Fundamental principles of rehabilitation and musculoskeletal tissue healing

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REVIEW

Fundamental principles of rehabilitation and musculoskeletal tissue healing

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Abstract

Objective: To review fundamental principles of tissue healing and physical rehabilitation as they apply to dogs recovering from cranial cruciate ligament (CCL) surgery.

Study design: Invited Review.

Sample population: None.

Methods: A multidisciplinary group of specialists in small animal surgery, rehabilitation/sports medicine, and human physical and occupational therapy reviewed the currently available evidence for rehabilitation post-CCL surgery. Because current evidence is limited, this group proposes guidelines for rehabilitation after CCL surgery based on the fundamental principles of tissue healing and physical therapy.

Results: This Review proposes four fundamental principles of small animal physical rehabilitation based on the foundations of tissue healing and patient-centric and goal-oriented therapy. Postoperative rehabilitation programs should be designed such that patient progress is based on individual assessment according to the degree of tissue healing, strength, and achievement of functional goals. Therapists must fully understand phases of tissue healing, reassess the patient frequently, and use clinical reasoning skills to progress treatment appropriately for the individual patient.

Conclusion: Until more robust evidence is available to guide treatment protocols, fundamental principles of rehabilitation should ideally be adhered to when providing rehabilitation, including after CCL surgery.

Clinical significance: While this Review specifically addresses post-CCL surgery rehabilitation, these fundamental principles should be applied broadly to animals enrolled in rehabilitation programs.

1 | INTRODUCTION

The benefits of postoperative rehabilitation after cranial cruciate ligament (CCL) surgery have been reported in several articles.[1-6] The lack of large, randomized, prospective studies

comparing cohorts treated with and without postoperative rehabilitation makes it difficult to give conclusive recommendations. While the initial data are supportive, there is a significant requirement for larger studies investigating the role of rehabilitation after CCL surgery. Furthermore, for long-term, multicenter, prospective studies to identify predictors of successful outcome after CCL surgery, a standardized approach to postoperative rehabilitation in dogs should be adopted.

As a primary step toward developing rehabilitation protocols for testing in multicenter clinical trials, we have reviewed the fundamental principles of physical rehabilitation as they apply to tissue healing after CCL surgery. We propose four basic principles of rehabilitation built around the phases of tissue healing and the specific goals of CCL surgery. Cranial cruciate ligament surgical treatments seek to reestablish normal joint kinematics, resolving pain and returning the patient to full function. While pain relief and improvement of function are well established goals of musculoskeletal rehabilitation, specific techniques can be adopted to improve neuroadaptation and selective muscular strengthening in the CCL surgical patient, seeking to improve joint kinematics. Rehabilitation therapists must understand these principles and use clinical reasoning skills when choosing and modifying therapeutic interventions based on acuity of injury and functional assessment of the individual animal. In addition, understanding the physiologic effects of the CCL injury and of the surgery on the stifle itself and on the rest of the body will help define the specific goals of post-CCL rehabilitation (Figure 1).

This Review presents the four fundamental principles of veterinary rehabilitation, their relevance to dogs with CCL insufficiency, and the specific goals of rehabilitation after CCL surgery. These principles should also apply to rehabilitation of other musculoskeletal conditions. This Review is intended to assist veterinary rehabilitation therapists with
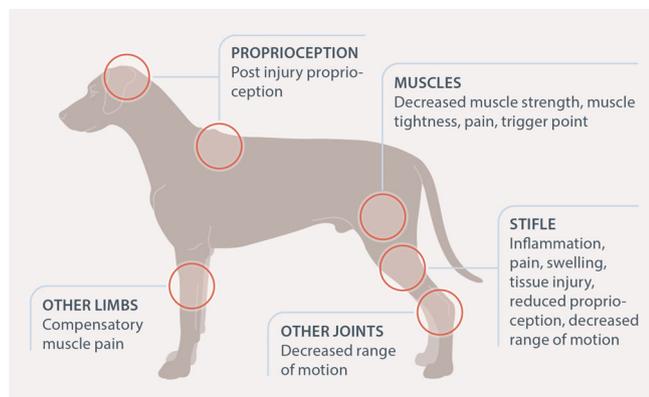

FIGURE 1 The initial cranial cruciate ligament injury and its surgical treatment result in physiologic changes affecting the musculoskeletal and nervous systems, both locally and peripherally. Therapists must design treatment plans that address the entire body

applying therapeutic techniques in a scientific and clinically reasonable manner. Furthermore, veterinary surgeons should appreciate the opportunities that rehabilitation therapy (when following these principles) may provide for their patients.

