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Paper

Extracorporeal shockwave therapy and therapeutic exercise for supraspinatus and biceps tendinopathies in 29 dogs

J. J. Leeman, K. K. Shaw, M. B. Mison, J. A. Perry, A. Carr, R. Shultz

Supraspinatus tendinopathy (ST) and biceps tendinopathy (BT) are common causes of forelimb lameness in large-breed dogs and have historically been treated with conservative management or surgery. Extracorporeal shockwave therapy (ESWT) and therapeutic exercise (TE) are thought to be treatment options for these conditions. The objectives of this study were to report the clinical presentations of dogs treated with ESWT for shoulder tendinopathies, to determine the association between shoulder lesion severity identified on ultrasonography or MRI and outcome, and to compare the outcomes of dogs treated with ESWT with and without TE. Medical records of 29 dogs diagnosed with shoulder tendinopathies and treated with ESWT were reviewed, and 24 dogs were diagnosed with either unilateral BT or BT and ST. None were found to have unilateral ST. Five dogs were diagnosed with bilateral disease. Eighty-five per cent of dogs had good or excellent outcomes determined by owner assessment 11–220 weeks after therapy. Outcomes were found to be better as tendon lesion severity increased (P=0.0497), regardless if ESWT was performed with or without TE (P=0.92). ESWT should be considered a safe primary therapeutic option for canine shoulder tendinopathies. Larger controlled prospective studies are needed to adequately assess these findings.

Introduction

Supraspinatus tendinopathy (ST) and biceps tendinopathy (BT) are injuries of the shoulder that appear to be over-represented in adult large-breed dogs that have an active lifestyle (Stobie and others 1995, Davidson and others 2000, Gilley and others 2002, Cook and others 2005, Lafuente and others 2009). With such tendinopathies, dogs tend to exhibit unilateral or bilateral chronic intermittent weightbearing forelimb lameness that worsens with exercise (Stobie and others 1995, Davidson and others 2000, Lafuente and others 2009). The exact cause of shoulder tendinopathies is unknown, however, literature suggests they may be due to chronic overuse injuries similar to those in human beings (Stobie and others 1995, Kannus and Natri 1997, Soslowsky and others 2000). Chronic overuse injuries develop after minor injuries of the muscle or tendon fail to heal appropriately, resulting in a non-healing lesion. It has been shown that increases in metalloproteinases (MMPs) and interleukins (ILs) contribute to degeneration after a short inflammatory phase in cultured tenocytes (Han and others 2009). Histology of chronic tendinopathies in dogs shows myxomatous degeneration and/or cartilaginous metaplasia, often without inflammation (Lafuente and others 2009). The tendons may also be mineralised or non-mineralised (Lafuente and others 2009). Contributing factors that are also thought to play a role in the pathogenesis of shoulder tendinopathies include degeneration due to ageing or trauma, joint mice entrapment secondary to osteochondrosis dissecans (OCD), and hypoxia secondary to hypovascularity of the affected tendon (Lincoln and Potter 1984, Vasseur and others 1985, Kujat 1990, Muir and others 1992, Stobie and others 1995, Tuite and others 1997). The supraspinatus and/or biceps tendon may be diseased in the same joint. Concurrent ST and BT of the same shoulder is believed to occur when the supraspinatus tendon becomes enlarged and impinges the adjacent biceps tendon (Fransson and others 2005).

Treatments for these injuries have historically included conservative management with activity restrictions, oral NSAIDs and/or intra-articular long-acting steroid injections (Piermattei and Flo 1997, Laitinen and Flo 2000, Cook and others 2005). Few studies document the efficacy of conservative management and when this therapy fails, surgical treatment is recommended (Stobie and others 1995, Laitinen and Flo 2000, Wall and Taylor 2002, Cook and others 2005). Surgical treatment is most commonly aimed at either excising the diseased portion of the supraspinatus tendon longitudinally near its insertion on the greater tubercle or releasing the proximal biceps tendon from its origin on the supraglenoid tubercle (Lincoln and Potter 1984,

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J. J. Leeman, DVM,
J. A. Perry, PhD, DVM, DACVIM, DACVS,
A. Carr, DVM, DACVR,
Department of Surgery, Seattle Veterinary Specialists, Kirkland, Washington, USA
K. K. Shaw, DVM, MS, PhD, DACVS, DACVSMR,
Department of Surgery, Animal Surgical Clinic of Seattle, Shoreline, Washington, USA
M. B. Mison, DVM, DACVS,
Department of Clinical Studies, School of Veterinary Medicine, University of Pennsylvania, Philadelphia, Pennsylvania, USA
R. Shultz, DVM, DACVR,
Vision Pet Imaging, Seattle, Washington, USA
E-mail for correspondence: jleeman2011@gmail.com

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Stobie and others 1995, Laitinen and Flo 2000, Wall and Taylor 2002, Cook and others 2005, Esterline and others 2005, Lafuente and others 2009). These procedures have been found to provide good to excellent long-term outcomes (Lincoln and Potter 1984, Stobie and others 1995, Laitinen and Flo 2000, Wall and Taylor 2002, Cook and others 2005).

