detrimental effects at 10 J/cm^2 (27). Since the range in the literature for wound healing is 1–40 J/cm^2 we chose a middle range, but still an aggressive dosage to increase the chance we would see a benefit, but avoid tissue damage. Recently the World Association of Laser Therapy indicated at least 5–7 J/cm^2 are needed to induce cellular change, suggesting this to be the low end of therapeutic dosages (28). This is potentially confirmed with the two recent wound healing studies showing no apparent benefit with PBM using 1 or 5 J/cm^2 in canines (23, 26). In our study, many of the patients were ready to go home prior to the full 7 day treatment was complete. Therefore, the success of laser therapy would need to be weighed against cost to client to remain in hospital or have the patients return for daily outpatient treatments. Non-laser treatment dogs appeared to have a wider scar and more crusting still present, with no hair growth over the incision or bridging epithelium at day 21. Perhaps eventually both groups would look the same further out in time. This is unclear since this study did not follow patients out longer than 21 days.

While this study focused on IVDD patients for a more consistent surgical scar, perhaps this study could be extrapolated to include PBM treatment for other canine surgical incisions or wounds. Similar wounds in the inflammatory phase of wound healing should theoretically respond similarly favorable as in this study. However, since these were uncomplicated, clean, surgical incisions and not open wounds, these conclusions cannot be drawn. It is also unclear if feline patients would need an altered dosage due to their different skin vascularity and healing properties.

A major limitation to this study includes the small sample size, but due to large differences between the groups statistical values were still found which were likely clinically significant. But due to sample size we could not draw conclusion on other interesting variables such as pain, steroid usage, neurologic function, or metabolic variables. This is the first veterinary study to use digital pictures and a scar scale score for surgical incisions. The reviewers were blinded to the treatment groups and pictures were taken uniformly to prevent patient identification by excluding dapple coloring, previous surgery on the back, and cropping into the incision and skin. However, the photographs were colored images and the length of the incisions and axial muscle were not uniform. So, while reviewers were blinded to the treatment group, they may have recognized the shape of an incision or curve of a spine while going through and scoring the randomly numbered images. Therefore, they may have noticed a healing trend on a patient's incision, but they were blinded to the treatment group. The more complete healing, with minimal scarring of wounds, has been shown to coordinate very strongly with overall tensile strength (3, 10, 18, 21, 23, 26). There are obvious incentives to a non-invasive wound healing scoring system. While the true test of tensile strength of wound healing between the two groups would have been more conclusive, the strong agreement between reviewers shows these animals did not need the added morbidity of serial biopsies. This study did not record total time of PBM in each patient. The dosage was predetermined and the incision-encompassing treatment area, but the size of the incision and patient varied; therefore, total joules and treatment times varied. In future studies, this would be a potentially valuable piece of information to record and help uniformity in PBM study reporting and comparison. Additional study limitations were the inability to draw conclusion about many of the things that are known risk factors to abnormal wound healing and operative related factors (i.e., details of scrub, core body temperature, surgery time).

CONCLUSION

The surgical incisions in these four dogs healed faster and more cosmetically with PBM induced by laser therapy using 8 J/cm2 daily for 7 days. The improved healing and cosmetic score could be seen beginning at day 7 and continued to be improved for 3 weeks after surgery.

AUTHORS CONTRIBUTIONS

JW, KG, and AW contributed to conception and design of the study. AW organized the database. JW, EB, JB, RB, JG, and LS analyzed the pictures and scored the patients. KG wrote the original grant application for this project. JW wrote the original draft of this manuscript. All authors contributed to manuscript revision, read, and approved the submitted version. The corresponding author takes primary responsibility for communication with the journal and editorial office during the submission process, throughout peer review, and during publication. The corresponding author is also responsible for ensuring that the submission adheres to all journal requirements including, but not exclusive to, details of authorship, study ethics, and ethics approval, clinical trial registration documents and conflict of interest declaration. The corresponding author should also be available post-publication to respond to any queries or critiques.

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Retrospective Multi-Center Analysis of Canine Socket Prostheses for Partial Limbs

*Theresa M. Wendland, Bernard Seguin and Felix M. Duerr**

Department of Clinical Sciences, Colorado State University, Fort Collins, CO, United States

Introduction: Socket prostheses for treatment of distal limb pathology are becoming increasingly prevalent in veterinary medicine, however, limited objective data is available. Objectives of the present study were to retrospectively evaluate owner satisfaction, clinical outcomes, and prognostic factors associated with dogs receiving socket prostheses for partial limbs in a larger patient population.

Materials and Methods: Client databases of a single prosthesis provider were reviewed to identify owners whose dogs had received a prosthetic device within the last 10 years. An online survey was developed to evaluate owner-reported outcomes. The survey inquired about anatomy of the residuum, concurrent disease, prosthesis use, rehabilitation, activity, complications, and owner satisfaction. Medical records and radiographs were requested from all participants. Radiographs were used to confirm level of amputation and evaluate for osseous complications. Survey responses were analyzed by assigning author-defined numeric scores defining clinical outcome and owner satisfaction.

Results: One-hundred thirty-seven owners were contacted. The response rate was 50/137 (37%); 47 responses were analyzed. Forty-six of 47 owners reported positive satisfaction; 1/47 was displeased. Forty-two of 47 dogs were scored to have acceptable to full function; 5/47 had unacceptable clinical function using the author-defined scoring system. A 62% short-term complication rate and a 19% long-term complication rate were reported. Skin sores were the most common short and long-term complication. There was a significant correlation between both clinical outcome scores and owner satisfaction with days per week spent in the prosthesis. Additionally, clinical outcome scores and owner satisfaction significantly varied between dogs with different durations of prosthesis wear with a trend toward better outcomes associated with longer prosthesis wear. Radiographs were obtained for 23/47 dogs to further define level of defect. The most proximal level of defect was mid-radius for the forelimb and mid-tibia for the hind limb. There was no correlation between level of defect and either owner satisfaction or clinical outcome.

Edited by:
*David Levine,
University of Tennessee at Chattanooga, United States*

Reviewed by:
*Annamaria Grandis,
University of Bologna, Italy
Nathan Peterson,
VCA West Los Angeles Animal Hospital, United States*

***Correspondence:**
*Felix M. Duerr
Felix.Duerr@colostate.edu*

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Discussion/Conclusion: Results of this survey suggest a high degree of owner satisfaction despite substantial complication rates. Based on preliminary data, further evaluation of socket prostheses as a limb-sparing option for treatment of distal limb pathology should be considered. Prospective clinical trials with objective outcome measures are required to draw firm conclusions.

Keywords: prosthesis, prosthetic, amputation, partial amputation, socket, orthotic

INTRODUCTION

The use of socket prostheses for companion animals is emerging as a more common treatment in the field of veterinary medicine (1, 2). Due to their growing prevalence and potential to change current practices in veterinary medicine, it is crucial to objectively assess the value and efficacy of socket prosthetics as a treatment option for distal limb pathology in veterinary patients.

Partial limb amputation is frequently performed in people so that a prosthesis may be used (3). Conversely, total limb amputation is considered the standard of care as a treatment for appendicular neoplasia, infection, trauma, and congenital defects affecting canine patients, even for distal limb pathology (4–10). This discrepancy in perspective and treatment approach is presumably due to bipedal vs. quadrupedal differences between people and dogs. However, recent kinetic and kinematic analyses of dogs who received total limb amputations of thoracic or pelvic limbs revealed significant alterations to locomotive biomechanics when compared to quadrupedal dogs (4, 11, 12). Such gait alterations may have deleterious effects on long-term musculoskeletal health and lead to other quality of life issues (13). These effects have been described clinically, though the long-term impact that total limb amputation has on orthopedic health has not been objectively studied. Additionally, while multiple surveys have been published in the veterinary literature indicating positive owner satisfaction with total limb amputation, owners still reported negative changes to their dog's mobility, attitude, and quality of life (6, 14–16). For example, Dickerson et al. found that 27% of owners reported a change in their dog's recreational activities, 42% reported some change in ability to maneuver stairs, 23% were unable to return to pre-amputation walking routines, 9% reported a change in their dog's attitude, and 12% reported that their dog did not return to pre-amputation quality of life (16).

It has been suggested that a prosthetic limb re-establishes quadruped gait and structure preventing development of secondary musculoskeletal disease (1). There are reports in the veterinary literature of horses, calves, and a single deer that have undergone partial amputation with socket prosthesis placement demonstrating the ability to restore quadrupedal function with such devices (17–19). To date, two retrospective studies have documented outcomes of socket prosthesis placement in dogs. One owner survey based study reported that 87.5% of patients (21/24) had the same to improved quality of life as they did prior to receipt of a prosthesis (20). Another study indicated that 83.3% of owners (10/12) reported a good to excellent quality of life following prosthesis placement (21). This may suggest that socket prosthetics could be a viable option for some canine patients. There are still many questions about prosthetic use in canine patients which have been left unanswered. While owner perceptions of quality of life and owner expectations regarding mobility have been assessed, overall owner satisfaction with prostheses as a treatment option has not yet been investigated. Another important question, which warrants further study, is the exact levels of amputation or limb defect which can be successfully treated with prosthetic devices. It is well-documented within human medicine that the level of limb defect has a strong correlation with clinical outcomes (22, 23). In the veterinary patient, suggestions of optimal limb length have been made by veterinarians and veterinary prosthetists based on clinical experience, however this has not been definitively established (20). Other prognostic factors, such as age, reason for prosthesis placement, frequency of use of the prosthesis, and whether or not rehabilitation was performed have yet to be identified.

The objectives of the present study are to retrospectively evaluate owner-perceived outcomes associated with dogs who received a socket prosthesis for a partial-limb and to identify overall owner satisfaction as well as prognostic factors for owner satisfaction and clinical outcomes. We hypothesized that overall owner satisfaction with prosthesis placement and use would be high. It was also hypothesized that distal limb defects would correlate with positive clinical outcomes and higher owner satisfaction with prosthetic devices compared to proximal limb defects.

MATERIALS AND METHODS

Case Selection

This was a survey-based study sent to owners of dogs who had undergone a partial limb amputation, had a congenital defect, or had a partial limb due to unknown causes. Dog owners who received socket prostheses in the last 10 years from a single veterinary prosthetic manufacturer[1] were identified by database review based on previously indicated willingness to participate in research. Identified owners were solicited via email for survey participation.

Prosthetic Devices

All prostheses were custom manufactured by a single veterinary prosthetic manufacturer (**Figure 1**). The device was created based on a mold of the patient's residuum created out of

[1]OrthoPets LLC, Denver, CO.

FIGURE 1 | Example of a thoracic limb prosthetic device for a patient with a mid-radius amputation.

FIGURE 2 | Photograph of a limb casted for a prosthetic device creating the mold used to manufacture the prosthetic.

fiberglass cast tape by the referring veterinarian (**Figure 2**). Initial prosthesis fitting, recommendations for prosthesis use, and aftercare associated with the device were all provided by the referring veterinarian. Complications were addressed by the veterinarian with support from the manufacturer, and any necessary revisions to the device were made by the veterinarian or by sending the device back to the manufacturer.

Survey and Medical Records

An online survey was developed to evaluate owner-reported outcomes and satisfaction associated with socket prosthesis use by canine patients. The survey was linked in an email and administered through an online survey tool[2]. Owners who chose to participate were required to identify their pet by name, provide personal contact information, and name a veterinarian involved in the management of the prosthesis for purposes of medical record obtainment and review. Following required identification and contact information, there were 31 required survey questions.

The survey (available in **Supplemental Materials**) inquired about breed, affected limb, reason for partial limb, level of amputation or defect, age at receipt of prosthesis, time between limb-loss and receipt of prosthesis, time spent in the prosthesis, patient activity prior to and following receipt of prosthesis, activities performed in the prosthesis, patient acceptance of the prosthesis, rehabilitation, complications, concurrent orthopedic and neurologic disease, and owner satisfaction. Each question had a text box for optional additional comments or clarification. There was also an optional text box included at the end of the survey for additional miscellaneous comments. For the question which inquired about level of limb defect, a diagram and detailed descriptions were provided to owners to select the level of defect.

Survey responses were analyzed by assigning scores to question responses related to clinical outcome (**Table 1**). The scored questions included information regarding frequency and duration of prosthesis wear, walking ability in the prosthesis, activity in the prosthesis, adaptive tasks performed with the prosthesis, acceptance of prosthesis donning, and complications experienced. Each question response was assigned a numeric value. Responses were assigned positive values if the factor was considered to be associated with a favorable clinical outcome

[2]SurveyMonkey, San Mateo, Cap.

and negative values were assigned to factors considered to be associated with unfavorable clinical outcomes. Question outcomes were numerically weighted based on the clinical implications and relevance as determined by the authors. For example, each short term complication was assigned a value of negative one while each long-term complication was assigned a value of negative two. Sums were tallied for each patient. A scale was created from the scores obtained based on factors determined by previous reports in the veterinary literature and by clinical experience (6, 16, 24). Scale cut-off points were determined arbitrarily prior to data analysis by comparing hypothetical numeric values to the clinical picture of a patient that would fall

TABLE 1 | All questions that were included in the author-defined clinical outcome scoring and the points assigned to each of the possible answers provided.

CLINICAL OUTCOME SCORING	
Scored question	**Point assignments**
How many days per week is the prosthesis worn on average?	+1 point for each day per week the device is worn
Approximately how many hours per day does your dog wear the prosthesis (on days it is worn)?	Less than 1 = 0 points; 1–3 = 1point; 3–6 = 2 points; 6–9 = 3 points; 9–12 = 4 points; 12–15 = 5 points; 15–18 = 6 points
For what purpose is the prosthesis used? (You may choose more than one answer)	+1 point for each purpose selected/listed
How well does your dog walk with the prosthesis?	Never = 0 points; holds up most of the time but places some steps = 2 points; holds up for some steps = 3 points; Uses for almost every step = 4 points
How well has your dog adapted to using the prosthesis for other tasks? Please select specific tasks your dog does well with the prosthesis (you may choose more than one).	+1 point for each purpose selected/listed;−1 point if the option "My dog does not use the prosthesis well for any tasks" is selected
Does your dog like having the prosthesis placed?	Avoids having it placed = 0 points; Doesn't mind = 1 point; Excited = 2 points
How has your dog's activity changed since receiving the prosthesis? For dogs who had an amputation, please compare to your dog's lifestyle prior to limb loss (i.e.,: before the problem started).	Moderate to marked decrease = −2 points; Mild decrease= −1 point; Same or don't know = 0 points; Mild increase = 1 point; Moderate to marked increase = 2 points
Has your dog experienced any short-term prosthesis complications? Examples: pressure or rub sores that resolved in <8 weeks and did not reoccur, quickly resolving pain associated with the amputation/defect site, swelling or size fluctuations of the amputated limb <8 weeks after amputation, etc.	−1 point for every complication selected/listed
Has your dog experienced any long-term prosthesis complications? Examples: Pressure or rub sores that lasted more than 8 weeks or reoccurred, chronic pain associated with the amputation/defect site, swelling or size fluctuations of the amputated limb more than 8 weeks after amputation, etc.	−2 points for every complication selected/listed

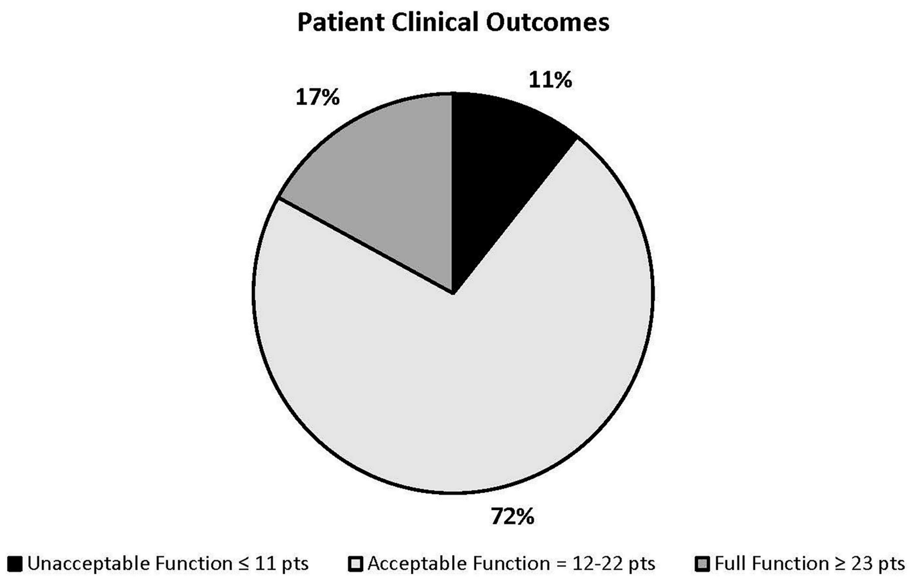

FIGURE 3 | Patient clinical outcome score ranges and percentage of patients who fall into each range.

into that range. A previously outlined clinical outcome scoring system was utilized as a guideline for outcome definitions: Full function was defined as restoration to, or maintenance of, full intended level and duration of activities and performance from pre-injury or pre-disease status. Acceptable function was defined as restoration to, or maintenance of, intended activities and performance from pre-injury or pre-disease status that is limited in level or duration. Unacceptable function was defined as all other outcomes (25). Outcomes were numerically defined as full function (≥23 points), acceptable function (12–22 points), and unacceptable function (≤11 points) with a possible score range of −13 to 34 (**Figure 3**).