2 | PRINCIPLE 1

Tissues follow a predictable pattern of healing

Each phase overlaps, and the duration of each phase varies depending on tissue type.[7,8] Rehabilitation therapists must thoroughly understand these phases as they relate to therapeutic interventions (Table 1).

Minimizing surgical trauma with accurate soft tissue handling will facilitate the initial phase of healing and joint neuroadaptation. The rehabilitation therapist will personalize strategies to support the healing phases on the basis of type of surgical technique and according to the response of the patient to surgery.

2.1 | Phases of musculoskeletal tissue healing

2.1.1 | Acute (inflammatory)

The acute phase of wound healing is characterized by gross signs of inflammation, including heat/warmth, erythema, pain, and swelling. On a cellular level, this phase includes migration of platelets and leukocytes to the site(s) of injury with release of degradative proteases, inflammatory proteins, and immunomodulatory cytokines.[7] During this phase, the biomechanical strength of the wounded tissue is weak, with strength provided by suture and fibrin within the blood clot.[8] This phase typically lasts approximately 72 hours after wounding/surgery.[7]

2.1.2 | Subacute (proliferative/reparative)

This stage of healing is characterized by angiogenesis, fibroplasia, increased collagen production, and epithelization. Early in the proliferative phase, granulation tissue fills any tissue defects (cutaneous wounds and deeper tissues). Early granulation tissue does not provide substantial gain in wound strength and includes provisional type III collagen.[7] As fibroblasts migrate into the wounded tissue, the provisional extracellular matrix is replaced by type I collagen.[7] Typically, the fastest rate of gain in wound strength occurs between 7 and 14 days postinjury, although final or complete regain of strength is not expected in this time period for musculoskeletal tissue.[7,8] It is also important to recognize that CCL surgeries involve healing of various tissues, with different rates of gain in wound strength. A clear understanding of the rate of tissue strengthening during healing is

TABLE 1 Examples of specific physical rehabilitation strategies based on stages of tendon-fascia healing

Healing stage	Cellular phase	Physical characteristics	Therapeutic intervention
Inflammatory stage	Vasodilation, invasion of platelets and inflammatory cells (neutrophils, monocytes and macrophages); chemical mediators include histamine, bradykinin, PGE_2	Edema, erythema, warmth, pain	Cryotherapy, ideally with compression
NSAID (unless contraindicated)
Manual therapy (joint distractions, compressions)
Modalities[a]: electrical stimulation, laser therapy, ultrasound, PEMF, ESWT
		Wound strength depends on provisional clot and sutures	
Fibroblastic stage	Growth factors (TGF- β1, BMP, CTGF) activate fibroblastic cells, which proliferate and produce elements of ECM; collagen fibers are initially randomly organized, forming a scar tissue	Subsidence of markers of inflammation	Manual therapy: passive ROM, soft tissue mobilization, joint mobilization
Modalities[a]: electrical stimulation, laser therapy, ultrasound, PEMF, ESWT
Therapeutic exercise: prescribed to meet goal of full weight bearing on the surgical limb while continuing to protect tissues
		Wound beginning to gain tensile strength	Continued pain management
Remodeling stage	Remodeling of the scar improves the organization and mechanical properties of the ECM; ongoing synthesis of collagen leads to tendon scar and adhesions	Inflammation should be resolved; pain, if present, may be due to osteoarthritis, DOMS, reinjury of healing tissue	Manual therapy as required based on patient assessment of surgical limb and rest of body; passive ROM, soft tissue mobilization including scar mobilization, joint mobilization
Modalities: generally discontinued in this phase unless patient assessment indicates specific requirement at surgical limb or rest of body
Therapeutic exercise: prescribed to increase active ROM and flexibility, build muscle strength and endurance, improve proprioception, improve cardiovascular fitness

Abbreviations: BMP, bone morphogenetic protein; CTGF, connective tissue growth factor; DOMS, delayed onset muscle soreness; ECM, extracellular matrix; ESWT, extracorporeal shockwave therapy; NSAID, nonsteroidal anti-inflammatories; PEMF, pulsed electromagnetic field therapy; PGE_2, prostaglandin E_2; ROM, range of motion; TGF- β1, transforming growth factor-β1.

