DEVELOPING A PHYSIOTHERAPEUTIC TESTING BATTERY FOR DOGS WITH STIFLE DYSFUNCTION

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ACADEMIC DISSERTATION

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ABSTRACT

Stifle dysfunction is one of the most common reasons for canine hindlimb lameness and an indication for dogs’ referral to physiotherapy. Until now, there has been a lack of testing batteries in animal physiotherapy, although these are an important part of the evaluation process in various patient groups in human physiotherapy.

Using 64 dogs, 43 with stifle dysfunction and 21 healthy dogs, congruity between fourteen physiotherapeutic evaluation methods, commonly used in dogs with stifle dysfunction, and six evaluation methods used by a veterinarian was evaluated. The eight best methods were chosen as items constituting a testing battery, the Finnish Canine Stifle Index (FCSI). The numerical scale of the testing battery was 0-263. Cronbach’s alpha for the internal reliability of the total FCSI score was good (0.727). Two cut-offs for the total score were set: 60 and 120, separating “adequate”, “compromised” and “severely compromised” performance level, based on their high sensitivities and specificities.

Another 57 dogs, 29 with some type of stifle dysfunction, 17 with ‘some musculoskeletal disease other than stifle dysfunction’ and 11 healthy dogs, were used to further study the psychometric properties of the testing battery. The dogs with stifle dysfunction showed a significant (P < 0.001) decrease in FCSI total score (93.3 ± 62) compared with the two other groups (29.5 ± 39.6 and 11.7 ± 21.0), demonstrating good responsiveness of the FCSI. Also the inter-tester reliability was excellent (ICC 0.784), with no significant differences between three physiotherapists performing the FCSI.

In conclusion, the overall functionality and outcome of rehabilitation in dogs with stifle dysfunction can be reliably evaluated with the new testing battery, the FCSI, developed here.
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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications, which are referred to in the text by their Roman numerals:

I  Ranking of physiotherapeutic evaluation methods as outcome measures of stifle functionality in dogs

II  Use of bathroom scales in measuring asymmetry of hindlimb static weight bearing in dogs with osteoarthritis

III Developing a testing battery for measuring stifle functionality and rehabilitation outcome; the Finnish canine stifle index, FCSI
   Hyytiäinen HK, Mölsä SH, Junnila JT, Laitinen-Vapaavuori OM, Hielm-Björkman AK. Submitted 2014

IV  The Finnish Canine Stifle Index (FCSI) – responsiveness to change and reliability
   Hyytiäinen HK, Boström AF, Lind KA, Morelius M, Lappalainen AK, Junnila JT, Hielm-Björkman AK, Laitinen-Vapaavuori OM. Submitted 2014

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ABBREVIATIONS

ANOVA One-way analysis of variance
AROM Active range of motion
CCL Cranial cruciate ligament
CEBP Centre of Evidence-Based Physiotherapy
CI Confidence interval
CTRL Control dogs
CTUG Canine Timed Up and Go
ECTS European Credit Transfer and Accumulation System
FCSI Finnish Canine Stifle Index
FINFUN Finnish neurological function test battery for dogs
GC Gait cycle
GRF Ground reaction force
IAPTAP International Association of Physical Therapists in Animal Practice
ICC Intraclass correlation coefficient
ICF International Classification of Functioning, Disability and Health
IMP Vertical impulse
LLLT Low-level laser therapy
NEMS Neural electrical muscle stimulation
OA Osteoarthritis
OTHER Dogs with some musculoskeletal disease other than stifle dysfunction
PCA Principal component analysis
PROM Passive range of motion
PVF Peak vertical force
ROM Range of motion
SD Standard deviation
STIF Dogs with any stifle dysfunction
SWB Static weight bearing
TENS Transcutaneous electrical neural stimulation
TPLO Tibial plateau levelling osteotomy
UG Universal goniometer
WCPT World Confederation for Physical Therapists
WHO World Health Organization
Functionality is one of the main goals of physiotherapy. According to the official definition by the World Health Organization’s (WHO) International Classification of Functioning, Disability and Health (ICF), functionality has three main levels, which are functioning at the level of the body or a body part, of the whole person and of the whole person in a social context (WHO 2008). In short, this means that physiotherapy should consider the person’s ability to move, to perform the activities of daily living and to participate in various actions, in various environments. In veterinary medicine, such a definition does not exist, but the same principles can still be applied.

Stifle-related problems, such as cranial cruciate ligament (CCL) disease, osteoarthritis (OA) and patellar luxation, are common orthopaedic hindlimb problems in dogs (Comerford et al. 2011, Canapp 2007). At the same time, they are also the predominant indication for dogs’ referral to physiotherapy. The most frequently encountered clinical physiotherapeutic problems in stifle dysfunction patients are pain, decreased weight bearing, atrophy and decreased range of motion (ROM) in joints. To date, the use and effect of physiotherapy in treatment of stifle-related dysfunction have been reported in several publications (Marsolais et al. 2002, Jerram et al. 2003, Monk et al. 2006, Jerre 2009, Liska et al. 2009, Moores et al. 2009, Rexing et al. 2009, Au et al. 2010, Eskelinen et al. 2012, Adrian et al. 2013, Wucherer et al. 2013). In addition to the primary problems, also secondary problems, such as overloading the contralateral limb (Ragetly et al. 2010), are taken into account.

No matter if the patient is human or animal, clinical reasoning is the key of physiotherapy. It has been defined as “the sum of the thinking and decision-making processes associated with clinical practice” (Higgs et al. 2008). As clinical reasoning is based on information collected from the patient’s status (Higgs et al. 2008, Levett-Jones et al. 2010), measurement in physiotherapy is important. It is done not only to ensure the safety and efficacy of the therapy as it progresses but also to provide information to other parties involved in the patient’s treatment process (Stokes 2010). According to the European Core Standards of Physiotherapy Practice (2008), published, standardized, valid, reliable and responsive outcome measures should be used to evaluate patients’ problems and changes in health status.

Individual components of movement and anatomy, such as range of motion, strength or muscle mass, and their impairment can be measured separately and objectively. However, used separately, these may not necessarily correlate with overall functionality and/or changes in functionality, and therefore, may not be
meaningful as such. Hence, the outcome measures should focus on or at least incorporate the activities and participation levels of functionality (Stokes 2010). These types of outcome measures combine several individual measures to achieve an overall functional result, taking the form of a testing battery.

In human rehabilitation, there are several testing batteries available. The Centre of Evidence-Based Physiotherapy (CEBP) provides a database with hundreds of clinical measurement instruments (CEBP 2014). A database for especially orthopaedic problems also exists (Orthopaedic scores 2014). Knee patients alone have several commonly used outcome measures (Lysholm et al. 1982, Tegner et al. 1985, Lequesne et al. 1987, 1997, Barber-Westin et al. 1999, Gustavsson et al. 2006, Frohm et al. 2012). However, to the best of our knowledge, no publications exist on such outcome measures in small animal orthopaedics.

There is a glaring need for validated evaluation methods and functional outcome measures in veterinary medicine and physiotherapy (Brown 2007, Cook 2007, Hesbach 2007, Innes 2007, Kapatkin 2007, Shultz 2007). Many evaluation methods used in human physiotherapy are currently also applied to veterinary patients (Hesbach 2007). However, only a few of them have been studied for their validity and/or reliability when used with orthopaedic canine patients (Jaegger et al. 2002, Hesbach 2003, Thomas et al. 2006, Baker et al. 2010, Smith et al. 2013).

Any new measurement method should be thoroughly tested for its reliability and validity for the species — and in some cases even for the breed for which it is used (Brown 2007). Only after reliability and validity testing can the measurement method be used with confidence (Cook et al. 2006). The user can then be assured that the results gained with the measurement method are trustworthy and the method can be used in both clinical practice and research.