The conservative and surgical managements described above are not without their respective risks. NSAIDs can be associated with potentially severe adverse events, but more importantly they often will not address the cause of pain. Based on histology, most lesions are non-inflammatory (Lafuente and others 2009). The administration of intra-articular long-acting steroids (ie, methylprednisolone acetate) have been shown to negatively affect articular cartilage by inducing chondrocyte apoptosis and accelerating osteoarthritis, which may already be present at the time of diagnosis (Bjarnason and others 1993, Fubini and others 2001, Farkas and others 2010). Surgery is considered invasive, requires anaesthesia and specialised equipment in some instances (ie, arthroscopy), and is not without the risk of postoperative complications (Cook and others 2005).

Extracorporeal shockwave therapy (ESWT) has been used in numerous human conditions since the 1980s (Ogden and others 2001). Shock waves were originally used for treatment of renal calculi in a procedure called lithotripsy, where calculi are essentially exploded and disintegrated by the waveform, and the pioneer investigators of lithotripsy noticed the shock waves induced changes in the nearby pelvic bone (Ogden and others 2001). Since then, ESWT has been investigated in numerous in vitro and in vivo models and used in many human orthopaedic conditions including chronic calcifying rotator cuff injuries, plantar fasciitis, patellar tendonitis and lateral epicondylitis of the elbow (Wang and others 2003a,b,c, Furia 2005, Rasmussen and others 2008, Metzner and others 2010). The exact mechanism of action that underlies the clinical effects of ESWT is not completely understood, however, it has been shown that the sound waves emitted from the hand-held trode are converted to mechanical energy within the targeted tissues. The greatest release of energy occurs when a change in density (acoustic impedance) is encountered, such as a bone-tendon interface. The released energy is thought to stimulate production and release of growth factors, such as proliferating cell nuclear antigen (PCNA), transforming growth factor (TGF), insulin-like growth factor (IGF), platelet derived growth factor (PDGF), vascular endothelial growth factor (VEGF) and fibroblast growth factor (FGF), which are responsible for tendon healing (Ogden and others 2001, Wang and others 2003a,b,c, Notarnicola and Moretti 2012). The reported biological effects of ESWT include modulation of inflammation, analgesia, neovascularisation, osteogenesis and realignment of tendon fibres (Wang and others 2003a,b,c, Notarnicola and others 2010).

There are currently three main types of shock waves being investigated for use in orthopaedic diseases in human and veterinary medicine: electrohydraulic, electromagnetic and piezoelectric. The device described in this study uses an electrohydraulic source (within water) to create shock waves. This type of source has a large focal area with deep penetration (up to 40 mm) and has been shown to promote tissue and bone healing in various orthopaedic conditions (Worp and others 2013). Radial shock wave is another type of therapy that does not actually produce true shock waves and is considered to be more of a mechanical, unfocused pressure wave (Worp and others 2013).

The use of ESWT has been infrequently reported in dogs, however, it is gaining attention due to the promising results identified in many human conditions (Wang 2012). A recent case series using electrohydraulic ESWT as treatment for shoulder disease (instability, calcification and inflammatory conditions) in 15 dogs showed 65 per cent of dogs were either improved or normal in the long term (Becker and others 2015). Two other case reports describing the usage of radial ESWT for ST and BT in dogs have resulted in good to excellent outcomes as well (Danova and Muir 2003, Venzin and others 2004). Electrohydraulic and radial ESWT have also shown promising results in dogs for management of osteoarthritis, patellar desmitis following tibial plateau levelling osteotomy and acceleration of bone healing (Millis and others 2005, Dahlberg and others 2005, Gallagher and others 2012, Duerr and others 2014).

Therapeutic exercise (TE) has been advocated in the rehabilitation of many canine shoulder injuries (Gilley and others 2002). Exercise protocols are often extrapolated from human literature and are aimed at protecting the joint, alleviating pain, maintaining joint motion and avoiding the onset of limb disuse (Marcellin-Little and others 2007). Additional goals of TE for tendinopathies include tissue healing, preservation or improvement of proprioception and restoration of limb function. There are two veterinary reports discussing physical activity during the recovery period following ESWT for the treatment of shoulder tendinopathies, however, the details from these studies are limited as the reports focused on the documentation of ESWT only (Danova and Muir 2003, Venzin and others 2004).

ESWT may be a viable non-invasive primary treatment option for dogs diagnosed with ST and BT. This procedure is often offered to owners as a first line treatment option for shoulder tendinopathies diagnosed at the authors' hospital, and TE is recommended as adjuvant therapy for an optimal outcome. It is the authors' clinical impression that most dogs have a good to excellent long-term outcome when ESWT and TE are combined. Given the paucity of literature available for the management of canine ST and BT with ESWT and TE, further investigation is warranted.

The objectives of the present study were (1) to report the signalment, physical exam and diagnostic findings of dogs treated with ESWT for shoulder tendinopathies, (2) to report the typical ESWT and TE protocols used at the authors' hospital, (3) to determine the association between shoulder lesion severity identified on ultrasonography or MRI and outcome, and (4) to compare the outcomes of dogs treated with ESWT, with and without TE, obtained by mailed owner questionnaires and follow-up telephone interviews.

Materials and methods

Inclusion criteria

Medical records (2010–2014) of dogs diagnosed with ST and/or BT that received ESWT were reviewed. Dogs without diagnostic imaging consistent with ST or BT and those with concurrent orthopaedic or neurological disorders of the affected shoulder joint were excluded from the study, including medial shoulder instability.

Data collection

Data retrieved included signalment, presenting complaint, history (including previous treatments), clinical signs, orthopaedic exam findings, imaging findings, ESWT therapy parameters, TE parameters and outcome. The outcome was obtained by a mailed owner questionnaire followed up with a phone interview by the primary author (JJL). All owners consented for their dogs to be included in the study.