[a]Limited clinical evidence in veterinary patients exists for these modalities at this time.

particularly important for surgical techniques that rely on periarticular fibrosis to provide passive stabilization.

2.1.3 | Chronic (maturation/ remodeling)

This phase represents remodeling of collagen and connective tissue and contraction of the scar. Collagen continues to be deposited at a slower rate than in the proliferative phase.[7] Collagen/connective tissue remodels on the basis of on the stresses placed on it (eg, Wolff's Law), so application of controlled external forces in the normal weight-bearing planes is essential for optimal maturation of connective tissue.[8] However, this tissue remains weaker than uninjured tissue until full healing is achieved. Bone is expected to achieve complete healing and 100% strength, although other musculoskeletal tissues may never achieve maximal strength if scar (fibrous) tissue remains unorganized within the wounded region.[8] Reliance on scar or fibrosis for mechanical stability will result in reduced strength and could predispose to repeated injury. Increase in mechanical strength of tissue takes months or even years.[8]

2.2 | Time to return to approximate normal strength

2.2.1 | Skin

Incised wounds that are well apposed (sutured) should achieve complete epithelization in 24 to 48 hours. If there is no gap formation, adequate strength is expected at 10 to 14 days (typical time for suture removal), although ultimate strength many never reach 100% (see Table 2).[7,8]

2.2.2 | Muscle

Depending on the degree of gap between fibers and the degree of injury, muscle may take 6 weeks to 6 months to regain approximately normal strength. The ultimate strength, flexibility, and susceptibility to reinjury of muscle is directly related to scar/fibrous tissue interposed between healing fibers.

2.2.3 | Tendon, ligament, fascia

Tendon, ligament, and fascial tissues are generally less vascular, and healing is expected to take up to 1 year to

TABLE 2 Approximate rates of tissue healing[a]

Tissue and grades of injury	0–3 d	4–14 d	3–4 wk	5–7 wk	2–3 mo	3–6 mo	6–12 mo	>1 year
Skin		▓	▓	▓	▓	▓	▓	▓
SQ		▓	▓					
Fascia			▓	▓				
Muscle								
DOMS (exercise induced)	▓	▓						
Grade 1	▓	▓	▓					
Grade 2			▓	▓	▓			
Grade 3				▓	▓	▓		
Tendon								
Acute			▓	▓				
Subacute					▓	▓		
Chronic						▓	▓	▓
Rupture/surgical repair						▓	▓	▓
Ligament (extra-articular)								
Grade 1		▓	▓					
Grade 2		▓	▓	▓				
Grade 3				▓	▓	▓	▓	
Intra-articular								Unlikely to fully heal
Bone				▓	▓			

Abbreviations: DOMS, delayed onset muscle soreness; SQ, subcutaneous.

[a]Expected time frame for tissue healing after injury. Rate of healing is influenced by the degree of tissue damage (Grade), particularly with muscle, tendon, and ligament injury. Muscle: Grade 1, mild damage (<5% of fibers), minimal loss of strength and function; Grade 2, moderate fiber damage, loss of strength and function; Grade 3, complete rupture of muscle/muscle-tendon and loss of function. Ligament: Grade 1, stretching, little/no tear, no joint instability; Grade 2, partial tear, mild instability; Grade 3, complete rupture, loss of function. The shaded cells correspond to the range of healing time for the specific tissue injury indicated in the left column. Healing time varies based on degree of tissue injury.

approach full strength. The speed and degree of healing will depend on the vascularity of the tissue and degree of injury.