The purpose of this study was to validate several commonly used physiotherapeutic evaluation methods and to develop a validated, indexed testing battery for evaluation of overall functionality of dogs with stifle dysfunction.
Veterinary physiotherapy is a young profession; the World Confederation for Physical Therapy (WCPT) was founded in 1951, but the first international animal physiotherapy association was only accepted as a subgroup in 2011. Currently, however, physiotherapy is considered to be an essential component of the treatment protocol of canine CCL patients (Edge-Huges et al. 2007, Au et al. 2010), as it has been for human anterior cruciate ligament patients for decades (Shelbourne et al. 1990, Halling et al. 1993, Irrgang et al. 2000, Grant et al. 2013). Research in animal physiotherapy is still a fraction of what it is in humans; however, in recent years the number of reports in the field has increased notably. The first book concerning canine rehabilitation was published in 1991 (Bromiley). Only a decade ago, stifle physiotherapy-related publications were recipe-like (Gross 2002, Bochstahler 2004), giving guidelines on therapy method selection, amount and timing. Today, research and publications provide a better understanding of the factors underlying dysfunction (Adrian et al. 2013, Hayes et al. 2013), hence supporting the clinical reasoning process.

2.1 COMPARISON BETWEEN THE HUMAN KNEE AND THE CANINE STIFLE JOINT

Both the human knee and the canine stifle consist of large amplitude femorotibial and femoropatellar joints, in addition to the smaller amplitude tibiofibular and fabellotibial joints. The femorotibial joint is a spiral, compound hinge joint, with mainly uniaxial movement in the cranio-caudal direction, i.e. flexion and extension, and a braking action. The femoropatellar joint, in turn, is a sliding joint with a gliding movement (Moore et al. 2006, Budras et al. 2007a, Griffith et al. 2007).

Although the canine stifle has been reported to anatomically resemble the human knee closely (Griffith et al. 2007), there are some differences. In the canine stifle, there are sesamoid bones in the heads of the gastrocnemius and popliteus, whereas in the human knee these do not exist. Also, the canine stifle has an intra-articular long digital extensor tendon, crossing the joint in the anterior lateral compartment (Cook et al. 2010), whereas in the human knee the corresponding structure is extra-articular (Moore et al. 2006).

There are also some crucial differences regarding the functionality of the stifle; when the canine tarsus is flexed, the stifle also has to be flexed, and when extending the tarsus, the stifle must also be extended (Arthurs 2011). Thus, if there is a
limitation in the ROM of either joint, a sitting or lying position cannot be performed optimally. Humans do not have such interlocking joints. Another obvious difference is the angulations of the canine hindlimb, which are lacking in the human lower limb. The canine stifle is at all times flexed to some extent during weight bearing, whereas weight bearing in humans is mainly on an extended joint (Cook 2012). The ROM of the human knee during level walking as well as on stairs is larger than that of the canine stifle (Richards et al. 2010), whereas tarsal joint ROM is larger in dogs than in the human ankle (Richards et al. 2010). Despite these differences, the canine stifle anatomy, structures and pathology resemble the human knee so much that translational studies can be made between the canine stifle and the human knee joint (Gregory et al. 2012).

2.2 PASSIVE COMPONENTS OF STIFLE ANATOMY

The ligaments and menisci represent the passive components within the joint (Neumann 2010a). Various ligamentous and tendinous structures, the three sacs of the joint capsule and the medial and lateral menisci stabilize the stifle joint. The tendons and ligaments supporting the stifle joint are presented in Figure 1 a-d. In addition to the structures presented in the figure, the ligaments related to the fibula, i.e. the caudal fibular ligament, the cranial ligament of the fibular head, the fabello-peroneal ligaments and the fibular collateral ligaments, also have a role in stifle joint stabilization (Budras et al. 2007a, Griffith et al. 2007, Evans et al. 2010). Further, in addition to stabilizing the joint, the ligaments contribute to the stifle function via their mechanoreceptors and proprioceptors (de Rooster et al. 2006).
**Figure 1a** A schematic figure of the passive components of a dog’s left stifle. Cranial view.
*Structures in the figure are indicated by colours as follows:*
- Medial meniscus and lateral meniscus
- In front, the meniscotibial ligament of the medial meniscus, behind it the transverse ligament
- Cranial cruciate ligament
- Caudal cruciate ligament

**Figure 1b** A schematic figure of the passive components of a dog’s left stifle. Caudal view.
*Structures in figure are indicated by colours as follows:*
- Lateral meniscus and medial meniscus
- Proximal portion: meniscofemoral ligament, distal portion: meniscotibial ligament of the lateral meniscus
- Cranial cruciate ligament
- Caudal cruciate ligament

**Figure 1c** A schematic figure of the passive components of a dog’s left stifle. Lateral view.
*Structures in figure are indicated by colours as follows:*
- Proximal part: tendon of quadriceps, distal part: patellar ligament
- Lateral femoropatellar ligament
- Lateral meniscus
- Tendon of long digital extensor
- Medial collateral ligament
- Tendon of popliteus
- Joint capsule containing the meniscus, and proximal majority of the tendon of the long digital extensor

**Figure 1d** A schematic figure of the passive components of a dog’s left stifle. Medial view.
*Structures in figure are indicated by colours as follows:*
- Proximal part: tendon of quadriceps, distal part: patellar ligament
- Medial femoropatellar ligament
- Medial meniscus
- Medial collateral ligament
- Joint capsule
2.2.1. DYSFUNCTION IN PASSIVE STRUCTURES OF THE STIFLE

The reason for canine CCL ruptures remains partly unclear. It may be due to either degeneration or trauma or both. Decreased angulation of hindlimb joints, increased tibial plateau angle, genetic factors, immune-mediated arthropathies, neutering, overweight and ageing, especially in large breed dogs, are factors that have been reported to predispose to CCL rupture (Vasseur et al. 1985, Whitechair et al. 1993, Duvall et al. 1999, Mostafa et al. 2009, Griffon 2010, Baird et al. 2014, Brown et al. 2014, Haynes et al. 2014). CCL rupture is frequently accompanied by meniscal injury (Dillon et al. 2014). Moreover, the disease is often bilateral, involving both stifles in approximately 40–50% of dogs (Buote et al. 2009, Grierson et al. 2011).

Another common disease of the stifle is patellar luxation, which can be either medial or lateral from the trochlear sulcus. Medial luxation is more common in smaller breed dogs and lateral luxation in larger breed dogs (Hayes et al. 1994, Alam et al. 2007, Kalff et al. 2014). Patellar luxation involves either abnormal anatomy or positional deviations between structures in relation to each other, resulting in a disturbance in the direction of forces in relation to the anatomy of the area (Towle et al. 2005, Gibbons et al. 2006, Boundi et al. 2009, Kalff et al. 2014). Injuries of the other ligaments of the stifle are usually trauma-related and rarely isolated, often being accompanied by other more pervasive stifle injuries.

All of the above diseases eventually lead to OA of the stifle (Innes et al. 2000, Alam et al. 2011). Secondary OA is the result of joint instability or abnormal cartilage loading. As the disease progresses, articular fibrillation, cartilage damage, subchondral bone sclerosis, osteophyte formation, periarticular soft tissue fibrosis and synovial membrane inflammation occur (Vaughan-Scott et al. 1997). Clinically, this means pain and loss of function of the joint. Primary OA, in turn, is associated with ageing, during which the cartilage tissue degenerates for unknown reasons (Vaughan-Scott et al. 1997).

2.3. ACTIVE COMPONENTS OF STIFLE ANATOMY

In addition to the passive structures, the active musculature involved in the function of the joint stabilizes it dynamically (Goslow et al. 1981, Slocum et al. 1993). A large muscle group acting on the stifle joint are the “hamstrings”, comprising the mm. biceps femoris, abductor cruris caudalis, semitendinosus and semimembranosus (Williams et al. 2008). Especially the m. semimembranosus has been suggested to have a role as a medial stabilizator of the joint (Williams et al. 2008). The function of the hamstrings on the joint is to flex the stifle during non-weight bearing, and to extend it during weight bearing. In addition to the hamstrings, other flexors of the stifle joint are the mm. popliteus, gastrocnemius, gracilis and, in an assistive role, the m. flexor digitalis superficialis (Budras et al. 2007b, Williams et al. 2008).
Extensors of the stifle joint are the mm. tensor fascia latae and quadriceps femoris, the latter consisting of four parts: mm. vastus lateralis, vastus medialis, vastus intermedius and rectus femoris. Musculus sartorius has two functions regarding the stifle joint; it flexes the joint with its caudal part and extends the joint with its cranial part. Innervation to the muscles involved in stifle function is provided mainly by the ischiadic, common peroneal, obturator, tibial and femoral nerves or branches thereof (Budras et al. 2007b). It should be noted that the mm. semimembranosus, semitendinosus, biceps femoris and gracilis also have a minor extensor role, although mainly being flexors of the joint (Williams et al. 2008). Musculus semitendinosus has been shown to act as an agonist of the CCL of the stifle, and mm. quadriceps and gastrocnemius as antagonists (Kanno et al. 2012).

