

Evidence for Canine Rehabilitation and Physical Therapy



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- Canine rehabilitation • Physical Therapy • Evidence-based medicine
- Musculoskeletal tissue disuse • Outcome assessment
- Therapeutic and aquatic exercises • Physical modalities
- Orthopedic rehabilitation • Neurologic rehabilitation

KEY POINTS

- Cartilage, muscle, tendons, ligaments, and bone undergo atrophy with decreased limb use. Appropriate rehabilitation of musculoskeletal conditions must incorporate this knowledge to safely remobilize and strengthen these tissues.
- The ideal outcome assessment instrument should be objective, easy to apply, inexpensive, noninvasive, and, most important, able to discriminate the effectiveness of treatments.
- Therapeutic and aquatic exercises, heat, cold, therapeutic ultrasound, electrical stimulation, therapeutic laser, extracorporeal shock wave, and pulsed electromagnetic fields have all been used in veterinary rehabilitation and have benefit.
- Research indicates that rehabilitation is useful for the treatment of various orthopedic and neurologic conditions.

Rehabilitation and physical therapy of companion animals are among the fastest growing branches of veterinary medicine. The scientific evidence regarding the efficacy of canine rehabilitation and physical therapy is relatively small, but that body of literature is growing. Twenty years ago, there was scant anecdotal information regarding rehabilitation in animals, and in particular, dogs. Most of the early literature pertaining to canine rehabilitation was based on the dog as a model for physical therapy in people. This information is important, yet it is often found in journals related to human physical therapy, and exercise and sport science. Fortunately, the advent of computer-based databases has increased the accessibility of these sources. Others

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have extrapolated information determined in human beings undergoing physical therapy, but these results may or may not apply to animals. Yet, it may be the best available information. Today, there is growing interest in answering not only the question, "Does it work?", but also "How does it work?", and "How much benefit is there?" Importantly, there is growing interest among surgeons, internists, neurologists, and members of the newly formed American College of Veterinary Sports Medicine and Rehabilitation. Clinicians involved with rehabilitation are challenged to ask questions related to canine rehabilitation and physical therapy, but more important, to find the answers through new research.

RESPONSES OF TISSUES TO DISUSE AND REMOBILIZATION

The responses of musculoskeletal tissues to disuse and remobilization in dogs and other animals have been reviewed.¹ This article reviews some of the important studies regarding dogs. It is obvious that if bones, cartilage, muscles, ligaments, and tendons are not loaded and used, atrophy occurs. The more important questions are "How much atrophy occurs?", and "Over what time frame do atrophic changes occur?" Equally important are the questions, "How can tissues be safely remobilized and strengthened" and "How long will it take to regain the lost tissue integrity?"

Cartilage

Chondrocytes, proteoglycans, collagen, and water are the main components of articular cartilage, and each plays a unique role in maintaining the structure and function of cartilage. With disuse or immobilization of joints, there is cartilage atrophy and thinning of articular cartilage, decreased synovial fluid production and distribution, diminished delivery of oxygen and nutrients to cartilage, reduced proteoglycan content and synthesis, and decreased cartilage stiffness. For example, 3 to 11 weeks of immobilization of a stifle joint in flexion results in 13% to 60% reduction of proteoglycan content in young dogs, and cartilage thickness may be reduced 9% to 50%.^{2,3} In addition, the method of joint immobilization affects cartilage. If joints are immobilized in flexion without weight bearing, cartilage atrophy occurs. Conversely, if joints are immobilized in extension and weight bearing is allowed, the joint may undergo degenerative changes. In any case, joint immobilization is not desirable. However, there are clinical situations that require joint immobilization. Knowledge of the changes that occur with immobilization and the time course of events helps in the development of a rehabilitation program to improve tissue integrity.

The length of immobilization, condition of cartilage, and the length and magnitude of weight bearing after immobilization affect cartilage recovery. After 6 weeks of immobilization, 3 weeks of free, low-intensity activity resulted in normal cartilage in 1 study.⁴ Longer periods of immobilization likely require longer recovery times. For example, immobilization for longer than 15 weeks may not result in complete recovery, even with 50 weeks of remobilization, in young dogs.⁵ Vigorous exercise after immobilization may be deleterious to cartilage. In 1 study, jogging young dogs 9.5 km/d at 5 km/h after immobilization for 3 weeks resulted in continued decreases in cartilage thickness (20%) and proteoglycan content (35%), even though proteoglycan synthesis increased (16%).⁶

Bone

Situations that prevent or reduce weight bearing on a limb result in reduced cortical and cancellous bone mass, cortical bone density and stiffness, and increased turnover in cancellous bone.^{7,8} The changes that occur after immobilization vary

depending on the length of immobilization, age of the animal, and the bone involved. The effects seem to be more profound in younger dogs. In fact, immature dogs demonstrated a 55% decrease in bone mass of the distal tibial metaphysis after 4 weeks of unilateral hindlimb cast immobilization in 1 study.⁹ Trabecular bone is affected to a greater degree than cortical bone, and the effects of immobilization are more extensive in the more distal weight-bearing bones.^{10,11} Biomechanical properties of cortical and cancellous bone are also significantly affected by immobilization. Forelimbs of dogs immobilized for 16 weeks had decreased cortical load, yield, and stiffness as well as cancellous bone failure stress, yield stress, and modulus, compared with control limbs.¹² In general, immobilized limb cancellous bone mechanical properties were 28% to 74% of control values, and cortical bone mechanical properties were 71% to 98% of control values.

Like cartilage, bone has the capacity to regain mass and biomechanical properties with remobilization. The potential for recovery of bone lost during disuse, both in the diaphyseal cortical and metaphyseal cancellous bone, was evaluated in young adult and old beagle dogs.¹³ After immobilization of a forelimb for up to 32 weeks, there was considerable recovery of the original bone loss during remobilization. In both age groups, the residual deficits increased with the duration of immobilization and were similar in the metaphysis and in the diaphysis. In addition, the distal, weight-bearing bones tended to show greater losses and also greater recovery of bone. Older dogs had greater residual deficits, most evident in the diaphysis. After 32 weeks of immobilization and 28 weeks of remobilization, a 50% loss in the third metacarpal diaphysis of younger dogs immediately after the immobilization period decreased to 15% (a 70% recovery), whereas older dogs had a 38% loss that decreased to 23% (a 40% recovery). In contrast, immobilization for 6 or 12 weeks resulted in complete recovery of bone after remobilization of 10 or 28 weeks, respectively. Mild treadmill activity after free remobilization may also be beneficial for dogs with immobilized limbs. Forelimb immobilization of 1- to 2-year-old dogs for 16 weeks, followed by a remobilization period of 16 weeks of kennel confinement and 16 weeks of treadmill exercise administered 3 times per week, resulted in the return of cortical and cancellous bone mineral density and mechanical properties to essentially normal levels.¹²

Muscle

Muscles are perhaps the most obvious musculoskeletal tissues that are recognized to undergo atrophy during periods of immobilization and disuse. Unlike bone, cartilage, ligaments or tendons, changes in muscle mass may be evident in dogs with limb injuries or during postoperative recovery by palpation or observation in severe cases of muscle atrophy. The muscles most vulnerable to disuse atrophy are the postural muscles that contain a relatively large proportion of type I (slow-twitch) muscle fibers, extensor muscles, and muscles that cross a single joint.^{14,15} Muscle strength decreases rapidly during the first week of immobilization, with further losses occurring more gradually over time.¹⁶ The change in muscle fiber size and fiber percentage was studied in dog quadriceps muscles after 10 weeks of rigid immobilization.¹⁵ Muscle fiber atrophy was greatest in the vastus medialis and least in the rectus femoris. Atrophy of type I fibers was, in order from most to least atrophied, vastus medialis, vastus lateralis, and rectus femoris; for type II fibers, atrophy of the vastus medialis was equal to vastus lateralis, and both atrophied more than the rectus femoris. Vastus medialis types I and II muscle fiber areas were only about one third of normal after immobilization. A similar study with 10 weeks of immobilization indicated that there was a significant decrease in both types I and II fiber areas, and muscle fiber areas

recovered to only approximately 70% of control values after 4 weeks of remobilization.¹⁷