2.2.4 | Bone

Bone is generally expected to regain full strength in approximately 12 weeks; rate and type of healing (indirect vs direct) is influenced by age of patient and surgical fixation. Primary bone healing is expected with a tibial plateau leveling osteotomy (TPLO).

3 | PRINCIPLE 2

Individualized treatment plans should be developed by the rehabilitation therapist and adjusted as frequently as required; the patients' progress through rehabilitation should be based on assessment of tissue healing, strength, and functional abilities/limitations

Cranial cruciate ligament disease in dogs includes a broad spectrum of clinical presentations, requiring an individual based approach to both surgical treatment and postoperative rehabilitation protocol. The rehabilitation therapist should have a full understanding of the entire surgical procedure performed (arthroscopy vs arthrotomy, meniscal treatment, cruciate ligament debridement vs preservation of intact ligament, osteotomy vs extracapsular repair). The ultimate goals of therapy and modalities used for treatment are unlikely to change because of these differences in surgical technique, but expectations for recovery and long term joint health can differ, particularly when meniscectomy or meniscal release has been performed.

Functional assessment of the patient should accompany evaluation of tissue healing at frequent intervals and prior to progression of therapeutic interventions. Functional evaluation can be divided into passive and active assessments.[9]

3.1 | Passive assessment

3.1.1 | Muscle mass

Muscle mass should be assessed either subjectively, evaluating for muscle symmetry, or objectively, with a Gulick girth measurement. Muscle atrophy is often present prior to surgery in dogs with chronic CCL disease, and muscle mass can be expected to decrease after surgery if early weight bearing and muscle activation does not occur.[2,10] Muscle hypertrophy is expected to occur over weeks to months, so this assessment is not required more frequently than once per month. Because thigh girth may be affected by variables other than muscle (such as hair coat and fat), the weight of the animal and the presence/absence of fur should be monitored and correlated with the girth measurement.

3.1.2 | Range of motion

Joint range of motion (ROM) should be assessed with a goniometer.[11] Stifle and tarsal $\pm$ hip flexion and extension should be measured at baseline and at regular intervals (every 2-4 weeks) to determine response to therapy. Restoration of normal knee joint ROM has been shown to influence return to function in man after anterior cruciate ligament (ACL) repair.[12,13] Restoration of normal joint arthrokinematics and osteokinematics (ROM) allow for optimal limb function and may avoid compensation at other joints in the kinematic chain.

3.2 | Active assessment

3.2.1 | Gait

Gait evaluation should be performed regularly and documented with descriptive language or a scale that describes full body motion. Subjective gait evaluation, except for severe lameness, is poorly correlated with force plate results, indicating that the observer may not identify subtle or mild lameness.[14] Force plate or pressure mat evaluation is neither required nor practical for progressing rehabilitation after CCL surgery, although it is considered important in the research setting. Gait evaluation should not be used as the sole criterion to measure progress in rehabilitation therapy.

3.2.2 | Static weight bearing

Static weight bearing should be assessed manually (modified manual strength test) and/or with the use of bathroom scales or a pressure mat.[15] These tests measure isometric strength and symmetry of weight distribution. Return of symmetric static weight bearing may lag behind dynamic weight bearing (walk or trot). A difference of approximately 6% between hind limbs has been described as normal for uninjured dogs; anything greater than this suggests weight shifting and unloading of the injured limb.[15] Manual strength testing is used to observe isometric strength and compensation after challenged three-leg standing. This test has not yet been validated in dogs, but it is used by some of the authors of this Review in the clinical setting.

3.2.3 | Functional test

- Sit position: observing for any asymmetry of the seated position and normal active ROM of the stifle and tarsus vs compensatory position such as decreased stifle or tarsal flexion, external rotation and/or abduction of the limb, sitting on the hip[9]
- Thrust from sitting: observing the dog move from a seated to stand position and use of the limb to move through the transition; any asymmetry or compensation is noted

- Down position: observing for any asymmetry of the down position and normal active ROM of the stifle and tarsus vs compensatory position such as decreased stifle or tarsal flexion, external rotation and/or abduction of the limb, sitting on the hip
- Down-to-stand: observing the dog move from a down position to stand position and use of the limb to move through transition; any asymmetry or compensation, such as sitting first, is noted.