Responses were also analyzed for owner satisfaction. The scored questions included owner-reported satisfaction level, whether or not they would chose this treatment option again for their dog, and whether they would recommend a prosthesis as a treatment option to another owner. Possible scores ranged from zero to six, with zero being considered dissatisfied and six being very satisfied (**Table 2**).

Clinical outcome and owner satisfaction were analyzed for correlations with other factors which may be prognostic indicators such as signalment, rehabilitation performed, concurrent disease, time between limb loss and receipt of prosthesis. Clinical outcomes and owner satisfaction were also compared against factors contained within each scored outcome, such as time spent in the prosthesis and complication rates. For statistical analysis, breeds were classified as x-small, medium, large, x-large breed, as designated by the American Kennel Club (26). If the breed description was unclear, the dog was classified as "other" and was analyzed as a separate category acknowledging that patient size was potentially highly variable. Each category was assigned a numeric value for purposes of statistical analysis.

When available, medical records and radiographs of survey respondents' dogs were obtained and reviewed for comparison with survey responses. When radiographs of the affected limb were not available, owners of dogs who were identified as still living were contacted to assess interest in having radiographs taken of the affected limb. Owners and their preferred veterinary clinics were contacted to arrange participation. Participating veterinary clinics were reimbursed for radiographs taken at their facility. All radiographs were used to compare owner-reported level of amputation or defect and to assess for radiographic signs of residual limb complications.

TABLE 2 | All questions that were included in the author-defined owner satisfaction scoring and the points assigned to each of the possible answers provided.

OWNER SATISFACTION SCORING

Scored question	Point assignments
How would you describe your level of satisfaction with your dog's prosthesis?	Unhappy = 0 points; Acceptable = 1 point; Better than acceptable = 2 points; Very happy = 3 points
Based on your experience, would you choose a prosthesis for your dog again?	Yes = 1 point; No = 0 points
Knowing what you do now, how likely are you to recommend a prosthesis to another dog owner?	Unlikely = 0; Likely = 1; Very likely = 2 points

Statistical Analysis

The data included in clinical outcome scores and owner satisfaction scores was analyzed using a non-parametric Kruskal-Wallis test to compare between data groupings. Spearman's Rho was used to evaluate correlation between the scores and other continuous variable. Continuous data were represented using means. However, if the data was not normally distributed then medians were used. A p-value of 0.05 was used for determining statistical significance. SAS v9.4[3] was used for all statistical analyses.

RESULTS

One hundred thirty seven owners were identified by the prostheses manufacturer as having met the inclusion criteria. Emails with survey links were sent to 137 owners with a 50/137 (36.5%) survey completion rate. The survey was sent three times at 2 week intervals to owners who had not yet responded. Three survey responses were excluded for prosthesis non-use or minimal-use. These three exclusions involved a severe injury unrelated to the prosthesis leading to prosthesis non-use prior to device receipt and two cases in which the prosthesis was newly received and had not yet been or had been minimally used at the time the survey was completed. This resulted in 47 survey responses included in the statistical analysis.

Thirty dogs were reported to have received a partial limb amputation, 11 had a congenital defect, and 6 had an unknown history resulting in a partial limb (**Figure 4**). The mean age at the time of prosthesis placement was reported to be 3.8 years and the median age was 3 years. The median time range between limb loss and prosthesis placement could not be accurately described for all dogs because owners reported an unknown timeframe for 22/47 dogs. In dogs for which the timeframe was known, the median timeframe range was 2–6 months between limb loss and prosthesis placement. Twenty-seven of 47 patients underwent some form of rehabilitation therapy post-prosthesis fitting. The most common duration of rehabilitation therapy performed was 2–3 months. The remainder of descriptive data can be found in the **Supplemental Material Dataset**.

Twenty-five of 47 (53.2%) owners responded that they were very satisfied with the outcome, 12/47 (25.5%) reported a better than acceptable outcome, 9/47 (19.1%) reported an acceptable outcome, and 1/47 (2.1%) was displeased with the outcome. Forty-five of 47 (95.7%) reported that in hindsight, they would choose this treatment option again. Forty-two of 47 (89.3%) dogs were considered to have

[3]SAS Institute Inc., Cary, NC.

acceptable function or full function clinical outcomes based on author-defined clinical outcome scoring criteria, while 5/47 (10.6%) were determined to have a poor clinical outcome by the same criteria. There was a significant correlation between clinical outcome scores and owner satisfaction scores ($r_s = 0.5400$, $p < 0.0001$).

Dogs spent from 0 to 7 days per week in their prostheses with a median of 7 days per week. There was a significant positive correlation between clinical outcome scores and days per week spent in the prosthesis ($r_s = 0.3146$, $p < 0.0313$). There was an even stronger positive correlation between owner satisfaction scores and days per week spent in the prosthesis ($r_s = 0.6662$, $p < 0.0001$). Dogs spent 0 h per day up to 15–18 h per day in their prosthetic devices with a median range of 2–6 h per day. Clinical outcome scores varied significantly between dogs with different hour durations that the prosthesis was worn ($p < 0.0001$) with better outcomes associated with longer prosthesis wear. Similarly, owner satisfaction significantly varied between the dogs with different hour durations of prosthesis wear ($p < 0.0258$) with more positive outcomes in dogs spending the greatest number of hours in their prostheses.

Other prognostic indicators evaluated included dog size and whether or not rehabilitation was performed prior to fitting of a prosthetic device (pre-habilitation). The relationship between clinical outcome scores and dog size ($p = 0.0898$) was approaching significance, with medium breed dogs appearing

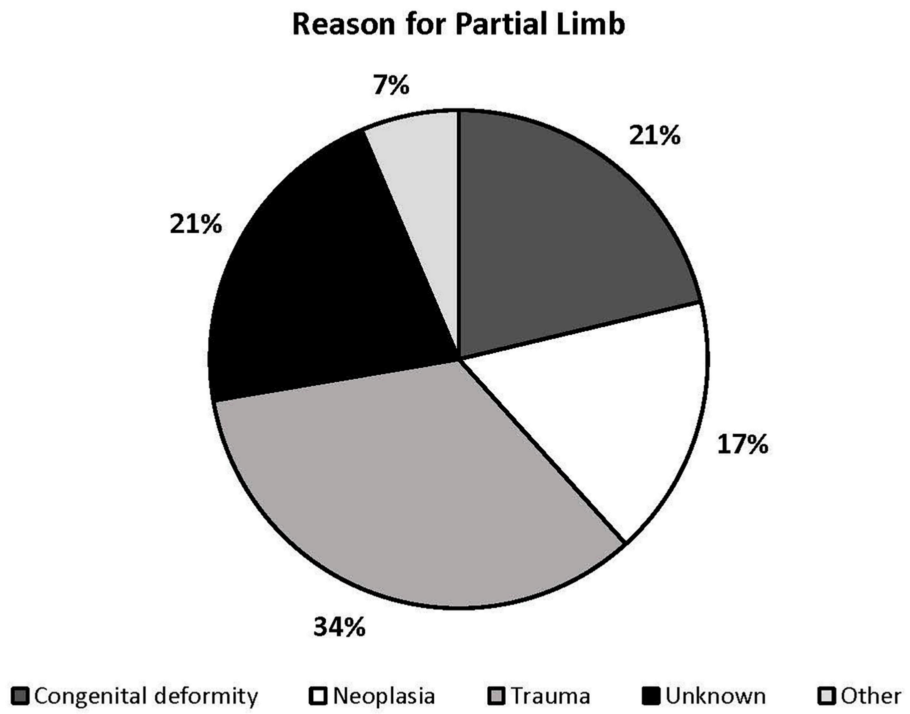

FIGURE 4 | Percentage breakdown describing the reason included dogs had a partial limb.

TABLE 3 | Defect levels and their respective mean Clinical and Owner Satisfaction Scores; There are greater than $n = 47$ limbs described due to multiple patients having more than one partial limb.

Level of limb defect	N	Mean clinical outcome score	Standard deviation (clinical outcome)	Mean owner satisfaction score	Standard deviation (owner satisfaction)	Number of limbs with level confirmed radiographically
1–Digital defects	4	15.3	7.4	5.3	1.5	4
2–At carpus/tarsus or distal to joint	32	16.4	5.8	5	1.2	19
3–Mid-radius/ulna or mid-tibia/fibula	8	17.3	4.3	5.4	1.1	1
4–Unknown	1	25	-	6	-	0

The number of limbs and the described defect level confirmed with radiographs of the partial limb is shown in the far right column. Again, it should be noted that this column contains 24 limbs, though radiographs were only obtained for 23 subjects. One subject had multiple affected limbs for which radiographs were provided.

to do clinically best. There was a significant difference in owner satisfaction scores and dog size ($p = 0.026$), with dogs of unspecified dog size associated with highest owner satisfaction. X-Small breed dogs and x-large breed dogs received the lowest scores in both clinical outcome and owner satisfaction. The relationship between clinical outcome scores and dogs receiving pre-rehabilitation ($p = 0.0714$) was approaching significance and there was a significant difference in owner satisfaction scores between dogs receiving pre-rehabilitation vs. those which did not receive pre-habilitation ($p = 0.0417$). Both clinical outcome scores and owner satisfaction scores were higher in dogs who did not receive pre-habilitation. Only 9/47 dogs received rehabilitation prior to receipt of their prosthesis.

Owner satisfaction scores were significantly different between categories of owner's ability to place the prosthesis ($p = 0.0063$) with ease of prosthesis placement related to owners with the highest satisfaction scores.

Level of defect, reason for partial limb, affected limb, time between limb loss and prosthesis placement, breed, age at the time of prosthesis placement, rehabilitation after prosthesis placement, or concurrent orthopedic or neurologic disease had no correlation to or significant differences with either owner satisfaction scores or clinical outcome scores. No correlations or significant differences were found between owner satisfaction scores and short- or long-term complications. Complication rates could not be statistically correlated to clinical outcome since complications were factored into this score.

There was a reported 61.7% ($n = 29$) short-term complication rate with sores being the most common complication ($n = 21$), followed by pain ($n = 5$), swelling ($n = 2$), and dermatitis ($n = 1$). A long-term complication rate of 19.1% ($n = 9$) was reported (sores $n = 7$, pain $n = 1$, and dermatitis $n = 1$).

Radiographs were obtained for 23/47 dogs to confirm and further define level of defect. All defects were found to be at the level of the mid radius/ulna or mid tibia/fibula or distal to this level. Sixteen of 23 owners (69.6%) correctly identified the exact level of limb defect, though all inaccurate reports were found to be just above or just below the joint level reported. There was no significant difference found between level of defect and either owner satisfaction scores ($p = 0.589$) or clinical outcome scores ($p = 0.4099$). A more detailed description of defect level can be found in **Table 3**. Only 1/23 patient radiographs of a mid-radial amputation revealed obvious radiographic signs of residual limb complication in the form of a distal residuum bursa. Veterinary records indicate that only one patient received a revision surgery to remove the bursa of the above mentioned patient.

DISCUSSION

To the authors' knowledge, this is the first multi-center study evaluating owner satisfaction with socket prosthesis use in dogs. Results of the present study suggest a high satisfaction rate among owners electing a socket prosthesis for treatment of distal limb pathology. Additionally, most owners surveyed would elect to choose this treatment option again, and would recommend the use of socket prosthetics to another dog owner. Clinical outcomes in the present study appeared slightly better than previously reported outcomes (21). However, criteria utilized to determine clinical outcome differed between studies, therefore, direct comparison of these outcome scores cannot be made.

Factors which may impact prognosis of patients receiving a socket prosthesis were also investigated. Level of amputation is of particular interest due to clinical application in making recommendations for surgical limb-sparing options. Level of limb defect has been demonstrated across multiple studies in human medicine to have a significant correlation with clinical outcomes (22, 23). In the veterinary patient, it has been recommended that socket prostheses can be considered with partial amputations as proximal as the proximal third of the radius/ulna and mid-tibia (2). These recommendations have been made based on clinical impressions of device suspension needs, limitation of planes of motion, and proprioceptive feedback to the patient (2). It has also been suggested that pelvic limbs with amputations at or below the tarsus provide benefit due to good suspension via the malleoli while a thoracic limb may be treated with a more proximal amputation due to anatomy and device suspension from the humeral condyles (20). Neither of these suggestions, however, have been supported by objective data at this time. In the recent literature, one study evaluated three dogs with mid-diaphyseal radius/ulna defects and one dog with a mid diaphyseal tibial defect (20). Specific outcomes for these dogs were not reported. Another study reported on three patients with an antebrachial defect and three patients with defects at the tarsocrural joint or proximal (21). Outcomes of 2/3 dogs with antebrachial defects were defined as good, 1/3 was poor. Outcomes of all dogs with defects at or proximal to the tarsocrural joint were defined as good; the precise level of defects was not defined for thoracic or pelvic limbs (21). Previous studies found no correlation between level of amputation and outcome measures, however, the low case numbers did not allow to draw firm conclusions (20, 21). The present study investigated a larger number of patients receiving prosthetic limbs and a combination of detailed description, diagrams, and radiographic review were used to accurately define level of amputation or defect. Despite these efforts, we were unable to establish a correlation or significant difference between level of defect and either owner satisfaction scores or clinical outcome scores. This may suggest that level of limb defect is of less importance in a quadrupedal patient than it is in a bipedal patient. On the other hand, the present study only identified eight cases with a defect at the level of the mid radius/ulna or tibia/fibula resulting in a small sample size making a Type II statistical error possible. Therefore, further investigation with a larger sample size and fewer patient variables is warranted to establish definitions of limb length and correlation to clinical outcome.

Of the possible prognostic factors investigated, time spent in the prosthetic device appeared to have the most profound association with owner satisfaction scores and clinical outcome scores with significant positive correlations. Dogs who utilized their prosthetic limbs more frequently generally had a more positive clinical outcome and higher owner satisfaction whereas dogs with poor clinical outcomes and lower owner satisfaction spent less time in their prosthetic devices on average than dogs with positive outcomes and owner satisfaction. This finding is similar to reports in the literature describing parents' satisfaction and outcomes for pediatric patients with prosthetic limbs. Parents' ratings of satisfaction were correlated with the amount of time the prostheses were worn and the extent to which their children used their prostheses for activities in a variety of contexts (27). It is unknown at this time, however, if a prosthetic device is more likely to be utilized if a patient and owner are having a positive experience or if the positive experience is secondary to regular, consistent prosthesis use. In people, reasons reported for infrequent prosthesis use or prosthesis rejection were dissatisfaction with prosthetic comfort, function and control (28). On the other hand, prosthetic use appears to increase with functional ability which has been associated with experience and practice (29). It is probable that there are multiple factors which influence the relationship between prosthetic use, satisfaction, and outcomes.

It should be of note that both clinical outcome scores and owner satisfaction scores were higher in dogs who did not receive pre-habilitation. Additionally, application of post-prosthesis placement rehabilitation had no correlation or significant difference to owner satisfaction or clinical outcome scores. This would seem counterintuitive since rehabilitation/pre-habilitation should theoretically have a positive impact on outcome based on previous human-based literature which has shown a higher probability of return to mobility and autonomy with timely admission to a rehabilitation facility (30). It is likely, that this finding is due to unidentified confounding factors: for example the patients receiving more extensive care in the form of pre-habilitation may have been more severely clinically affected requiring more in depth intervention or did not respond well to the prosthetic due to clinical presentation. It would be expected that such patients may have lower clinical outcome scores and lower owner satisfaction scores. Again, a prospective study is needed to answer this question.

No correlations or significant differences were found between owner satisfaction scores and short- or long-term complications, however complication rates were generally high and should be of note when considering prosthetic limbs as a treatment option. Sores were by far the most common complication. Carr et al. previously reported patient factor complications such as sores and infections at 20.83% and Phillips et al. has reported a 58.3% complication rate (20, 21). This difference in reported complication rates may have to do with complication definitions, prosthesis manufacture, and variability in other patient factors, initial disease etiology, or the multi-center nature of the present study. All of these studies, including the present study, have demonstrated high rates of complications. Owners electing this treatment should be made aware of potential complications prior to electing a socket prosthesis as a treatment option.