Changes in muscle mass are common in dogs with cranial cruciate ligament rupture, and after surgical treatment of the injury. In an experimental study, dogs had a cranial cruciate ligament transected, followed by immediate stabilization with an extracapsular procedure.¹⁸ Results of this study revealed muscle atrophy of the surgical leg by 2 weeks, with muscle mass beginning to return between 4 and 8 weeks; significant atrophy was still present 8 weeks after surgery. In addition, the contralateral nonsurgical limb underwent hypertrophy, possibly because of the increased loading on that limb during recovery. A study of dogs with naturally occurring cranial cruciate ligament deficiency evaluated patients before surgical treatment and 1.5, 7, and 13 months after surgery.¹⁹ The degree of quadriceps muscle atrophy present before surgery correlated significantly with the degree of cartilage fibrillation, indicating a relationship with the severity of the condition. Although there was slightly greater muscle atrophy 6 weeks after surgery, muscle mass improved 7 and 13 months after surgery, although significant residual muscle atrophy remained in many dogs even after 1 year. A measure of quadriceps atrophy may be a useful tool for assessing long-term outcome.

The clinical aspects and biochemical changes in dogs with induced muscle atrophy followed by various levels of physical rehabilitation were studied.²⁰ Muscle atrophy was induced by joint immobilization for 30 days. Groups included (1) control, (2) massage, passive range of motion, and neuromuscular electrical stimulation (NMES), (3) massage, passive range of motion and aquatic therapy in underwater treadmill, and (4) massage, passive range of motion, NMES, and aquatic therapy on an underwater treadmill. Degree of lameness, range of motion, thigh circumference, and serum creatine kinase and lactate dehydrogenase levels were measured. The authors concluded that therapeutic modalities such as massage, passive range of motion, NMES, and underwater treadmill walking accelerate clinical recovery in dogs with induced muscle atrophy.

Tendons and Ligaments

As with other musculoskeletal tissues previously discussed, tendons and ligaments undergo changes with disuse and immobilization. In many cases of tendon or ligament injury, a period of immobilization is necessary to prevent catastrophic failure of the affected structure(s). However, there is an adverse decline in structural and material properties of ligaments and tendons with immobilization of the joints that they cross. Even if some joint motion is allowed, stress deprivation rapidly reduces the mechanical properties of the tendon and ligament tissues.²¹ The bone-tendon/bone-ligament complex is especially affected by immobilization.

In general, the cross-sectional area of the ligament or tendon is reduced; the parallel structure of fibrils and cells is disorganized; collagen turnover, synthesis, and degradation are increased with a net decrease in collagen mass; and glycosaminoglycan, hyaluronic acid, chondroitin sulfate, dermatan sulfate, and water content are decreased.²¹ Remobilization returns the mechanical properties to near normal over time, but the recovery of the bony insertion sites is prolonged compared with the ligament-tendon mid substance. The effect of immobilization on the cranial cruciate ligament of dogs was studied using a model of internal skeletal fixation for 12 weeks.²² The femur-ligament-tibia complex failed at the tibial insertion of the ligament for both experimental and control limbs. However, the load at failure and stiffness of the immobilized limbs were 45% and 73%, respectively, of the nonimmobilized cranial cruciate ligament. The loss of collagen was greater in the tibia and femur than in the cranial

cruciate ligament, and correlated with mechanical failure at the bone insertion. The importance of bone resorption owing to disuse and its relationship to strength of the medial collateral and cranial cruciate ligament complexes was also evaluated in a cast immobilization study. Changes in the tibial insertion of the ligament were apparent, including the presence of osteoclasts, large fibroblasts, and replacement of bone by loosely arranged fibrous tissue.²³ Restriction of activity to cage confinement also causes significant bone atrophy of the tibial insertion sites of the collateral ligaments if adequate activity is not allowed. Additionally, there is decreased thickness of ligament and tendon fiber bundles, greater extensibility per unit load, and unchanged collagen content after immobilization.²⁴

Although the mechanical properties of immobilized ligaments return to normal relatively quickly, the load to failure of the bone–ligament–bone complex lag behind, indicating that there is asynchronous healing of the bone–ligament–bone complex.²¹ After 6 weeks of immobilization of the lower limbs of dogs, 18 weeks of remobilization was necessary for return of the normal structural properties of the medial femoral–tibial ligament complex.²³ In fact, up to 1 year of remobilization may be required for normalization of the ligament–tibia complex in some instances, whereas the mechanical properties of the ligament return to normal in a relatively short period of time, as newly synthesized collagen fibers gradually mature and strengthen with subsequent stress resumption of activity. Maintaining some joint motion and reducing the period of immobilization may help to preserve ligament and tendon properties. The article regarding rehabilitation of selected orthopedic conditions by Henderson et al in this edition provides additional details regarding these principles.

OUTCOME ASSESSMENT

Before determining whether or not a particular rehabilitation program has positive effects on a group of patients, adequate outcome assessment tools must be available to measure the response(s) to treatment(s). The ideal outcome assessment instrument should be objective, easy to apply, inexpensive, noninvasive, and most important, able to discriminate the effectiveness of treatments.

Activities of Daily Living and Return to Function

Activities of daily living and return to function are perhaps the most clinically useful indicators of the success of rehabilitation programs. Neurologic patients may be evaluated regarding the ability to complete certain tasks, such as changing body position without assistance, maintain a standing position for a given time, walk without falling or stumbling, and performing activities such as going up several steps or negotiating Cavaletti rails. Recent technology has made measurement of activity in the home environment relatively accessible and inexpensive. Pedometers, accelerometers, and global positioning system (GPS) devices worn by dogs give an absolute or relative indication of the amount of activity dogs have in their home environment.²⁵ These measurements may be important in obese dogs undergoing weight loss, or arthritic dogs that have decreased activity. Some devices have the ability to send a report to the owner by Wi-Fi or Bluetooth to a smart phone or computer.

The effectiveness of rehabilitation programs in working or sporting dogs is perhaps more easily measured by performance on the job or during an event. For example, the time achieved by a dog competing in flyball is relatively easy to measure. Other sports that have different obstacles and distances for each competition, such as agility and lure coursing, may not be measured as reliably with a particular time, but their relative performance against common competitors and the level of competition are

reasonable indicators. Some working dogs, such as police dogs, may not be able to return to vigorous duties such as apprehension work, but they may be able to return to explosive and narcotic detection duties.

A 6-minute walk test determines the distance that an animal can walk in 6 minutes, and has been evaluated in healthy dogs and dogs with pulmonary disease.²⁶ The 6-minute walk test is used in human medicine to assess impairment, and to provide an objective measurement of disease progression and response to therapy. Healthy dogs walked 522.7 ± 52.4 m, whereas dogs with pulmonary conditions walked 384.8 ± 41.0 m. The authors concluded that the 6-minute walk test was easy to perform and discriminated between healthy dogs and dogs with pulmonary disease. However, further studies in dogs with other conditions are needed. In particular, the distance walked depends on the handler, the motivation of the dog, and the speed of the handler.