4 | PRINCIPLE 3

Specific, measurable, attainable, and relevant goals should be set for each rehabilitation patient

4.1 | Establishing rehabilitation goals

Goals must focus not only on postoperative limb function but should consider the entire body (Figure 2). Surgical stabilization addresses only the affected stifle joint, whereas physical rehabilitation should be tailored to address the entire body. Animals with CCL disease often present with comorbidities such as hip or elbow dysplasia or complicating factors such as obesity or bilateral disease. Chronic CCL disease will result in muscle atrophy of the affected limb, loss of ROM of the stifle and ipsilateral tarsus, and compensatory changes in the paraspinal muscles and remainder of the body. Realistic goals and timelines for recovery should consider not only the isolated CCL rupture but the whole animal.

The goals of rehabilitation therapy after CCL surgery should be modified throughout the phases of healing and will vary for individual animals on the basis of chronicity of injury, comorbidities, and surgical technique. The goals listed in Figure 2 should be adapted to each individual's requirements and specifically based on the preoperative and immediate postoperative assessment.

4.2 | Osteotomy vs extracapsular surgical techniques

The most common methods for surgical stabilization of the CCL-deficient stifle can broadly be divided into extracapsular (eg, circumfabellar suture, Tightrope CCL, anchor techniques) and osteotomy (eg, TPLO, tibial tuberosity advancement [TTA], CORA-based leveling osteotomy [CBLO]) techniques.[16-20] The outcomes of techniques and recovery progression have been directly compared in few studies.[21-25] However, there are general differences in expectations for recovery and slight modifications in rehabilitation therapy, depending on the type of surgery performed.

4.2.1 | Osteotomy stabilization techniques

The goal of tibial osteotomy is to correct "dynamic" instability of the stifle due to CCL insufficiency.[17-20] These procedures seek to eliminate cranial tibial subluxation (tibial thrust) only during the stance phase of gait by changing the biomechanical forces across the stifle joint.[19] These procedures do not eliminate cranial drawer motion because they are missing a static stabilizer such as an extracapsular prosthetic ligament. For this reason, regaining muscle strength may be particularly important for controlling instability in the non–weight-bearing phases and in pivoting activities in which rotational moments may be significant. Furthermore, recent studies have provided evidence that these techniques fail to stabilize the stifle in up to 30% of cases for TPLO and 70% of cases for TTA.[26-28] These data further support the requirement of muscle strengthening exercise postoperatively. In addition, studies in animal models have provided evidence of a direct contribution of muscle forces to joint adaptation.[29]

Additional important considerations for osteotomy procedures:

Goals during rehabilitation post-CCL surgery	Pain Management	Manual Therapy	Therapeutic Exercise	Therapeutic Modalities	Client Education
Decrease pain, inflammation, effusion, swelling	X	X		X	X
Facilitate tissue healing	X	X	X	X	X
Balance tissue protection vs. load	X		X		X
Restore muscle flexibility		X	X	X	
Restore joint function: arthro- and osteokinematics		X	X		
Promote weight bearing and dynamic stabilization		X	X		X
Normalize proprioception		X	X		
Restore normal neuromuscular patterning			X		
Normalize muscle strength, endurance and mass			X		
Weight loss, if indicated			X		X
Address compensatory issues in other limbs/ spine	X	X	X	X	
Hastened and guided return to activity			X		X

FIGURE 2 Goals of rehabilitation after cranial cruciate ligament surgery and techniques employed by rehabilitation therapists to achieve predetermined goals