The muscles involved in stifle function are often also involved in hip and tarsal function, and their function in relation to the stifle may not be isolated merely to the stifle.

2.3.1. DYSFUNCTION IN ACTIVE COMPONENTS OF STIFLE ANATOMY

Although the muscle mass of a surgically treated CCL patient’s m. quadriceps often remains smaller than that of the contralateral limb (Mostafa et al. 2010), the problem does not only lie in the loss of mass, suggesting a lack of strength in the muscles. Dynamic stifle stability and motor control are also repressed. This is well-recorded in humans with anterior cruciate ligament rupture (Williams et al. 2001, Baczkowicz et al. 2013, Di Stasi et al. 2013, Roos et al. 2014), but has only recently been recognized in dogs with CCL disease (Adrian et al. 2013, Hayes et al. 2013).

The implications of impaired motor control may be severe. An example of this would be an abnormality in the hamstring reflex in canine CCL disease. The hamstrings limit the cranial tibial translation, hence protecting the CCL from strain and limiting cranial tibial subluxation in an stifle with an injured CCL. If the reflex timing is not correct, the force of the mm. quadriceps and gastrocnemius may overpower the hamstrings, thereby causing strain in the CCL (Hayes et al. 2013).

Dysfunction in the complex motor control system plays a role not only in rehabilitation of the ruptured CCL but also in prevention of OA after CCL rupture. A potential rupture of the contralateral CCL could possibly be prevented or at least minimized by putting emphasis on hindlimb muscle control during rehabilitation (Mostafa et al. 2010, Adrian et al. 2013, Hayes et al. 2013).
2.4. BIOMECHANICS OF THE STIFLE

Biomechanics, including kinetics and kinematics, is an important factor in animal functionality. Kinetics is the study of the effects of forces and torques on a body, and kinematics describes the motion of the body, regardless of the forces and torques that may have produced the movement (Neumann 2010a).

Range of motion describes the amount of motion in a joint. It may be either a passive range of motion (PROM) produced by a source other than the subject’s own activated muscle or an active range of motion (AROM) produced by the subject’s own muscle work (Neumann 2010a). PROM measurements in the stifles of three different breeds of dogs have been reported. The maximum flexion reported was $33^\circ \pm 9-18^\circ$, and the largest extension $162^\circ \pm 8-17^\circ$ (Jaeger et al. 2002, Thomas et al. 2006, Nicholson et al. 2007). Although the AROM during walking and trotting is less than the PROM, a $10^\circ$ loss in passive extension can cause a visible lameness in the dog (Jandi et al. 2007).

When studying various breeds on ground and treadmill, flexion and extension of the stifle during walking and trotting have ranged between $86.4^\circ$ and $165.3^\circ$, with a mean flexion of $11.9^\circ$ and mean extension of $147.5^\circ$, calculated from the available references (Lauer et al. 2009, Agostinho et al. 2011, Durant et al. 2011, Ragetly et al. 2012, Brady et al. 2013). During ambulation the period from a heel strike of a limb to the next heel strike of that same limb is described as a gait cycle (GC). The GC is a combination of stance phases and swing phases. During a stance phase a limb is in contact with the ground, supporting the body weight. During a swing phase there is no ground contact, and the limb is free of weight bearing as it is protracted (Simoneau 2010). The range of motion in the stifle joint during a GC changes according to the phase of the GC; during the swing phase the highest flexion is recorded in the middle of the swing phase or at the beginning of the late swing phase and the highest extension at the very end of the swing phase. In the stance phase, the highest flexion is present at late stance and the highest extension at the very beginning of the stance phase (Fu et al. 2010, Durant et al. 2011, Bockstahler et al. 2012, Brady et al. 2013).

Lameness and alterations in joint kinematics are obvious signs of stifle dysfunction, but there may also be asymmetry in the use of stifle joints in healthy dogs. Laterality, when defined by a total support moment (algebraic sum of the extensor moments at the hip, knee and ankle joints (Winter 1980)), may affect the joint moments and power profiles, as well as the joint angles (Colborne 2008, Colborne et al. 2011). There is a difference in the timing of the stifle joint moments in the non-dominant and dominant limbs. The flexor effect changes to an extensor effect at approximately 15% before the midstance on the non-dominant side. On the dominant side, the flexor effect remains until midstance. Therefore, the extensor moment amplitude is larger on the non-dominant side during the second half of the stance phase. Also, the
moment is smaller on the right stifle of a right-sided dog, whereas in other joints of the hindlimb the moment is higher in the dominant limb (Colborne et al. 2011). The angle of the stifle joint during stance time has been reported to be 5° more flexed on the dominant limb of a healthy dog (Colborne 2008). In addition, the position of the dominant crus was 3-4° more cranially inclined through the stance phase than the non-dominant crus (Colborne 2008).

Speed plays an important role in movement. With an increase in speed of trotting from 1.99 to 3.30 m/s, the stifle flexors are affected with a significant increase in positive power at the beginning of the support phase (Colborne et al. 2006). Alterations in gait kinetics also depends on speed; stance time shortens more than swing time as speed increases (Colborne et al. 2006).

2.5. BIOMECHANICS IN RELATION TO STIFLE DYSFUNCTION

As a dog steps on the ground, its limb produces a force towards the ground. Based on Newton’s third law, the ground simultaneously then provides an equal force towards the limb. This force is called the ground reaction force (GRF) (Simoneau 2010). During a stance phase forces in three directions can be measured: vertical (including both peak vertical force (PVF) and vertical impulse (IMP)), cranio-caudal and latero-medial. In obese dogs, both PVF and peak horizontal force in propulsive and braking directions are higher than in lean dogs (Brady et al. 2013).

Evident changes and asymmetries in movement are well-reported in CCL and stifle OA pathology. The vertical GRF as well as the joint reaction force, angular velocity, flexor moment and power of the stifle joint during the stance phase are decreased in stifles with CCL disease (Madore et al. 2007, Ragetly et al. 2010). Moreover, there is less movement in the joint during the swing phase, and the extension in the push-off phase of healthy limbs is absent in CCL-diseased stifles (Ragetly et al. 2010). Peak caudal forces, caudal impulses and cranial and caudal limb loading are lower in CCL-diseased dogs. This means that during the stance phase dogs with stifle OA load, brake and propulse earlier than healthy dogs, although the amount of forces is less (Madore et al. 2007).

In a study by Ragetly et al. (2012), a group of dogs predisposed to CCL disease based on the tibial plateau and femoral anteversion angle was studied. These dogs were reported to have a 8.4° larger flexion angle in their stifles during the stance phase, and the energy produced by muscles involved with the stifle joint were reported to be almost double in the early stance phase and flexion, compared with non-predisposed dogs (Ragetly et al. 2012). In addition, the tarsal extension was reported to be 18° less than in the controls (Ragetly et al. 2012), which is interesting considering the previously mentioned co-operation between the two joints in the dog.
The stride length of the CCL rupture dogs’ affected hindlimb is shorter and the ROM of stifle joint is smaller than in healthy dogs (Sanchez-Bustinduy et al. 2010). The stifle angular velocity as well as the paw velocity are highly significantly different in CCL rupture dogs than in control dogs (Sanchez-Bustinduy et al. 2010). After surgical treatment, the duration of the stance phase does not quite normalize, nor does the velocity of the limb normalize 12 weeks’ postoperatively after tibial plateau leveling osteotomy (TPLO) (de Medeiros et al. 2011).

It is known that overweight dogs have altered kinematics relative to their normal-weight peers (Brady et al. 2013). Stride length in obese dogs is 8% shorter than in their lean counterparts. During stride the amount of joint movement in other major joints of the hindlimb differs from that of healthy dogs, although the ROM of the stifle joint does not (Brady et al. 2013). However, the abnormal kinematics in other joints also affects the stifle joint, as function of limbs joints cannot be totally isolated during ambulation.