Gait Analysis

Gait may be analyzed subjectively or objectively, with pros and cons of each. Subjective analysis is relatively quick, inexpensive, and does not require equipment. Experience is important, but even seasoned gait evaluators may have difficulty characterizing gait abnormalities, especially if several joints or limbs are involved. In general, our eyes focus on the most obvious abnormality or factor contributing to gait asymmetry. However, multiple areas are affected frequently, including the spine. In addition, the sensitivity of subjective gait analysis is less compared with objective methods of gait evaluation. Conversely, objective gait measures, such as force platform or pressure walkways, generally assess only walking and trotting. Evaluation of activities such as ascending and descending stairs or stepping over obstacles may be difficult with objective gait analysis, but are readily evaluated subjectively. In fact, some dogs with relatively normal gait assessment by force platform analysis may have difficulty negotiating stairs.

Again, technology has made subjective gait analysis somewhat easier. Watching dogs walking and trotting on a treadmill may allow a more consistent gait pattern with minimal distractions. Also, the evaluator is able to watch a specific limb, joint, or footfall pattern repeatedly without moving or changing their focal distance. Filming dogs and assessing gait in slow motion allows observation of subtle gait abnormalities that may not be detected at real-time speed. Several software applications have become available to evaluate joint motion relatively inexpensively, but the accuracy of these programs must be validated and compared with traditional gait analysis techniques. Recording the gait of dogs is advised to compare changes over time because the ability to recall previous gait evaluations may be difficult, and subjective scoring systems may not distinguish subtle changes.

Weight bearing at a stance may be performed with computerized systems²⁷ or with simple systems, such as bathroom scales. Hyytiainen and coworkers²⁸ assessed the asymmetry of hind limbs of dogs with osteoarthritis (OA) by using a force platform during gait and in static weight bearing by using bathroom scales. The sensitivity of static weight-bearing measurements using bathroom scales was 39%, and specificity was 85%. The authors concluded that bathroom scales are a reliable, simple, cost-effective, and objective method for measuring static weight bearing and can be used as an outcome measure when rehabilitating dogs with osteoarthritic changes in the hind limbs.

Objective gait analysis has documented normal forces (kinetic gait analysis), and joint motion and stride length (kinematic gait analysis) during walking and trotting (Figs. 1 and 2).²⁹⁻³¹ In addition, several studies have evaluated gait in dogs with



Fig. 1. A 1-year-old German shepherd dog with a partially amputated right hind limb is walking on a pressure-sensitive walkway for objective assessment of his weight distribution before receiving a prosthetic foot. (Photograph courtesy of D Marcellin-Little.)

various musculoskeletal abnormalities or neurologic conditions, including hip dysplasia, elbow arthritis, and cranial cruciate ligament rupture.^{32–36} Most studies have shown compensatory changes in joints and limbs as a result of a primary problem. Further, a technique known as inverse dynamics combines kinetic and kinematic gait analysis and estimates muscle moments surrounding the joints.^{37–39}

Joint Motion

Joint motion has traditionally been measured with a goniometer (**Fig. 3**). The normal joint motion of Labrador retriever dogs and cats has been established.^{40,41} There is good correlation with goniometric measurements made from radiographs at maximum joint flexion and extension angles. In addition, different evaluators may obtain similar measurements when appropriate bony landmarks are used. Goniometry has been used to evaluate stifle range of motion in dogs with cranial cruciate ligament insufficiency. There seems to be an association with lameness and stifle extension after stifle stabilization surgery.

Additional information is needed regarding goniometry of different breeds and body types. Also, information regarding goniometry of various conditions and the response to rehabilitation is lacking. Furthermore, joint flexion and extension angles are commonly measured, but other accessory joint motions have not been adequately



Fig. 2. A dog is instrumented with reflective markers for kinematic evaluation of gait. (From Millis DL, Levine D. Assessing and measuring outcomes. In: Millis DL, Levine D, editors. Canine rehabilitation and physical therapy. St Louis (MO): Saunders; 2014. p. 224; with permission.)

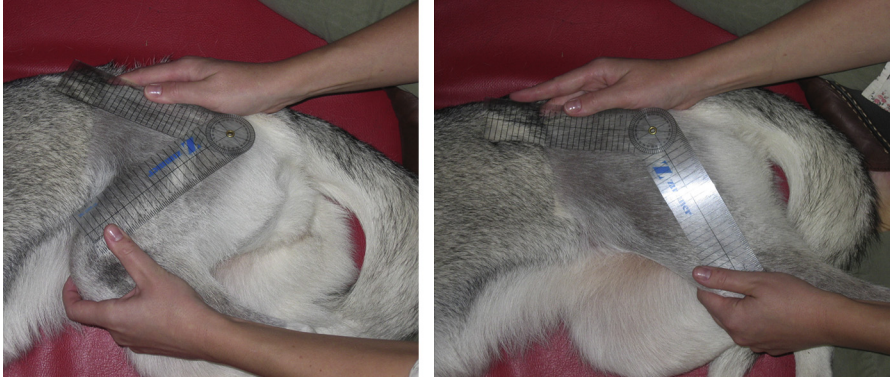


Fig. 3. A 1-year-old Siberian husky is evaluated for the left pelvic limb disuse after a femoral head ostectomy. The range of motion of the hip joint is evaluated using a plastic goniometer. Hip flexion (*left*) is 55° and hip extension (*right*) is 123°. Both flexion and extension are less than anticipated, reflecting periarticular fibrosis. (*Photograph courtesy of D Marcellin-Little.*)

evaluated, such as spins, glides, and distraction motions. These motions are small relative to flexion and extension, but nevertheless may provide valuable information in certain musculoskeletal conditions. Dogs sometimes circumduct, or wing in or out, during gait. Evaluation of these motions may also be useful.

Muscle Mass

Muscle atrophy and weakness are common after injury, and regaining muscle mass and strength are among the main goals of rehabilitation. Subjective evaluation of muscle atrophy is commonly performed by palpating both limbs simultaneously while the animal is in a standing position. Experienced evaluators can detect relatively subtle differences. More objective methods include dual-energy x-ray absorptiometry, magnetic resonance imaging, quantitative computerized tomography, and ultrasound (US) measurement of muscle mass. These methods are relatively expensive and may require heavy sedation or anesthesia. A practical method is to measure limb circumference using a spring-tension tape measure (**Fig. 4**). Measurements made without a spring-tension tape measure are inaccurate because the end tension of the tape depends on the subjective tensioning of the evaluator. A spring tension allows a consistent amount of end tension to be applied. In addition, specific bony landmarks must be used to establish the area of circumference measurement. Estimating the region of measurement or using soft tissue landmarks, such as the fold of the flank, result in inaccurate and inconsistent measurements and should not be used.

A muscle condition score has also been developed for cats that evaluates muscle mass, which can be independent of body fat content.⁴² Evaluation of muscle mass includes visual examination and palpation over temporal bones, scapulae, lumbar vertebrae, and pelvic bones. A similar scoring system may be valid for dogs.