Physical examination

A complete physical and orthopaedic exam of all limbs was performed, including flexion and extension of the scapulohumeral joint and deep palpation of the supraspinatus and proximal biceps tendons along the musculotendinous junction and tendinous insertions. Results of the biceps stretch test and shoulder abduction were recorded if specifically stated in the medical record. Lameness evaluation was recorded as either weightbearing or non-weightbearing based on lack of consistent lameness scoring used between clinicians.

Diagnostic imaging

Radiography (lateral and craniocaudal), ultrasonography (Phillips HDI3000, Phillips, Bothell, Washington, USA) and/or MRI (Phillips Gyroscan Intera 1.5 T, Phillips, Bothell,

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Washington, USA) were performed. Radiographs and ultrasounds had to have been reviewed or performed by a board certified radiologist to be included in the study. For ultrasonography, dogs were positioned in lateral recumbency with the examined leg up. The infraspinatus, supraspinatus and biceps tendons were evaluated, and the limb was abducted and externally rotated to visualise the tendons and intertubercular groove. The biceps tendon sheath, and external surface of the adjacent humerus and scapula were evaluated. The glenohumeral joint was also taken through flexion and extension while evaluating the biceps tendon. Both shoulders were not examined in every case. For MRI, the dogs were anaesthetised using individualised protocols. The dogs were positioned in lateral recumbency and scans included sagittal and transverse planes of the following sequences: T1, T2, T2 Fat Sat. Additional three-dimensional (T1, T2) sagittal sequences were reformatted into transverse and dorsal planes to evaluate the tendons, bones and synovial structures. Lesions identified on all imaging modalities were recorded and classified as mild, moderate and severe based on the radiologist's interpretation.

Diagnosis

Shoulder disease was diagnosed based on history and physical exam findings. Specific diagnoses of ST and/or BT were made by the addition of diagnostic imaging. Medial shoulder instability and elbow disease were ruled out or not suspected based on the absence of physical exam and diagnostic findings.

ESWT parameters

Dogs were sedated for ESWT due to discomfort associated with therapy and flow-by oxygen was provided throughout the procedure. An approximately 4 cm×4 cm region of skin overlying the craniomedial aspect of the affected glenohumeral joint was clipped. The shaved region was prepped for therapy by wiping away excess hair with an alcohol swab and application of ultrasound coupling gel. A focused electrohydraulic shockwave system (VersaTron 4 Paws, Pulse Veterinary Technologies, Alpharetta, Georgia, USA) was used in the present study. The manufacturer's guideline for trode size (5 mm or 20 mm), energy (E) and number of pulses to be administered was used to determine the appropriate settings for each individual patient. For BT, the trode was placed perpendicular to the craniomedial shoulder and therapy was administered by slowly moving the trode parallel to the biceps tendon fibers repeatedly, extending from its origin at the supraglenoid tubercle to the proximal humerus (intertubercular groove). For ST, therapy was administered similarly by moving the trode parallel to the tendon fibers, extending from its origin at the musculotendinous junction of the supraspinatus muscle and extending to its insertion on the greater tubercle. For concurrent ST and BT, a combination of both techniques was performed. Dogs were treated on an outpatient basis and were discharged with analgesia to use as needed for five days. NSAIDs were not recommended for one week following therapy. ESWT was typically recommended every 3 weeks for three treatments.

Activity recommendations

Activity and TE protocol recommendations during and after the course of ESWT were variable due to the clinical impression of each patient and clinician preference (see online supplementary appendix A). Specific TE included eccentric strengthening, such as theraband exercises, down to stand, wheelbarrowing, walking in water, and cavalettis. Core strengthening exercises included bird dog, begging, and challenged standing. Active and passive stretching were also recommended based on the individual patient. TEs were demonstrated to the owners by either a trained surgery technician or assistant (when owners elected at-home TE) or performed by a Certified Canine Rehabilitation Assistant (when owners elected TE at the authors' facility). Owners were asked at the time of follow-up if their pet's activity in between ESWT treatments and after completion of the ESWT series consisted of no activity restrictions, restricted activity limited to leash walking or the prescribed TE. Restricted activity was defined as leashed walking only without any TE. For all dogs, it was recommended that no running, jumping or rough playing be allowed until permitted by the attending clinician. The recommended duration of leash walking was five minutes two to three times per day. This was increased by five minutes each week throughout the course of therapy as long as no lameness was noted and the patient's normal length of walk was reached. If lameness was observed, owners were instructed to revert to the previous week's activity instructions for an additional week before trying to increase their pet's activity again. Hydrotherapy, therapeutic laser (settings not recorded) and use of complimentary therapies such as acupuncture were also noted. The frequency of all activities and TE were recorded as one to three, three to five or more than five times per week.

Outcome

Questions regarding the recovery period after completion of the series of ESWT, current medication administered and owner assessment of outcome were recorded. Post-ESWT outcome was defined as excellent if complete improvement and no lameness was observed by the owners, good if there was improvement but lameness was still observed and poor if there was no improvement or worsening of lameness, as previously described (Lafuente and others 2009).

Data analysis

The association of shoulder lesion severity (detected via ultrasonography and MRI) of dogs receiving ESWT, with or without concurrent TE, and outcome was performed using a Mantel-Haenszel chi-squared test. The outcomes of dogs who received ESWT and TE were compared with dogs who received ESWT and no TE at any time point in between or following completion of the ESWT series. The data were compared between groups using a chi-squared test. A P value <0.05 was considered statistically significant for both analyses.

