A single hydrotherapy session increases range of motion and stride length in Labrador Retrievers diagnosed with elbow dysplasia

Tate Preston[a] and Alison P. Wills[a*]

[a]*Department of Animal and Agriculture, University Centre Hartpury, Hartpury, Gloucester, Gloucestershire, United Kingdom GL19 3BE*

* Corresponding author. Tel.: 01452702347.

E-mail address: Alison.Wills@Hartpury.ac.uk (A.P. Wills).

Abstract

Canine elbow dysplasia is a debilitating condition of unknown aetiology and is a common cause of forelimb lameness in dogs. Canine hydrotherapy is a therapeutic approach rapidly increasing in popularity for the treatment of range of musculoskeletal pathologies. In this study, kinematic analysis was used to assess the effect of a customised hydrotherapy session on the range of motion, stride length and stride frequency of healthy Labrador Retrievers (n=6) and Labrador Retrievers diagnosed with bilateral elbow dysplasia (n=6). Reflective kinematic markers were attached to bony anatomical landmarks and dogs were recorded walking at their preferred speed on a treadmill before and 10 minutes after a single hydrotherapy session. Range of motion, stride length and stride frequency were calculated for both forelimbs. Data were analysed via a robust mixed ANOVA to assess the effect of hydrotherapy on the kinematic parameters of both groups.

Range of motion was greater in the healthy dogs at baseline ($p<0.05$). Hydrotherapy increased the range of motion of the forelimbs of both groups ($p<0.05$); dogs with elbow dysplasia demonstrated a greater improvement in range of motion than healthy dogs ($p<0.05$). Hydrotherapy stride length ($p<0.01$) of all dogs, but differences were not seen between the two groups. Stride frequency increased after hydrotherapy only in the left limb ($p<0.05$) in all dogs.

These results support the potential of canine hydrotherapy as a therapeutic tool for the rehabilitation and treatment of Labradors with elbow dysplasia. Furthermore, results indicate that hydrotherapy might improve the gait and movement of healthy dogs. However, whether these results are transient or sustained remains undetermined.

Keywords: Elbow dysplasia; dogs; hydrotherapy; kinematics; gait analysis

Introduction

Canine Elbow Dysplasia (ED) is a common developmental disorder affecting the canine cubital joint (Burton et al., 2008; Michelsen, 2013). Elbow dysplasia is a non-specific term encompassing several elbow pathologies, most commonly fragmented medial coronoid process, ununited anconeal process, osteochondrosis and osteochondritis dissecans of the medial humeral condyle, with some authors also including elbow incongruity and articular cartilage erosion (Kirberger and Fourie, 1998). Fragmented medial coronoid process, ununited anconeal process and osteochondritis dissecans can present singularly or in any combination (Kramer et al., 2006), and can occur concurrently in a single elbow (Fitzpatrick and Yeadon, 2009).

The epidemiology, pathogenesis, diagnosis and treatment of ED has been extensively investigated, but the aetiology eludes investigators (Gemmill et al., 2005). Elbow dysplasia can be extremely debilitating and cause lameness, but no current medical or surgical procedures alter the progression of the disorder or cure it (Kirberger and Fourie, 1998; Michelsen, 2013). Furthermore, the complex mode of inheritance and environmental variables in disease expression preclude genetic testing from providing a simple solution (Michelsen, 2013).

Elbow dysplasia is inherited as multifactorial polygenic traits, with the different manifestations appearing to be inherited independently (Kirberger and Fourie, 1998). Medium and large breed dogs tend to manifest signs most frequently (Meyer-Lindenberg et al., 2006), but ED has also been documented in Dachshunds and French Bulldogs (Narojek et al., 2008; Sjöström, 1998). The incidence of the different forms of the disease appears to be breed dependent, with Rottweilers and Labradors often developing fragmented medial coronoid processes, German Shepherds having a high percentage of ununited anconeal processes (Morgan et al., 2000).

Diagnosing ED can be challenging for a number of reasons, particularly in dogs presenting with thoracic limb lameness (Houlton, 2009). Dogs present with varying degrees of lameness, which can be exacerbated with exercise (Kirberger and Fourie, 1998). Physical exam findings include pain, joint effusion, joint capsule thickening, muscle atrophy and osteoarthritis (Morgan et al., 2000).

Treatment for ED should ideally occur before osteoarthritis develops, however, this depends on early diagnosis of individual cases, with dogs displaying mild to moderate incongruity being good surgical candidates (Michelsen, 2013; Morgan et al., 2000; Palmer, 2011). Investigators have examined various surgical interventions for different forms of ED (Cook et al., 2008; Danielson et al., 2006; Fitzpatrick and Yeadon, 2009; Palmer, 2011; Preston et al., 2001; Turner et al., 1998), but a lack of controlled studies limits the interpretation of efficacy of these interventions (Michelsen, 2013).