The limitations of this study include the survey-based, owner-reported, retrospective nature. The response rate was relatively small considering previous indication by owners that they would not mind follow-up communication regarding their experience. It is possible that non-responders included dissatisfied owners. Multiple emails seeking survey participation were sent, though additional forms of communication, such as phone calls, were not pursued with non-responding individuals. The questionnaire used has not been previously validated and is based primarily on clinical experience and previously applied surveys; interpretation of data is likely influenced by researcher perception and experience. Survey interpretation by owners may have also been variable. It has been demonstrated that surveys contain an inherent bias due to the unknown factors of survey non-responders (31). Additionally, the data collected in this study were dependent on the owners' ability to recall events, outcomes, and feelings that occurred up to many years in the past. Medical records could not be obtained for all patients, therefore subjective owner responses could not be compared with imaging and veterinary records in more than half of the cases. The survey respondents were not selected in a random, rather from a database and a population of owners selecting a specific treatment option. These owners all had a significant time and often financial investment in the prescribed prostheses, therefore, response bias was highly likely. It may also account for the high level of owner satisfaction and discrepancies between owner satisfaction and clinical outcome. Owner perception can also be highly influenced by the care that they have received throughout treatment; while the prosthesis manufacturer was consistent for all owners surveyed, experience likely varied due to working with a multitude of veterinary practices prescribing and managing the devices. Experience level of the involved veterinary professional was not determined. Lastly, given the variability among patients evaluated in this survey, the sample size was too small to make definitive conclusions about prognostic factors that may influence prosthesis use.

Despite the aforementioned limitations, the overall high satisfaction rate and positive clinical outcomes demonstrated by this survey based study support continuation of further investigation into the use of socket prosthetic use in dogs. This study in combination with similar recent analysis of socket prostheses indicate that socket prostheses may be considered as an option for dogs with a partial limb due to amputation or congenital defects. Further clinical research using objective outcome measures is necessary to fully support the data represented in the present analysis.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of Federal Policy for the Protection of Human Subjects, U.S. Department of Health and Human Services. Since the data gathered by the owners focused solely on their animals it does not meet the federal definition of a human subject and therefore did not require review by the Institutional Review Board.

AUTHOR CONTRIBUTIONS

TW, FD, and BS contributed to conception and design of the study. TW created the initial survey which was revised and edited by FD and BS. TW organized the data set and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2019.00100/full#supplementary-material

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Effects of 1-MHz Ultrasound on Epaxial Muscle Temperature in Horses

Henry S. Adair[1]* and David Levine[2]

[1] Department of Large Animal Clinical Sciences, College of Veterinary Medicine, The University of Tennessee, Knoxville, TN, United States, [2] Department of Physical Therapy, The University of Tennessee at Chattanooga, Chattanooga, TN, United States

Objective: The purpose of this study was to examine the tissue temperature changes that occur at various depths during 1.0-MHz ultrasound (US) treatments of the epaxial muscles in horses.

Animals: Ten healthy adult mares with no lameness or orthopedic disease weighing between 465 and 576 kg were studied.

Procedures: Two 1.0 MHz US treatments, one at an intensity of 1.0 W/cm^2 and one at 2.0 W/cm^2, were administered to the epaxial region. Needle thermistors were inserted in the epaxial muscles below the skin surface at depths of 1.0, 3.0, and 5.0 cm, directly under the US treatment area. Depths were verified with diagnostic ultrasound. Both intensities of US treatment were performed on each horse over a 20 cm^2 area for 10 min using a sound head with an effective radiating area of 10 cm^2. Treatments were administered in random order. Tissue temperature was measured before, during, and for an additional 10 min after the end of US treatment. Mean temperatures for each time point, location, and intensity was recorded at 30 s intervals. A mixed model analysis of variance (ANOVA) with repeated measures was used to test for differences in these means. Individual differences in the means was tested for by a Least Significant Difference (LSD) mean separation test.

Results: At the completion of the 10 min US treatment, the temperature rise at an intensity of 1.0 W/cm^2 was 1.55°C at the 1.0 cm depth, 1.18°C at 3.0 cm depth, and 1.29°C at 5.0 cm depth. At an intensity of 2.0 W/cm^2, temperatures rose 2.48°C at the 1.0 cm depth, 1.24°C at 3.0 cm depth, and 1.95°C at 5.0 cm depth.

Conclusion and Clinical Importance: The main findings of the study is that use of therapeutic ultrasound with a 1.0 MHz US for 10 min in horse's epaxial muscles when clipped creates the greatest heat at 1.0 cm. The heat in the tissues at 5 cm depth is more than at 3 cm depth.

Keywords: equine, ultrasound, muscle, heating, ultrasonic therapy, temperature, horse

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****Correspondence:***
Henry S. Adair
sadair@utk.edu

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INTRODUCTION

Therapeutic ultrasound is a commonly used treatment for its thermal and non-thermal effects in treating a variety of conditions in both animals and humans (1–4). Thermal effects of ultrasound have been shown to reduce pain (5–9), decrease sub-acute and chronic edema (10–12), reduce muscle spasms (7, 13, 14), and facilitate the stretching of collagenous tissue (15–17). Non-thermal ultrasound has been shown to stimulate tissue repair, reduce pain caused by trigger points, and reduce edema (10–12). To achieve thermal benefits of ultrasound and increase tissue extensibility, tissue temperatures must be increased above normal levels (15, 16). Increasing tissue temperatures by 1°C is known to increase the tissues metabolic rate, and >2°C to reduce chronic inflammation, decrease pain, increase blood flow, decrease muscle spasms, and increase extensibility of collagen (15–21). These studies suggest that a 2–4°C increase in tissue temperature is effective in improving flexibility/range of motion (ROM) in both animals and humans (15–17). The majority of ultrasound research has been done on humans and dogs. However, therapeutic ultrasound is a modality that is often used in the equine population. Due to the lack of studies validating the effects of ultrasound on horses, further research must be conducted to establish ultrasound protocols for the equine population.

While ultrasound can be administered at many different frequencies, the majority of research has been done using 1.0 and 3.0-MHz. In human and canine studies, 1.0-MHz has been shown to heat tissue most effectively at depths between 2.0 and 5.0 cm, with 3.0 cm being the depth where maximum heating occurs (17–20, 22). Conversely, 3.3-MHz has been shown to be most effective at heating tissues between 1.0 and 2.5 cm (23, 24). In a human study, continuous 3.0-MHz ultrasound at an intensity of 0.5 W/cm^2 was applied over the gastrocnemius muscle belly for 10 min (21). The peak increase in tissue temperature at a depth of 2.0 cm was 2.8°C (21). Additionally, the only published study evaluating the effects of therapeutic ultrasound on equine muscle and tendon temperature used a frequency of 3.3-MHz and an intensity of 1.5 W/cm^2 (25). Using this level of ultrasound for 20 min, over a 15.0 cm^2 area, mean temperature increase at 1.0 cm was 1.3°C, 0.7°C at 4.0 cm and 0.7°C at 8.0 cm (25).

The objective of this study was to identify the heating effect 1.0-MHz ultrasound will have at 1.0, 3.0, and 5.0 cm depths in equine epaxial muscle using intensities of 1.0 and 2.0 W/cm^2.

MATERIALS AND METHODS

Ten adult mixed breed mares free from any orthopedic disease or lameness, weighing 465–576 kg were studied. Ages ranged from 4 to 12 years. All experimental procedures were approved by the University of Tennessee's (Knoxville, TN USA) Animal Care and Use Committee. For thermocouple placement, horses were restrained in stocks. Detomidine HCl[1] (0.01 mg/kg intravenously {IV}) was given prior to thermocouple placement to prevent horse movement and ensure accurate placement of thermocouples. Detomidine was not administered during treatment.

Hair was clipped from a 25 cm^2 square treatment area over the right and left longissimus dorsi muscle at the level of the second lumbar vertebrae. The center of the clipped area was 10 cm lateral to the midline. The skin in this area was prepared for aseptic insertion of sterile, hypodermic needles using povidone-iodine scrub and sterile, isotonic saline (0.9% NaCl) solution. Three mls of mepivacine HCl (20 mg/ml) was injected subcutaneously through a 25-gauge, 1.6 cm needle within a 2 cm^2 area that was in the center of the clipped area. Within this 2 cm^2 area, one 20-gauge, 3.81 cm needle and two, 20-gauge, 8.89 cm spinal needles were inserted. The needles were inserted toward midline at a 75° angle using diagnostic ultrasound[2] to guarantee proper depth of 1.0, 3.0, and 5.0 cm and to avoid the lumbar vertebrae transverse process. After calibration[3], a flexible, implantable thermistor probe[4] was inserted through the lumen of each needle into the muscle, and the needles were removed by sliding them over the thermistor and out of the tissue. Once the needles were removed the thermistors were secured in placed by 1-inch medical tape outside the treatment area. The thermistors were connected to a microcomputer interfacing with the computer program[5] that recorded temperature every 30 s.

Temperature was recorded for 5 min to establish baseline temperature at each treatment depth. A 20 cm^2 template was used to outline the treatment area centered at the thermistor insertion area. Ultrasound was applied, using standard ultrasound transmission gel, for 10 min via a sound head with an effective radiating area of 10 cm^2. The ultrasound unit[6] was calibrated[7] by an authorized calibration service immediately prior to use in this study. The 20 cm^2 area received 10 min of continuous ultrasound at 1-MHz and either 1.0 or 2.0 W/cm^2 that was determined through random assignment (either right or left longissimus muscle) (**Figure 1**). Temperature was recorded every 30 s during treatment and for 10 min after treatment ended. At the end of the measurement period, the thermistors were removed and each horse was administered phenylbutazone (4.4 mg/kg IV).

Statistical Analysis

Mean temperatures for each time point, location, and intensity were calculated using computer software[8]. A mixed model analysis of variance (ANOVA) with repeated measures was used to test for differences between the heating obtained at the three different depths, and for the two different intensities at these three depths. Individual differences in the means was tested for by a Least Significant Difference (LSD) mean separation test. To test if tissue temperature change over time at each location and depth was significantly different, area under the curve (AUC) was calculated with a log linear trapezoid rule. ANOVA and LSD

[1]Dormosedan®: Zoetis United States, Florham Park, NJ, USA.

[2]MyLab 40, Esaote, Indianapolis, IN.
[3]InstaCal 5.83, Measurement Computing Corporation, Norton, MA.
[4]Thermes USB, Physitemp Instrument, Inc., Clifton, NJ.
[5]DasyLab 9, Measurement Computing, Norton, MA.
[6]Mettler Sonicator 730x, Mettler Electronics Corp, Anaheim, CA.
[7]TTT Medical Equipment Repair, 2372 Salem Valley Road. Ringgold, GA.
[8]Microsoft Excel 2016, Microsoft, Redmond, WA.

mean separation were calculated by computer software[9]. Results were considered significant at $P < 0.05$.

[9]SAS Institute, Cary, NC.

FIGURE 1 | Performing the ultrasound using standard ultrasound transmission gel, for 10 min via a 1.0 MHz sound head with an effective radiating area of 10 cm^2.

RESULTS

Implantation of thermistors and ultrasound treatment were well-tolerated by all horses. At the site of thermistor implantation the longissimus dorsi muscle averaged 8 cm in depth (range 6–9 cm). No post-procedure complications were encountered.

Temperature began to rise within 30 s of initiating treatment at both intensities and at all depths (**Figures 2**, **3**). At the termination of treatment there was a slow but steady decline in temperature at both intensities and at all depths. However, at the end of the measurement period (10 min after treatment ended) temperatures at both intensities and all depths were still above baseline. Baseline temperature was 38.3, 39.4, and 39.8°C at a depth of 1.0, 3.0, and 5.0 cm, respectively.

When using an intensity of 1.0 W/cm^2, the maximum rise in temperature in the epaxial musculature at a depth 1.0 cm was 1.55°C, and this temperature was reached at the end of treatment. At a depth of 3 cm, the maximum rise in temperature was 1.18°C, which was reached at the end of treatment. At a depth of 5 cm, the maximum rise in temperature was 1.29°C, which was reached at the end of treatment (**Table 1**).

When using an intensity of 2.0 W/cm^2, the maximum rise in temperature in the epaxial musculature at a depth 1.0 cm was 2.48°C, and this temperature was reached 9 min into treatment.

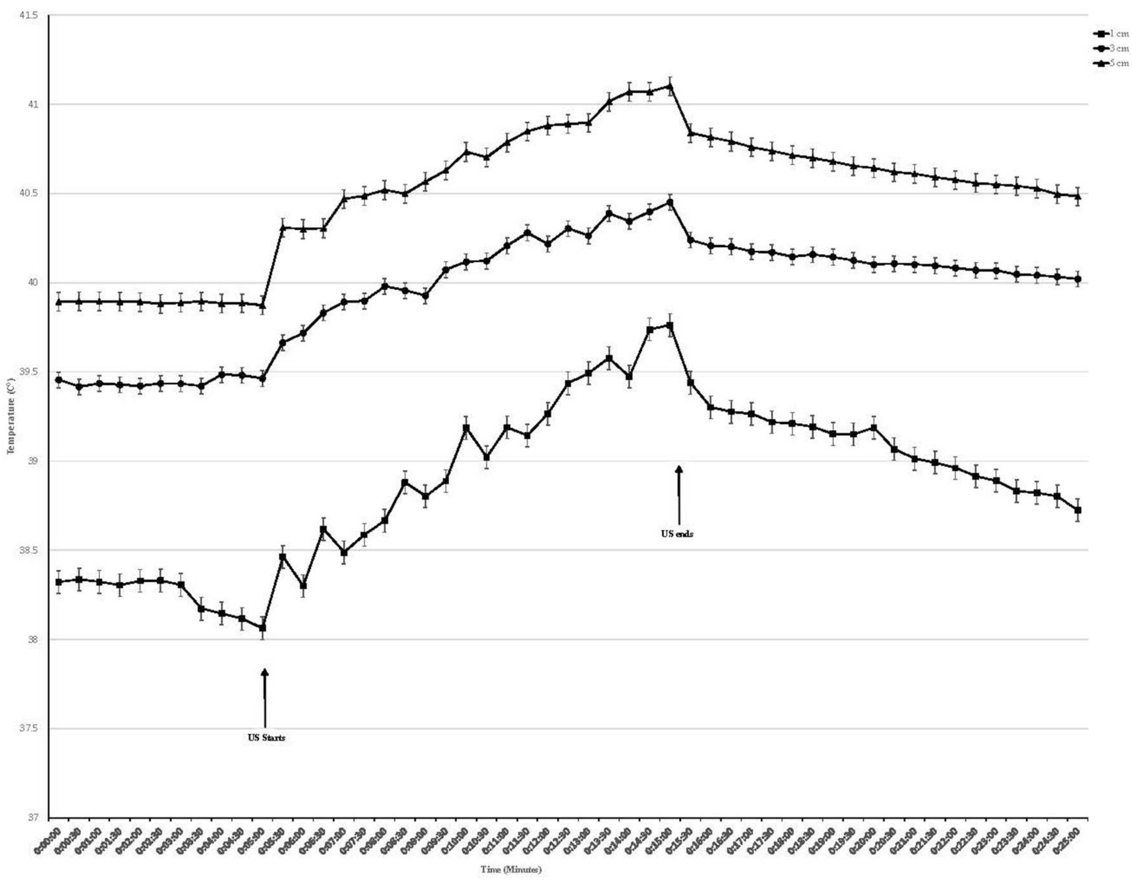

FIGURE 2 | Tissue temperature change in epaxial muscles during therapeutic ultrasound at 1.0 W/cm^2. Ultrasound starts at 5 min and ends at 15 min. Values presented as mean ± SEM.