Results

The records of 32 dogs that received ESWT for either unilateral or bilateral shoulder tendinopathies were reviewed. Three dogs were excluded from the study due to concurrent ipsilateral caudal humeral OCD (2) or based on the presence of and a peripheral nerve sheath tumour identified on follow-up MRI after no improvement with ESWT was observed (1). None of the dogs included in the present study were diagnosed with concurrent medial shoulder instability, as there was no evidence of medial glenohumeral ligament pathology on MRI and was thought to be an unlikely diagnosis for the dogs that did not undergo an MRI. Therefore, 29 dogs were included in the study (Table 1). Ten dogs were found to have unilateral BT while no dogs were found to have unilateral ST. The remaining 14 dogs with unilateral shoulder disease were diagnosed with concurrent ST and BT of the same shoulder. The five dogs diagnosed with bilateral disease were found to have one or both tendons affected in each shoulder.

The 29 dogs included in the study comprised were comprised of 10 spayed females, 18 neutered males, and one intact male. Various breeds were affected, including labrador retrievers (nine), German shepherd dog (two), German shepherd mix (three), American bulldog (two) and one each of the following: rottweiler, Belgian sheepdog, vizsla, flat-coated retriever, cattle dog, wheaton terrier, corgi, German shorthair pointer, whippet, blue heeler, pit bull mix, Cavalier King Charles spaniel and coonhound. Mean age and weight at presentation were 5.97 years (SD 2.7, range 0.8–10.4 years) and 31.14 kg (SD 9.1, range 13.6–44.6 kg), respectively.

The most common presenting complaints were either unilateral (26) or bilateral (3) forelimb lameness. The duration of clinical signs was recorded in 28/29 (96.6 per cent) dogs in the study. The average duration of clinical signs before presentation was

TABLE 1: Twenty-nine cases of canine shoulder tendinopathies

Dog	Age (years)	Sex	Breed	Lesion severity	Shoulder tendinopathy	Radiographs	Ultrasonography	Shoulder MRI	ESWT (# TX)	No restrictions	Restricted activity	Rehabilitation (H/F)	Length of recovery (weeks)	Outcome	Current medications or nutraceuticals
D1	5	FS	Rottweiler	–	Right supraspinatus and biceps tendons	N	Y	Y	3	–	–	–	–	Lost to follow-up	Lost to follow-up
D2	10	MN	German shepherd dog	Moderate	Bilateral supraspinatus tendons	Y	Y	N	3	–	–	Home	52	Good	No
D3	0.8	MN	American bulldog	–	Left supraspinatus and biceps tendons	Y	N	Y	1	–	–	–	–	Lost to follow-up	Lost to follow-up
D4	9.8	MN	Belgian sheepdog	–	Left supraspinatus and biceps tendons	N	N	Y	1	–	–	–	Never recovered	Not answered	Not answered
D5	6.3	MN	Labrador	–	Bilateral supraspinatus and biceps tendons	N	Y	N	3	–	–	–	–	Lost to follow-up	Lost to follow-up
D6	10	MN	Labrador	Moderate	Left biceps tendon	N	Y	N	3	–	Yes	–	3	Excellent	Yes
D7	5.9	MI	Labrador	Severe	Left supraspinatus and biceps tendons	N	N	Y	1	–	Yes	–	12	Excellent	No
D8	7	MN	German shepherd dog	Mild	Left supraspinatus and biceps tendons	Y	N	N	3	–	–	Home	Never recovered	Good	Yes
D9	6.4	FS	German shepherd mix	Moderate	Right biceps tendon	Y	Y	N	3	–	–	Home	24	Excellent	Yes
D10	10	FS	Vizsla	Mild	Left supraspinatus and biceps tendons	Y	N	Y	1	–	Yes	–	1	Good	No
D11	5	MN	German shepherd mix	Mild	Left supraspinatus and biceps tendons	Y	Y	N	2	–	–	Home	Never recovered	Poor	Yes
D12	8	FS	Labrador	–	Bilateral supraspinatus tendons	N	N	Y	3	–	–	–	–	Lost to follow-up	Lost to follow-up
D13	7	MN	Flat-coated retriever	Mild	Left biceps tendon	Y	Y	N	3	–	–	Home	Immediately	Excellent	No
D14	8	MN	Wheaton terrier	Moderate	Right biceps tendon	N	N	Y	2	–	–	Home	Immediately	Good	No
D15	5.6	MN	Corgi	Mild	Left biceps tendon	Y	N	Y	3	–	–	Home	52	Good	No
D16	4	FS	Labrador	Mild	Bilateral supraspinatus and biceps tendons	N	Y	Y	3	–	–	Facility	Never recovered	Poor	Yes
D17	10.4	MN	German shepherd mix	Mild	Left biceps tendon	Y	Y	Y	2	–	–	Home	5	Excellent	Yes
D18	3	MN	Cattle dog	Moderate	Bilateral supraspinatus and biceps tendons	N	N	Y	3	–	–	Home	In recovery	Excellent	No
D19	2.4	MN	American bulldog	–	Left supraspinatus and biceps tendons	N	N	Y	3	–	–	–	Never recovered	Not answered	Not answered
D20	6.5	MN	Labrador	Moderate	Left supraspinatus and biceps tendons	N	Y	N	3	–	–	Home	Immediately	Good	No
D21	4.17	FS	Labrador	Moderate	Bilateral supraspinatus and biceps tendons	N	Y	N	3	–	–	Home	52	Good	No
D22	10.1	FS	German shorthaired pointer	Mild	Left biceps tendon	N	Y	N	3	–	Yes	–	Never recovered	Poor	Yes
D23	5.17	FS	Whippet	Moderate	Right biceps tendon	N	N	Y	3	–	Yes	–	Never recovered	Good	Yes
D24	3	FS	Blue heeler	–	Right biceps tendon	Y	N	Y	3	–	–	–	–	Lost to follow-up	Lost to follow-up
D25	6.4	FS	Labrador	Moderate	Right supraspinatus and biceps tendons	Y	N	Y	3	–	–	Facility	Immediately	Excellent	Yes
D26	5	MN	Pit bull mix	–	Left supraspinatus and biceps tendons	N	N	Y	2	–	–	–	–	Lost to follow-up	Lost to follow-up
D27	3.7	MN	Labrador	Moderate	Left supraspinatus and biceps tendons	Y	Y	N	1	Yes	–	–	Never recovered	Good	No
D28	3	MN	Cavalier King Charles	–	Right biceps tendon	N	Y	Y	3	–	–	–	–	Lost to follow-up	Lost to follow-up
D29	1.6	MN	Coonhound	Moderate	Left supraspinatus and biceps tendons	Y	Y	Y	3	–	–	Home	12	Excellent	Yes