Medial coronoid disease is the most common pathological presentation of ED, with Labradors often affected (Kirberger and Fourie, 1998). Studies to date have suggested arthroscopic fragment removal reduces morbidity in milder cases (Bouck et al., 1995; Evans et al., 2008; Meyer-Lindenberg et al., 2003; Palmer, 2010). However, the only controlled prospective study comparing surgery with medical management of medial coronoid disease failed to demonstrate a benefit of surgery and indicated that dogs experience loss of function post-operatively (Burton et al., 2011). With conservative options only recommended in cases of mild cartilage damage (Burton et al., 2011; Michelsen, 2013), regardless of whether dogs are surgically or medically managed, there is a clear requirement for alternative options such as hydrotherapy to be investigated for the rehabilitation of dogs with ED.

Hydrotherapy is a conservative approach to rehabilitation that may reduce pain and restore range of motion (ROM) in dogs suffering from ED, however, scientific research confirming the efficacy of hydrotherapy is limited (Houlding, 2011). Therapeutic exercise is a key component of all rehabilitation programmes and is recommended as part of the concurrent care of any animal, albeit without clinical evidence of efficacy (Saunders, 2007). Buoyancy can help to encourage stiff joints into an improved ROM; consequently, hydrotherapy has been recommended for multiple musculoskeletal pathologies (Monk, 2007; Prankel, 2008). Dogs subjected to swimming showed an increased ROM compared to those subjected to walking following surgery for cranial cruciate ligament rupture (Marsolais et al., 2003). Furthermore, dogs subjected to exercise on a water treadmill as part of a physiotherapy programme after cranial cruciate ligament rupture repair showed greater ROM compared to dogs that only participated in home exercise (Monk et al., 2006). Water treadmill exercise can be altered to best meet the requirement of individual animals, with variables such as water depth and treadmill speed resulting in altered gait parameters (Barnicoat and Wills, 2016; Millis and Levine, 2014). Because dogs with ED have decreased ROM after surgery, modalities such as hydrotherapy that facilitate an increase in elbow ROM could help conserve or restore ROM post-operatively (Barthélémy et al., 2014).

Therefore, we investigated the effect of a single session of hydrotherapy on elbow ROM and stride parameters when walking on a treadmill of both healthy dogs and dogs that had been diagnosed with ED. We hypothesised that dogs would have an increased ROM as a result of increased limb flexion (Monk et al., 2006) after undergoing a session of hydrotherapy.

Materials and Methods

Ethical approval for this study (ETHICS2015-05) was received from the University Centre Hartpury ethics committee on 20th November 2015 and work was conducted in line with institutional ethical guidelines.

Experimental Population

The study was conducted at Cheshire Canine Hydrotherapy centre, Cheshire, and Cotswold Dog Spa at Hartpury College, Gloucester, between November 2015 and March 2016. All therapists involved had an ABC small animal hydrotherapy certificate. We examined six clinically sound Labradors (median age 2.0; range 1 to 4) and six Labradors with bilateral elbow dysplasia (median age 5.5; range 2 to 6). Sexes were equally distributed, with three males and three females in each group. The sample size for the ED (n = 6) and control group (n = 6) was determined by the number of cases that fit the inclusion criteria and for which owner permission could be obtained that were referred to either of the two centres between November 2015 and March 2016. We did not calculate an a priori sample size.

Each dog underwent a full veterinary examination prior to participating and owners were required to complete a consent form. Dogs with ED had been referred by their veterinarian for hydrotherapy. We recorded the referral details for these dogs, including currently prescribed and previous medication (if any), type of elbow dysplasia and method of diagnosis (Table 1).

Inclusion and Exclusion Criteria

Inclusion criteria required participants to be Labradors with a non-specific diagnosis of bilateral elbow dysplasia obtained by diagnostic imaging. All dogs underwent diagnostic imaging (radiography and or computed tomography) prior to referral. Referring clinicians also assigned the specific pathologic diagnosis (osteochodritis dissecans, fragmented medial coronoid process or ununited anconeal process, Table 1). Exclusion criteria included Labradors that had previously undergone surgery on either elbow, Labradors with concurrent musculoskeletal pathologies or spinal disease, Labradors over the age of eight, and non-Labrador breeds. Dogs undergoing a multi-modal treatment plan including other therapies (physiotherapy, acupuncture etc.) were also excluded. The attending hydrotherapist determined prior to commencement of data collection whether dogs with elbow dysplasia were able to walk comfortably on the dry treadmill; dogs unable to walk comfortably were excluded for ethical reasons. Labradors in the control group had to be clinically sound adults of normal weight with no history of musculoskeletal or other disorders.