More objective methods of assessing muscle mass include measurement of limb circumference. Four devices were evaluated for measuring limb circumference at 4 locations on the canine hindlimb and forelimb.⁴³ Repeated measurements were made by multiple observers at the mid thigh, tibial tuberosity, the hock, and carpus bilaterally. Measurements with a spring tension tape measure and a retractable tape measure resulted in significantly smaller values at each site than an ergonomic measuring tape and a circumference measuring tape. Interobserver variation was



Fig. 4. The circumference of the dog in **Fig. 3** is measured using a spring-tension tape measure. The circumference was 31 cm on the left (affected side, pictured) and 35 cm on the opposite side. (*Photograph courtesy of D Marcellin-Little.*)

3.6 times greater than intraobserver variation. These results illustrate the importance of consistency when obtaining these measurements. The spring tension tape measure allows a constant end tension to be applied, eliminating subjective interpretation of how snug to pull the tape measure. In addition, specific anatomic landmarks and proper application of the tape measure can give repeatable readings between observers when using careful attention to detail.⁴⁴

Measurement of muscle strength is more challenging. Although muscle mass and muscle strength are related, there is not a perfect correlation. Assessment of muscle strength in people is based on maximal effort to lift a load. This requires conscious knowledge of the task at hand. Because dogs cannot be instructed to provide maximum effort against a load, they must be coaxed or motivated to do so. This is difficult to do so consistently in an individual, no less in a group of dogs. Muscle maximal isometric extension torque has been measured in dogs, but requires anesthesia and placement of electrodes near motor nerves.⁴⁵

Body Condition

Body condition, including lean tissue mass and body fat, has been measured with dual-energy x-ray absorptiometry, electrical impedance, and isotope dilution. These are impractical for clinical use, and body condition scoring performed by experienced evaluators has good correlation with more objective means.^{46,47} However, owners often underestimate their dog's body condition score, making it important that an experienced person does the assessment.

Pain Assessment

Assessing pain is important in veterinary rehabilitation and methods of evaluation have been a focus of investigation. Although physiologic parameters have been investigated, these are most useful for assessing acute pain, such as immediately postoperatively. Evaluation of chronic pain has focused on behavioral characteristics. Ordinal and visual analog scores have been used to assess pain. Questionnaires have been

developed that address specific areas of focus. The canine brief pain inventory is based on similar instruments used in people and has been validated in dogs with OA and bone cancer.⁴⁸⁻⁵¹ The Helsinki Chronic Pain Index was found to be a reliable tool to assess chronic pain by owners of dogs with OA.⁵² Other pain assessment instruments are also available, including the Glasgow Composite Measure Pain Scale and the University of Melbourne Pain Scale, which evaluate features of acute pain.

Functional Scales

In addition to pain assessment, assessment of function has been evaluated, especially for spinal cord injury. A functional scoring system for dogs with acute spinal cord injuries is based on 5 stages of recovery of use of pelvic limbs. Each stage is subdivided based on recovery patterns, with a score of 0 to 14 possible.⁵³ The Texas Spinal Cord Injury Score for Dogs evaluates gait, proprioceptive positioning, and nociception. A score between 0 and 10 is possible.⁵⁴ A canine orthopedic index has also been developed and tested.⁵⁵⁻⁵⁷ Additional validated scoring systems are needed in other areas, especially for orthopedic conditions other than OA.

THERAPEUTIC AND AQUATIC EXERCISES

Waining and others did a survey to determine the current status of canine hydrotherapy in the United Kingdom by sending a questionnaire to 152 hydrotherapy centers throughout the United Kingdom.⁵⁸ Although only 89 responded, they found that hydrotherapy was a rapidly growing business. Although stand-alone centers predominated, many hydrotherapy facilities were connected to other businesses, including boarding kennels and general veterinary practices. The most common conditions treated with hydrotherapy were ruptures of the cranial cruciate ligament (25%), hip dysplasia (24%), and OA (18%).

The complications from swimming in a chlorinated swimming pool were evaluated in 412 dogs.⁵⁹ The side effects included dry hair (20.63%), dry skin (18.93%), and abrasion wounds at the armpit (15.78%), all of which increased with greater frequency of swimming. Other adverse effects were red eye (13.59%), otitis (6.31%), and a small number of respiratory problems (0.49%).

The effect of water temperature on heart rate and respiratory rate during swimming was evaluated in 21 small breed dogs.⁶⁰ Dogs swam for 20 minutes in different water temperatures: 25, 33°C and 37°C. Heart rate and respiratory rate were monitored every 5 minutes during swimming. Blood samples were obtained before and after swimming for blood glucose and lactate concentrations. Dogs that swam in 25°C water had the highest heart rate and serum glucose levels. The highest respiration rate was found in dogs that swam in 37°C water. Serum lactate significantly increased after 20 minutes of swimming at all water temperatures. The authors suggested that dogs swim in 33°C water to prevent tachycardia, hyperventilation, and hyperthermia.

Changes in heart rate with swimming have been evaluated in small, medium, and large dogs.⁶¹ Heart rates were measured every minute for 34 minutes after the fifth swimming session. Heart rates were significantly different between small, medium, and large dogs. An equation was developed that could predict heart rate of each group of dogs (small, medium, and large dogs). From their results, the authors recommended that the limits on the length of time swimming should be 15 to 30 minutes, depending on the breed (size) of dog.

Kinematic or motion analysis has been used to evaluate joint motion in dogs performing therapeutic exercises, including wheel-barrowing, dancing, incline and decline slope walking, ascending and descending stairs, Cavaletti walking, sit to

stand, ground treadmill walking, underwater treadmill walking, and swimming.^{62–65} Although there is a growing body of literature regarding normal dogs performing these exercises, additional information is needed regarding dogs with musculoskeletal issues performing these exercises and, more important, changes in response to rehabilitation.

THERAPEUTIC MODALITIES

Physical modalities are often used in the treatment of small animal patients. Modalities may be rather simple, such as cold and heat therapy, or more complex, such as NMES and extracorporeal shockwave therapy (ESWT). Therapeutic lasers are also increasingly used, and are the subject of an article by Pryor and Colleagues elsewhere in this issue. Although there is a relatively large volume of literature regarding the characteristics and use of modalities used in rehabilitation, there are relatively few studies in dogs, and most of these evaluate various characteristics of the modality, such as tissue temperature change with thermal modalities. There are even fewer studies evaluating clinical efficacy. Further, many clinicians combine several modalities in a single patient and there is virtually no information regarding whether combining modalities results in an additive, synergistic, or negative benefit.

Cryotherapy

Cryotherapy is often applied in the early postinjury or postoperative period to reduce blood flow, inflammation, swelling, and pain. Most studies of cryotherapy in dogs have focused on changes in tissue temperature. One study indicated that intra-articular temperature of the stifle joint of dogs decreased with increased time of cryotherapy application.⁶⁶ The greatest decrease in intra-articular temperature occurred in with ice water immersion. Rewarming of the stifle also took the longest with ice water immersion.

Cooling of different tissue depths for various times of cryotherapy application has also been investigated.⁶⁷ Skin and superficial tissues were cooled to the greatest extent. Deeper tissues had a more gradual decrease in tissue temperature. Rewarming was also slower in deeper tissues. Rewarming of tissues depends on the length of cryotherapy application. For example, muscle rewarming time to baseline temperatures was 60 minutes for 10 minutes of cryotherapy application time, 100 minutes for 15 minutes of application time, 130 minutes for 20 minutes of application time, 140 minutes for 25 minutes of application time, and 145 minutes for 30 minutes of application time. A study in our laboratory has shown similar results for cooling and rewarming at various tissue depths.⁶⁸ Millard and colleagues⁶⁹ also measured the effect of cold compress application on tissue temperature in 10 healthy, sedated dogs. Temperature changes were measured at 0.5, 1.0, and 1.5 cm tissue depths in a shaved, lumbar, epaxial region. Cold (-16.8°C) compresses were applied with gravity dependence for 5, 10, and 20 minutes. Temperature after 5 minutes of application at the superficial depth was significantly decreased, compared with control temperatures. Application for 10 and 20 minutes significantly reduced the temperature at all depths, compared with controls and 5 minutes of application. Twenty minutes of application significantly decreased temperature at only the middle depth, compared with 10 minutes of application. The authors concluded that 10 to 20 minutes of application caused a further significant temperature change at only the middle tissue depth; however, for maximal cooling, the minimum time of application should be 20 minutes. Changes in tissue temperature and adverse effects of application for longer than 20 minutes require further evaluation because it is possible that tissue damage may occur.