ESWT, extracorporeal shockwave therapy; FS, female spayed; H/F, hindlimb/forelimb; MI, male intact; MN, male neutered; TX, treatments.

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26.2 weeks (SD 26.2, range 3–96 weeks), with 27 of the 28 dogs having chronic lameness of four weeks or greater. Before presentation at the authors' hospital, 24/28 patients (85.7 per cent) received some sort of previous therapy including rest, NSAIDs, acupuncture or intra-articular corticosteroid injections. The duration of these prior treatments was not routinely reported in the medical records. Prior therapy was not identified in the history of one dog. Four dogs had a history of concurrent ipsilateral non-shoulder degenerative joint disease (DJD) at the time of presentation. Three of these dogs were diagnosed with elbow DJD, two of which were suspected to be secondary to fragmented medial coronoid processes (FMCP) detected by CT or MRI. The third dog had a history of FMCP and previous bilateral coronoidectomies performed arthroscopically approximately four months before presentation. One of the four dogs with concurrent ipsilateral DJD had radiographic evidence of metacarpophalangeal joint DJD. Additionally, two dogs had a known history of non-compressive cervical intervertebral disc disease (IVDD) previously diagnosed with MRI.

Orthopaedic examination

On gait evaluation, 14 dogs were observed to have a weight-bearing lameness. The remaining dogs were either not found to be visibly lame at the time of evaluation or the gait description was not described in the medical record. No dogs were found to have non-weightbearing lameness. Orthopaedic exam revealed pain on palpation of the intertubercular groove/greater tubercle (19), decreased range of motion of the glenohumeral joint (2) and spasms of the surrounding musculature on deep palpation (6). Outcomes of the biceps stretch test and shoulder abduction was not specifically noted in any of the dogs' records, but is routinely performed during orthopaedic examinations. No dog in the study was recorded to have any neurological deficits.

Diagnostic imaging

Diagnostic imaging of the affected glenohumeral joint(s) included radiographs (13), ultrasonography (15) and MRI (19). The diagnosis of BT and ST was made by one of these modalities or a combination thereof; however, radiographs alone were never used as a sole method of diagnosis. Plain survey radiographs (lateral, craniocaudal) were performed in 13 dogs (Tables 1 and 2). None of the dogs had skyline views as part of the study. Significant findings were identified in four dogs, while 9 of 13 (69.2 per cent) radiographic studies did not reveal any abnormalities. Unilateral (8) or bilateral (7) glenohumeral ultrasonography was performed in 15 dogs. Bilateral ultrasonography was performed for comparison of normal anatomy rather than suspicion of bilateral disease based on orthopaedic exam in all seven dogs who underwent a bilateral exam. The severity of pathology identified on unilateral ultrasonography included mild (4), moderate (3) or no evidence of pathology (1). Pathology identified on bilateral ultrasonography included mild (2) and moderate (5) changes on the affected limb and mild (3), moderate (1) or no (3) changes of the contralateral non-clinical shoulder. Patients having an MRI were anesthetized using a combination of the following medications: acepromazine[c] 0.01–0.05 mg/kg intravenously (IV)/intramuscularly (IM), a benzodiazepine (ie. diazepam[d] 0.2–0.5 mg/kg IV, midazolam[e] 0.2–0.5 mg/kg IV/IM), an opioid (ie. methadone[f] 0.2–0.4 mg/kg IV/IM, hydromorphone[g] 0.1–0.2 mg/kg IV/IM, oxymorphone[h] 0.05–0.1 mg/kg IV/IM), and an anticholinergic (glycopyrrolate[i] 0.005–0.01 mg/kg IV/IM). Propofol[j] (3–6 mg/kg IV) or etomidate[k] (1–2 mg/kg IV) were used as induction agents, and isoflurane[l] was used as the maintenance agent. MRI was performed in 18 dogs, of which 13 had unilateral shoulder evaluation and 5 had evaluation of both shoulders. Four of the five dogs underwent a bilateral exam for comparison of normal anatomy and were not lame on the non-clinical limb used for comparison. The cervical spine was also evaluated in eight dogs undergoing MRI. Identified shoulder pathology detected in the primarily affected limb was reported as mild (6), moderate (11) or severe (2). Pathology was identified as normal (1), mild (three) or moderate (1) in the contralateral shoulder for the five dogs that underwent a bilateral exam; no dogs were reported to have severe pathology of the contralateral shoulder. Eight dogs had a concurrent cervical MRI to rule out a neurological cause of lameness (root signature). Two dogs were diagnosed with non-compressive IVDD at C6-C7, which was not thought to be contributing to the dogs' lameness. Six dogs had a normal cervical spine exam.