Kinematic Markers

Three reflective adhesive markers (diameter 18mm) were placed by the same investigator using double-sided adhesive tape on bony anatomical landmarks whilst the subject was weight bearing on all four limbs. The markers were positioned in accurately defined anatomical landmarks on the left forelimb and right forelimb: one distal to the elbow joint, another near the rotation centre of the joint, and a third proximal to the joint.

Treadmill Protocol

All dogs were recorded walking on a dry treadmill before and after they underwent a customised hydrotherapy session. The gait analysis was conducted approximately 10 minutes after the hydrotherapy session was completed. This time included drying the dog prior to beginning the treadmill protocol. The primary investigator and hydrotherapist were not blinded to whether dogs were control or experimental subjects. Experimental trials were recorded using an AZ1VR Action Cam HDR-AZ1 video camera (Sony) sampling at 60 frames per second. Each dog had its collar and lead removed and was fitted with a safety harness. Dogs were encouraged to move on to the treadmill using the harness and lead. The dogs were held on a leash by a handler positioned at the front of the treadmill and positioning of the head was kept as constant as possible using a food incentive in order to achieve a uniform gait. The treadmill was started at a low speed that was increased gradually until the dogs were walking at 1.2 m/s, however, if the dog could not walk comfortably at this pace, the speed was reduced to 1.0 m/s. This decision was determined by the acting hydrotherapist. Once the dog established a steady gait in walk the duration of recording was 120 seconds (Barnicoat and Wills, 2016). There was a short acclimatisation period which was subjectively determined by the hydrotherapist for each individual.

Hydrotherapy Protocol

Hydrotherapy sessions all used the same therapeutic techniques in a pool specifically designed for canine hydrotherapy. The sessions included timed intervals or laps in the water guided by a therapist with a focus on facilitating ROM in the elbow joint. All therapists recorded the protocol used in the session and each session lasted 20 minutes. All dogs were fitted with an appropriately sized safety harness to enable the hydrotherapist to control the direction of the dog whilst swimming (Prankel, 2008).

Data Analysis

Video recordings were analysed using Dartfish Analyser motion capture software (Dartfish). The ROM of the elbow (measured in degrees) was calculated by maximum extension minus maximum flexion of the right and left elbow joint. The extension and flexion was calculated for 40 strides for each limb before and after the hydrotherapy session. Therefore, a total of 160 strides were analysed for each subject.

Stride Parameters

Stride parameters including stride length (defined as the distance between two successive contacts of the same limb in metres, (m), stride time (s) and stride frequency (defined as the number of strides taken per unit time, Hz) were calculated for each limb for each subject. Mean stride length and mean stride frequency were calculated using 40 strides per limb before and after the hydrotherapy session.

Statistical Analysis

All statistical analyses were performed in R version 3.3.2; package WRS2 (R Core Team, 2016). Data were tested for normality and were found to be non-parametric. Therefore, robust bootstrapped two-way mixed ANOVAs were used to test for differences in ROM, stride length and stride frequency before and after the hydrotherapy session and for differences between the healthy and elbow dysplasia groups. The condition of the dogs (healthy or ED) was the between groups variable and hydrotherapy (before or after) was the within groups variable. Stride length and stride frequency measured from the left and right forelimbs were analysed separately for both the healthy and elbow dysplasia groups due to potential differences between limbs in the dogs with bilateral pathology.

Results

All dogs successfully completed the experimental protocol and therefore a total of 960 strides from twelve dogs (six healthy, six elbow dysplasia) were taken forward for statistical analysis. Baseline kinematic characteristics and kinematic profiles for all subjects after hydrotherapy can be seen in Table 2.

Range of Motion

Healthy Labradors showed a greater ROM of the right and left elbows than Labradors with ED ($\varphi = 15.87$, $p<0.0001$ for right; $\varphi = 13.92$, $p<0.05$ for left; Fig. 1).

Healthy Labradors showed a greater ROM of right and left elbows ($\varphi = -7.35$, $p <0.0001$ for right; $\varphi = -8.04$, $p<0.05$ for left) after the session. However, Labradors with ED increased the ROM of right and left elbows ($\varphi = 7.94$, $p<0.05$ for right; $\varphi = 12.91$, $p<0.0001$ for left) more than healthy Labradors after the hydrotherapy session (Fig. 1).