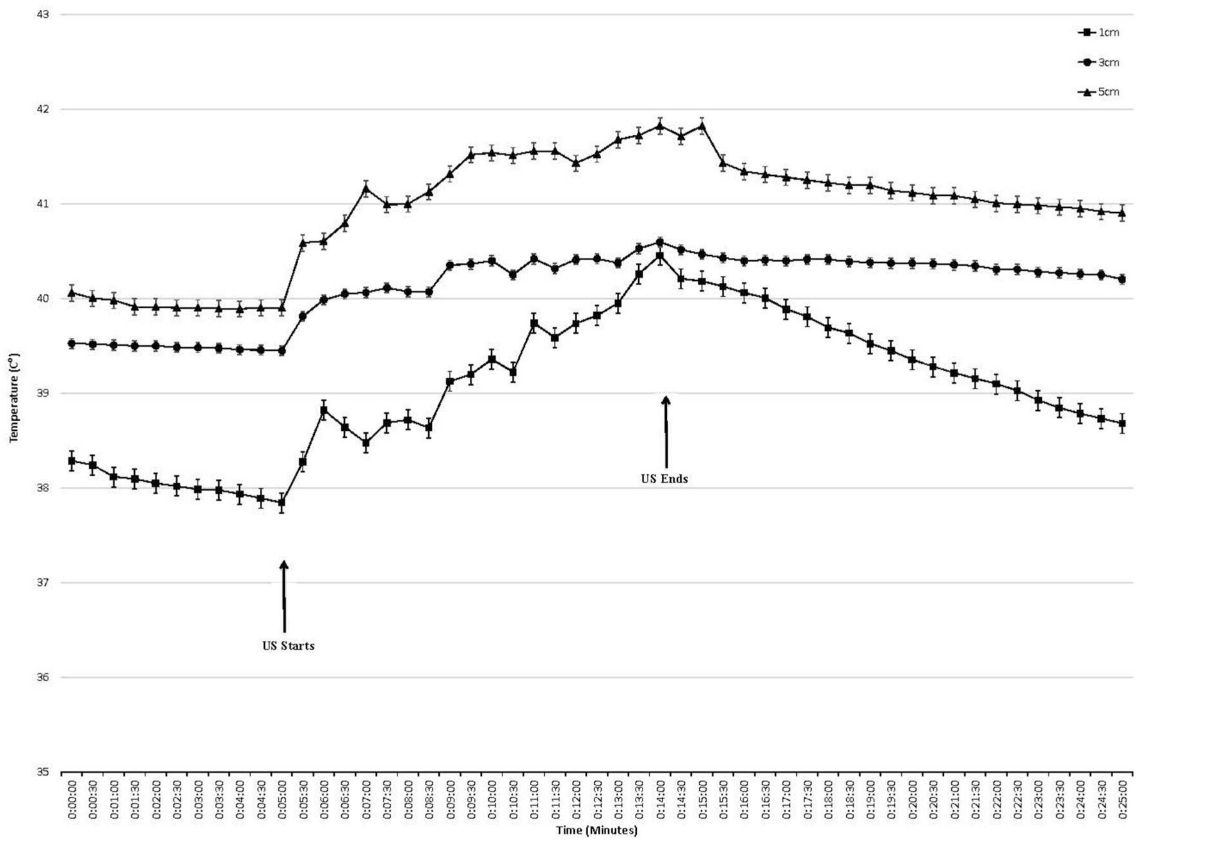

FIGURE 3 | Tissue temperature change in epaxial muscles during therapeutic ultrasound 2.0 W/cm^2. Ultrasound starts at 5 min and ends at 15 min. Values presented as mean ± SEM.

At a depth of 3 cm, the maximum rise in temperature was 1.24°C, which was reached 9 min into treatment. At a depth of 5 cm, the maximum rise in temperature was 1.95°C, which was reached 9 min into treatment (**Table 1**).

At a depth of 1.0, 3.0, and 5.0 cm, the 2.0 W/cm^2 intensity heated tissues significantly more than the 1.0 W/cm^2 intensity ($p < 0.01$) (**Table 1**).

Ten minutes after the conclusion of the treatment, the tissues temperatures for the 1.0 W/cm^2 setting were still elevated from baseline with temperatures of 38.7, 40.0, and 40.5°C for depths of 1.0, 3.0, and 5.0 cm, respectively. For the 2.0 W/cm^2 the tissue temperatures were 38.7, 40.2, and 40.9°C for depths of 1.0, 3.0, and 5.0 cm, respectively.

DISCUSSION

Tissue temperatures at baseline were greatest at the 5.0 cm depth, followed by 3.0 cm, followed by the 1.0 cm depth. This was anticipated, as the deeper tissues are closer to the body's core and consistent with previous studies on horses, dogs, and humans (18, 19, 22–24) (**Figures 2**, **3**).

While statistical significance was reached between 2.0 and 1.0 W/cm^2 intensities at all depths, the difference at 3.0 cm was small and likely not clinically significant. Statistical significance was reached in the 3.0 cm condition as the values all trended upward (though just slightly) when comparing 2.0–1.0 W/cm^2.

The difference in the overall increase between the 3 cm depth vs. the 5 cm depth was unexpected. If one considers tissue absorption and the half-value layer (the depth by which 50% of the ultrasound beam intensity is absorbed into the tissue, reducing the intensity as it travels through tissue) one would predict that the temperature at 5 cm would be lower than the temperature at 3 cm (26). However, Demmink et al., utilizing cadaver tissues, found that different tissue geometries (different thermal and acoustical properties can influence the depth limit for the different temperature ranges (27). Utilizing thermal images that only depicted the tissue temperature change, they demonstrated that tissue geometry and properties have an influence on the heating depths (27). Ultrasound penetrates through tissue high in water content and is absorbed in dense tissues that are high in protein where it will have its greatest effects (23). The denser the medium, the more the ultrasound beam will be absorbed by the tissues and possibly result in a greater heating effect (23). Highly collagenous regions that may be exposed include superficial cortical bone, periosteum, menisci, synovium and capsules of joints, myofascial interfaces, intermuscular scars, fibrotic muscle, tendon sheaths, and major nerve trunks (28). If the 5 cm thermocouple was closer to the

TABLE 1 | Increase in tissue temperature after 10 min treatment time with a therapeutic ultrasound.

Tissue depth	Baseline temperature	Conclusion of 10 min US (peak temperature)	Ten minutes following treatment end
1.0 W/cm^2 ULTRASOUND INTENSITY			
1.0 cm	38.3°C, 95% CI [38.1–38.5]	39.8°C, 95% CI [39.7–39.9]	38.7°C, 95% CI [38.6–38.8]
3.0 cm	39.4°C, 95% CI [39.2–39.6]	40.5°C, 95% CI [40.4–40.6]	40.0°C, 95% CI [39.9–40.1]
5.0 cm	39.8°C, 95% CI [39.6–40.0]	41.1°C, 95% CI [41.0–41.2]	40.5°C, 95% CI [40.4–40.6]
2.0 W/cm^2 ULTRASOUND INTENSITY			
1.0 cm	38.1°C, 95% CI [37.9–38.3]	40.5°C, 95% CI [40.4–40.6]*	38.7°C, 95% CI [38.6–38.5]
3.0 cm	39.4°C, 95% CI [39.2–39.6]	40.6°C. 95% CI [40.4–40.8]*	40.2°C, 95% CI [40.0–40.4]
5.0 cm	39.8°C, 95% CI [39.6–40.0]	41.8°C, 95% CI [41.7–41.9]*	40.9°C, 95% CI [40.8–41.0]

*Values denoted by *significantly different from 1.0 W/cm^2 ($P < 0.05$).*

bone/muscle interface then a higher temperature could occur due to reflection off of the bone. In this study we used diagnostic ultrasound to determine location of the thermistor tip and to try and ensure that the thermistors were placed only in muscle. The average depth of longissimus dorsi muscle at this level was 8 cm before the transverse process was encountered. Since the deepest thermistor was at 5 cm the possibility heating from the bone was low. However, the longissimus dorsi muscle has fascial planes that may absorb more of the ultrasound beam thus heating more that the underlying muscle. We made no attempt to avoid these fascial planes so excess heat generated by the increased collagenous tissue may have occurred. Additionally, one must consider the thermoregulation effect of blood circulation (27). The muscle tissue at the 3 cm depth may have had higher circulation leading to a greater rate of heat dissipation.

The effects of detomidine sedation must be considered when performing ultrasound treatment. One must avoid profound sedation so that the horse is able to avoid excessive heat in the tissues. The dose of detomidine used in this study has been shown not to effect the ability of the horse to detect and avoid a noxious thermal stimulus (29, 30). The effects of detomidine administration on muscle function must also be considered. Edner et al. studied the relationship of muscle perfusion and metabolism with cardiovascular variables before and after detomidine injection during propofol/ketamine anesthesia in horses (31). They found that detomidine caused profound hypertension and bradycardia and decreased cardiac output and muscle perfusion (31). However, 10 min after detomidine injection muscle perfusion had recovered to pre-injection levels (31). Since measurements were not begun until 30 min after detomidine administration the effects on muscle perfusion should be minimal. Kruljc and Nemec found that a dose of 0.022 mg/kg significantly reduced muscle EMG activity (32). However, this dose was twice that used in this study. Wooldridge et al, found no effect of detomidine on esophageal skeletal muscle and postulated that the previously reported effect may be centrally mediated (33). Since this study was evaluating the thermal effect of ultrasound on muscle, a centrally mediated effect on muscle function should not affect the results.

Previous studies suggest that a 2–4°C increase in tissue temperature is effective in improving flexibility/range of motion (ROM) in both animals and humans (15–17). The use of 1.0-MHz US in this study caused >2.0°C tissue-temperature elevation in only 1 of the 6 US conditions (2.0 W/cm^2, 1.0 cm depth). Two other conditions were close to reaching a 2°C increase (1.0 W/cm^2 at 1 cm depth and 2.0 W/cm^2 at the 5 cm depth). Increasing either the treatment time or the US intensity may have achieved an increase in tissue temperature to therapeutic levels in these conditions. In comparing intensities, the 2.0 W/cm^2 intensity elevated tissue temperature significantly higher than the 1.0 W/cm^2 intensity at all depths. Because the temperature increase was short-lived in all conditions studied, for optimal gains in range of motion, stretching should be applied if possible, during the last half of the treatment, and immediately after cessation of treatment.

CONCLUSIONS

This study demonstrates that statistically significant heating occurs in the epaxial muscles of horses during 1.0 MHz US with the greatest heating occurring at a depth of 1.0 cm. However, the lower end of the therapeutic range of tissue heating was only reached at 2.0 W/cm^2, 1.0-cm depth. Increasing treatment time or US intensity may lead to further increase in tissue temperature.

ETHICS STATEMENT

All experimental procedures were approved by the University of Tennessee's (Knoxville, TN, USA) Animal Care and Use Committee.

AUTHOR CONTRIBUTIONS

HA and DL were involved in study design, data collection, data interpretation, and preparation of the manuscript.

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Effect of Therapeutic Ultrasound on Calcaneal Tendon Heating and Extensibility in Dogs

Betzaida Acevedo[1], Darryl L. Millis[1], David Levine[2] and Jose L. Guevara[3]*

[1] Veterinary Orthopedic Laboratory, Department of Small Animal Clinical Sciences, University of Tennessee College of Veterinary Medicine, Knoxville, TN, United States, [2] Department of Physical Therapy, The University of Tennessee at Chattanooga, Chattanooga, TN, United States, [3] Department of Small Animal Clinical Sciences, University of Tennessee College of Veterinary Medicine, Knoxville, TN, United States

Objective: To (1) characterize the warming pattern of canine calcaneal tendons during and after four different therapeutic ultrasound (US) treatment protocols, and (2) to quantify changes in tarsal flexion immediately after therapeutic US treatment, and following return to baseline temperature.

Design: A prospective, crossover, experimental study.

Animals: Ten adult hound-type breed dogs.

Procedure: Therapeutic ultrasound (3.3 MHz) was applied to one calcaneal tendon of anesthetized dogs using four different settings applied in random fashion (1.5 and 1.0 W/cm^2 continuous, and 1.5 and 1.0 W/cm^2 pulsed US) while the temperature of the tendon was recorded by a thermistor needle. The contralateral tendon was used to compare extensibility of the treated soft tissues by measuring changes in tarsal joint flexion before, immediately after, and 5-min after continuous US treatment at 1.5 W/cm^2 for 10 min.

Results: The greatest increase in tendon temperature occurred with continuous US at 1.5 W/cm^2. Pulsed US resulted in minimal tendon heating. Most of the increase in tissue temperature occurred within the first 3 min of US application. Tarsal flexion increased significantly following US treatment; however, it returned to near baseline within 5 min after US was discontinued.

Conclusion and Clinical Relevance: Continuous US of the calcaneal tendon at 1.5 W/cm^2 resulted in the greatest increase in tissue temperature while maintaining a safe range of tissue temperature increase. Tendon heating and heat dissipation were slightly different from what has been reported for muscle. Our results suggest that 3.3 MHz US applied to tendon for >3 min may not provide additional tissue temperature increase. Therapeutic US resulted in increased tarsal flexion, however the change was only transitory. Therefore, stretching exercises should be performed during and immediately after US.

Keywords: therapeutic ultrasound, tendon temperature, tendon heating, tendon extensibility, canine calcaneal tendon

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Fintan John McEvoy, University of Copenhagen, Denmark

Reviewed by:
Maria Fahie, Western University of Health Sciences, United States
Raphael Labens, School of Animal and Veterinary Sciences, Charles Sturt University, Australia
James Miles, University of Copenhagen, Denmark

****Correspondence:***
Darryl L. Millis
dmillis@utk.edu

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INTRODUCTION

Therapeutic ultrasound (US) is a commonly used modality for the rehabilitation of soft tissues of the musculoskeletal system. The frequency and intensity of US, the duration and duty cycle of therapy, as well as the size and cellular properties of the target tissue, interact to produce a spectrum of non-thermal (mechanical) and thermal effects. The US beam consists of high frequency (>20 kHz) ultrasound waves created by mechanical vibrations and the rapid expansion and contraction of piezoelectric crystals in the head of the US probe. The physical effects resulting from compression and rarefaction of energy are referred to as acoustic streaming and acoustic cavitation. These non-thermal phenomena have been shown to accelerate the inflammatory phase of wound healing (1), promote ion transport, increase cellular permeability (2), increase fibroblast protein synthesis (3, 4), and promote shifts in extracellular ion concentration gradients (5).

Thermal effects vary and are correlated to the magnitude of tissue warming. As the US beam penetrates into the tissues, molecules absorb energy from the waves, which increases the rate of molecular oscillation, and results in tissue warming. Previous research has demonstrated a correlation between the magnitude of temperature increase and the thermal effects produced. A mild increase of tissue temperature by 1 to 2°C, resulted in a 13% increase of the metabolic rate for each degree Celsius (6–8). A moderate increase of 3°C to 4°C has been shown to decrease pain, muscle spasm, chronic inflammation, and increase blood flow. An increase of 4°C is required to increase collagen tissue extensibility, thus improving the flexibility of the tissues, requiring less force to stretch tissues (6, 8–11).

It has also been demonstrated that the composition and morphology of individual tissues, as well as differences among species, influence the acoustic and thermal properties of the target tissue and may alter heating patterns and thermal effects. Early studies evaluated the *ex vivo* tendons of laboratory animals and discovered that heating and stretching tendons could increase tendon extensibility if applied in moderation; however, excessive heat or tension could cause irreversible damage (12–14). Additional research suggested that US energy was absorbed more efficiently in collagen dense structures, prompting these structures to heat more rapidly and to a higher temperature than adipose tissues which absorbed less energy and consequently had smaller temperature increases (15).

While a small amount of variability may be expected due to species differences, independent studies using a similar study design suggest that human muscles treated with US may increase temperature faster than canine muscles and this pattern persisted throughout the treatment period, resulting in human muscle temperatures that almost doubled compared to values reported in a canine study (16, 17). In humans, therapeutic US frequency has been widely studied concluding that US at 1.0 MHz is absorbed primarily by tissues at a depth of 3–5 cm and that a frequency of 3.3 MHz is recommended for superficial tissues at depths of l−2 cm (18). A study of dogs was performed to evaluate the effects of 3.3 MHz US of caudal thigh muscle temperature and demonstrated that significant muscle warming occurs. After US treatment for 10 min using an intensity of 1.0 W/cm^2, muscle temperature increased 3.0°C at a depth of 1.0 cm and 2.3°C at 2.0 cm depth. Using an intensity of 1.5 W/cm^2, the temperature increased 4.6°C at a depth of 1.0 cm, 3.6°C at 2.0 cm depth, and 2.4°C at 3.0 cm depth (17).

Distinct tissue heating patterns in different species should prompt additional investigation of tissue temperature changes with therapeutic US in dogs in order to determine appropriate protocols to provide therapeutic effects while preventing administration of sub-therapeutic or injurious treatments. Previous human studies have examined the rate of tissue warming in ligaments, the musculotendinous junction of tendons, and muscles (9, 10, 19). One study has evaluated the effect of therapeutic US on the rate and amount of muscle warming in dogs, however, to the authors' knowledge, no studies have been performed to assess the heating pattern of canine tendons treated with US, or the effect of US on the extensibility of soft tissues and its resultant effect on joint motion. The purposes of this study were to (1) characterize the warming pattern of canine calcaneal tendons during and after four different therapeutic US treatment protocols, and (2) to quantify changes in tarsal flexion immediately after therapeutic US treatment, and following return to baseline temperature.