ESWT parameters

ESWT was performed under tailored heavy sedation, whichincluded a combination of the following medications: acepromazine 0.01–0.05 mg/kg IV/IM, α-2 agonist (ie. dexmedetomidine[m] 0.004–0.01 mcg/kg IM), a benzodiazepine (ie. diazepam 0.2–0.5 mg/kg IV, midazolam 0.2–0.5 mg/kg IV/IM), an opioid (ie. fentanyl[n] 2 mcg/kg IV bolus, methadone 0.2–0.4 mg/kg IV/IM, hydromorphone 0.1–0.2 mg/kg IV/IM, oxymorphone 0.05–0.1mg/kg IV/IM), and propofol (3–6 mg/kg IV). Most dogs received a total of three treatments of ESWT (20), however, some dogs received one (5) or two (4) depending on the clinician's recommendation and owner compliance. A 5 mm (15) or 20 mm (13) trode was utilised depending the size of the patient, using energy levels between E4 (0.14 m^j/mm^2) and E6 (0.15 m^j/mm^2). An average of 989 pulses (750–1000) were administered per treatment. Treatments were repeated on average every 21 days (21–28) for three treatments using the same settings. Tramadol[p] (2–4 mg/kg orally q 8–12 hours) was prescribed following ESWT for analgesia. A single minor complication was recorded after ESWT in dog 4, which included localised erythema of the prepared procedural site within 24 hours of treatment. This dog only received this one treatment because its owner elected to discontinue ESWT.

Follow-up

Of the 29 dogs included in the study, follow-up data retrieved via mailed owner questionnaire and a follow-up phone call were available for 21 dogs. Eight dogs were lost to follow-up (7) or did not complete the study due to a local skin reaction (1). For all dogs, the mean time since the last ESWT was 95 weeks (SD 65.9, range 11–220 weeks). This included two dogs that were euthanased at 20 weeks (dog 10) and 52 weeks (dog 14) after ESWT for reasons unrelated to shoulder disease. Additionally, this included another dog (dog 21) that was diagnosed with bilateral disease on two separate occasions and treated with ESWT at two separate time points. It had been 52 weeks since the last ESWT on the right shoulder and 104 weeks since ESWT on the left shoulder at the time of the last follow-up for this study.

Activity

Twenty of the 21 owners that were able to be contacted reported their pet's activity for the time period in between ESWT treatments and following completion of ESWT (Table 3). In between ESWT treatments, a single dog received no activity restrictions, while 5 dogs had restricted activity (no TE), and 14 dogs had TE of varying frequencies and protocols. Following completion of the recommended ESWT series, 2 dogs had no activity restrictions, 5 dogs had restricted activity with gradual return to normal activity (but no specific TE) and 11 dogs continued TE as they gradually returned to normal activity. The activities and TE were continued for as long as directed by the primary clinician and were based on the clinical outcome of each individual patient. The TE performed during and after ESWT were similar and included a combination of eccentric strengthening, core strengthening, and stretching (active and passive).

Outcome

The average recovery period for all dogs was 16 weeks duration (0–52 weeks). Eighty-five per cent (17/20) of owners reported a good to excellent outcome, while 3 owners reported a poor outcome (Table 4). One owner did not answer this question for

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TABLE 2: Diagnostic imaging findings in 29 dogs with shoulder tendinopathies

Diagnostic modality	Shoulder findings	Number of dogs
Radiographs	Mineralisation of the supraspinatus tendon or within the intertubercular groove	3
	Caudal humeral head osteophytosis	1
Ultrasonography	Biceps tendon effusion	7
	Biceps tendon impingement	6
	Mineralisation	5
	Heterogeneous tendon lesion	5
	Hypoechoic lesion within supraspinatus tendon	4
	Hypoechoic lesion within biceps tendon	3
	Core lesion	3
MRI	Tendon hyperintensity	12
	Biceps tendon impingement	12
	Supraspinatus tendon enlargement	12
	Biceps tendon effusion	9

TABLE 3: Reported activity for 20 dogs receiving ESWT

Activity between ESWT treatments	Number of dogs (n=20)	Activity following ESWT treatments	Number of dogs (n=18)
No restrictions	1	No restrictions	2
Restricted activity	5	Restricted activity	5
TE	14	TE	11
Home	11	Home	9
1–3×/week	2	1–3×/week	2
3–5×/week	2	3–5×/week	3
More than 5×/week	6	More than 5×/week	4
Not reported	2	Not reported	0
Facility	1	Facility	2
1–3×/week	1	1–3×/week	1
3–5×/week	0	3–5×/week	0
More than 5×/week	0	More than 5×/week	0
Not reported	0	Not reported	0
Not reported	2	Not reported	0

ESWT, extracorporeal shockwave therapy; TE, therapeutic exercise

TABLE 4: Reported outcomes for 20 dogs receiving ESWT

Outcome	Total number of dogs (n=20)	Dog receiving analgesia (n=5)	Dogs receiving nutraceuticals (n=5)
Excellent	8	2	3
Good	9	1	2
Poor	3	2	0

ESWT, extracorporeal shockwave therapy

unknown reasons. Ten dogs were currently on medications and/or nutraceuticals for treatment directly related to the shoulder injury at the time of follow-up.