2.6. CURRENT CONCEPTS OF CANINE STIFLE PHYSIOTHERAPY

At the beginning of last decade in Finland, animal physiotherapy practices following surgical treatment of CCL disease patients were somewhat variable. It was common for patients to be referred to physiotherapy at around six weeks’ post-surgery. This policy was influenced by Monk et al. (2006), who published a paper on the effects of early intensive physiotherapy on the rehabilitation and treatment outcome of these patients. Nowadays, the common practice is to start active physiotherapy at two weeks’ post-surgery for CCL patients.

After treatment of stifle pathology, several rehabilitation procedures have been proposed (Gross 2002, Marsolais et al. 2002, Millis et al. 2004a, Monk et al. 2006, Edge-Huges et al. 2007, Jerre 2009, Liska et al. 2009, Au et al. 2010). However, the effect of physiotherapy after surgical treatment of CCL on stifle function has been studied in only three reports. In two of them (Marsolais 2002, Monk 2006), physiotherapy was found to be beneficial. In one (Jerre 2009), swimming and electrical stimulation as therapy methods were reported not to improve the outcome of these patients relative to controls treated with the same surgical technique.

The therapy methods used vary between the two studies reporting a benefit. Marsolais et al. (2002) used massage, PROM, walking and swimming at intervals. Monk et al. (2006), in turn, included massage of thigh muscles, PROM of stifle, functional weight bearing exercises, cold, underwater treadmill and progressive active therapeutic exercises in their protocol. Jerre (2009) used swimming and transcutaneous electrical neural stimulation (TENS), and also gave instructions for massage and stretching to the owner. In all of these reports, physiotherapy started from 2 hours to 2 or 3 weeks after surgery, and the active rehabilitation...
period lasted until 6 to 12 weeks' postoperatively. Also, the intensity of physiotherapy varied markedly between the reports: 2 times a day for 5 days every second week for 3 separate weeks postoperatively (Marsolais et al. 2002), 3 times per week for 6 weeks (Monk et al. 2006) and 2 times per week for 4 weeks, then once a week for 8 weeks (Jerre 2009).

Reports of physiotherapy as part of treatment in other stifle-related diseases exist, although the efficacy of therapy as such has not been the target of the studies. Physiotherapy has been described as a part of successful quadriceps contracture treatment (Moores et al. 2009), and in two reports (Liska et al. 2009, Eskelinen et al. 2009) physiotherapy is presented as a normal part of the total stifle replacement protocol.

2.6.1. PASSIVE THERAPY METHODS IN STIFLE DYSFUNCTION REHABILITATION

Cold is one of the most commonly used therapies in stifle rehabilitation in dogs (Monk et al. 2006, Rexing et al. 2010). Cold compresses alone have been shown to limit swelling (Rexing et al. 2010). Either cold combined with bandaging or bandaging combined with microcurrent treatment provided more effective treatment than bandaging alone in the acute phase after extracapsular treatment of CCL rupture (Rexing et al. 2010). In human knee patients, the use of cold compression has been shown to result in less pain and swelling and increased ROM postoperatively than in the control group without cold compression (Schröder et al. 1994). In human arthritic patients, cold is also used as a pain-relieving method (Peter et al. 2011).

Although massage has been reported as a component of stifle rehabilitation (Marsolais et al. 2002, Monk et al. 2006, Jerre 2009), some current human guidelines do not recommend massage in physiotherapy protocols for knee arthritis, instead emphasizing more active strategies (Peter et al. 2011). However, massage should not be overlooked as a management method in dogs due to its clear diminishing effect on pain and stress (Sutton 2004, Edge-Huges et al. 2007).

Passive range of motion exercises (Marsolais et al. 2002, Monk et al. 2006, Edge-Huges et al. 2007, Au et al. 2010) are usually perceived as the flexion – extension of the stifle joint performed either by the therapist or by the owner according to the therapist’s instructions. The aim of these exercises is to increase or maintain ROM through repeated movement. Moreover, PROM may include various specific manual mobilization techniques performed by the therapist, which, in addition to increasing the ROM and limiting the pain, aim to affect proprioception by stimulating ruffini endings and Pacinian corpuscles (Edge-Huges et al. 2007, Goff et al. 2007b).

Electrotherapy modalities, such as TENS and neural electrical muscle stimulation (NEMS), have also been reported as part of the stifle patient’s rehabilitation. Despite Jerre’s (2009) finding that TENS was not an effective treatment method in dogs
after surgical treatment of CCL, Levine et al. (2002) have shown that it does have some positive effects on dogs with stifle OA. Johnson et al. (1997), in turn, delivered conflicting results when rehabilitating dogs with surgically treated CCL with NEMS. All clinical signs (lameness score, thigh circumference and OA findings) other than GRF were significantly better in dogs with EMS treatment than in control dogs, who received only cage rest and showed a slow return to normal movement. Moreover, several publications encourage the use of NEMS with CCL patients (Gross 2002, Millis et al. 2004a, Edge-Huges et al. 2007), probably based on authors’ personal experience.

The effect of low-level laser therapy (LLLT) on canine stifle disease or dysfunction has not yet been studied. However, use of LLLT might still be indicated, as it promotes tissue healing and decreases inflammation and pain (Baxter 2002, Canapp 2007). LLLT has been reported as a component of the rehabilitation of a total stifle replacement patient (Eskelinen et al. 2012).

2.6.2. ACTIVE THERAPEUTIC EXERCISES IN STIFLE DYSFUNCTION REHABILITATION

Active therapeutic exercises are the most important part of physiotherapy. They involve any type of therapy that aims to affect the healing process through the patient’s own active movement. Examples of active therapeutic exercises are hydrotherapy, balance board or cushion training, stairs, ground shapes or other obstacles that affect the movement of the dog. The exercises are often progressive in nature (Edge-Huges et al. 2007).

Hydrotherapy, either swimming or walking on an underwater treadmill, is a therapy method often used when rehabilitating stifle patients (Marsolais et al. 2002, Levine et al. 2004, Monk et al. 2006, Jerre 2009, Au et al. 2010). The benefits of water as an element come from its density, specific gravity, buoyancy, hydrostatic pressure, viscosity, surface tension and refraction (Levine et al. 2004, Monk et al. 2006). Swimming causes significantly larger ROM in the stifle joint than walking on land. This has been shown with both healthy dogs and dogs with surgically treated CCL disease (Marsolais et al. 2003). The mean angular velocities and the ROM of the stifle are smaller in CCL-treated dogs than in healthy ones (Marsolais et al. 2003). When comparing dry and underwater treadmill, the extension of the stifle in early stance phase is equal if the water level is lower than the stifle (Levine et al. 2004). With the underwater treadmill in the late stance phase, the extension decreases if the water is above the depth of the stifle (trochanter major), and the joint flexion angles become smaller especially in submerged joints (Levine et al. 2004).

Swimming facilitates different movement patterns than walking, and it is therefore not appropriate to train walking through swimming (Bockstahler et al. 2004). In addition, swimming is an open kinetic chain task, meaning that there is
no ground contact or weight bearing during the movement (Neumann 2010a). Some surgical treatment techniques for CCL disease rely on weight bearing to provide stability to the joint (Au et al. 2010). As swimming does not provide weight bearing, it actually works against the basic principles of surgical treatment. Thus, swimming is not an ideal therapy method for these patients. The importance of functionality in therapeutic exercises should always be emphasized. This means that the exercise should have some relation to the movements performed during normal ambulation or during activities of daily living.

In human knee rehabilitation, therapeutic exercises have been shown to have an effect on the symptoms of knee OA (Fransen et al. 2008, Benell et al. 2011, Kruse et al. 2012). Exercises used in humans after anterior cruciate ligament surgery include hamstring and quadriceps muscle group strengthening, vibration and proprioceptive balance (Kruse et al. 2012). The importance of the receptor system of the knee and the role of proprioception are well known (Hewett et al. 2002, Neumann 2010b). Although no studies have been conducted on the effect of a balance board and balance cushion exercises on the proprioception of dogs, these are nevertheless very commonly used in small animal physiotherapy (Hamilton et al. 2004, Edge-Huges et al. 2007).