MATERIALS AND METHODS

Ten healthy adult hound-type dogs, 4–6 years of age and weighing 17–30 Kg, were included in the study reported here. Experimental procedures were approved by the University of Tennessee Animal Care and Use Committee. A sequential two-phase repeated-measures crossover study design was performed. The first phase evaluated calcaneal tendon warming patterns with four different therapeutic US treatment protocols. The second phase assessed the effect of one protocol on the extensibility of the calcaneal tendon and related soft tissues. Before each phase, dogs were premedicated with acepromazine maleate (Boehringer Ingelheim) (0.05–0.10 mg total dose, intramuscularly) and butorphanol tartrate (Torbugesic, Fort Dodge Animal Health) (0.4 mg/kg of body weight, intramuscularly). Anesthesia was mask-induced, and dogs were intubated and maintained under general anesthesia with isoflurane in 100% oxygen. Dogs were placed in lateral recumbency on circulating warm water blankets and covered with blankets to help maintain normal core temperature.

The limb chosen for US treatments was randomly determined for each dog by coin toss (if heads, US was performed on the left leg first, if tails, US was performed on the right leg first). For the first phase, the hair was clipped over the caudal, medial, and lateral aspect of the calcaneal tendon, because hair has been shown to impede ultrasound transmission in dogs (20). The skin was surgically prepared with 2% chlorhexidine acetate and 70% isopropyl alcohol. The tendon and surrounding tissues were left undisturbed to allow local temperatures to stabilize. A 23 G thermistor needle (MT 23/5 Physiotemp Instruments,

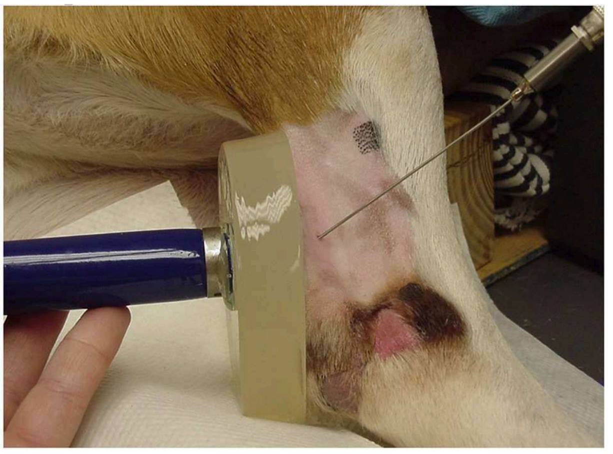

FIGURE 1 | Instrumentation of a dog for data collection, showing the positions of the gel pad, US unit, and thermistor needle inserted into the calcaneal tendon (Thermistor needle aimed slightly oblique only for demonstration purposes).

Clifton, NJ) was inserted into the tendon in a lateral to medial direction with the tip of the needle placed in the approximate center of the tendon. The thermistor needle was connected to a digital monitor (Dianachart Inc, Rockaway, NJ) interfaced with a computer that recorded the tissue temperature at 15-s intervals for each trial. A 1.0 cm thick 10 cm diameter gel standoff pad (AQUAFLEX, Parker Laboratories, Orange, NJ) was applied directly to the caudal aspect of the calcaneal tendon. The skin-pad and pad-US head interfaces were liberally coated with standard US transmission gel warmed to body temperature (Aquasonic 100, Parker Laboratories, Orange, NJ) (**Figure 1**) (21). A therapeutic US unit (Mettler Electronics, Corp., Anaheim, CA, 92805 U.S.A) was calibrated immediately prior to the study. The US was administered using a 1 cm^2 diameter transducer head to an outlined 2 cm^2 treatment length over the tendinous portion of the common calcaneal tendon, at a frequency of 3.3 MHz for 10 min. Dogs received four randomly ordered US treatments of continuous duty cycle at 1.0 W/cm^2, continuous duty cycle at 1.5 W/cm^2, pulsed 20% duty cycle at 1.0 W/cm^2, and pulsed 20% duty cycle at 1.5 W/cm^2. Randomization for the order of treatment in each dog was performed by drawing a treatment card from a box. After US application was initiated, tendon temperature was recorded every 15 s during the 10-min treatment period and for 10 min after US to evaluate the rate of cooling. Between treatments, temperature was recorded every 30 s for 3 min to reestablish baseline temperature of the tissue prior to application of US. After reaching baseline temperature and being certain that equilibrium was achieved, the next treatment was applied until all four treatments were completed during a single anesthetic episode.

During a separate time at least 1 week after phase one, the contralateral calcaneal tendon was prepared for the second phase. Dogs were anesthetized as previously described for the first phase and the hair was clipped over the calcaneal tendon. Goniometry was used to obtain an objective measurement of tarsal flexion. The tarsal joint was moved through a complete range of motion to determine the axis of joint rotation. The tarsal joint landmark points for goniometry were identified as previously described by Jaegger et al. (lateral aspect of the fibular head, lateral malleolus, and the proximal end of the fifth metatarsal bone) and marked with a permanent ink marker on both limbs, allowing consistent placement of the goniometer (22).

Tarsal flexion with the stifle maintained in extension was used as a measure of relative tendon extensibility and was determined prior to treatment. Normally, minimal tarsal flexion occurs when the stifle is maintained in extension. If calcaneal tendon extensibility increases, tarsal flexion increases even while the stifle is extended. Dogs were placed in lateral recumbency with the limb to be measured placed in a specially designed jig to maintain the stifle joint in extension while the tarsal joint was flexed (**Figure 2**). A constant amount of force was used while flexing the tarsal joint by applying 4 kg of tensile force perpendicular to the metatarsal bones using a tension gauge (model PTH-AF 2, Pain Diagnostic and Treatment Corporation, Great Neck, NY). Three measurements of tarsal flexion were made, and the mean was calculated. The limb used in the first phase served as an untreated control. The untreated control was measured to ensure that any increase in tarsal flexion was due to US treatment and not because of repeated stretching. Continuous US was applied to the treated tendon at 1.5 W/cm^2 for 10 min using the gel pad and US transmission gel because this treatment gave the greatest amount of tissue warming, while still being in the safe thermal zone. Tarsal flexion measurements were repeated as described and data recorded immediately after the US treatment on both limbs. Dogs were not manipulated or treated for the subsequent 5 min post-treatment. After the 5-min period, tarsal flexion was again measured in both the treated and untreated control limb, and mean measurements were calculated. The investigator making the measurements (DM) was blinded to treatment and control limbs.

STATISTICAL ANALYSIS

Commercially available software, Statistical Package for the Social Sciences, (SPSS Inc. Version 25.0. Armonk, NY: IBM Corp.) was used to determine the average tendon temperature at each time point for each treatment (Pulsed 1.0 W/cm^2, Pulsed 1.5 W/cm^2, Continuous 1.0 W/cm^2, and Continuous 1.5 W/cm^2). No significant differences in variances and normality of data were confirmed prior to additional statistical testing. Two mixed model analyses of variance (ANOVA) with repeated measures (the first to evaluate heating during treatment, the second to evaluate cooling after treatment) were performed to compare the changes in mean tendon temperature. Significant differences between individual means were determined using a *post-hoc* least significant difference (LSD) mean separation test. Changes to the mean angle of tarsal flexion were compared with a one-way analysis of variance (ANOVA) and significant differences were evaluated *post-hoc* with a Tukey-Kramer test. Results were considered significant at $P < 0.05$.

FIGURE 2 | Dog with limb placed in jig to maintain stifle extension while 4.0 kg of tension (determined by use of a tension gauge) was applied to the metatarsal region for flexion of the tarsus.

RESULTS

There were significant treatment, time, and treatment*time interactions among the US treatments applied to the tendons ($P < 0.0001$). Mean tendon temperature increases of 0.65, 1.5, 2.5, and 3.5°C were measured after 10 min of treatment with pulsed US at 1.0 W/cm^2, pulsed US at 1.5 W/cm^2, continuous US at 1.0 W/cm^2, and continuous US at 1.5 W/cm^2, respectively (**Figure 3**). The mean maximum tendon temperature increases were 0.9°C, 1.7°C, 3.1°C, and 4.1°C for each of the four treatments (**Figure 4**). At the end of the 10-min treatment time, tendons treated with continuous US at 1.5 W/cm^2 had significantly greater temperature increase than tendons treated with pulsed US at 1.0 W/cm^2 or 1.5 W/cm^2 ($P < 0.001$). The increase in tendon temperature with continuous US at 1.0 W/cm^2 was also significantly greater than tendons treated with pulsed US at 1.0 W/cm^2 ($P < 0.001$) (**Figure 4**). Tendons treated with US reached maximum or near maximum temperatures in <3 min of treatment (**Figure 4**).

Mean temperature decreased significantly in the first minute for tendons in both of the continuous US groups ($P < 0.001$), with mean tendon temperature decreasing by more than 1°C in the 1.0 W/cm^2 and by more than 1.8°C in the 1.5 W/cm^2 group (**Figure 4**).

Differences in the three tarsal joint flexion measurements before calculating the mean ranged from 1 to 5 degrees, with most within 1–3 degrees. Mean tarsal flexion significantly increased by 6.6° after 10 min of 1.5 W/cm continuous US treatment, representing a 5% increase from the initial measurement ($P < 0.001$) (**Figure 5**). Five minutes after US was discontinued, mean tarsal flexion was not significantly greater in the treated limbs compared to the pre-US treatment values or the untreated controls ($P < 0.773$) (**Figure 5**). The untreated control limbs showed no significant change in mean tarsal flexion between the two measurements.

DISCUSSION

This is the first study describing the thermal effects of therapeutic US on canine calcaneal tendons and tendon extensibility to the authors' knowledge. The study reported here showed that treatment with continuous 3.3 MHz US at an intensity of 1.5 W/cm^2 consistently increased canine calcaneal tendon mean temperatures *in vivo* more than 3.0°C above baseline tendon temperature. On average, tendon temperatures rose above this level <3 min after starting therapy and remained elevated for the final 7 min of treatment, yet tissue temperatures did not increase to the point that tissue damage would be expected. The mean tendon temperature increase noted with continuous US at an intensity of 1.0 W/cm^2 was less, but still significant (**Figure 3**). Pulsed US treatments at intensities of 1.5 W/cm^2 and 1.0 W/cm^2 produced significantly less tendon temperature increase and did not increase group mean tendon temperature 3°C above baseline at any time point.

In veterinary rehabilitation, therapeutic US is commonly used to warm connective and periarticular tissues prior to performing stretching exercises. Previous studies have revealed that tissues with higher protein content, such as bone, cartilage, tendons, and ligaments, absorb a larger proportion of energy from US waves and consequently are heated more rapidly than adipose tissues, which absorb less energy and experience smaller increases in temperature (23–25). Although no study has explicitly compared differences in tissue heating between species, results from previous research suggest that while collagen heating trends may persist (collagen dense tissues absorb more energy from US waves and experience a greater temperature increase), the rate and tissue response to heating may be different in each species, and tissues within species (9, 11, 17, 18).

Tissue warming in humans has been shown to increase collagen extensibility and improve flexibility, prompting the recommendation that, to achieve optimal lengthening, tissues should be warmed prior to stretching (10, 14, 19). Previous research proposed a therapeutic temperature increase to between 40 and 45°C in people (8), however, recent studies report that many subjects do not tolerate temperatures >42°C, and heating tissues ≥45°C can result in tissue damage (11, 26, 27). Recent studies have suggested that warming tissues >3°C above baseline may result in a significantly greater range of motion, presumably as a result of the viscoelastic properties of collagen (10). In a study performed in healthy human muscle by Draper et al. thermistors were placed at depths of 2.5 and 5.0 cm in the musculotendinous junction of the triceps surae for 1.0 MHz treatment and at depths of 0.8 and 1.6 cm for 3.3 MHz treatment. The rate of temperature increased per minute at the two depths for 1.0 MHz exposure, ranged from 0.04°C at an intensity of 0.5 W/cm^2 up to 0.38°C at an intensity of 2.0 W/cm^2. Corresponding values for treatment with 3.3 MHz ranged from 0.3°C at an intensity of 0.5 W/cm^2

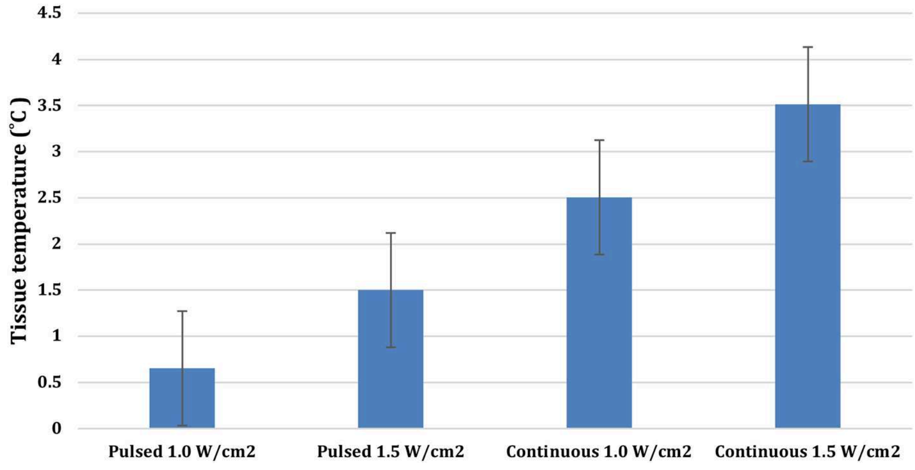

FIGURE 3 | Mean temperature increase in calcaneal tendons at the end of a 10-min 3.3 MHz US treatment using the four different treatment protocols (Bars represent standard error).

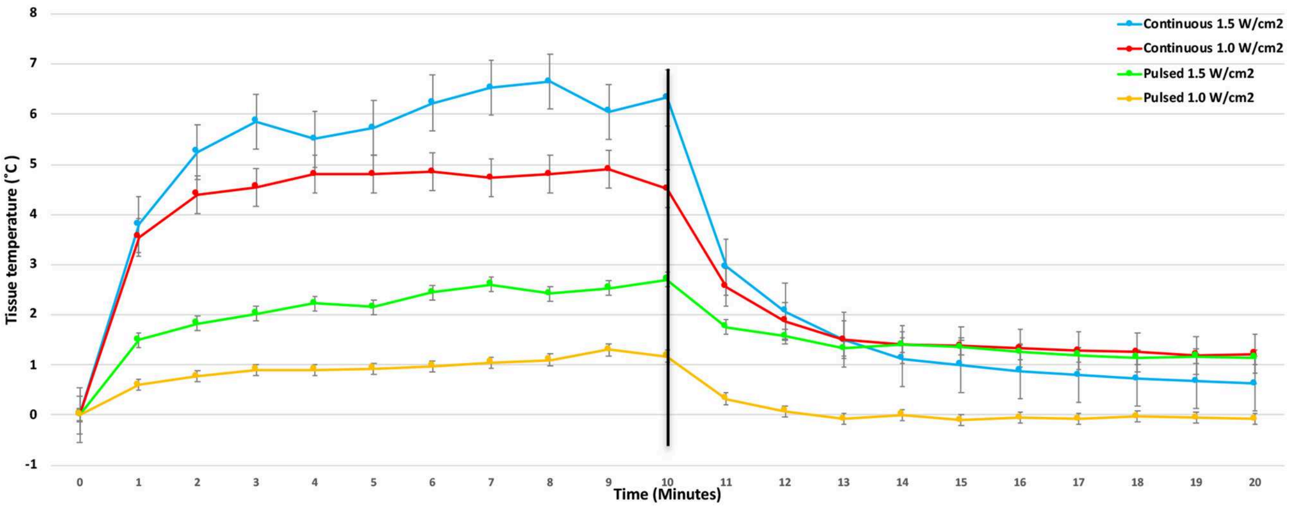

FIGURE 4 | Mean change in calcaneal tendon temperature during and after the 10-min 3.3 MHz US treatment using four different treatment protocols (Bars represent standard error).

up to 1.4°C at 2.0 W/cm^2. The 3.3 MHz frequency heated faster at all intensities. Because these studies describe responses to US in humans, it is necessary to characterize heating patterns in the tissues of veterinary patients, since variations in thermal and acoustic tissue properties may alter the absorption and retention of US energy.