Stride Length

Healthy Labradors had a longer right and left limb stride length ($\varphi =0.02$, $p<0.05$ for right; $\varphi = 0.03$, $p<0.05$ for left) than Labradors with ED at baseline. Hydrotherapy increased stride length of both limbs ($\varphi = -0.02$, $p<0.05$ for right; $\varphi = -$

0.02, $p<0.01$ for left) when all dogs were examined together. Labradors with and without ED did not differ in this increase in stride length attributed to hydrotherapy (φ = -0.01, p= 0.351 for right; φ = 0.01, p= 0.136 for left; Fig. 2).

Stride Frequency

Stride frequency did not differ between healthy Labradors and Labradors with ED at baseline (φ =- 0.10, p= 0.188 for right; φ = -0.05, p= 0.549 for left). Hydrotherapy did not alter stride frequency of the right limb (φ = -0.03, p = 0.090), but increased stride frequency of the left limb (φ=-0.05, $p<0.0001$) when both groups were examined together. Labradors with and without ED did not differ in the change in stride frequency after hydrotherapy (φ = 0.01, p = 0.865 for right; φ = 0.02, p= 0.261 for left; Fig. 3).

Discussion

We found that hydrotherapy improved ROM of the elbow in the left and right forelimb of healthy Labrador Retrievers, but improved ROM more in Labrador Retrievers with elbow dysplasia. Additionally hydrotherapy increased stride length in both groups to a similar extent, but did not affect stride frequency.

Swimming promotes an increased ROM, as has been demonstrated in studies assessing limb movement during aquatic exercise (Marsolais et al., 2003; Owen, 2006). This is similar to our observations. However, as our study did not examine gait during water treadmill exercise, data may not be directly comparable. Increased circulation to the forelimbs might reduce pain and allow muscle relaxation resulting in a freer gait (Kamioka et al., 2010). Healthy dogs increased elbow ROM similarly to dogs with ED, which may have implications for elite performance, where an increased ROM and, consequently, stride length, might facilitate increased top speeds (Hudson et al., 2012). However, there is a possibility that the temperature of the water (30ºC) could act as a type of thermotherapy which could improve muscle elasticity and joint extensibility (Wilcock et al., 2006). If so, this effect of increased ROM and stride length might be transient. Some researchers have proposed that the temperature of the water could have an analgesic effect which could also explain the increased ROM observed immediately after the session (King, 2016).

Our study corroborates previous work where swimming dogs showed increased joint ROM (Marsolais et al., 2003), and human studies that have reported increased biomechanical function after aquatic exercise (Denning, 2010; Kamioka et al., 2010). An improved ROM can assist in providing long-term analgesia in addition to improving the overall function of the limb (Canapp et al., 2009). A study investigating the use of hydrotherapy for post-operative rehabilitation of dogs has suggested that an improved ROM can reduce the chance of re-injury and facilitate a rapid return to function (Monk et al., 2006) However, Monk et al., (2006) only documented short-term improvements in ROM, so positive changes in ROM might not persist. Despite this, improving the function of the affected limbs should impact positively on the welfare of affected animals, enabling them to undertake normal locomotor activities with less pain. In addition to an overall ROM, changes in flexion and extension are also important, as maintaining ROM in dogs with ED can be difficult. This is particularly true post-surgery where decreased ROM has been documented in ED dogs (Barthélémy et al., 2014). Our study suggests that hydrotherapy might provide a valid means of maintaining elbow ROM in dogs that have undergone surgical procedures.

A single session of hydrotherapy increased the stride length of both control groups. This is consistent with the increase in ROM of the elbow joint that was also observed in both groups, however, changes in flexion and extension of other joints might also have contributed to the increased SL observed. As has been previously reported in obese dogs, dogs with ED in our study had shorter stride length than healthy dogs (Brady et al., 2013). However, this differs from studies of dogs with hip dysplasia, where stride length was longer in affected dogs than healthy animals during over ground locomotion (Bennett et al., 1996). An increased stride length may be beneficial in performance dogs as increasing stride length along with changes in other gait parameters may enable dogs to reach higher speeds (Hudson et al., 2012). However, increasing speed is not a primary aim of therapy for pathological animals; rather, the longer stride length might represent return to a normal gait pattern.