Also different ground surfaces and shapes are used to enhance the therapeutic exercises; a 5% incline or decline on the treadmill does not affect the muscle activity of the quadriceps any more than walking on a flat surface. However, at the beginning of the stance phase, hamstrings activate significantly more during an incline than during a decline, whereas at the end of the stance phase the hamstrings activate more during an incline than during a decline or on a flat surface (Lauer et al. 2009). Moreover, in a treadmill incline, the extension in the stifle decreases relative to the decline situation (Lauer et al. 2009). Further, walking uphill has been shown to decrease stifle flexion (Richards et al. 2010). Flexion, on the other hand, may be emphasized in stair accent; 27.5° more than in level-ground trotting, with the overall ROM being almost 20° larger in stair accent than in trotting (Durant et al. 2011). Hurdles are also used as part of active therapeutic exercises, and they have been shown to increase both stifle extension and flexion (Richards et al. 2010).

2.7. EVALUATION OF CANINE STIFLE REHABILITATION

The physiotherapeutic examination of the patient starts with observation of positions, posture and movement of the dog (Goff et al. 2007a). If needed, various questionnaires, such as the Glasgow University Veterinary School Questionnaire, the Canine Brief Pain Inventory or the Helsinki Chronic Pain Index, may be used to measure or clarify the dog’s level of pain and related changes (Wiseman-Orr et al. 2006, Brown et al. 2007, Hielm-Björkman et al. 2009). An important part of
the physiotherapeutic examination is palpation of the musculoskeletal structures. Specific active and passive movement tests may be done, and some functional tests are performed (Goff et al. 2007a). The methods can be divided into subjective and objective evaluation methods.

2.7.1. SUBJECTIVE EVALUATION METHODS

Although often considered inferior to objective methods in research, subjective methods are an important part of the physiotherapeutic evaluation. In horses, for example, an association between a physiotherapist’s palpation findings and a fracture diagnosis of either pelvis or hindlimbs, has been shown (Hesse et al. 2010). The ability of an experienced manual physiotherapist to detect even a 1° temperature change by means of palpation has been reported (Levine et al. 2014). Also a physiotherapist’s ability to visually evaluate ROM in human joints, such as the elbow, has been demonstrated to be high (Blonna 2012). When comparing a visually evaluated ROM of a knee with universal goniometer (UG) measurements, the intra-tester reliability of flexion by an intra-class correlation coefficient (ICC) was shown to be 0.93 and of extension 0.94, while the inter-tester reliability of flexion was 0.86 and extension 0.82 (Watkins et al. 1991).

2.7.1.1. Evaluating positions and position changes

Part of evaluating a dog’s functionality is to assess its ability to perform different positions, the quality of the positions and position changes (Millis 2004b, Canapp 2007b, Hesbach 2007). Paying attention to the types of compensations presented during these positions, such as sitting or lying position, gives important information regarding possible limitations to movement and underlying reasons. However, when this thesis work was started, these methods had not yet been validated, although in daily use in veterinary physiotherapy practice.

2.7.1.2. Visual lameness evaluation

The most common evaluation method used by veterinarians and physiotherapists alike is undoubtedly the visual lameness evaluation. Usually the rating of lameness is done on a numerical scale, graded from 0 ( = clinically sound) to 5 ( = could not be more lame) (Quinn 2007) or from 0 ( = no lameness ) to 4 ( = non-weight bearing) (Mostafa et al. 2009). Although commonly used in orthopaedic and physiotherapeutic examinations of small animals, it is a weak method of lameness
evaluation relative to the force platform, and also has a poor agreement between evaluators unless the lameness is severe (Quinn et al. 2007, Waxman et al. 2008). Visual lameness evaluation may be done on a level ground to detect asymmetry in weight bearing or by adding such obstacles as hurdles or stairs (Millis 2004c). In addition to determining the grade of weight bearing lameness, the physiotherapist also observes the quality of movement of the dog, e.g. AROM in limbs during movement (Hesbach 2007).

2.7.2. OBJECTIVE EVALUATION METHODS

To measure outcome after physiotherapeutic interventions, objective, validated and reliable measurement methods are preferred.

2.7.2.1. Universal goniometer

Numerous studies in humans have shown the inter-tester reliability for the universal goniometer (UG) to be only weak to moderate (Armstrong et al. 1998, Lenssen et al. 2007, Carter et al. 2009), with an error limit of 10° in both flexion and extension (Armstrong et al. 1998).

However, the intra-tester reliability in humans has been shown to be good (Watkins et al. 1991, Carter et al. 2009). Nevertheless, error due to the measurer is an important factor when considering the accuracy and reliability of UG results. In human cadaveric wrist measurement, errors of 6° in flexion and 7° in extension have been reported (Lessen et al. 2007). On the other hand, in human total knee arthroplasty patients, errors as large as 18° in flexion and 8° in extension have been noted (Carter et al. 2009). In human elbow ROM measurements, the intra-measurer error limit has been defined to be at 6° in flexion and 7° in extension (Armstrong et al. 1998).

The UG has proven to be a reliable method in measuring dogs’ stifle PROM (Jaegger et al. 2002, Thomas et al. 2006). Surprisingly, in dogs, the intra-tester accuracy of UG has been found to be somewhat better than in humans. In one study on dogs, a 4° accuracy was reached (Crook 2001), whereas another study presented an accuracy of 1–6° (Jaeger et al. 2002). The UG reliability has also been shown to be superior to the electrogoniometer in dogs (Thomas et al. 2006).

It should, however, be kept in mind that there is a margin of error to the reliability of the tool itself: a ±2.9° inter-goniometric variance is present when a hinged UG is used (Loder et al. 2007). Validity and reliability of use of the goniometer in dogs have been studied using UGs with 1° or 2° increments (Jaeger et al. 2002, Thomas
et al. 2006). Experience of the measurer does not seem to affect the reliability of UG measurement in humans or in dogs (Armstrong et al. 1998, Jaeger et al. 2002).

In addition to putting emphasis on intra-measurer reliability and intra-goniometer reliability (i.e. the same measurer should measure with the same device to obtain the most reliable results), an important part of measuring ROM is the standardization of the protocol, and especially the positioning of the dog’s hindlimb (Nicholson et al. 2007). The limb should be placed so that the ROM of the joint in question is not affected by the positioning of the adjacent joints or soft tissues (Nicholson et al. 2007). As normal values have been reported based on standardized ways of measuring, these protocols should be followed when measuring PROM in order to yield comparable results (Jaegger et al. 2002, Nicholson et al. 2007).

Sedation has not been described to affect the results of UG measurement relative to measurements taken from an alert dog (Jaeger et al. 2002), but general anaesthesia may affect the results (Thomas et al. 2006). Another factor that might affect the results of stifle ROM measurement is atrophy, as leaner hamstring muscle mass may allow more flexion of the stifle joint, and larger muscle mass may limit the flexion (Jaeger et al. 2002).

### 2.7.2.2. Tape measure in thigh circumference measurement

A tape measure has been used to objectively quantify the muscle mass in hindlimbs (Moeller et al. 2010). One method of measuring the thigh circumference is to put the dog in lateral recumbency and measure circumference at 70% distal from the trochanter major, with the stifle in full extension (Millis 2004b). Some recent studies have, however, shown weakness in the method of using a tape measure in measuring dogs’ hindlimb circumference (Baker et al. 2010, Smith et al. 2013). According to one study, the inter- and intra-tester reliability for measuring the circumference of both the proximal crus and the mid thigh was poor (Smith et al. 2013). Another study has compared four different tape measures commonly used (Gulick II, retractable, ergonomic and circumference measuring tape) and found variance in the results obtained with the different tools. The study also showed a weak inter-tester reliability and emphasized the importance of a single measurer performing all measurements with the same device (Baker et al. 2010).

### 2.7.2.3. Bathroom scales

Bathroom scales have been used in small animal orthopaedic research to measure outcome of an intervention through static weight bearing (SWB) between hindlimbs. Bathroom scales were used as a measurement tool when studying the healing of the
canine tibial cortex and osteotomies under external fixation (Meadows et al. 1990, Aro et al. 1991). Recovery after total stifle joint transplantation in dogs was also evaluated according to the changes in SWB measured with two industrial scales set under the hindlimbs (Schäfer et al. 2000). These studies point out the importance of measuring SWB as an outcome measure. Bathroom scales are affordable and fast and easy to use in clinical work. With humans, it is a very commonly used tool (Bohannon et al. 1989, Bohannon et al. 1991, Hurkmans et al. 2003). This method had not, however, been validated for dogs.