- Soft tissue swelling around the stifle and tarsus is common after TPLO; cryotherapy and other modalities may need to include the distal tibia/ tarsus.
- Partial weight bearing is typically expected within 24 to 48 hours after surgery.
- Various implants are used, depending on the procedure performed. Therapists must understand the location of implants relative to the type of osteotomy performed. If heat-generating modality (select class IV therapeutic lasers, ultrasound) is being used, aim beam to avoid metal implants at all phases of recovery and adjust for pigmented skin or hair.[30]
- Osteotomy typically involves elevation of the pes anserinus (conjoined tendons of sartorius, gracilis, semimembranosus muscles). Therapists should expect restrictions in these muscles, and modalities/manual therapy should be directed toward these tissues.
- TPLO has a high incidence of patellar tendon thickening postoperatively (although this is infrequently considered clinically significant).[31] There is some concern for quadriceps eccentric muscle contractions, particularly during the subacute/early proliferative phase, contributing to patellar tendon strain, although this has not been scientifically documented. Therapists should use caution with squats/sit to stand in the subacute phase, particularly when full osteokinematic ROM has not been restored.
- Osteotomies are not expected to be fully healed until 8 to 12 weeks postoperatively, although many dogs will be fully weight bearing long before this time. Caution must continue with activity because the implants and osteotomy remain at risk for complications with explosive activity.
- Tibial osteotomy does not correct for internal tibial rotation unless accompanied by an extracapsular stabilization technique (Arthrex TPLO implant, lateral fabellar sutures). Some dogs may develop "pivot shift," characterized by internal tibial rotation with lateral tarsal deviation during the stance phase.[32] Typical treatment for this gait abnormality is therapeutic strengthening of the biceps femoris and working on establishing normal cocontraction of quadriceps and hamstrings.

4.2.2 | Extracapsular stabilization technique

The goal of extracapsular stabilization is to provide static stabilization during the joint adaptation phase in the CCL-deficient stifle. The technique should provide enough stability during the recovery until the combination of passive envelope (joint and fascia) and muscle forces successfully stabilize the joint. This is achieved practically by limiting the dog to low impact exercises while improving ROM and strengthening muscles. The traditional recommendations for postoperative care after modified retinacular imbrication technique and lateral suture techniques have included strict activity restrictions for 8 weeks, followed by unrestricted activity with the assumption that

fibrosis should be sufficient by 3 months and stability is no longer provided by the suture.[33-35] After considering these theories and recommendations, one could argue against rehabilitation techniques that may disrupt fibrosis, such as passive and active ROM. However, Marsolais et al[1] compared traditional activity restrictions to formal rehabilitation that included passive ROM (PROM) and swimming (active ROM) between weeks 3 and 7 postextracapsular suture repair and found significantly improved limb function (measured by peak vertical force [PVF] and vertical impulse [VI]) in the rehabilitation group at 6 months postoperatively.

It is challenging to balance restoration of joint ROM without risking disruption of fibrosis and/or stretching the implant, so therapists should avoid end ROM in the first 3 weeks postoperatively and prioritize pain management, weight-bearing, and isometric exercise.

Additional considerations:

- Extracapsular procedures typically involve incision through the fascia lata/biceps femoris and elevation of the cranial tibial muscle; manual therapy and modalities should be directed toward these tissues as appropriate.
- Expectations for weight bearing will likely vary based on the extracapsular stabilization technique performed.
- The stifle joint normally has approximately 15° of internal rotation ROM during trotting.[36] This physiologic internal rotation is coupled with flexion during most activities (screw home mechanism), suggesting that an extracapsular technique that provides excessive restraint to internal rotation may also limit flexion. Passive and active ROM exercises are strongly indicated after these techniques.
- Expectations for full recovery/ stability of the stifle are not as predictable as they are with osteotomy procedures. Criteria for progression and return to function are often delayed compared to osteotomy procedures, particularly for dogs > 15 kgs.[22]

5 | PRINCIPLE 4

The foundation of veterinary physical rehabilitation includes pain management, therapeutic exercise, manual therapy, and guided return to activity. Therapeutic modalities may play a beneficial yet supplementary role in therapeutic plans. Client education is an important role of the rehabilitation therapist

Cranial cruciate ligament surgery causes tissue inflammation, swelling, pain and, consequently, delayed return to function, as does any major orthopedic procedure. The combination of therapeutic modalities (eg, cold compression therapy), exercise, and manual therapy can lead the patient to earlier return to function. The rehabilitation therapist will likely interact more frequently than the surgeon with the

client in the convalescent period and should provide guidance to the client in controlled activity, home environment adaptations, and return to full activity.