Stride frequency was less affected by a session of hydrotherapy than the other gait parameters recorded. There was no difference in stride frequency between the two conditions and stride frequency was only increased by hydrotherapy for the left limbs. This finding is likely due to a chance finding because of individual variation in the small sample population, rather than a real effect – it would be difficult to explain this finding from a physiological perspective. An increased number of subjects would help to elucidate the effect of hydrotherapy on stride frequency. Previous research in dogs and horses has demonstrated that stride frequency decreases with increasing depth when walking on an underwater treadmill (Barnicoat and Wills, 2016; Scott et al., 2010). However, there has been limited research conducted in quadrupeds investigating the effect on stride frequency after a session of hydrotherapy has been completed. One study conducted in human patients with osteoarthritis concluded that there was no difference in stride frequency between groups that had undergone underwater treadmill and land based exercise (Denning, 2010).

Overall, our findings suggest that hydrotherapy represents a valid therapeutic intervention for Labradors with ED and that alterations in gait parameters are evident immediately after a session. However, further research is needed to investigate whether these effects persist and how this might affect the required frequency of hydrotherapy. This is the first study to investigate the effect of hydrotherapy on ROM of dogs with ED and, as such, we have nothing in the literature with which to compare or contrast our findings. Data gained from healthy animals in this study supports the previous understanding that hydrotherapy might benefit athletic dogs (Levine et al., 2004; Marcellin-Little et al., 2005). Whilst only Labradors were recruited in this study to attempt to control for breed variation in gait parameters, the sample size (n = 6 per condition) was quite limited. Future research could utilise larger populations and assess a range of breeds, as different breeds are predisposed to the various clinical manifestations of the disease (Morgan et al., 2000). Due to the variation in the underlying pathophysiology between the different clinical presentations, these animals might respond differently to hydrotherapy. In this study, the passive ROM of the ED dogs was not measured with a goniometer prior to the commencement of the study, therefore the severity of the pathology was not quantified which may have introduced variability into the data. In addition, the control group were not age matched to the ED group and as such, they may have had early stage pathology that was not clinically diagnosed. It is suggested that future studies gain passive ROM data from pathological animals to provide a more detailed understanding of the severity of their lameness prior to them undergoing hydrotherapy.

As the effect of hydrotherapy seen in both the healthy and pathological animals could be attributed to a non-specific conditioning or training effect (Denning, 2010), it would have strengthened this work to have a control group of dogs with ED that did not undergo hydrotherapy. However, it would be difficult to attribute a conditioning or training effect to a single hydrotherapy session. We did not perform a sham treatment with ED dogs for ethical reasons, but this could be considered in future work, particularly if the sample population contained young animals with low grade ED. Alternatively, a control group that underwent a walking protocol could be utilised to help to determine whether the effect is attributable to hydrotherapy or just training in general.

This experiment utilised 2D as opposed to 3D kinematic analysis to assess gait parameters and research has suggested that this might result in a loss of accuracy (Miró et al., 2009). Conversely, many studies utilise 2D kinematic analysis to assess both angular and linear variables. Nevertheless, due to the pattern of dysplastic limbs being rotated inward with the elbows rotated outward there may have been an effect of hydrotherapy on mediolateral movement that was not assessed in this study (Morgan et al., 2000). As some small differences in movement have been detected between treadmill and overground locomotion in dogs, it is possible that the effects seen might differ slightly from terrestrial locomotion (Torres et al., 2013). This study allowed dogs a short period of acclimatisation to the treadmill prior to any data being collected, however, dogs did not undergo multiple habituation sessions over several days as has been suggested to ensure repeatability of stride parameters (Gustås et al., 2016, 2013).

We did not explore the effect of other common therapeutic modalities such as acupuncture and passive range of motion exercises on the ROM of dogs with ED.

Future work could explore whether these therapies represent a better option for dogs with ED than hydrotherapy, and could appraise the efficacy of a multi-modal approach.

Conclusions

It is possible to observe significant differences in kinematic parameters of Labradors with and without ED after a single session of hydrotherapy. These changes may be beneficial in the management of pathological animals and reiterates the current understanding that hydrotherapy is an appropriate therapeutic intervention for these animals. Further work is needed to explore whether these changes are still evident after the cessation of hydrotherapy.

Conflict of Interest

This research did not receive any specific grant from funding agencies in the public, commercial or not for profit sectors.

Acknowledgements

Preliminary results were presented as an abstract and poster presentation at the Society for Experimental Biology annual main meeting in Brighton, United Kingdom in July 2016. The authors would like to thank Samantha Whalley and Tessa Lewis for their assistance and for allowing us use of facilities for data collection. The authors would also like to thank Victoria Purves and Zoe Miles for help with recruiting participants and assistance with data collection.

References

Barnicoat, F., Wills, A.P., 2016. Effect of water depth on limb kinematics of the domestic dog (*Canis lupus familiaris*) during underwater treadmill exercise.