2.7.2.4. Pressure sensitive walkway

Pressure sensitive walkways have been used to measure the outcome of treatment in surgically treated stifle dysfunction in dogs (Gutbrod et al. 2013, Souza et al. 2014). They are an objective, quantitative tool for evaluating the effect of therapy through temporospatial factors (Kim et al. 2011). The walkways give information on such parameters as the GC length and duration, stance time and indexed value of total pressure (Gaitfour Users Manual 2009), or PVF and IMP depending of the product used. When a dog ambulates over the walkway, an accompanying software program interprets changes in pressure on the sensors imbedded in the mat (GaitFour Users Manual 2009). Normal values for the temporospatial factors for Labrador retrievers at walk have been established, with the authors simultaneously presenting a protocol for collecting such information using the pressure sensitive walkways (Light et al. 2010). In healthy dogs, the pressure sensitive walkway has been reported to present systematically lower PVF and IMP values than the force platform. The same phenomenon was recorded in the front limbs of lame dogs (Lascelles et al. 2006). However, although these two devices measure different things, the pressure sensitive walkway does give consistent results, therefore being reliable to use so long as straight comparisons are not made (Lascelles et al. 2006).

2.7.2.5. Force platform

Based on piezoelectric gauges sensing the forces and accompanied software translating the data, force platforms are yet another method of quantifying dogs’ movement, in this case through horizontal and vertical GRFs. Dogs with stifle dysfunction can be examined on a force platform both in walk and trot (Evans et al. 2003). In small animal stifle orthopaedics, the most commonly presented values are the PVF and IMP (Budberg et al. 1988, Marsolais et al. 2002, Conzemius et al. 2005, Lascelles et al. 2005, Madore et al. 2007, Voss et al. 2008, Wucherer et
Due to its objectivity, the force platform has achieved a “golden standard” status in lameness evaluation (Evans et al. 2005).

2.8. TESTING BATTERIES IN HUMAN PHYSIOTHERAPY

Outcome measures used with human knee patients include both owner-completed questionnaires and clinician-completed testing batteries. The emphasis of this thesis is on the latter. The psychology dictionary (2014) defines a testing battery as “a set or series of correlated presumptions delivered at one time, with scores documented separately or mixed to produce a single score.” When evaluating function of the patient and clinically meaningful change in the patient’s performance level, the testing battery type of outcome measurement is preferable to individual measurements (Stokes 2010).

The decision of which testing battery to use is based on several factors. First, the purpose and aim of the testing must be defined; discrimination, evaluation or prediction of a disease or a patient’s status. Second, the most suitable testing battery for the group of subjects being tested must be selected; in humans, task-specific, age-specific or diagnosis-specific tests can be separated. Third, the psychometric properties of the testing batteries affect the decision, as do personal preferences, skill of the therapist and time, space and equipment available (Shumway-Cook et al. 2012).

There are several testing batteries for human knee patients. Anterior cruciate ligament injury in humans is often trauma-related (Moses et al. 2012, LaBella et al. 2014), and most of the patients are athletes. A good example of a knee-related testing battery is the Nine-Test Screening Battery For Athletes, used, for instance, with soccer players (Frohm et al. 2012). The testing battery is used to screen the athlete’s movement patterns, as non-functional patterns may predispose the athlete to injuries. This testing battery includes active tasks such as the deep squat test, the one-legged squat test, the in-line lunge test, the active hip flexion test, the straight leg raise test, the push-up test, the diagonal lift, the seated rotation test, and the functional shoulder mobility test. Each item is scored from 3 (= correct with no compensatory movements) to 0 (= pain present), and the highest total score of the test is 27 points, indicating no non-functional patterns.

Another testing battery to evaluate performance in sports-related items is the Cincinnati Knee Rating System, which includes six items: walking; using stairs; squatting and kneeling; straight running; jumping and landing; hard twists, cuts and pivots. The lowest total score is 120 and the highest 240, with a higher score indicating better performance (Noyes et al. 1989, Barber-Westin et al. 1999).

The Score of Lysholm and Gillquist for Evaluating Athletes After Knee Ligament Surgery consists of eight items: limp, support, stair climbing, squatting, walking-,
running- and jumping-related instability, pain, swelling, and atrophy of thigh. The total score is 0-100, with a higher score indicating better function. Four cut-offs for the level of outcome are provided: 65 or less indicating poor, 66-81 fair, 82-92 fair to good, 93-97 good to excellent and 98-100 excellent outcome (Lysholm et al. 1982).

Originally generated for evaluating functional status of total knee arthroplasty patients, the Knee Society Scale includes 10 items, some active and functional (tasks performed by the testee) and some passive measurements, e.g. range of motion measurement or degree of valgus position of the joint. If the passive measurements and functional performance are both optimal, the patients can obtain a maximum final score of 200 points (Insall et al. 1989).

For evaluation of knee osteoarthritis patients, The Index of Severity for Osteoarthritis of the Knee has been divided into three main categories: pain or discomfort, maximum distance walked and activities of daily living. Each of these categories includes 2-5 items. The items in the second and third categories (the active categories) are maximum distance walked and walking aids required, and ability to climb up and down stairs, squat or bend the knee and walk on an uneven ground. Minimum total score of the index is 0, maximum 24. Final score indicates the level of handicap, with a score of 0 indicating no, 1-4 mild, 5-7 moderate, 8-10 severe, 11-13 very severe and above 14 extremely severe handicap (Lequesne et al. 1987, 1991, 1997).

2.9. TESTING BATTERIES IN ANIMAL PHYSIOTHERAPY

To our knowledge, there are no equivalent clinician-completed testing batteries for dogs with stifle dysfunction, although some testing batteries for other impairments in dogs exist. Two tests derived from human medicine have been validated in dogs. The 6-Minute Walk Test is used for functional exercise capacity in humans (American Thoracic Society 2002). A canine version of the test has been used for evaluating the physical performance level of dogs with pulmonary disease and induced congestive heart failure, and it has been reported to be able to separate the pulmonary-diseased dogs from healthy ones, as well as dogs with and without heart failure (Boddy et al. 2004, Swimmer et al. 2011). Another test, the Canine Timed Up and Go (CTUG), which measures the time it takes for a dog to stand up from a lying position and to ambulate a distance of 7 metres, has also been assessed for its validity and intra- and inter-tester reliability. It can be used to evaluate changes in orthopaedic lameness in dogs (Hesbach 2003). In humans, the original Timed Up and Go test is used to evaluate functional mobility in the elderly and in Parkinson’s and Alzheimer’s patients (Steffen et al. 2008, Ries et al. 2009, Mangione et al. 2010).
Three testing batteries have been developed and validated specifically for neurological canine patients: the hindlimb functional scoring system (Olby et al. 2001), the Texas Spinal Cord Injury Score (Levine et al. 2009) and the Finnish neurological function test battery (FINFUN) (Boström et al. 2014). Like the human testing batteries, these three batteries for dogs give a numerical score indicating the level of impairment of the patient. The third battery, FINFUN, is especially targeted to evaluating functionality.

2.10. EVALUATING A TESTING BATTERY

Important factors in all testing batteries are sensitivity, specificity, validity, reliability and responsiveness.

Sensitivity describes the level to which the test detects the dysfunction (i.e. can find dysfunctional individuals in a group of dogs), and specificity describes the level to which the test manages to rule out dysfunction when it is not present (i.e. does not give false positives) (Altman et al. 1994).

Validity describes the internal solidity of the testing battery. Face validity indicates the degree to which the test measures what it is supposed to measure (Mosier 1947). Construct validity, in turn, indicates the level to which the test behaves as it is expected to behave (Anastasi 1950). Concurrent or criterion validity is the degree to which the test agrees with other comparable tests (Cronbach et al. 1955).

Reliability describes the ability of the testing battery to repeat the results. It can be tested through various approaches: test-retest (different time, same measure), parallel testing (same time, different measures) and internal consistency (same time, same measure) (Kuder et al. 1937, Cronbach 1947, Nunnally et al. 1978). The test-retest method includes both inter-tester reliability, i.e. how comparable the results obtained by two measures are, and intra-tester reliability, i.e. how comparable the results of one measurer are when obtained at separate measuring times (Bartko et al. 1976).