Tendons treated with continuous US at 1.5 W/cm^2 and a frequency of 3.3 MHz exhibited significantly greater tarsal flexion immediately after treatment, increasing by 6.6° (5%) relative to flexion before heating. This finding agrees with human studies that have demonstrated an increased range of motion after US has been applied to musculotendinous junctions, however, these comparisons should be made cautiously since variations in tissue composition and architecture may produce different heating patterns (10, 11, 19, 28). The relatively small increase in tarsal flexion must also be considered in light of the sensitivity of clinical goniometry measurements. The three replicates of measurements were within 5° of each other, which is similar to the variability of 2–5° of measurements of the major joints in Labrador retrievers measured in the study by Jaegger et al. Still, the increased range was only 6.5°. The rapid loss of the increased tarsal flexion following US may have been related to a rapid decrease in tissue temperature. Based on the Phase 1 results of tendon heating with US, when tendon flexion range of motion was measured 5 min after US therapy ended, mean tendon temperature would have been only 0.56°C warmer than the baseline temperature if the temperature change in the tendon behaved similarly.

Our results regarding increased tarsal flexion with increased temperature followed by decreased flexion after cooling are

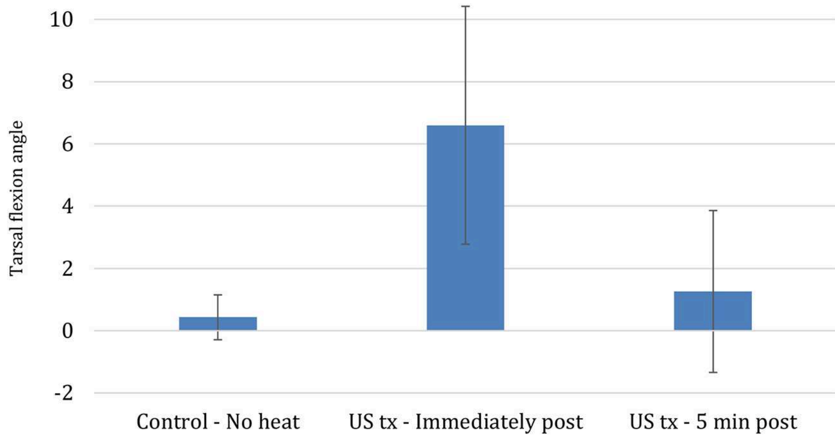

FIGURE 5 | Mean change in tarsal flexion between different conditions (Bars represent standard error).

consistent with previous reports that have described a "stretching window" after therapeutic US; however, this is the first confirmation of such a phenomenon occurring in canine tendons (9, 16). We believe that repeated stretching was unlikely to increase tarsal flexion because the limb of the control non-heated tendon did not exhibit changes in tarsal flexion with repeated measurements. A similar study using human Achilles tendons also found that ultrasound and stretch increased mean dorsiflexion range of motion in all sessions significantly more than stretch alone (10).

Our study confirmed that canine calcaneal tendons could be heated with therapeutic US to improve tendon extensibility; however, the magnitude and rate of tendon heating differed from the expected pattern. Studies performed in humans by Draper et al. and Chan et al. supported this idea and have demonstrated that under similar treatment settings (1.0 W/cm^2 at 3 MHz administered over an area equivalent to 2 effective radiating areas (ERA- 4.5 cm^2) in human muscle, at a depth of 0.8 cm, temperature increased 5.8°C over a 10-min. US treatment with an average of 0.6°C/minute, compared with the human patellar tendon which reported a temperature increase of 8.3°C over a 4-min US treatment with an average rate of 2.1°C/minute (9, 16). This rate of temperature increase in tendon was 3.45 times faster than in muscle.

Using similar therapeutic US settings (1.0 W/cm^2 and a frequency of 3.3 MHz), Levine et al. demonstrated that temperature increase at the end of 10-min treatment time in canine muscle at a depth of 1 cm was 3.0, 2.3°C at a depth of 2.0 cm, and at a depth of 3 cm was 1.6°C. In this study, canine calcaneal tendons (∼1 cm thick) treated with the same settings resulted in a mean temperature increase of 2.5°C at the end of treatment. In the first minute of treatment, mean calcaneal tendon temperature increased by 2.0°C when US was applied at an intensity of 1.0 W/cm^2, and by 2.1°C when US was applied at an intensity of 1.5 W/cm^2. The different heating patterns and the maximum magnitude of temperature change were likely associated with the energy produced by the US probe at the two intensities. These values reveal that canine muscle appears to have a relatively steady increase in tissue temperature during US treatment, while canine calcaneal tendon temperature in this study increased significantly faster within the first 2 min, and then stayed almost constant for ∼8 min of treatment time.

A recent, similar study published by Montgomery et al. evaluated temperature change of equine superficial digital flexor tendons using continuous 3.3 MHz US treatment at 1.0 or 1.5 W/cm^2 intensities for 10 min. Temperatures increased 3.5 and 5.2°C for the 1.0 and 1.5 W/cm^2 intensities, respectively. Furthermore, temperature rose 2°C after 3 min using 1.0 W/cm^2, and within 2 min using 1.5 W/cm^2. Compared to our study, canine calcaneal tendon temperature increased 2°C in the first minute using the two different treatment settings, which is slightly faster.

Rehabilitation requires a gradual return to use with special attention to gradual stretching of tendons to encourage return to normal function over time. The thermal effects of US may have relevance in the treatment of a variety of musculoskeletal conditions in the dog. Clinical application of tendon heating and extensibility could be considered for the treatment of conditions that can cause tightening or contraction of tendons which is not uncommon following an injury or after prolonged immobilization periods required for a tendon injury to heal. However, caution is recommended in applying US heating and stretching of healing tendon injuries to avoid laxity or breakdown of tendon repairs. When applying therapeutic US to tissue it is difficult to predict the thermal effects in an individual patient because tissue heating is influenced by a number of factors including tissue density and origin, anatomic location, properties of surrounding structures, blood flow, stage in the course of healing, and body composition. Additional variability may also have been associated with the systemic and peripheral changes secondary to general anesthesia, which is not used in the clinical application of US. The purpose of general anesthesia in this study was simply to allow the thermistors to be placed and maintained without undue discomfort to the dogs.

The authors believe that the external environment should also be considered as a source of variability since tissues dissipate heat more rapidly in an environment with colder ambient temperatures. Also, environmental heat loss may play a significant role in the heating and cooling patterns exhibited in canine calcaneal tendons because these structures are less vascular and minimally covered by other tissues in the distal third of the pelvic limb, potentially making them more susceptible to changes in environmental temperatures. To minimize the influence of these variables, dogs were maintained in a room with constant temperature and were maintained on circulating warm water blankets and covered with blankets to help maintain core body temperature. Another possible source of tissue heating with US is that the thermistor needle could have been heated with US, and the heat generated by this process may have been transferred to the tissues in addition to US treatment of the tendon (29). However, the power used on cadaver tissues in that study ranged from 40 to 600 W/cm^2, while we used 1 and 1.5 W/cm^2. The heating artifact at 40 W/cm^2 was relatively small, and this power of US likely would have caused severe tissue damage. In addition, the thermistors used in our study are designed to minimize thermal conduction.

The authors acknowledge a number of limitations in the present study that warrant further investigation. Warming patterns were only evaluated in the common calcaneal tendon in a small population of morphologically similar healthy dogs. Other tendons may have different tissue properties including insulation by fat and muscle which may alter absorption and retention of US energy. Additionally, the administration of anesthetic agents may alter thermoregulatory controls and it is unclear if tendons experience secondary effects as well. Future studies examining the thermal effect of US on a variety of tendons and different body types may provide a more complete characterization of the heating patterns and extensibility in canine tendons.

In conclusion, a 10-min session of continuous US applied with an intensity of 1.5 W/cm^2 at a frequency of 3.3 MHz was capable of increasing mean canine calcaneal temperatures more than 3.0°C. Calcaneal tendons heated in this fashion with application of a controlled stretch force immediately after treatment exhibited significantly greater tarsal flexion angles possibly due to increased extensibility of the calcaneal tendon following treatment. However, the increase was temporary and after a 5-min rest period, there was no significant difference between mean tarsal flexion angles in the treated and control groups. The temporary nature of the increase in tarsal flexion is consistent with an increase in tendon extensibility secondary to the changes in viscoelastic properties in tissues when they are heated.

ETHICS STATEMENT

Experimental procedures were approved by the University of Tennessee Animal Care and Use Committee. These were laboratory animals, and therefore there was no owner consent.

AUTHOR CONTRIBUTIONS

We certify that all authors meet the qualifications for authorship as listed below: (1) substantial contributions to the conception or design of the work or the acquisition, analysis, or interpretation of data for the work; (2) drafting the work or revising it critically for important intellectual content; (3) final approval of the version to be published; (4) agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Surface Electromyography of the Vastus Lateralis, Biceps Femoris, and Gluteus Medius in Dogs During Stance, Walking, Trotting, and Selected Therapeutic Exercises

Hannah McLean[1]*, *Darryl Millis*[1] *and David Levine*[2]

[1] *Department of Small Animal Clinical Sciences, University of Tennessee College of Veterinary Medicine, Knoxville, TN, United States,* [2] *Department of Physical Therapy, University of Tennessee at Chattanooga, Chattanooga, TN, United States*

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***Correspondence:**
*Hannah McLean
hthurma2@gmail.com*

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Objective: The objective of the study reported here was to evaluate the muscle activity patterns of the vastus lateralis (VL), biceps femoris (BF), and gluteus medius (GM) during stance, walking, trotting, and selected therapeutic exercises in clinically sound, healthy dogs. Our hypothesis was that the muscle activity during all exercises would differ from muscle activity at the stance.

Methods: Surface electromyography of the selected muscles was performed during stance, walking, trotting, elevation of forelimbs on a platform, elevation of forelimbs on a platform with hindlimbs on an inflatable balance device, stepping up onto and over an obstacle, standing on a wobble board, dancing backwards, and wearing a leg weight at the walk and the trot. The maximal and mean muscle amplitude (μV) reflecting activity during several motion cycles were compared among the exercises.

Results: Mean EMG amplitude of the BF was significantly higher in all exercises ($p < 0.05$) in comparison to stance. Mean EMG amplitude of the VL was significantly higher ($p < 0.05$) during walking, trotting, dancing backwards, stepping up and over an obstacle, and at a trot with a leg weight as compared to stance. Mean EMG amplitude of the GM was significantly higher ($p < 0.05$) during trotting, at a walk and a trot with a leg weight, standing on a wobble board, stepping up and over an obstacle, and dancing backwards when compared to stance. Of the studied exercises, dancing backwards increased the mean EMG amplitude of the BF and GM to the largest degree. Stepping up and over an obstacle increased the mean EMG amplitude of the VL to the largest degree.

Conclusion: Compared to stance, the majority of therapeutic exercises examined increased muscle activity to varying degrees in the BF, VL, and GM. Our results may help clinicians to choose specific exercises to target specific muscles during conditioning, strengthening and rehabilitation.

Keywords: surface electromyography, canine, rehabilitation, exercise, physical therapy

INTRODUCTION

Therapeutic exercises are an essential part of rehabilitation of musculoskeletal and neurologic injuries of veterinary patients. Therapeutic exercises to improve active joint motion, and to build strength, power and speed are used to help return the patient to as normal a function as possible (1, 2). When designing therapeutic exercise programs for veterinary patients, multiple factors should be considered including the diagnosis, affected tissues and their stage of healing, pre-morbid and co-morbid conditions, available range of motion in the joints exercised, and overall health of the patient including cardiovascular status (1–3). To fully develop a specific therapeutic exercise program, knowledge of muscle activity patterns and joint biomechanics during various exercises is necessary. In human medicine, surface electromyography has been used extensively to study muscle roles and interactions in healthy and pathologic states. A recent study published by Chen et al. (4) evaluated activations of the vastus lateralis, vastus medialis oblique and the gluteus medius muscles in females during hip abduction and external rotator movements, and open and closed kinetic chain knee extension movements. This study suggested that selective gluteus medius muscle activation was induced during hip abduction and external rotation movements, accompanied by an increase in vastus lateralis muscle activation. It also revealed that in open and closed kinetic chain knee movements, the ratio of the vastus lateralis to the vastus medialis oblique muscle activity approached 1:1. More selective vastus medialis oblique muscle activation was induced during the closed kinetic chain knee movement (4). While the degree of specificity of exercise prescription in veterinary medicine is not as developed as in human medicine, it is expanding, in part, due to studies using electromyography.

Several studies have evaluated canine muscle activity using needle or surface electromyography (sEMG) (5–11) while walking, trotting, and during other exercises. One study compared the activity patterns of the vastus lateralis, biceps femoris, and gluteus medius in sound dogs during over ground walking, walking on a treadmill at an 11% incline or decline, and walking over cavaletti rails (10). This study concluded that cavaletti and incline walking exercises significantly increased vastus lateralis and gluteus medius activity compared to over ground walking (especially during the early swing phase) (10). Another study evaluated the EMG activity of 4 forelimb muscles (biceps brachii, supraspinatus, infraspinatus, and the long head of the triceps brachii) in border collies during two specific agility tasks (jumping and A-frame). This study concluded that all of the muscles were activated at higher levels compared to walking (1.7–10.6 times based on the activity) and that jumping is an especially demanding activity for dogs (7). These studies allow the veterinary practitioner a better understanding of the pattern of muscle activation during these specific tasks and allows for a better understanding of the potential causes of injuries.

The objective of the study reported here was to analyze the mean and maximum muscle activation patterns of the vastus lateralis (VL), biceps femoris (BF), and gluteus medius (GM) during stance, walking, trotting and specific therapeutic exercises in clinically sound, healthy dogs. Our hypothesis was that the muscle activity during all therapeutic exercises would differ from the muscle activity at the stance. Our overall goal was to help guide clinicians in the selection of specific exercises to selectively strengthen the BF, VL, and GM in dogs during physical rehabilitation.

MATERIALS AND METHODS

Dogs

Privately owned and clinically sound dogs ($n = 12$; 2 Standard Poodles, 1 Golden Retriever, 1 Australian shepherd, and 9 Mixed Breed Dogs) were enrolled in the study with written owner consent. Dog ages and weights ranged from 1 to 9 years (mean 3.8 years) and 17–33.1 kg (mean 25.6 kg), respectively. Dogs were only included in the study if they had a body condition score of 4 or 5 on a scale of 9. Five dogs were female and seven were male. All dogs were spayed or neutered. All dogs had a complete neurologic and orthopedic examination prior to enrollment; dogs were excluded if they showed any signs of visible lameness or pain upon palpation of the joints, spine, or skeletal muscles or if a gait abnormality at the walk or trot, posture abnormality, or any other orthopedic or neurologic conditions were detected. In order to confirm that dogs had no lameness, kinetic data were obtained using a force platform (AMTI, Watertown, MA). Four valid trials for each side of the dog were obtained at a trot. For a trial to be considered valid, dogs must have no sudden deviation of gait, sudden head movements, turning of the head during gait, or any other motion that might affect collection of kinetic data. Velocity and acceleration of the dog and handler were maintained between 1.7 and 2.1 m/s and $\pm$ 0.40 m/s^2, respectively, using five photocells and a start-interrupt timer system. Mean peak vertical force values were used to identify weight-bearing asymmetry for each dog; dogs were excluded from the study if there was >5% asymmetry of the forelimbs or hindlimbs. No dogs were excluded based on kinetic analysis criteria. This study was approved by the University of Tennessee Institutional Animal Care and Use Committee and was performed in accordance with AAALAC and USDA guidelines.

sEMG

Muscle potentials were recorded using a telemetric unit (Myomotion; Noraxon USA, Inc., Scottsdale, AZ). Self-adhesive dual surface electrodes (4 cm × 2.2 cm) with an inter-electrode distance of 2 cm were used. The electrodes were positioned and attached to the shaved, clean skin of the left pelvic limb, and the muscle activities of the VL, the cranial part of the BF, and the GM were evaluated using the same methodology as previously described (8–11). For each muscle, the dual electrodes were placed with the dog in a standing position and the feet positioned squarely underneath the body. The same examiner placed the electrodes on each muscle to ensure consistent positioning. For the BF muscle, the electrodes were placed in the middle third of the distance between the ischial tuberosity and patella. For the VL muscle, the distance between the iliac crest and patella and between the patella and greater trochanter were measured. The central points of these lines were connected, and the electrodes were placed in the center of the resulting line (**Figure 1**). For the

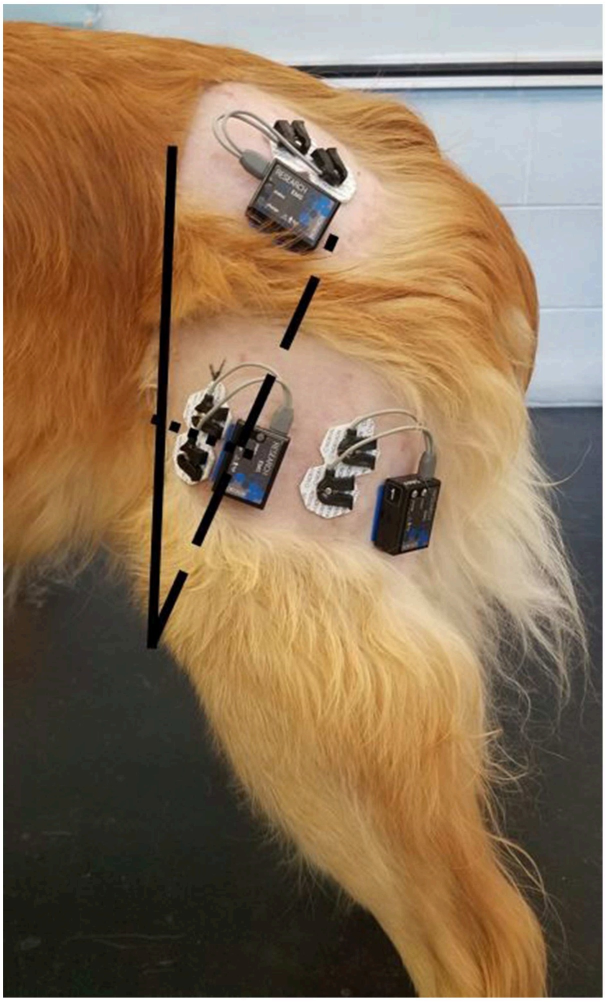

FIGURE 1 | Placement of the surface electrodes over the vastus lateralis, biceps femoris, and gluteus medius. For the vastus lateralis, the solid line represents the distance between the iliac crest and the proximal aspect of the patella; the dashed line represents the distance between the greater trochanter and the proximal aspect of the patella; the dotted line represents the junction between the middle of the dashed and solid lines.