In a postoperative study of dogs undergoing extracapsular repair for cranial cruciate ligament rupture, cold compression and cold compression with bandaging were found to be equally beneficial in reducing stifle swelling in the first 72 hours.⁷⁰ Cold compression was applied for 20 minutes by wrapping the leg from the stifle to the hock with a large cold pack and holding it in place with an elastic bandage once daily.

Thermotherapy

There is relatively little information regarding heat therapy in dogs. In general, heat is used to increase blood flow, increase collagen extensibility, and perhaps provide some mild analgesia. In 1 study, the effect of warm compress application on tissue temperature in 10 healthy dogs was evaluated.⁷¹ Tissue temperature was measured at depths of 0.5, 1.0, and 1.5 cm in a shaved lumbar, epaxial region in sedated dogs. Warm compresses (47°C) were applied with gravity dependence for 5, 10, and 20 minutes. After 5 minutes of heat application, tissue temperature at all depths was significantly increased, compared with the control temperatures. Application for 10 minutes resulted in even greater temperature at all depths, compared with 5 minutes of application. Tissue temperature with 20 minutes of application was not different at the superficial or middle depths, compared with 10 minutes of application. Overall, temperature increases at the deep depth were minimal. The authors suggested that application of a warm compress should be performed for 10 minutes. Changes in temperature at a tissue depth of 1.5 cm were minimal or not detected. However, the optimal compress temperature to achieve therapeutic benefits is still unknown.

Electrical Stimulation

Electrical stimulation has been used for many purposes in veterinary rehabilitation, including increasing muscle strength, muscle reeducation, increasing range of motion, pain control, accelerating wound healing, edema reduction, muscle spasm reduction, and enhancing transdermal administration of medication (iontophoresis). Transcutaneous electrical nerve stimulation (TENS) is widely recognized as a form of electrical stimulation that is used to modify pain, although technically nearly all clinical electrical stimulators elicit their actions through transcutaneous surface electrodes to stimulate nerves. Neuromuscular electrical nerve stimulation (NMES) or electrical muscle stimulation (EMS) is used for muscle reeducation, prevention of muscle atrophy, and to enhance joint movement.

For muscle strengthening, NMES creates a tetanic muscle contraction. NMES units have varying intensities and pulse durations to provide an electrical stimulus that results in depolarization of the motoneuron. A group of researchers determined the electrical impulse duration thresholds (chronaxy) for maximal motor contraction of various muscles without stimulation of pain fibers in dogs.⁷² The chronaxy of a muscle is the pulse duration needed to obtain A α fiber depolarization with an intensity value twice that of the rheobase (the intensity that causes A α fiber depolarization when the pulse duration is ≥ 100 milliseconds). The chronaxy is important because it is the optimal pulse duration to cause depolarization of the A α fibers and a resultant muscle contraction without recruiting nociceptive fibers. Eleven muscles were tested: Supraspinatus, infraspinatus, deltoideus, lateral head of the triceps brachii, extensor carpi radialis, gluteus medius, biceps femoris, semitendinosus, vastus lateralis, cranial tibial, and the erector spinae. The rheobase was used to determine the chronaxy for each of the 11 muscles in 10 dogs. Chronaxy values for stimulation of the biceps femoris, semitendinosus, and lower limb muscles were lower in dogs compared with humans. Chronaxy values did not differ between dogs and humans for the other muscles. Using

specific chronaxy values for NMES should provide adequate stimulus for muscle strengthening with minimal stimulation of pain fibers.

The use of EMS has been studied in dogs recovering from surgical transection and subsequent stabilization of the cranial cruciate ligament-deficient stifle. In 1 study, dogs were subjected to an EMS treatment protocol for the thigh muscles 3 weeks after stabilization.⁷³ EMS-treated dogs had significantly better lameness score than did control dogs, with less palpable crepitation of the stifle, fewer degenerative radiographic changes, greater thigh circumference, and less gross cartilage damage. However, EMS-treated dogs had more medial meniscal damage, possibly as a result of increased limb use.

The effect of low-frequency NMES to increase muscle mass was studied in the quadriceps muscle of dogs with induced muscle atrophy.⁷⁴ Muscle atrophy was induced by immobilizing the left stifle joint for 30 days with transarticular external skeletal fixation. NMES began 48 hours after removal of the immobilization device, with dogs treated 5 times per week for 60 days at a frequency of 50 Hz, with pulse duration of 300 milliseconds, and an on/off time ratio of 1:2. Morphometry of vastus lateralis fibers obtained by muscle biopsy indicated a significant increase in muscle fiber transverse area of the treated group at 90 days compared with that identified at the time of immobilization. The authors concluded that low-frequency NMES results in hypertrophy of the vastus lateralis muscle in dogs after temporary rigid immobilization of the knee joint. Using the same model, these researchers also evaluated NMES at a frequency of 2500 Hz, with a pulse duration of 50%, and an on/off ratio of 1:2.⁷⁵ Although there was no difference between dogs receiving NMES and untreated controls regarding thigh circumference, cross-sectional morphometry of vastus lateralis fibers of treated dogs was greater on day 90 compared with that observed at the time of immobilization and untreated controls. Treated dogs also had improved goniometric measurements 30 days after immobilization ended. They concluded that this form of NMES also resulted in hypertrophy of the vastus lateralis muscle in dogs after induced muscular atrophy.

The effects of TENS have also been investigated in dogs with osteoarthritic pain in the stifle.⁷⁶ Five dogs with chronic mild OA were treated with premodulated electrical stimulation (70 Hz) applied to the affected stifle. Ground reaction forces were determined before treatment, immediately after treatment, and at 30-minute intervals over a 4-hour period. Significant improvement in ground reaction forces was found 30 minutes after treatment. These differences persisted for 210 minutes after TENS application and were significant 30, 60, 120, 150, and 180 minutes after treatment. However, the greatest improvement was found immediately after treatment. In this study, positive benefits of TENS application were apparent in dogs with osteoarthritic stifle joints.

The effects of low (TENS), medium (interferential), and high (microwave) electrotherapies on suppression of chronic pain in dogs with ankylosing spondylitis were studied.⁷⁷ Treatments were performed 15 minutes daily for 10 days. All groups had a significant decrease in pain at rest, during activity, or during palpation, with TENS having the greatest effect. Although all dogs improved clinically, none resulted in complete improvement of lameness.

Therapeutic Ultrasonography

Therapeutic ultrasound (US) is also commonly used in veterinary rehabilitation for its thermal and biologic effects. The thermal effects are especially beneficial for enhancing tissue extensibility, whereas the biologic effects may be useful for tissue

and wound healing. Several studies have evaluated various properties of US treatment in dogs.

US energy does not transmit through air very well, and is best transmitted to the skin by clipping the hair to avoid trapped air and to use US coupling gel. US is also absorbed by tissues with high protein content, such as hair. A study was conducted in dogs to determine tissue temperature change when delivering US through intact, short, and clipped hair coats.⁷⁸ Heating of tissues did not occur with hair intact, despite using US gel on the hair and skin. The hair temperature increased, however. US delivered through short hair coats resulted in some tissue temperature increase, but the best results were obtained by clipping hair before US application.