Comparative Exercise Physiology 12, 199–207. doi:10.3920/CEP160012

Barthélémy, N.P., Griffon, D.J., Ragetly, G.R., Carrera, I., Schaeffer, D.J., 2014. Short- and Long- Term Outcomes After Arthroscopic Treatment of Young Large Breed Dogs With Medial Compartment Disease of the Elbow. Veterinary surgery 43, 935–943.

Bennett, R.L., DeCamp, C.E., Flo, G.L., Hauptman, J.G., Stajich, M., 1996. Kinematic gait analysis in dogs with hip dysplasia. American journal of veterinary research 57, 966–971.

Bouck, G.R., Miller, C.W., Taves, C.L., 1995. A comparison of surgical and medical treatment of fragmented coronoid process and osteochondritis dissecans of the canine elbow. VCOT Archive 8, 12–18.

Brady, R.B., Sidiropoulos, A.N., Bennett, H.J., Rider, P.M., Marcellin-Little, D.J., DeVita, P., 2013. Evaluation of gait-related variables in lean and obese dogs at a trot. American journal of veterinary research 74, 757–762.

Burton, N.J., Dobney, J.A., Owen, M.R., Colborne, G.R., 2008. Joint angle, moment and power compensations in dogs with fragmented medial coronoid process. Veterinary and Comparative Orthopaedics and Traumatology (VCOT) 21, 110–118.

Burton, N.J., Owen, M.R., Kirk, L.S., Toscano, M.J., Colborne, G.R., 2011. Conservative versus arthroscopic management for medial coronoid process disease in dogs: a prospective gait evaluation. Veterinary Surgery 40, 972–980.

Canapp, S., Acciani, D., Hulse, D., Schulz, K., Canapp, D., 2009. Rehabilitation therapy for elbow disorders in dogs. Veterinary surgery 38, 301–307.

Cook, J.L., Hudson, C.C., Kuroki, K., 2008. Autogenous osteochondral grafting for treatment of stifle osteochondrosis in dogs. Veterinary surgery 37, 311–321.

Danielson, K.C., Fitzpatrick, N., Muir, P., Manley, P.A., 2006. Histomorphometry of fragmented medial coronoid process in dogs: a comparison of affected and normal coronoid processes. Veterinary Surgery 35, 501–509.

Denning, M.M., 2010. The effects of aquatic exercise on physiological and biomechanical responses.

Evans, R.B., Gordon-Evans, W.J., Conzemius, M.G., 2008. Comparison of three methods for the management of fragmented medial coronoid process in the dog-A systematic review and meta-analysis. Veterinary and Comparative Orthopaedics and Traumatology (VCOT) 21, 106–109.

Fitzpatrick, N., Yeadon, R., 2009. Working algorithm for treatment decision making for developmental disease of the medial compartment of the elbow in dogs. Veterinary Surgery 38, 285–300.

Gemmill, T.J., Mellor, D.J., Clements, D.N., Clarke, S.P., Farrell, M., Bennett, D., Carmichael, S., 2005. Evaluation of elbow incongruency using reconstructed CT in dogs suffering fragmented coronoid process. Journal of small animal practice 46, 327–333.

Gustås, P., Pettersson, K., Honkavaara, S., Lagerstedt, A.-S., Byström, A., 2016. Kinematic and spatiotemporal assessment of habituation to treadmill walking in Labrador retrievers. Acta Veterinaria Scandinavica 58, 87.

Gustås, P., Pettersson, K., Honkavaara, S., Lagerstedt, A.S., Byström, A., 2013. Kinematic and temporospatial assessment of habituation of Labrador retrievers to treadmill trotting. The Veterinary Journal 198, e114–e119.

Houlding, B., 2011. Canine hydrotherapy: where are we now? Veterinary Record 168, 405–406.

Houlton, J., 2009. Advances in canine elbow disease. Veterinary Surgery 38, 133–134.

Hudson, P.E., Corr, S.A., Wilson, A.M., 2012. High speed galloping in the cheetah (Acinonyx jubatus) and the racing greyhound (Canis familiaris): spatio-temporal and kinetic characteristics. Journal of Experimental Biology 215, 2425–2434.

Kamioka, H., Tsutani, K., Okuizumi, H., Mutoh, Y., Ohta, M., Handa, S., Okada, S., Kitayuguchi, J., Kamada, M., Shiozawa, N., 2010. Effectiveness of aquatic exercise and balneotherapy: a summary of systematic reviews based on randomized controlled trials of water immersion therapies. Journal of Epidemiology 20, 2–12.