GM muscle, the electrodes were placed at the midpoint of the distance between the iliac crest and greater trochanter.

sEMG Acquisition Procedure

Surface electromyography was performed during stance, walking, trotting, and during different therapeutic exercises. Before the testing sessions were recorded, each dog was allowed to walk and trot through the testing area with the sensors attached until they were visibly comfortable and no obvious gait asymmetry was present as a result of instrumentation. Surface EMG activity, measured in microvolts, was recorded simultaneously for all muscle groups while the dogs performed each of the exercises, and all exercises were performed during the same testing period so that the electrodes were not moved during data collection.

The measurement for stance was taken with the dog standing squarely in the testing area. The remaining exercises were divided into static and dynamic exercises. All exercises were performed in the same order, with a 2 min break between exercises to allow for rebuilding of the testing area between each exercise.

The static exercises included:

1. Elevation of the forelimbs onto a 30 cm tall platform (Sports Klimb, FitPAWS, Longmont, CO) (**Figure 2**).
2. Elevation of the forelimbs onto the same 30 cm platform with the hindlimbs on a 15 cm tall inflatable balance device (CanineGym® K9FITbone, FitPAWS, Longmont, CO) (**Figure 3**).
3. Standing on a round 91 cm balance board (FitPAWS® Wobble Board, FitPAWS, Longmont, CO) (**Figure 4**).

Dynamic exercises included:

1. Walking at a comfortable speed for three trials of 7–10 strides.
2. Trotting at a comfortable speed for three trials of 7–10 strides.
3. "Up and over" which required each dog to walk up onto a 30 cm tall platform (Sports Klimb, FitPAWS, Longmont, CO) and immediately walk down the other side (**Figure 5**).
4. Backwards dancing (**Figure 6**).

After these exercises were finished the testing area was cleared and a 0.27 kg (0.6 lb) limb weight (Weight Adjustable Hands Free® Wrist Weights, All Pro Exercise Products, Hillsborough, NJ) was applied just proximal to the hock. The dogs were allowed to become accustomed to the weight for 2–3 min, and were then walked and trotted at a comfortable speed for three trials of 7–10 strides.

Data Processing

As previously described, the raw EMG data (in microvolts) were full-wave rectified and filtered using a low pass filter at 4 Hz (8, 10). The raw data were then smoothed using a root mean square envelope of 100 ms. The mean and maximal amplitude of each exercise were then calculated. For static exercises, 10 s of continuous raw EMG data was analyzed. For dynamic exercises, 3 strides of the left hindlimb were analyzed.

Statistical Analysis

Data were analyzed using mixed model analysis, with the mean and maximum as the response variables, exercise and muscle as the fixed effects, and subject as the random effect. Diagnostic analysis was performed on residuals and ranked transformation was applied if non-normality and unequal variance were present. *Post-hoc* multiple comparisons for fixed effects were conducted with Tukey's adjustment. Statistical significance was identified at a significance level of 0.05. All analysis was conducted using PROC MIXED in SAS 9.4 TS1M3 from SAS Institute Inc. (Cary, NC).

RESULTS

Mean Amplitude

For all exercises evaluated in this study, the BF had significantly greater ($p < 0.05$) mean amplitude than the VL or the GM

FIGURE 2 | Elevation of the forelimbs onto a 30 cm tall platform.

FIGURE 3 | Elevation of the forelimbs onto the same 30 cm platform with the hindlimbs on a 15 cm tall inflatable balance device.

FIGURE 4 | Standing on a round 91 cm balance board.

(**Figure 7**). The VL also had significantly greater ($P < 0.05$) mean amplitude than the GM in all exercises evaluated.

Maximal Amplitude

For all exercises evaluated in this study, the BF had significantly greater ($p < 0.05$) maximal sEMG amplitude than the VL or the GM (**Figure 8**). The VL had significantly greater ($P < 0.05$) maximal sEMG amplitude than the GM in all exercises.

DISCUSSION

Our main purpose was to evaluate the muscle activity patterns of the VL, BF, and GM during stance, walking, trotting and specific therapeutic exercises in clinically sound, healthy dogs. We chose to evaluate the BF, VL and GM muscles because they are major stabilizers of the hip and stifle, and they are large and superficial enough to have reasonable expectations of obtaining sEMG activity (12, 13). These muscles also tend to atrophy with orthopedic disease or injury (14). In this study each exercise and muscle had similar trends between maximal amplitude and mean amplitude. In theory, therapeutic exercises could have a brief high peak vs. a low average while other exercises could have a longer sustained contraction with a lower peak. At this time, it is unknown whether longer sustained contractions or brief periods of maximal amplitude are more important for strengthening and function. Our hypothesis that the muscle activity during all therapeutic exercises would differ from the muscle activity at a stance was supported for all exercises in the BF for both mean and maximal sEMG activity. The mean amplitude of the VL was not significantly different between stance and walking with the leg weight or in the static exercises. The mean amplitude of the GM was not significantly different between stance and walking or with the static exercises.

The biceps femoris was most activated during the dynamic exercises such as dancing backwards and the up and over although it was significantly elevated over stance in both mean and maximal amplitude for all exercises. It was our goal to measure primarily the cranial portion of the biceps femoris

FIGURE 5 | Up and over.

FIGURE 6 | Backwards dancing.

responsible for hip and stifle extension. It is possible that the increased response of the biceps femoris in the dynamic exercises may be attributed, in part, to additive effects and cross talk. This cross talk or sum-signal of nearby muscles could be from the caudal portion of the biceps femoris responsible for stifle flexion, which may increase the mean amplitude because of continual activation throughout the gait cycle during dynamic exercises. It is also conceivable that we could have cross-talk from the semitendinosus or semimembranosus muscles, further contributing to this signal.

The vastus lateralis was maximally activated during the up and over and dancing exercises. This may be due to the increased load placed on this muscle to do the work of pushing the body weight a vertical distance in the up and over exercise, which is similar to stair ascent (3). The vastus may have been maximally activated by the dancing backwards exercise because of the additional force placed on just the two pelvic limbs, and possibly because of a sustained eccentric contraction of the quadriceps muscle with increased stifle flexion which occurs with dancing backward as compared with normal walking or dancing forward.

The gluteus medius was most active during the leg weight trotting and backwards dancing exercises. We theorize that this may be due to the increased hip extension and dynamic movement during these exercises. During trotting, there is a 5° increase in hip extension and during dancing backwards there is a 28° increase in hip extension compared with walking (3). The mean amplitude of the gluteus medius was lowest in the static exercises.

The diminished mean and maximal activation of all three muscles groups with the addition of the leg weight at the walk was an unexpected finding. We postulate that this may be due to the limited amount of weight applied, activation of other muscle groups to assist with advancing the limb with added weight, or due to a change in gait with the addition of the leg weight. Although all dogs were allowed a short time to acclimate to the leg weight, there was still an observable subjective change in their gait. This subjective change was characterized by a shortened stride length, diminished stance time and an increased postural sway to the unweighted hind limb. A small unpublished kinetic study performed by the investigators revealed a diminished vertical impulse and peak vertical force in hindlimbs with the same weight applied. It was observed that the dogs became asymmetric and applied more force to the opposite hindlimb and the contralateral forelimb in order to compensate for the diminished weight bearing on the limb with the leg weight applied. It is possible that additional time for acclimation may have reduced or eliminated the gait asymmetry. However, in a clinical situation, it may not be possible to devote long periods of time for acclimation. Therefore, we believe that our results likely mimic the clinical situation.

Another consideration in translation of our data to clinical use is that electromyography is often used to infer the pattern of production of force by skeletal muscle. According to Roberts et al., the interpretation of muscle function from the EMG is challenged by the fact that factors such as type of muscle fiber, muscle length, and force-velocity curve can all influence the relationship between electrical and mechanical activity of a muscle (15) In his study, Roberts evaluated muscles of wild turkeys with simultaneous measurements of EMG, muscle force,

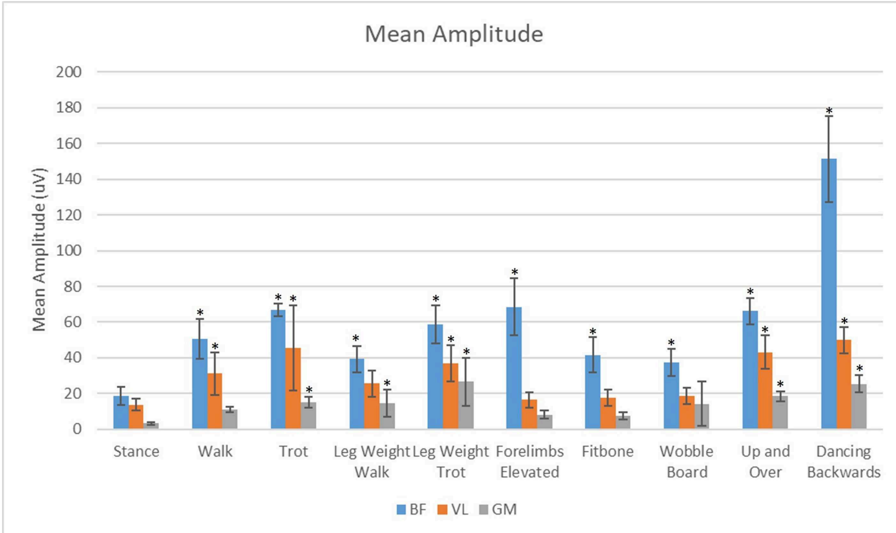

FIGURE 7 | Analysis of the effects of exercise on mean sEMG amplitude of the biceps femoris (BF), gluteus medius (GM), and vastus lateralis (VL) muscles. *Significant difference from stance ($p < 0.05$).

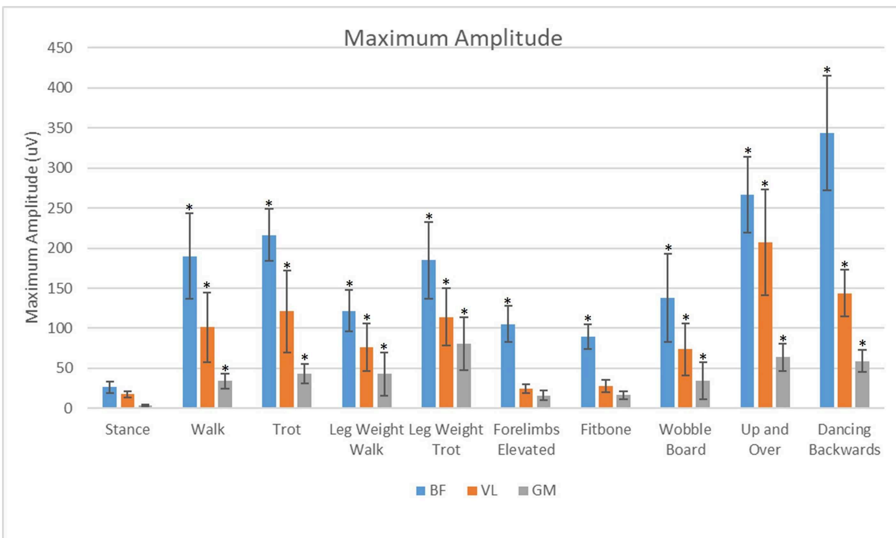

FIGURE 8 | Analysis of effects of exercise and muscle on maximum amplitude of the biceps femoris (BF), gluteus medius (GM), and vastus lateralis (VL). *Significant difference from stance ($p < 0.05$).

and fascicle length in hindlimb muscles. This allowed them to probe the quantitative link between muscle contraction force and EMG. They concluded that during stance, force amplitude was linearly related to mean EMG amplitude but that forces during swing phase were lower than predicted from the stance phase force–EMG relationship. Together the results suggest that any inference of force from EMG must be done cautiously when a broad range of activities is considered.

Although our results provide significant information to advance our knowledge of surface EMG in dogs performing specific exercises, there are several limitations to this study. Results of surface EMG measurements can be affected by multiple factors. A surface EMG represents a sum signal of the target and nearby muscle activities which can result in falsely reported muscle activity. This phenomenon is termed cross-talk. Cross-talk may have been limited with the use of ultrasound guided fine wire EMG. We elected surface EMG due to the less invasive nature and reported similarities between fine needle and surface electromyography in the human vastus medialis and biceps femoris muscles (16). Another challenge of EMG recording in dogs is that the skin is freely movable and the electrodes may have moved over other muscle bellies during the exercises. Body fat content has also been shown to influence sEMG measurements (17). In this study we attempted to minimize this effect by working with dogs of similar size and body condition score. Based on the symmetry of ground reaction forces in the pelvic limbs of each dog, it was assumed that muscle activity would be symmetrical in both pelvic limbs, but this assumption has not yet been proven. Although the instrumented limb may have had different muscle activation compared with the contralateral limb, we believe this effect was minimal. However, it is possible that our results might have been influenced by the fact that we tested only the left pelvic limb.

The goal of this study was to build upon previous research in order to begin to catalog the timing and magnitude of muscle amplitude for many different muscles powering a variety of types of locomotion. In humans, these amplitudes in normal and abnormal movement have been elucidated allowing for a better understanding of muscle activation during exercise thus allowing targeted strengthening and conditioning protocols to be prescribed. The specific results of this study aim to help the practitioner build upon previous work by Bockstahler et al. (8) and Breitfuss et al. (10) but include many additional exercises as well as a larger sample size. The muscle amplitude during the new exercises described in this study is novel research which has not yet been published. This may help the practitioner determine which exercises could help with strengthening and conditioning of the specific muscles in the study. The muscles described in this study were chosen due to their specific atrophy during both acute and chronic conditions of the coxofemoral and stifle joints such as cranial cruciate ligament injury and osteoarthritis. A 2006 study by Monk (18) revealed that there was significantly reduced thigh circumference in cranial cruciate deficit limbs prior to surgery but that early intensive post-operative therapy can help prevent continued muscle atrophy and build muscle mass and strength. The results of this study can additionally provide the practitioner with specific knowledge of muscles. For example, to specifically target the biceps femoris, adding additional weight to the affected limb results in muscle amplitude. This weight may be in the form of body weight training such as elevating the forelimbs (as with the dancing and forelimbs elevated exercise) or by increasing the force on the muscle by increasing velocity (such as at the trot or trotting with a leg weight).

Despite these challenges, our study provides new insights and basic data on the muscle activity of the pelvic limbs during various exercises as compared to a stance. Mean EMG amplitude of the BF was increased in all exercises in comparison to stance with the largest increase observed during the dancing exercise and elevation of forelimbs. Mean EMG amplitude of the VL was greatest during dancing, and stepping up and over an obstacle. Mean EMG amplitude of the GM was increased primarily during dancing, up and over, and at the trot with a leg weight. Our results should be considered when deciding on a specific exercise to strengthen the BF, VL, or GM muscles in an individual canine rehabilitation program.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the institutional animal care and use committee. The protocol was approved by the institutional animal care and use committee.