One study examined tissue temperature changes of canine caudal thigh muscles at various depths during 3.3 MHz US treatments.⁷⁹ Dogs received 2 US treatments at intensities of 1.0 and 1.5 W/cm². Both intensities of US treatment were performed over a 10-cm² area for 10 minutes using a sound head with an effective radiating area of 5 cm². At the completion of the 10-minute US treatment the temperature rise at an intensity of 1.0 W/cm² was 3°C at the 1-cm depth, 2.3°C at 2 cm, and 1.6°C at 3.0 cm. At an intensity of 1.5 W/cm² tissue temperatures rose 4.6°C at the 1.0-cm depth, 3.6°C at 2 cm, and 2.4°C at 3 cm. Tissue temperature increases were gradual and cumulative over the time of US application. However, tissue temperatures returned to baseline within 10 minutes after treatment in all dogs, indicating that heating is relatively short lived.

The response of tendons to US treatment of tendons may differ from muscles because tendons are relatively smaller and have less blood supply. Four US treatments were randomly applied to the common calcaneal tendon of dogs: (1) Continuous US at 1.0 W/cm², (2) continuous US at 1.5 W/cm², (3) pulsed mode US at 1.0 W/cm², and (4) pulsed mode US at 1.5 W/cm².⁸⁰ Continuous mode US resulted in significantly greater tendon heating than pulsed US, and the magnitude of temperature increase should be safe for tissues. In addition, 1.5 W/cm² continuous US resulted in significantly greater tendon heating than 1 W/cm² continuous US. Mild increases in tendon temperature occurred with pulsed mode US (all <1.5°C), but there were no differences between 1 and 1.5 W/cm² pulsed mode US. The pattern of heating seems to be different between tendon and muscle. Although muscle has a relatively steady increase in tissue temperature during US treatment, tendon temperature in this study increased relatively rapidly within the first 2 minutes, and then stayed relatively constant for the remaining 8 minutes of treatment time. Increasing tendon extensibility with US was also studied. Using a standard amount of force, pre and post US treatment of the calcaneal tendon using 1.5 W/cm² continuous mode US resulted in significantly increased hock flexion immediately after treatment, but by 5 minutes after US, hock flexion returned to near baseline.

Extracorporeal Shockwave Therapy

Extracorporeal shockwaves are acoustic waves of high pressure and velocity that are delivered to tissues to produce biologic effects, including analgesia, neovascularization, production of growth factors, and improved tissue healing. There are 2 main types of ESWT units—focused and radial. Focused shockwave units have the ability to deliver the sound wave to a relatively small range of tissue depth, and units focus the energy to various depths using a variety of methods. The advantage of focused units is that the energy can be delivered to the area that requires treatment, and a relatively high amount of energy can be delivered. Radial shockwave units deliver the energy to the surface, and the energy waves spread out over a large volume of tissue. The sound energy is delivered to a relatively large amount of tissue, but if the target

tissue is deep to the surface, much of the energy that is delivered dissipates by the time the sound reaches the intended region. Also, the therapist must be careful that there are truly sound waves that are being delivered because many of these devices merely deliver a mechanical concussive force. Clinically, ESWT has been used in people for the management of plantar fasciitis, lateral epicondylitis, calcifying tendinitis, femoral head necrosis, and the treatment of delayed union and nonunion fractures; in horses for insertion desmopathies, bone spavin, tendon and ligament calcification, navicular disease, exostoses, fractures and microfractures, back pain, and OA of tarsometatarsal and distal intertarsal joints; and in dogs for hypertrophic nonunions, tendonitis, spondylosis, and OA.

Mueller and coworkers⁸¹ evaluated the effect of radial ESWT on dogs with hip OA. Dogs with hip OA were treated with ESWT 3 times at weekly intervals. Six dogs with hip OA were not treated and served as controls. Ground reaction forces were obtained before and 6, 12, and 24 weeks after treatment. Treated dogs had a more symmetric gait; however, untreated dogs also had similar changes in peak vertical force at 6 weeks.

Results of analgesia were similar to a study of canine stifle OA, in which 3 shock-wave treatments (200 shockwaves were applied to each of 4 sites using a 20-mm focused depth applicator, followed by 175 shocks to each of the same 4 sites using a 5-mm focused depth applicator, at an energy flux density of 0.14 mJ/mm², for a total of 1500 shocks) were administered 3 weeks apart.⁸² Peak vertical force and vertical impulse were improved at 21 days and continued to improve to the end of the study, at 98 days. Despite these improvements, the changes were not significant from control groups, perhaps because of small numbers of animals in each group.

Our group reported significant improvement in ground reaction forces of dogs with elbow or hip OA compared with control groups.⁸³ A follow-up study of another group of dogs with elbow OA only confirmed these findings and suggested that the amount of improvement with ESWT is similar to what would be expected when treating with an average nonsteroidal anti-inflammatory drug (NSAID), although the dogs were already receiving treatment for their arthritis, including NSAIDs.⁸⁴

ESWT also apparently has benefit in the treatment of tendon–bone and ligament–bone interface conditions. Evaluation of the bone–tendon interface in experimental dogs has revealed increased neovascularization after treatment, indicated by an increase in neovessels and angiogenic markers, such as vascular endothelial growth factor, endothelial nitric oxide synthase, and proliferating cell nuclear antigen expression.⁸⁵ ESWT was used for the treatment of supraspinatus calcifying tendinopathy in dogs. One dog had subjective and objective improvement in lameness 21 days after ESWT.⁸⁶ Another dog in the same report was bilaterally affected and improvement was noted 28 and 49 days after treatment in the right limb but not in the left limb. In both cases, disruption of the calcified material was not apparent after treatment. ESWT has also been evaluated for the treatment of patellar ligament desmitis in dogs after undergoing tibial plateau leveling osteotomy (TPLO).⁸⁷ Dogs that had TPLO surgery were evaluated preoperatively and 4, 6, and 8 weeks after TPLO. At 4 and 6 weeks, treated dogs received 600 shocks with an energy level of 0.15 mJ/mm² with a focused depth of application of 5 mm on the patellar ligament. There was a significant difference in distal patellar ligament thickness between groups at 6 and 8 weeks postoperatively.

One of the first uses for ESWT in people was the treatment of delayed and nonunion fractures. In a radial nonunion model performed in dogs, 80% of the dogs exhibited a bridging callus 6 weeks after shockwave treatment; by 9 weeks, there was narrowing

of the fracture gap and an increase in the bridging callus, and finally complete bony union 12 weeks after treatment.⁸⁸ Persistent radiographic nonunion was present in 4 of 5 of the control dogs, however. Wang and colleagues⁸⁹ described the effects of ESWT in an acute fracture model on 16 tibiae of 8 laboratory dogs. In this study, radiographic callus formation was not better than control specimens until 12 weeks after treatment. Cortical bone at 12 weeks was histologically denser, thicker, and heavier than control callus, signifying the potential advantage of treating acute fractures. Therefore, it can be assumed that ESWT treatment improves the quality and mechanical qualities of bone during fracture repair. Shockwave therapy is associated with decreased incidence of disturbed fracture healing, and may be indicated for use in patients with multiple fractures, open fractures, animals with a concurrent systemic disease, or geriatric animals.⁹⁰

Pulsed Electromagnetic Fields

Pulsed electromagnetic fields (PEMF) have been used in the treatment of OA with mixed results. A clinical study evaluated the effects of PEMF on OA in dogs compared with the NSAID firocoxib.⁹¹ Twenty-five dogs were treated with PEMF once a day and 15 dogs were treated with firocoxib once daily for 20 days. Blinded clinical examination and owner's assessment before and after the therapy, as well as 4 and 12 months later, indicated that both groups had decreased clinical signs of OA. In the PEMF group, the effects were sustained for the 12-month study, whereas the control group tended to return to baseline values after the end of the 20-day treatment. Unfortunately, there was no control group in this study that used only subjective evaluation methods.