When developing a measurement tool for evaluating a patient’s health status at different time-points, responsiveness is important. Responsiveness refers to the test’s ability to detect clinically meaningful change over time (Stratford et al. 1996).
3. OBJECTIVES OF THE STUDY

The main objectives of the thesis were as follows:

1. To validate and rank some of the most common physiotherapeutic evaluation methods used in dogs with stifle dysfunction.

2. To investigate the use of bathroom scales in measuring static weight bearing in hindlimbs of dogs with stifle dysfunction and to report the normal variation of weight bearing between the hindlimbs in a static state.

3. To combine information of the previous two studies and to develop a testing battery with a numerical scale for evaluating the overall functional status of dogs with stifle dysfunction.

4. To report the responsiveness and inter-tester reliability of the testing battery developed.
4. MATERIALS AND METHODS

4.1. STUDY DESIGN

All four studies were prospective case-control studies. Three of the studies were completely blinded (I, II, III), and the fourth (IV) was blinded with regard to the inter-tester reliability.

4.2. ANIMALS

For Studies I-III, 43 dogs with surgically treated CCL and 21 control dogs were recruited from another study conducted at the Helsinki University Veterinary Teaching Hospital (Mölsä et al. 2014). The CCL dogs had a unilateral, surgically treated cranial cruciate ligament rupture with a minimum time interval of one year between surgery and evaluation. They also had OA findings in their surgically treated stifle. Any possible pain medication (nonsteroidal anti-inflammatory drugs, opioid or corticosteroid pain medication) and nutraceutical and fatty acid supplements were withdrawn at a minimum of 7 days, long-term corticosteroids 30 days, and pentosan polysulphate 90 days before the evaluation. The control dogs did not have any known orthopaedic problems or abnormal findings in the orthopaedic examination. They had radiographic screening results free of hip dysplasia according to the Federation Cynologique Internationale screening protocol (grade A or B) (Suomen kennelliitto 2014).

In Study IV, 57 veterinarian-referred dogs without neurological symptoms that attended physiotherapy at the Veterinary Teaching Hospital of the University of Helsinki during 1.6.2013-1.4.2014 were included. Dogs may have had varying medications for their different diseases during the study, but due to ethical reasons their medication was not interrupted nor tempered for the benefit of the study. The dogs were divided into three groups: dogs with any stifle dysfunction (STIF), dogs with some musculoskeletal disease other than stifle (OTHER) and control dogs (CTRL). An open invitation was sent to all 4th and 5th year veterinary students studying at the Helsinki University Veterinary Faculty to enrol healthy dogs in the CTRL group. The first 16 dogs offered were enrolled. The control dogs were considered healthy based on an orthopaedic examination, pressure sensitive walkway analysis and radiological examination of stifle and hip joints.

All four studies were approved by the University of Helsinki Ethics Review Board at Viikki Campus. A written consent from dog owners was obtained from both cohorts.
4. MATERIALS AND METHODS

4.3. RANKING AND VALIDATING PHYSIOTHERAPEUTIC EVALUATION METHODS (I-III)

To evaluate criterion validity, i.e. the degree to which the test agrees with other comparable tests, the results of 14 physiotherapeutic evaluation methods were compared with the results of clinical evaluation methods used by the veterinarian, including orthopaedic examination, force platform analysis, radiological examination and conclusive assessment. Within all of the following evaluation methods used in Studies I-III, the dogs were classified into three to four or possible five groups according to their findings, for further analysis. These groups are presented in Table 1, where, depending on the method, 0 = represents normal or no findings, 1 = mild findings, no findings or symmetrical performance, 2 = moderate findings, decreased performance / symptoms in left hindlimb, 3 = severe findings, decreased performance / symptoms in right hindlimb, 4 = bilateral findings. Some variables were assigned into four groups and others only into three, as some methods cannot differentiate bilaterally symptomatic from bilaterally asymptomatic findings (Table 1).

4.3.1. FOURTEEN-ITEM PHYSIOTHERAPEUTIC EXAMINATION (I)

The studied methods were visual evaluation of lameness, visual evaluation of diagonal movement, visual evaluation of symmetry in sitting and lying (visual evaluation of functional AROM), visual evaluation of sit-to-move, lie-to-move (difference in thrust of hind-limbs through functional tests), and movement on stairs, evaluation of hindlimb muscle atrophy, manual evaluation of hindlimb static weight bearing (SWB), quantitative measurement of SWB of hindlimbs with bathroom scales and measurement of PROM of hindlimb stifle flexion and extension and tarsal flexion and extension using a UG. A more specific description of the methods is presented in Appendix 1, and grouping based on the performance level in each method is shown in Table 1.

One physiotherapeutic evaluation method, the measurement of SWB with bathroom scales, was assessed further (II) to determine its reliability (repeatability) and the normal variation of symmetry of SWB in dogs with surgically treated CCL and OA in their stifles. In addition, information regarding static weight bearing in this patient group was gained.

Since the dogs were of different breeds and sizes, the means of the SWB measurements were converted from kilograms to percentages proportional to the
total weight, and the results were handled as such. The mean difference (± SD) in SWB between the hindlimbs proportional to the body weight of control dogs was 3.3% (± 2.7%), i.e. 6%, which was considered normal.

Based on the normal limit of 6%, the results of OA dogs’ SWB were interpreted as 1 = symmetrical weight bearing if the difference in SWB was less than 6%, 2 = decreased weight bearing in the left hindlimb or 3 = decreased weight bearing in the right hindlimb. To allow comparison between levels of OA, the dogs were categorized into two groups: not severe and severe OA. The not severe group consisted of dogs evaluated as mild OA in the radiological evaluation, and the severe group combined moderate and severe OA.

4.3.2. ORTHOPAEDIC EXAMINATION (I-III)

The orthopaedic examination performed by a veterinary surgeon consisted of palpation of the limbs and spine, assessing for crepitation, swelling, decreased ROM and instability, evaluation of conscious proprioception and withdrawal reflex and lameness evaluation on a scale from 0 to 4 (where 0 = no lameness and 4 = non-weight bearing lameness) (Table 1) (Mostafa et al. 2009)

4.3.3. FORCE PLATFORM ANALYSIS (I-III)

Force platform analysis was done by processing signals from a force platform (Kistler Type 9286, Kistler Instrumente AG Winterhur, CH-8408, Switzerland) and a start-interrupt timer system with a computer-based software program (Aquire 7.3, Sharon Software Inc., DeWitt, MI, USA). Velocities and acceleration were determined by three photoelectric cells placed 1 m apart and a start-interrupt timer system. Five valid runs over the force plate at a velocity of 2.10-2.50 m/s (1.70-2.10 m/s for two dogs) and acceleration of -0.5 to +0.5 m/s² per each ipsilateral limb pair were recorded. Means of body weight-corrected peak vertical force (PVF) and vertical impulse (IMP) were calculated. Based on these means ± standard deviation (SD) and the difference between left and right limbs [-|mean difference|-SD ; |mean difference| + SD], dogs were classified as shown in Table 1.
4. MATERIALS AND METHODS

4.3.4. RADILOGICAL EXAMINATION (I-III)

For Studies I-III, radiographs of stifles and hip joints were taken under sedation bilaterally from the dogs with surgically treated CCL. Mediolateral and craniocaudal views were taken from the stifles, and an extended ventrodorsal view was taken from the hip joints. Radiographs were graded according to the amount of OA seen, using a scale from 0 to 3, where 0 = no OA findings, 1 = mild OA findings, 2 = moderate OA findings and 3 = severe OA findings (Table 1) (de Rooster et al. 1999). No radiographs were taken of the control group dogs.

4.3.5. CONCLUSIVE ASSESSMENT (I-III)

The conclusive assessment consisted of the veterinary surgeon’s subjective final clinical assessment, which was based on the combined results of the orthopaedic, force platform and radiographic evaluations. Dogs were grouped as presented in Table 1.