A significant association was identified between severity of the tendon lesion diagnosed via MRI or ultrasonography and outcome (P=0.0497), with the best outcomes reported in dogs with the moderate or severe lesions. Additionally, there was no statistically significant difference identified (P=0.92) in outcome when comparing dogs receiving ESWT and TE and those who received ESWT without TE.

Discussion

The present study demonstrated that the majority of dogs receiving ESWT for shoulder tendinopathies had acceptable results, with 85 per cent of dogs having good or excellent outcomes. The authors recognise this finding in light of two very interesting results from their statistical analysis: (1) the best outcomes were found in dogs with increased lesion severity (P=0.0497) and (2) there were no differences in outcomes identified between dogs who received ESWT with or without TE (P=0.92).

It is more common at the authors' practice to recommend the combined use of ESWT and TE as primary therapies for mild to moderate cases of shoulder tendinopathies rather than for severe cases. Surgery is typically the recommendation for severe lesions, however, all clients are made aware that ESWT is a treatment for any degree of tendinopathy. Therefore, the single case in the present study that had ESWT for a severe lesion with an excellent outcome may be responsible for a potentially biased finding.

Despite these findings, the authors believe the results of the present study provide useful information as a pilot study for the management of canine shoulder tendinopathies with ESWT and TE. This non-invasive approach may eliminate a surgical procedure, however, surgery could still be performed without consequence in those dogs who do not respond to ESWT with or without TE. Additionally, the authors have found that most owners at their hospital are interested in a non-invasive treatment with little risk before pursuing surgical options for shoulder tendinopathies.

The clinical presentations of the dogs in the present study are comparable to those of previous reports. Dogs presented with either unilateral or bilateral chronic intermittent forelimb lameness that worsened with exercise. Ten dogs were diagnosed with unilateral BT and 14 dogs were diagnosed with unilateral concurrent ST and BT. No dogs in the present study were diagnosed with unilateral ST. Curiously, this finding was untrue for bilateral shoulder tendinopathies, as 60 per cent (3/5) of those cases were diagnosed with bilateral ST with normal biceps tendons. The cause of this difference between unilateral and bilateral diagnoses is unclear at this time. This finding suggests that patients that are suspected to have unilateral shoulder tendinopathies and are unable to have a diagnostic ultrasonography or MRI be treated for both ST and BT.

The most common breeds diagnosed with ST or BT in the present study were labrador retrievers and German shepherd dogs (including mixes), which are consistent with previous studies (Piermattei and Flo 1997, Lafuente and others 2009). The same studies report the rottweiler with increased frequency as well, however, the authors reported only a single case of a rottweiler. This may suggest that labrador retrievers and German shepherd dogs may be a predisposed breed or simply an over-represented breed in the general population.

Approximately 70 per cent of survey radiographs of the affected shoulder did not reveal any significant findings, however, three dogs were found to have mineralisation in the area of the insertion of the supraspinatus tendon and proximal biceps tendon. One dog was found to have evidence of DJD of the caudal humeral head. These findings are consistent with previous reports that many dogs with shoulder tendinopathies may have minimal to no abnormalities seen on survey radiographs of the affected limb, and therefore shoulder pathology should not be ruled out based on normal radiographic findings (Davidson and others 2000, Laitinen and Flo 2000, Kramer and others 2001, Lafuente and others 2009, Muir and Johnson 1994). It is also quite common to identify mineralisation in similar areas of the non-clinical contralateral shoulder of affected dogs (Davidson and others 2000). This has led to the speculation that mineralisation may not correlate with lameness, and can often be an incidental finding.

Ultrasonography and MRI findings in the present study were consistent with those described in previous reports (Long and Nyland 1999, Esterline and others 2005, Fransson and others 2005, Chao and others 2008, Murphy and others 2008, Lafuente and others 2009, Mistieri and others 2012). The most common pathological finding on shoulder ultrasonography and MRI in the present study was enlargement of the supraspinatus tendon with impingement of the biceps tendon in 16 cases (ultrasonography (5), MRI (11)). It would have been interesting to

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determine the agreement between all three imaging modalities, however, based on the retrospective nature of the study and the fact that few cases had both ultrasonography and MRI performed, this analysis was not possible.

We did not report the use of arthroscopy as a diagnostic modality for diagnosing ST or BT or ruling out other orthopedic conditions of the same limb, such as elbow disease. Diagnoses of ST and BT was successfully made by US and/or MRI and arthroscopy was not necessary, however concurrent orthopedic disease of other joints was ruled out in most dogs based on history and absence of physical exam and radiographic findings. However, there were three dogs with previously diagnosed elbow DJD and FMCP. Two dogs were diagnosed using advanced imaging while the third was diagnosed via arthroscopy. These dogs were originally found to be painful on elbow manipulation and further evaluation was warranted. Unlike these three cases, it is important to note that elbow disease may be challenging to completely rule out without the use of advanced imaging and/or arthroscopy (Punke and others 2009).