One randomized, controlled, blinded, clinical trial of dogs suggested that pulsed signal therapy was useful in treating 60 patients with OA.⁹² Dogs in the treatment group received PST for 1 hour on 9 consecutive days. Outcome measures were performed on days 0, 11, and 42. The PST group performed significantly better than the control group as measured by the Canine Brief Pain Inventory Severity and Interference scores. Joint extension and peak vertical force were not significant after adjusting for multiple comparisons. The authors concluded that the PST group performed better than the control group according to owner assessment. There was a trend toward improvement in the PST group for objective force plate assessment of gait.

It is possible that PEMF may potentiate the response to morphine analgesia after abdominal surgery. A randomized, controlled, clinical trial evaluated PEMF therapy on postoperative pain in dogs undergoing ovariohysterectomy.⁹³ Although no clear benefit was seen in this study, the results suggested that PEMF may augment morphine analgesia after ovariohysterectomy in dogs.

One of the original tenets in the clinical use of PEMF stems from the fact that bone has streaming electrical fields when loaded. Therefore, it is logical to assess whether the external use of PEMF aids bone healing. The effect of PEMF on the healing of experimental lumbar spinal fusions was evaluated in dogs.⁹⁴ After surgery, 1 group was stimulated with a pulse burst-type signal PEMF for 30 minutes a day, another group was stimulated with the same PEMF for 60 minutes a day, and a third group received no active PEMF stimulation. No difference in the radiographic or histologic appearance of the fusion mass could be detected between the stimulated and control groups, suggesting that PEMF stimulation had no effect on the healing of posterior spinal fusions in this canine model. However, PEMF used in the late phase of bone healing in a tibia defect model stimulated bone healing in dogs that were stimulated 1 hour per day for 8 weeks.⁹⁵ Callus area increased earlier in the PEMF group, and

maximum torque, torsional stiffness, new bone formation in the osteotomy gap, and mineral apposition rate were greater in the PEMF group.

If PEMF has value in bone healing, other wounds may also benefit from treatment. The effects of PEMF on the healing of open and sutured wounds was evaluated in dogs.⁹⁶ Open and sutured skin wounds were created over the trunk of dogs. The PEMF-treated dogs received treatment twice a day starting the day before surgery and for 21 days after surgery. PEMF treatment resulted in enhanced epithelialization of open wounds 10 and 15 days after surgery. PEMF treatment also shortened wound contraction time.

REHABILITATION OF ORTHOPEDIC CONDITIONS

Cranial Cruciate Ligament Rupture

Rehabilitation is commonly performed after surgery for orthopedic patients, or as a part of conservative treatment of some orthopedic conditions. Understandably, the most information pertains to postoperative rehabilitation of cranial cruciate ligament rupture. One of the first studies regarding postoperative rehabilitation of dogs after extracapsular repair of naturally occurring cranial cruciate ligament rupture found that dogs receiving rehabilitation had improved stifle extension and thigh circumference compared with dogs not undergoing a rehabilitation program.⁹⁷ A large study also evaluated the relationship between stifle joint motion and lameness after TPLO surgery for dogs with cranial cruciate ligament rupture.⁹⁸ They found that loss of extension or flexion $\geq 10^\circ$ was responsible for worse clinical lameness scores. Also, OA in the cranial femorotibial joint was associated with loss of stifle joint extension. Loss of extension or flexion should be assessed in dogs with persistent clinical lameness after TPLO so that early intervention can occur. This study provides guidelines to define clinically relevant loss of extension or flexion of stifle joint after TPLO.

A study of Labrador retrievers undergoing extracapsular repair followed by postoperative rehabilitation found that dogs had improved weight bearing as measured with force platform compared with those not undergoing rehabilitation.⁹⁹ Another study evaluated the influence of immediate physical therapy on the functional recovery of hind limbs of dogs with experimental cranial cruciate ligament rupture and surgical extracapsular stabilization.¹⁰⁰ The authors found that dogs undergoing immediate physical rehabilitation had better functional gait recovery. In addition, the therapeutic modalities used in the immediate postoperative period did not cause instability of the operated knee.

Another study evaluated the use of carprofen, an NSAID, during rehabilitation after extracapsular stabilization for cranial cruciate ligament rupture.¹⁰¹ The results suggested that although both carprofen-treated and untreated dogs undergoing rehabilitation improved over time, carprofen treatment did not result in greater weight bearing, thigh circumference, range of motion, or perceived exertion. A similar study by the same group of researchers found similar results for the NSAID deracoxib, suggesting that NSAIDs during the chronic phase of rehabilitation may not be necessary.¹⁰²

Other surgical procedures for stifle stabilization also apparently benefit from physical rehabilitation. A study evaluated the effects of early intensive postoperative physical rehabilitation on limb function in dogs after TPLO for cranial cruciate ligament rupture.¹⁰³ Six weeks after TPLO, the physical rehabilitation group had significantly larger thigh circumference than a home exercise group. In addition, the affected limb had the same thigh circumference as the unaffected limb, whereas differences persisted in the home exercise group. Stifle maximum extension and flexion were significantly greater in the physical rehabilitation group, compared with the home

exercise group after surgery. The authors concluded that a properly managed early physical rehabilitation program after TPLO may help to prevent muscle atrophy, build muscle mass and strength, and increase stifle joint flexion and extension.

Another study of dogs undergoing either a home or professional rehabilitation program after extracapsular repair for cranial cruciate ligament rupture found no differences in outcome.¹⁰⁴ However, only subjective gait analysis, stifle stability by drawer motion, and thigh circumference were evaluated.

Short-term (3, 5, and 7 weeks postoperatively) and long-term (6 and 24 months) functional and radiographic outcomes of cranial cruciate ligament injury in dogs treated with postoperative physical rehabilitation and either TPLO or extracapsular repair were determined in 65 dogs.¹⁰⁵ The rehabilitation program was the same in both groups. Radiographic OA scores significantly progressed 24 months after surgery in all dogs. Peak vertical force increased from preoperative to 24 months postoperatively in both groups, and there were no differences between groups. Therefore, there were apparently no differences in outcome measures used in this study comparing 2 different surgical techniques with the same rehabilitation protocol. Unfortunately, groups not receiving rehabilitation were not studied.

Although intracapsular repair of cranial cruciate ligament rupture is not commonly performed, a study evaluated the influence of physical rehabilitation on functional stifle recovery and joint stability.¹⁰⁶ Eight dogs were allocated into control and rehabilitation groups. Rehabilitation was initiated immediately postoperatively, including cryotherapy, passive range of motion, massage, stretching, NMES, hot packs, and underwater treadmill walking. Therapeutic exercises included walks on grass and hard floor, ball, ramp, cones, obstacles, platform, and mattress. Gait evaluation, thigh circumference, stifle goniometry, hind limb and stifle radiography, and joint stability (drawer test) were assessed preoperatively and 45 and 90 days postoperatively. The authors concluded that rehabilitation immediately after intracapsular surgical reconstruction for cranial cruciate ligament rupture produced a satisfactory functional recovery and did not worsen stifle instability. Others have also evaluated the role of postoperative rehabilitation in experimental dogs receiving intracapsular repair. Muzzi and co-workers^{107,108} evaluated the effect of physiotherapy after arthroscopic repair of the cranial cruciate ligament using an intracapsular arthroscopic technique with fascia lata as an autogenous graft. Eight dogs were included in a postoperative physiotherapy group and the other 8 in a temporary immobilization group. The first phase of study concluded that physiotherapy has beneficial effects on early limb function during the rehabilitation period. In the second part of the study they found that postoperative physiotherapy decreases degenerative joint disease progression and stimulates the incorporation of the graft.