Physical rehabilitation should begin immediately postoperatively and continue ideally until the patient has returned to full activity. Rehabilitation techniques include manual therapy, therapeutic exercise, and therapeutic modalities, all employed with the goals of relieving pain, enhancing tissue healing, and returning the patient to activity. Rehabilitation therapists may provide guidance on environmental modification/adaptation and assistive devices, when indicated. Veterinarians practicing canine rehabilitation may also make recommendations for pharmaceutical pain management, diet, and nutritional supplements and provide treatments such as acupuncture.

5.1 | Pain management

Veterinary rehabilitation has been described as the treatment of injury or illness to decrease pain and restore function. Adequate pain management is essential for optimal healing after surgery and for progression through a rehabilitation program. Pain management will include a multimodal approach including pharmaceutical as well as nonpharmaceutical methods such as therapeutic modalities (ice/compression, neuromuscular electrical stimulation) and manual therapy (joint compressions).[37-41] Some rehabilitation therapists may provide acupuncture as an additional method of pain management.

5.2 | Therapeutic exercise

Therapeutic exercise is the cornerstone of physical therapy and veterinary rehabilitation. Exercises should be prescribed to meet predetermined goals, with the initial objective of achieving full weight bearing of the surgical limb (during gait and static), followed by increasing strength, assessed by serial strength testing or scoring. Therapeutic exercises should also focus on active ROM, neuromuscular patterning, and proprioception.[42]

A formal, in-clinic program is ideally combined with a home exercise program (HEP) because clinic-based rehabilitation that includes hydrotherapy (pool or underwater treadmill) has been documented to improve function in the short term (6 months) after CCL surgery.[1,2,5] In-clinic rehabilitation is also expected to improve client compliance with the HEP and provide a safe outlet for physical and mental stimulation while the dog is otherwise under activity restrictions. There is not a single best protocol, but two or three sessions per week starting two to three weeks postoperatively is typically recommended.[1,2,5]

Exercise progression is essential to challenge the body and build strength (overload principle).[43,44] However, progression should be based on the patient's ability to correctly complete a given exercise or activity (eg, walking, sitting) without compensation or fatigue. Patients should be provided short rest breaks between exercises and sets, and proper execution of the exercise after rest is required to consider progression. Therapists should only progress exercises after visually observing the dog, ideally in the clinic, but virtual observation via video may be considered in select cases. Progression may include increasing the number of repetitions of an exercise, duration of hold time or walking time, or intensity (such as increasing height of raised limbs or performing the exercise on an unstable surface).[42,43]

5.3 | Manual therapy

Manual therapy is considered an important component of post-CCL surgery rehabilitation. It should begin immediately postoperatively and continue as long as it is required to achieve predetermined goals. Therapists should be trained in proper techniques of joint and soft tissue mobilization with goals of reducing pain and swelling and restoring normal arthrokinematics and osteokinematics. Clients should be instructed on performing basic manual therapy techniques to desensitize the patient to human touch and facilitate early gains in PROM and flexibility.

Manual therapy techniques include

- Effleurage to decrease soft tissue swelling
- Joint compressions to decrease joint effusion
- Joint mobilization to reduce pain and improve arthrokinematics
- Passive ROM hip, stifle, tarsus to improve osteokinematics
- Soft tissue mobilization/ massage (petrissage)

5.4 | Therapeutic modalities

Therapeutic modalities transfer energy to the body for a therapeutic purpose.[45] Sources of energy include thermal (cryotherapy and heat), electromagnetic radiation (laser and pulsed electromagnetic field therapy), sound (ultrasound, extracorporeal shock wave therapy), electric (neuromuscular electrical stimulation, transcutaneous electrical stimulation), and mechanical (compression). Goals of therapeutic modalities are typically to decrease inflammation, pain, and swelling/edema and to hasten tissue healing.[45] Therapeutic modalities, if used, should be employed with specific goals in mind and adjusted on the basis of acuity of tissue healing. Most modalities offer the most potential benefit during the acute and subacute (proliferative) phases of healing.