King, M.R., 2016. Principles and Application of Hydrotherapy for Equine Athletes. Veterinary Clinics of North America: Equine Practice 32, 115–126.

Kirberger, R.M., Fourie, S.L., 1998. Elbow dysplasia in the dog: pathophysiology, diagnosis and control: review article. Journal of the South African Veterinary Association 69, 43–54.

Kramer, A., Holsworth, I.G., Wisner, E.R., KASS, P.H., Schulz, K.S., 2006. Computed tomographic evaluation of canine radioulnar incongruence in vivo. Veterinary Surgery 35, 24–29.

Levine, D., Rittenberry, L., Millis, D.L., 2004. Aquatic therapy. Canine rehabilitation and physical therapy. St Louis: Saunders 264–276.

Marcellin-Little, D.J., Levine, D., Taylor, R., 2005. Rehabilitation and conditioning of sporting dogs. Veterinary clinics of north America: small animal practice 35, 1427–1439.

Marsolais, G.S., McLean, S., Derrick, T., Conzemius, M.G., 2003. Kinematic analysis of the hind limb during swimming and walking in healthy dogs and dogs with surgically corrected cranial cruciate ligament rupture. Journal of the American Veterinary Medical Association 222, 739–743.

Meyer-Lindenberg, A., Langhann, A., Fehr, M., Nolte, I., 2003. Arthrotomy versus arthroscopy in the treatment of the fragmented medial coronoid process of the ulna (FCP) in 421 dogs. VCOT Archive 16, 204.

Meyer- Lindenberg, A., Fehr, M., Nolte, I., 2006. Co- existence of ununited anconeal process and fragmented medial coronoid process of the ulna in the dog. Journal of small animal practice 47, 61–65.

Michelsen, J., 2013. Canine elbow dysplasia: Aetiopathogenesis and current treatment recommendations. The Veterinary Journal 196, 12–19.

Millis, D., Levine, D., 2014. Canine rehabilitation and physical therapy. Elsevier Health Sciences.

Miró, F., Santos, R., Garrido-Castro, J.L., Galisteo, A.M., Medina-Carnicer, R., 2009. 2D versus 3D in the kinematic analysis of the horse at the trot. Veterinary research communications 33, 507–513.

Monk, M., 2007. Hydrotherapy. Animal physiotherapy: assessment, treatment and rehabilitation of animals 187–198.

Monk, M.L., Preston, C.A., McGowan, C.M., 2006. Effects of early intensive postoperative physiotherapy on limb function after tibial plateau leveling osteotomy in dogs with deficiency of the cranial cruciate ligament. American journal of veterinary research 67, 529–536.

Morgan, J.P., Wind, A., Davidson, A.P., 2000. Hereditary bone and joint diseases in the dog: osteochondroses, hip dysplasia, elbow dysplasia. Schlütersche.

Narojek, T., Fiszdon, K., Hanysz, E., 2008. Canine elbow dysplasia in different breeds. Bull Vet Inst Pulawy 52, 169–173.

Owen, M.R., 2006. Rehabilitation therapies for musculoskeletal and spinal disease in small animal practice. The European Journal of Companion Animal Practice 16, 137–148.

Palmer, R.H., 2011. BURP: Arthroscopy vs. mini-arthrotomy, in: Proceedings of the American College of Veterinary Surgeons Symposium, Chicago, USA. pp. 120–122.

Palmer, R.H., 2010. Arthroscopic and open surgical treatment of MCPD/OCD, in: Proceedings 25th Annual Meeting of the International Elbow Working Group, Bologna, Italy. pp. 14–20.

Prankel, S., 2008. Hydrotherapy in practice. In practice 30, 272.

Preston, C.A., Schulz, K.S., Taylor, K.T., Kass, P.H., Hagan, C.E., Stover, S.M., 2001. In vitro experimental study of the effect of radial shortening and ulnar ostectomy on contact patterns in the elbow joint of dogs. American Journal of Veterinary Research 62, 1548–1556.

Saunders, D.G., 2007. Therapeutic exercise. Clinical techniques in small animal practice 22, 155–159.

Scott, R., Nankervis, K., Stringer, C., Westcott, K., Marlin, D., 2010. The effect of water height on stride frequency, stride length and heart rate during water treadmill exercise. Equine Veterinary Journal 42, 662–664. doi:10.1111/j.2042-3306.2010.00194.x

Sjöström, L., 1998. Ununited anconeal process in the dog. Veterinary Clinics of North America: Small Animal Practice 28, 75–86.