Conservative management of cranial cruciate ligament instability is performed in some situations when surgery is not possible. Comerford and colleagues did a survey of cranial cruciate ligament rupture management in small dogs (<15 kg).¹⁰⁹ Immediate surgical management was chosen by 15.5% of the respondents, and 63.4% of those performed extracapsular stabilization, 32.9% corrective osteotomies and 6.8% intra-articular stabilization. Conservative management included NSAIDs (91.1%), short leash walks (91.1%), weight loss (89.0%), hydrotherapy (53.6%), physiotherapy (41.9%), and cage rest (24.2%). Based on the survey, they concluded that conservative management was still widely used for treatment of cranial cruciate ligament rupture in dogs weighting less than 15 kg. A prospective, randomized clinical trial of larger, overweight dogs with cranial cruciate rupture had either TPLO or conservative treatment, consisting of physical therapy, weight loss, and NSAIDs.¹¹⁰ Although both groups improved on average, the surgically treated group had better peak vertical

force than the conservative group at the later assessments. Surgical treatment group dogs had a higher probability of a successful outcome (67.7%, 92.6%, and 75.0% for the 12-, 24-, and 52-week evaluations, respectively) versus nonsurgical treatment group dogs (47.1%, 33.3%, and 63.6% for 12-, 24-, and 52-week evaluations, respectively).

Mostafa and coworkers evaluated the morphometric characteristics of the pelvic limb musculature of Labrador retrievers with and without cranial cruciate ligament deficiency, using radiography (widths of quadriceps, hamstrings and gastrocnemius were expressed relative to tibial length) and dual energy x-ray absorptiometry evaluation of the lean content of the same muscle groups.¹¹¹ They concluded that atrophy may predominantly affect the quadriceps muscle in affected dogs, and dominance of the gastrocnemius muscle over restraints to the cranial tibial thrust may be associated with predisposition to cranial cruciate ligament deficiency in Labrador retrievers. If confirmed, this dynamic imbalance between muscle groups of the rear limbs could serve as a basis for screening programs and preventive rehabilitation.

Osteoarthritis

Dogs with OA may also benefit from physical rehabilitation as part of the overall treatment program. Owners of Labrador retrievers with OA and restricted joint motion were given instructions for a home stretching program. Owners performed 10 passive stretches with a hold of 10 seconds twice daily. After 21 days, goniometric measurements showed that the passive stretching had significantly increased the range of motion of the joints by 7% to 23%.¹¹² The effects of a weight reduction program combined with a basic or more complex physical rehabilitation program on lameness in overweight dogs with OA was evaluated.¹¹³ Caloric restriction combined with intensive physical rehabilitation improved mobility and facilitated weight loss in overweight dogs. The authors concluded that dietary management and physical rehabilitation may improve the health status more efficiently than dietary management alone.

Aquatic therapy may be especially useful for patients with OA because of the buoyancy, resistance, and hydrostatic pressure properties of water.¹¹⁴ One study evaluated whether swimming improves function of osteoarthritic hip joints in dogs.¹¹⁵ Fifty-five dogs were randomized to 1 of 3 groups: OA with swimming, non-OA with swimming, and non-OA without swimming. All animals were allowed to swim for a total of 8 weeks (2 days per week, with 3 cycles of swimming for 20 minutes, with a 5-minute rest period between cycles). Clinical evaluation of the OA with swimming group found that lameness, joint mobility, weight bearing, pain on palpation, and overall score were significantly improved at week 8 compared with pretreatment. Although an OA nonswimming group hindered definitive conclusions, the authors felt that swimming 2 days per week for 8 weeks can improve the function of joints with OA.

Muscles may play a role in joint adaptation, limb loading, and joint degeneration. Conversely, joint degeneration affects the control of muscle forces and joint position awareness. The changes in muscle forces acting on joints with OA have been studied experimentally in cats.¹¹⁶ Cats with transection of the cranial cruciate ligament have decreased stifle extensor and hock extensor muscle forces, and reduced ground reaction forces. There are also changes in the muscle firing patterns and the coordination of extensor and flexor muscle groups while ambulating. These findings were then applied to studies regarding loading of articular cartilage by controlled nerve stimulation of muscle groups to create muscle forces that load joints.¹¹⁶ The authors found that loading cat stifles for 30 to 60 minutes results in upregulation of messenger RNA of specific metalloproteinases and some of their inhibitors. Progressing further with a muscle weakness model using botulinum toxin injections in rabbit stifle

extensor muscles, the authors were able to measure a 60% to 80% decrease in muscle force, which was associated with changes in external ground reaction forces.¹¹⁶ More important, the muscle weakness seemed to be associated with degeneration of cartilage in the absence of joint instability. Based on their results, the researchers concluded that muscle health and muscle rehabilitation are key components in the prevention of, and recovery from, joint injury and disease.

Other articles have suggested rehabilitation protocols for various musculoskeletal conditions based on clinical experience in dogs and people, but the efficacy of these protocols has not been adequately studied.

REHABILITATION OF NEUROLOGIC CONDITIONS

The effect of physical rehabilitation was studied in dogs with degenerative myelopathy to evaluate whether mean survival time was significantly affected.¹¹⁷ Animals that received intensive physiotherapy had longer survival time (mean, 255 days) compared with that for animals with moderate (mean, 130 days) or no (mean, 55 days) physiotherapy. In addition, the authors found that affected dogs that received physiotherapy remained ambulatory longer than did animals that did not receive physical treatment.

There is a report of successful treatment of a dog with traumatic cervical myelopathy treated with surgery, positive pressure ventilation, and physical rehabilitation, and another of 3 dogs with paresis or paralysis owing to compression of the caudal cervical spinal cord that were successfully treated with physiatry.^{118,119}

Exercises have been described, along with their effects on mobilization of the lumbar spinal nerves and dura mater.¹²⁰ The clinical effects of these exercises have not been evaluated, however.

CONTRAINDICATIONS TO INTENSIVE REHABILITATION

The science of canine physical rehabilitation should consider every aspect of treatment because it is possible that physical rehabilitation may have unwanted outcomes. The effect of physical rehabilitation on dystrophin-deficient dogs was studied.¹²¹ Golden retriever muscular dystrophy is a dystrophin-deficient canine model genetically homologous to Duchenne muscular dystrophy in humans. Muscular fibrosis secondary to cycles of degeneration/regeneration of dystrophic muscle tissue and muscular weakness leads to biomechanical adaptation that impairs the quality of gait. Physical therapy in people is controversial and there is no consensus regarding the type and intensity of physical therapy. In this study of dogs, the effect of physical rehabilitation on gait biomechanics and deposition of muscle collagen types I and III in dystrophin-deficient dogs was studied. Two dystrophic dogs underwent a rehabilitation protocol of active walking exercise, 3 times per week, 40 minutes per day, for 12 weeks. Two dystrophic control dogs maintained their routine of activities of daily living. The rehabilitation protocol accelerated morphologic alterations in dystrophic muscle and resulted in slower velocity of gait. Control dogs that maintained their routine of activities of daily living had a better balance between movement and preservation of motor function.

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