AUTHOR CONTRIBUTIONS

We certify that all authors meet the qualifications for authorship as listed below: (1) substantial contributions to the conception or design of the work or the acquisition, analysis, or interpretation of data for the work, (2) drafting the work or revising it critically for important intellectual content, (3) final approval of the version to be published, (4) agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Goniometric Assessment in French Bulldogs

Maira Rezende Formenton[1], Lidiane Gonçalves de Lima[2], Flávia Gardilin Vassalo[3], Jean Guilherme Fernandes Joaquim[3], Laryssa Petrocini Rosseto[4] and Denise Tabacchi Fantoni[1]*

[1] Department of Surgery, School of Veterinary Medicine and Animal Science, University of São Paulo, São Paulo, Brazil, [2] Veterinary Practitioner, Ribeirao Preto, Brazil, [3] Physical Therapy Department, Instituto Bioethicus, Botucatu, Brazil, [4] FisioPet, Ribeirao Preto, Brazil

Goniometry is a low-cost, user-friendly and widely available technique used by different veterinary medicine professionals to estimate joint range of motion (ROM). Studies providing breed-specific reference ranges for goniometric measurements are scarce and there is a lack of information regarding joint angles in French Bulldogs. This prospective study set out to determine normal ROM for the carpus, elbow, shoulder, tarsus, stifle and hip joints in healthy, adult French Bulldogs using goniometry. We hypothesized ROM would be similar in this and other dog breeds. Twenty dogs met the inclusion criteria. Sample size was calculated using power analysis based on previous studies. Goniometric measurements were made by a single examiner. Limbs were measured in random order and three measurements made per joint. Dogs were not sedated. Joint angles measured in French Bulldogs in this study were similar to those reported in Labrador Retrievers (shoulder, carpal, and tarsal flexion), Rottweilers (shoulder, carpus, and hip flexion), and Dachshunds (hip, stifle, and tarsal flexion). Similar flexion angles and ROM were detected in right and left limb joints. Findings of this study suggest similar ROM in French Bulldogs and other dog breeds. Lack of radiographic assessment and the fact that goniometric measurements were made by a single examiner were the major limitations of this study.

Keywords: canine, goniometry, small animals, physical therapy, range of motion, dogs

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David Levine, University of Tennessee at Chattanooga, United States

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Stephanie Shaver, Midwestern University, United States
Maria Fahie, Western University of Health Sciences, United States
Tisha Harper, University of Illinois at Urbana-Champaign, United States

****Correspondence:***
Maira Rezende Formenton
mairaformenton@gmail.com

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INTRODUCTION

Goniometric measurement of joint angles is widely used by orthopedic surgeons and physical therapists to estimate joint range of motion (ROM). Goniometry is a static, low-cost, user-friendly method, and an extremely efficient and reliable ROM assessment tool (1–3). It is also thought to be a useful technique for routine monitoring of patient progression and response to physical rehabilitation, given the close relationship between decreased joint angles and joint stiffness in osteoarthritic patients (1, 4). There is a great need to determine breed-specific ROM in dogs (5, 6), as related literature is limited to a few studies in Labrador retrievers (2), German shepherds (7), and Rottweilers (8).

French Bulldogs have recently enjoyed increasing popularity among brachycephalic breeds (9). Kyphosis and several vertebral malformations have been reported in dogs of this breed, with significant clinical and body conformation implications (10). Still, popular as French Bulldogs may be, joint angles have not been quantified in this breed.

Joint angles can be measured with animals in the lateral recumbent or standing position, via manipulation of thoracic and pelvic limb joints (i.e., passive joint flexion, extension, abduction and adduction, and measurement of joint angles achieved during these movements) (2, 7). Goniometric assessment includes measurements of shoulder flexion and extension, as well as elbow, carpus, hip, stifle and tarsus flexion and extension (11, 12). This study set out to determine normal ROM of the shoulder, elbow, carpus, hip, stifle and tarsus joints in healthy, non-sedated French Bulldogs using goniometry.

METHODS

This study was approved by the Ethics Committee for Animal Use of the School of Veterinary Medicine and Animal Science, University of São Paulo, protocol No. 1571120219. Patients were recruited from five different cities located in the state of São Paulo, Brazil. Patient selection was based on clinical history and evaluation, including inspection, joint palpation and ancillary tests. Inclusion criteria were as follows: male or female adult dogs aged 16–48 months, with body condition score ranging from 4 to 6 on a 1-to-9 scale (13). Owners were interrogated as to history of orthopedic conditions or trauma. Animals were inspected in the standard anatomical position for signs of musculoskeletal changes, pain or asymmetries. Subjective muscle asymmetry findings were assessed using perimetric measurements taken with a measuring tape. Clinical and gait assessment at the walk and trot were carried out to search for lameness and joint abnormalities; these were followed by joint palpation in full ROM for signs of crepitus, effusion or instability. Patients were also submitted to specific orthopedic tests, such as the tibial compression (cranial tibial thrust), the patellar luxation and the Ortolani test (14).

Seven exclusion criteria (EC) were defined to ensure the selection of dogs with no apparent musculoskeletal dysfunction that might interfere with goniometric assessment, as follows:

- EC1: Signs of lameness, joint noises and/or limb rotation at the walk and/or trot.
- EC2: Presence of atrophy, asymmetries, or musculoskeletal changes confirmed by perimetric measurement.
- EC3: Joint crepitation, edema, or instability on palpation.
- EC4: Pain manifestations during clinical evaluation.
- EC5: Pregnancy.
- EC6: Positive tibial compression (cranial tibial thrust) test.
- EC7: Positive Ortolani test.

Goniometric assessment was performed with dogs lying on the examination table. Dogs were manually restrained with their owner's assistance; no sedation was required. A plastic 35 cm, 0° to 180° system universal goniometer with two-degree increments (Carci®, São Paulo-SP, Brazil) was used. Dogs were placed in left or right lateral recumbency and the goniometer positioned according to instructions given previous authors (2, 15). Measurements were made by a single examiner (animal rehabilitation specialist with 3 years of professional experience). Range of motion was measured in flexion and extension; three measurements were made per joint for increased accuracy. Limb order was randomly selected using Random Number Generator App.

Shoulder, elbow, carpus, hip, stifle, and tarsus ROM were measured with joints in maximum flexion and extension. Data were analyzed using Google Sheets software. Arithmetic means, standard deviations (SD) and coefficients of variation (CV) were calculated for statistical analysis. Minimum sample size (6 animals) was determined by power analysis ($p < 0.05$; 95%) based on carpal and hip extension measurements derived from similar trials (2) and a pilot study. Correct placement of the goniometer is shown in **Figure 1**. Anatomical landmarks used as reference points for goniometer positioning are described in **Table 1**.

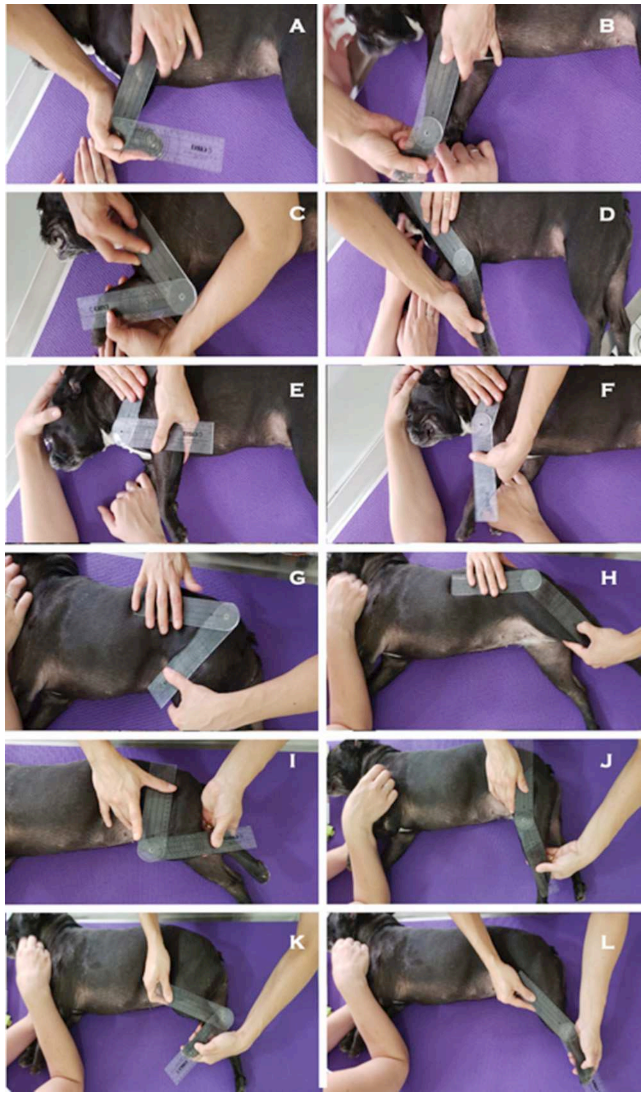

FIGURE 1 | Correct goniometer positioning **(A)** carpal flexion; **(B)** carpal extension; **(C)** elbow flexion; **(D)** elbow extension; **(E)** shoulder flexion; **(F)** shoulder extension; **(G)** hip flexion; **(H)** hip extension; **(I)** stifle flexion; **(J)** stifle extension; **(K)** tarsal flexion; and **(L)** tarsal extension.

RESULTS

Thirty-seven dogs were evaluated; of these, 17 (46%) met one or more EC; the final sample comprised 20 dogs (54%; 5 males and

TABLE 1 | Anatomical landmarks used as reference points for goniometer positioning prior to joint flexion and extension angle measurements, according to instructions given elsewhere (2, 15).

Joint	Position of goniometer center and arms
Carpus	The center of the goniometer was placed over the axis of joint rotation. One arm of the goniometer was placed along the long axis of metacarpal bones III and IV and the other one along the longitudinal axis of the antebrachium
Elbow	The center of the goniometer was placed over the axis of joint rotation. One arm of the goniometer was placed along the longitudinal axis of the antebrachium and the other one along the longitudinal axis of the humerus
Shoulder	The center of the goniometer was placed over the axis joint of rotation. One arm of the goniometer was placed along the longitudinal axis of the humerus and the other one along the spine of the scapula
Tarsus	The center of the goniometer was placed over the axis joint of rotation. One arm of the goniometer was placed along the longitudinal axis of metatarsal bones III and IV and the other one along the tibial shaft
Stifle	The center of the goniometer was placed over the axis of joint rotation. One arm of the goniometer was placed along the tibial shaft and the other one along the longitudinal axis of the femur
Hip	The center of the goniometer was placed over the axis of joint rotation. One arm of the goniometer was placed along the longitudinal axis of the femur and the other one along a line joining the tuber sacrale and tuber ischiadicum

15 females). Joint angle and ROM data of dogs in this sample are shown in **Table 2**.

Coefficients of variation express standard deviation as a percentage of the average and may be low, medium or high (>10%, 10–20%, and 20–30%, respectively). Coefficients of variation above 30% are thought to be too high to ensure data quality. In this study, CV values fell within the low, medium or high ranges and did not exceed 30%. Therefore, this data set was deemed homogeneous. Also, comparative analysis of right and left side measurements revealed similar angles, suggesting symmetrical muscle thickness, and ROM overall.

DISCUSSION

This study described normal ROM of the shoulder, elbow, carpus, hip, stifle and tarsus joints in healthy, non-sedated French Bulldogs based on goniometric measurements. Shoulder extension angles in this study were similar to those reported in Labrador Retrievers (2) and cats (16), whereas shoulder, carpal, and tarsal flexion angles reflected those reported in Labrador Retrievers (2). Shoulder, carpus, and hip flexion angles were also comparable to ranges reported in Rottweilers (8). Range of motion was similar in left and right limbs. Full shoulder extension movements are thought to be uncommon in dogs (2). This may explain conflicting findings in this study and the reluctance of some animals to extend their shoulders. Dogs in this sample did not show signs of pain; however, arthritis or other joint/bone abnormalities cannot be ruled out, as radiographic assessment was not performed.

According to Freund et al. (3), radiographic and goniometric measurements of the canine stifle differ. However, radiographic assessment of joint angles is uncommon and goniometric measurement in lateral recumbency is the method of choice in routine practice of physical therapy (3, 4).

Studies comparing goniometric and radiographic measurements in non-sedated and sedated dogs failed to reveal significant impacts of sedation on radiographic measurements of joint angle (2). French Bulldogs in this study did not require sedation given their docile temperament.

Findings of this study are in keeping with data reported in a goniometric study evaluating hip, stifle and tarsal flexion angles in Dachshunds (17). In that study (17) pelvic limb muscle mass was thought to make landmarks for goniometer placement particularly difficult to palpate compared to long-legged dogs. Precise location of anatomical landmarks mitigates problems associated with placement of a flat goniometer on chunky, curvy limbs.

In this study, standard deviations, and coefficients of variation were calculated for improved accuracy of angle estimates (3, 7, 18). Coefficients of variation express standard deviation as a percentage of the average and may be low, medium or high (>10%, 10–20%, and 20–30%, respectively). Coefficients of variation above 30% are thought to be too high to ensure data quality. In this study, CV values fell within the low, medium or high ranges and did not exceed 30%. Therefore, this data set was deemed homogeneous. Also, comparative analysis of right and left side measurements revealed similar angles, suggesting symmetrical muscle thickness and ROM overall.

Comparison of findings reported by different investigators is thought to add reliability to research data (2, 17). Similar goniometric studies in dogs of the French Bulldog breed are lacking, therefore no comparisons could be made. Goniometric data collection by multiple examiners is also recommended. However, goniometric measurements made by different experienced examiners are not thought to be significantly different (2) and manipulation by a single examiner may minimize stress levels in canine patients. Also, the single examiner in this study does have the advantage of consistency in technique.

Major limitations of this study include: lack of radiographic confirmation of joint/limb soundness, lack of comparative radiographic measurements of ROM and technical difficulties associated with goniometric measurements in dogs with well-developed pelvic and thoracic limb muscles such as French Bulldogs.

CONCLUSION

This study revealed symmetrical ROM in left and right pelvic and thoracic limb joints in French Bulldogs.

TABLE 2 | Mean maximum flexion and extension angles and range of motion of right and left thoracic and pelvic limb joints of French Bulldogs, and respective standard deviations (SD) and coefficients of variation (CV).

Joint	Extension		Flexion		Range of motion	
	Right limb Mean ± SD CV	Left limb Mean ± SD CV	Right limb Mean ± SD CV	Left limb Mean ± SD CV	Right limb Mean ± SD CV	Left limb Mean ± SD CV
Shoulder	160 ± 19	160 ± 20	51 ± 8	52 ± 9	109 ± 24	108 ± 24
	12.09%	12.34%	16.29%	17.50%	21.84%	21.77%
Elbow	174 ± 11	175 ± 9	51 ± 13	49 ± 12	123 ± 18	126 ± 16
	6.24%	5.00%	24.67%	23.98%	14.63%	12.78%
Carpus	204 ± 8	204 ± 8	32 ± 7	32 ± 7	172 ± 10	172 ± 10
	4.03%	4.01%	22.69%	21.53%	5.54%	5.75%
Hip	181 ± 7	179 ± 7	58 ± 10	59 ± 10	123 ± 14	121 ± 14
	4.14%	4.07%	17.47%	16.84%	11.05%	11.23%
Stifle	172 ± 8	174 ± 8	58 ± 8	59 ± 10	114 ± 12	115 ± 12
	4.72%	4.33%	14.22%	17.02%	10.28%	10.70%
Tarsus	188 ± 7	188 ± 6	40 ± 6	39 ± 7	149 ± 8	149 ± 9
	3.74%	3.05%	16.33%	16.60%	5.36%	5.76%

Similar ROM in French Bulldogs and other dog breeds support the reliability of data collected in this study. However, assessment by more than one examiner and the inclusion of radiographic measurements might have further increased data accuracy. Findings of this study will benefit future studies and practitioners who are rehabilitating French Bulldogs.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The animal study was reviewed and approved by University of São Paulo. Written informed consent was obtained from the owners for the participation of their animals in this study.

AUTHOR CONTRIBUTIONS

MF contributed with study design, writing, and review. LL contributed to the goniometric assessment of the dogs. FV and LR contributed with study design, writing, and pictures. JJ and DF contributed to review.

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Conflict of Interest: FV and JJ currently work for Bioethicus Institute; LR works for FisioPet.

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