The current use of ESWT for treatment of musculoskeletal injuries in dogs was extrapolated from equine and human medicine due to the similarity of healing properties amongst species. The goal of therapy is to microscopically cause interstitial and extracellular biological responses to allow tissue regeneration to occur. Recent studies demonstrate ESWT modulates neovascularisation, differentiation of mesenchymal stem cells and local release of angiogenetic factors to promote this tissue regeneration. Specifically related to the healing of tendon injuries, ESWT has been shown to stimulate tenocyte proliferation and collagen synthesis as well (Chao and others 2008). Tenocyte proliferation has been found to be mediated by early upregulation of PCNA and TGF-β1, followed by collagen synthesis. Other growth factors that have been shown to be significantly unregulated during tendon healing include IGF-I, PDGF, VEGF and FGF (Notarnicola and Moretti 2012). Additionally, ESWT has been shown to downregulate inflammatory mediators, MMPs and ILs, which are normally found in high concentrations in diseased tendons (Han and others 2009).

There are currently three case reports and a single case series documenting the use of ESWT for canine shoulder tendinopathies, all with positive outcomes (Danova and Muir 2003, Venzin and others 2004, Becker and others 2015). A single article documents the use in two adult labrador retrievers diagnosed with calcifying STs (Danova and Muir 2003). These dogs received one treatment each using a radial shockwave unit. The recovery period, including TE or other rehabilitation techniques, was not reported extensively for these cases. One dog had no activity restrictions while the second had restrictions (leash walking) following ESWT. Both dogs were not found to be visibly lame at the time of the recheck exam, however, pain could still be elicited during manipulation of the affected shoulder joint. Force plate analysis was performed before and after therapy for both dogs, showing improvement in peak vertical force of the affected limb. Both dogs were subjectively assessed as having good outcomes. The third case report documented the use of an undefined form of ESWT for biceps tenosynovitis in a 15-month-old Bernese mountain dog (Venzin and others 2004). This dog underwent three sessions of ESWT with improvement, both clinically and on follow-up imaging. Unfortunately, lameness recurred six months later due to glenohumeral DJD. A recent larger cases series evaluated electrohydraulic ESWT in 15 dogs with shoulder instability, calcification and inflammatory conditions (Becker and others 2015). This study found positive outcomes for both, the short term (three to four weeks following completion of ESWT) and the long term (120–1830 days following completion of ESWT). In the short term, three of nine dogs had resolution of lameness, while the remaining six of nine dogs had improvement in lameness. Long-term evaluation revealed either an improved or normal outcome in 7 of 11 dogs. Post-treatment activity consisted of leashed walks until three to four weeks following the final ESWT. The outcomes of these case reports and case series are comparable to the results of the current study.

ESWT was performed without complication in all cases under heavy sedation using drug protocols tailored to the individual dog. One study reports the use of general anaesthesia, however, the authors do not think this is necessary for the administration of ESWT (Dahlberg and others 2005). In the authors' experience, adequate sedation was best achieved by using acepromazine and either methadone or hydromorphone as an intramuscular premedication, followed by boluses of fentanyl and propofol intravenously as needed. No dogs required intubation and all dogs were discharged later the same day with tramadol to use as needed for the following three to five days.

Most dogs received a total of three treatments of ESWT over a six-week period. The manufacturer guidelines recommend anywhere from one to three treatments every two to three weeks or until clinical improvement. There were no reported side effects of ESWT besides a single case of erythema at the ESWT site, which prompted discontinuation of further treatments. However, few reports of post-ESWT discomfort and hyperpigmentation at the sites of administration have been reported by owners after treating unrelated orthopaedic diseases at the authors' hospital.

Management of canine shoulder diseases in combination with physical rehabilitation has been described, and is mainly extrapolated from human literature (Gilley and others 2002). The goals of physical rehabilitation for shoulder injuries are to protect patients from further injury, avoid limb disuse, maintain or restore normal joint motion, and maintain or restore normal strength of the shoulder and other forelimb muscles (Gilley and others 2002). Shoulder joint immobilisation, including harness that cross the cranial aspect of the shoulder, should be kept to a minimum because of the negative impact on joint motion and muscle mass. Adjunctive treatment modalities, such as underwater treadmill, therapeutic laser, therapeutic ultrasonography, acupuncture and thermotherapy may be used in combination with TE at the discretion of the attending rehabilitation veterinarian.

Limitations of the present study include its retrospective nature, subjective outcome assessment and low statistical power. Without control groups, it is reasonable to question whether the positive outcomes were due to ESWT, TE or the combination of both. It is also important to note that some dogs may have improved regardless of treatment due to their own natural healing ability during a long restful period and activity modification. It would be valuable to assess the effects of each individual therapy and the combination of ESWT and TE through a high-powered, prospective, randomised, controlled study utilising objective outcome measurements such as lameness and pain scores, force plate analysis and goniometry.

Canine shoulder tendinopathies are common causes of chronic forelimb lameness in middle-aged large-breed dogs. ESWT and TE have been used with increased frequency in veterinary medicine for treatment of multiple musculoskeletal diseases. The authors' pilot study suggests that ESWT, with or without TE, is a reasonable treatment option for dogs with any degree of shoulder tendinopathy. Large randomised prospective studies are indicated in order to make the most accurate conclusions.

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Extracorporeal shockwave therapy and therapeutic exercise for supraspinatus and biceps tendinopathies in 29 dogs

J. J. Leeman, K. K. Shaw, M. B. Mison, J. A. Perry, A. Carr and R. Shultz

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