Torres, B.T., Moëns, N.M.M., Al-Nadaf, S., Reynolds, L.R., Fu, Y.-C., Budsberg, S.C., 2013. Comparison of overground and treadmill-based gaits of dogs. American journal of veterinary research 74, 535–541.

Turner, B.M., Abercromby, R.H., Innes, J., McKee, W.M., Ness, M.G., 1998. Dynamic proximal ulnar osteotomy for the treatment of ununited anconeal process in 17 dogs. Veterinary and comparative orthopaedics and traumatology: VCOT.

Wilcock, I.M., Cronin, J.B., Hing, W.A., 2006. Physiological response to water immersion. Sports medicine 36, 747–765.

Table 1. Referral information for dogs with elbow dysplasia

Participant and subject number	Participant Age (Years)	Diagnostic modality	Diagnosis[a]	Grade of elbow dysplasia[b]	Previous medication	Treatment/medication during study	Treatment/medication changes during study
Ruby (9)	6	Radiography	Bilateral OCD	Grade 1+	Previcox	Previcox	None
Mack (11)	3	Radiography	Bilateral FCP	Grade 1+	Cartrophen	Synaquin	None
Riley (10)	5	Computed Tomography	Bilateral FCP	Grade 1+	Metacam	Metacam, Tramadol	Metacam swapped to Previcox
Floyd (12)	6	Radiography	Bilateral FCP	Grade 1+	Metacam	Metacam	None
Flo (5)	2	Radiography	Bilateral UAP	Grade 1+	NSAID	NSAID	None
Ruby (2)	6	Radiography	Bilateral OCD	Grade 1+	NSAID	NSAID	None

[a]Diagnosis of dogs at the time of referral, OCD = osteochondrosis dissecans, FCP = fragmented medial coronoid process, UAP = ununited anconeal process.

[b]Referral information provided from the veterinarian to the hydrotherapy centres at the time of referral did not routinely contain detail of the grade of elbow dysplasia.

Table 2. Baseline kinematic characteristics for both groups and percentage change from baseline after hydrotherapy.

Subject	Group[a]	Baseline ROM[b] (°)	ROM After Hydrotherapy (°)	% Change in ROM	Baseline SL[b] (m)	SL After Hydrotherapy (m)	% Change in SL	Baseline SF[b] (Hz)	SF (Hz) After Hydrotherapy	% Change in SF
1	Control	36.50	37.99	+4.08%	0.225	0.265	+17.70%	0.850	0.900	+5.88%
3	Control	56.69	60.34	+6.44%	0.260	0.265	+1.92%	0.980	0.865	-11.73%
4	Control	51.35	52.79	+2.80%	0.295	0.295	0.00%	0.810	0.825	+1.85%
6	Control	50.58	56.19	+11.09%	0.275	0.275	0.00%	0.855	0.895	+4.68%
7	Control	47.55	52.33	+10.05%	0.260	0.295	+13.46%	0.835	1.030	+23.35%
8	Control	45.01	40.61	-9.78%	0.250	0.285	+14.00%	0.915	0.955	+4.37%
2	ED	18.14	31.64	+74.42%	0.230	0.265	+15.20%	0.825	0.865	+3.30%
5	ED	27.05	37.70	+39.37%	0.230	0.250	+8.70%	0.765	0.815	+6.54%
9	ED	24.35	33.21	+36.38%	0.190	0.205	+7.89%	0.950	0.910	-4.21%
10	ED	29.25	45.14	+54.32%	0.230	0.260	+13.04%	1.020	1.135	+11.27%
11	ED	33.19	49.31	+48.57%	0.230	0.245	+6.52%	1.080	1.100	+1.85%
12	ED	29.41	44.21	+50.32%	0.240	0.265	+10.41%	0.980	1.020	+4.08%

[a] Group of the subject, ED = elbow dysplasia.

[b] Baseline values represent the mean of the right and left limbs of subjects. ROM = range of motion, SL = stride length, SF = stride frequency.

Figure Legends

Fig. 1. The change in mean range of motion (degrees) of individual healthy Labradors (control) and Labradors with elbow dysplasia (elbow) before and after a session of hydrotherapy. Results for both forelimbs for each dog are displayed.

Fig. 2. The change mean stride length (m) of individual healthy Labradors (control) and Labradors with elbow dysplasia (elbow) before and after a session of hydrotherapy. Results for both forelimbs for each dog are displayed.

Fig. 3. The change in mean stride frequency (Hz) of individual healthy Labradors (control) and Labradors with elbow dysplasia (elbow) before and after a session of hydrotherapy. Results for both forelimbs for each dog are displayed.