5.5 | Return to activity

The meaning of *full activity* depends on whether the dog is a pet or a working/sporting dog. Pet dogs can return to full

activity after they can perform all activities of daily living in a controlled environment and have demonstrated strength, basic proprioception/agility, and normal ROM and have been cleared by the attending surgeon. Expectations should be set for clients, with instructions for what to do if lameness occurs after return to activity. The dog is typically rested for 1-2 days, followed by more gradual reintroduction of activity.

Returning to sport or work will require a sport/work-specific conditioning program based on tasks required of the individual dog and event. These programs typically last an additional 8-12 weeks and are beyond the scope of these general recommendations. Future guidelines may be developed specifically for returning canine athletes and working dogs to competition or the field.

Pet owners will often ask whether formal rehabilitation post-CCL surgery can prevent rupture of the contralateral CCL. It has been shown that dogs with unilateral CCL rupture have bilateral abnormal hamstring reflex activation, suggesting that neuromuscular imbalance may contribute to CCL rupture.[46] Others have studied morphometric characteristics of Labradors with CCL deficiency and found the quadriceps group to be atrophied relative to the hamstring and gastrocnemius muscles.[47] This may be due to dampened afferent proprioceptive signaling in CCL-deficient knees, causing altered recruitment and coordination of muscles.[48] While there remains much to learn about the etiology of CCL disease in dogs, it stands to reason that therapeutic exercises directed toward hamstring muscle strengthening and dynamic stability of the stifle could potentially alter the progression of CCL disease. While canine and human CCL ruptures differ in many ways, the incidence of ACL tears can be reduced by up to 70% in human female athletes through specific neuromuscular education and proprioceptive training.[49,50] Level of activity is a known risk factor for contralateral tears in man, and these patients may benefit particularly from rehabilitative interventions.[51]

At this time, the incidence of contralateral tears after formal rehabilitation in dogs with unilateral CCL rupture has not been investigated. This is an important area of research, and investigators who seek to answer this question are encouraged to design rehabilitation protocols that not only follow the guidelines suggested here but focus particularly on proprioceptive and neuromuscular training.

5.6 | Rehabilitation for nonsurgical partial CCL tears

While this Review focuses on rehabilitation after CCL surgery, there are some dogs that may be treated with nonsurgical techniques, such as orthotics or intra-articular therapies.[52-54] It was beyond the scope of our objective to review the evidence (or relative lack thereof) for nonsurgical CCL management techniques. However, the fundamental principles of tissue healing and rehabilitation therapy should continue to be applied. In these cases, the rehabilitation period is prolonged relative to postoperative therapy.

In the best case scenario, grade 1-2 ligament sprains take 2-6 months to heal (Table 2). This can be expected with extra-articular ligaments such as the medial collateral ligament.[55,56] Partial CCL tears fall in the category of grade 1-2 sprains, but the intra-articular, extrasynovial location of the CCL renders the ligament unlikely to heal.[55,56] An experimental canine study provided promising evidence for healing of partial CCL tears after multiple injections of platelet-rich plasma.[54] However, at this time, the evidence is insufficient to suggest that naturally occurring partial CCL tears will fully heal in dogs with treatment by intra-articular therapy or rehabilitation techniques. There is limited evidence that a conservative approach including nonsteroidal anti-inflammatory drugs, weight loss, and physical rehabilitation may yield successful outcomes in approximately two of three patients 1 year after CCL rupture.[57] The goals of therapy for nonsurgical patients are to support the body while natural periarticular fibrosis occurs, to strengthen the hamstring group, to provide pain management, and weight loss (if indicated).

In conclusion, this Review provides general guidelines for physical rehabilitation post-CCL surgery based on physiologic principles of tissue healing and fundamental standards of physical therapy. According to a 2017 survey of veterinary surgeons (Eiermann et al, unpublished data, October 2018), more than 90% of respondents would find specific, evidence-based guidelines valuable in managing post-CCL surgery patients. Multicenter, prospective, clinical trials should be designed with protocols developed based on the guidelines presented in this Review. Until additional data and guidelines become available, rehabilitation therapists and surgeons are encouraged to follow the fundamental principles outlined in this Review when developing rehabilitation programs for their patients.

CONFLICT OF INTEREST

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