4.4. DEVELOPING AN INDEXED TESTING BATTERY (III, IV)

After ranking and validating the physiotherapeutic evaluation methods (I), the eight best ranked items were selected to form a testing battery, the Finnish Canine Stifle Index (FCSI) (III). The selected items were evaluation of sitting and lying positions, symmetry in thrust of hindlimbs in getting up from sitting and lying positions, evaluation of muscle symmetry, measurement of symmetry of SWB between hindlimbs using bathroom scales and measurement of stifle PROM (both flexion and extension) with an UG. To create an index, all performances in all items were scored. The scoring is presented in Table 2. In some of the items (sitting and lying positions, symmetry in thrust of hindlimbs in getting up from sitting and lying positions, evaluation of muscle symmetry) the score per limb was either 0 or 2. Other items (measurement of symmetry of SWB between hindlimbs and measurement of stifle PROM) would be scored on an ordinal scale from 0 to 3 based on values defined according to the results of control dogs.

To test the sensitivity and specificity of the testing battery, each dog’s FCSI score was compared with four of the most commonly used clinical evaluation methods used by a veterinarian: orthopaedic examination, radiological examination of OA changes in stifles and hips, force platform analysis and conclusive assessment (III).

To define a cut-off value between adequate and challenged performance based on the total score, a ROC analysis was done (III). This cut-off was confirmed again in the fourth study, where the control dogs were distinguished from the other two study
### Table 1. Grouping used to describe dog’s performance in physiotherapeutic evaluation methods and evaluation methods used by a veterinarian.

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Method</th>
<th>Group 0</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual evaluation of lameness and movement in stairs</td>
<td>Normal movement and equal weight bearing</td>
<td>Random asymmetry of movement</td>
<td>Obvious asymmetry of movement *)</td>
<td>Weight bearing or non-weight bearing lameness, constant mis-stepping on stairs</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Oblique body position during movement</td>
<td>N/A</td>
<td>Symmetrical</td>
<td>Oblique, hindquarters to the right</td>
<td>Oblique, hindquarters to the left</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Active range of motion during sitting and lying position**)</td>
<td>N/A</td>
<td>No findings</td>
<td>Any finding in left limb</td>
<td>Any finding in right limb</td>
<td>Bilateral finding in hindlimbs</td>
<td></td>
</tr>
<tr>
<td>Symmetry in hind limb thrust from sitting and lying positions to standing position</td>
<td>N/A</td>
<td>Symmetrical thrust between hindlimbs</td>
<td>Less thrust in left hindlimb</td>
<td>Less thrust in right hindlimb</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Muscle mass symmetry evaluation</td>
<td>N/A</td>
<td>Symmetrical muscle mass in hindlimbs</td>
<td>Decreased muscle mass in left hindlimb</td>
<td>Decreased muscle mass in right hindlimb</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Passive range of motion (PROM) ***))</td>
<td>N/A</td>
<td>Bilaterally normal PROM</td>
<td>Decreased PROM in the left hindlimb</td>
<td>Decreased PROM in the right hindlimb</td>
<td>Bilaterally decreased PROM</td>
<td></td>
</tr>
<tr>
<td>Manual evaluation of hind limb static weight bearing: ****)</td>
<td>N/A</td>
<td>Symmetrical</td>
<td>Bearing less weight on left hindlimb</td>
<td>Bearing less weight on right hindlimb</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Measurement of static weight bearing symmetry between hind limbs with bathroom scales *****)</td>
<td>N/A</td>
<td>Symmetrical weight bearing</td>
<td>Decreased weight bearing in the left hindlimb</td>
<td>Decreased weight bearing in the right hindlimb</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Orthopaedical examination</td>
<td>N/A</td>
<td>No findings in hindlimbs</td>
<td>Findings in left hindlimb</td>
<td>Findings in right hindlimb</td>
<td>Bilaterally abnormal</td>
<td></td>
</tr>
<tr>
<td>Force platform analysis</td>
<td>N/A</td>
<td>Hindlimbs symmetrical</td>
<td>Applying less force in left hindlimb</td>
<td>Applying less force in right hindlimb</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Radiological evaluation</td>
<td>N/A</td>
<td>Bilaterally no signs of OA in either stifle or hip joint</td>
<td>Radiological stifle or hip OA in left hindlimb</td>
<td>Radiological stifle or hip OA in right hindlimb</td>
<td>Bilateral radiological stifle or hip OA</td>
<td></td>
</tr>
<tr>
<td>Conclusive assessment</td>
<td>N/A</td>
<td>No findings in hindlimbs</td>
<td>Findings in left hindlimb</td>
<td>Findings in right hindlimb</td>
<td>Bilateral findings</td>
<td></td>
</tr>
</tbody>
</table>

**Specifications used in Table 1:**

*) Abnormal movement patterns such as abduction during swing phase, decrease or increase in either caudal or cranial stance phase and bunny-hopping or weight bearing only in one direction on stairs

**) Visual evaluation for possible external rotation, decrease in flexion of stifle and tarsus and abduction of the limb

***) Normal set by control dogs mean +SD and mean – SD: stifle < 51.7° and > 147.7° tarsus < 40.3°, and > 169.5° (I)

****) Weight on limb and resistance when lifted

***** Normal set by control dogs mean percentage difference between hindlimbs: mean + SD (3.3% + 2.7%) (II)
groups. A second cut-off was set to distinguish dogs with severe dysfunction from
dogs with less severely compromised performance or adequate performance (IV).
In addition, sensitivities and specificities were calculated for both cut-off limits (IV).

Table 2. Scoring of items in the Finnish Canine Stifle Index (FCSI).

<table>
<thead>
<tr>
<th>Item</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting and lying positions *)</td>
<td>No compensations detected</td>
<td>One compensation detected</td>
<td>Two compensations detected</td>
<td>Three or more compensations detected</td>
</tr>
<tr>
<td>Symmetry of thrust from both sitting and lying positions</td>
<td>Adequate</td>
<td>N/A</td>
<td>Weaker thrust</td>
<td>N/A</td>
</tr>
<tr>
<td>Evaluation of muscle mass symmetry in hindlimbs</td>
<td>Adequate</td>
<td>N/A</td>
<td>Weaker muscle mass</td>
<td>N/A</td>
</tr>
<tr>
<td>Measurement of static weight bearing between hindlimbs **)</td>
<td>Dogs within normal variation</td>
<td>Dogs within 2SDs</td>
<td>Dogs within 3SDs</td>
<td>Dogs scoring above 3SDs</td>
</tr>
<tr>
<td>Passive range of motion ***)</td>
<td>Dogs within normal variation</td>
<td>Dogs within 2SDs</td>
<td>Dogs within 3SDs</td>
<td>Dogs scoring above 3SDs</td>
</tr>
</tbody>
</table>

*) Possible compensations: decreased flexion in stifle and/or tarsus, external rotation of the limb, abduction of the limb, sitting on either hip or other severe compensations (any type of deviation from normal symmetrical positions of an animal due to pain or mechanical restrictions in the musculoskeletal system)

**) Cut-off values for the scoring were calculated based on the average percentage difference between hindlimbs’ static weight bearing in the control group (([SWB (left limb) - SWB (right limb)]/dog’s weight)*100)

***) Cut-off values for the scoring were calculated based on the average range of motion in the stifles in the control group

4.5. STUDYING RELIABILITY AND RESPONSIVENESS OF THE TESTING BATTERY (IV)

The three groups of dogs of the second study population (STIF, OTHER, CTRL) were
tested using the FCSI at their first physiotherapy appointment and re-tested at 6 and 10 weeks from baseline. Three testing visits were used to investigate responsiveness of the FCSI. Three veterinary physiotherapists were taught to perform the testing battery and score the performances in a standardized manner. During one of the visits two physiotherapists tested the dog to evaluate intertester reliability. Both written instructions and a practical introduction session were provided before commencing the study.
In Study IV, control dogs’ hips were radiographed and graded according to the Federation Cynologique Internationale (Suomen Kennelliitto 2014) screening protocol (grade A or B) to ensure that they were free of hip dysplasia. Also their stifle joints were radiographed in mediolateral and craniocaudal projections to rule out osteoarthritis and osteochondrosis. An orthopaedic examination was performed as in Study III.

4.6. STATISTICAL METHODS

All statistical analyses were done with the SAS® System for Windows, either version 9.2e (II) or 9.3 (I, III, IV) (SAS Institute Inc., Cary, NC, USA), and in all cases a p-value of < 0.05 was considered significant.

4.6.1. STUDY I

Fisher’s exact test was used to evaluate the significance of the association between each physiotherapeutic evaluation method and each of the following clinical evaluation methods used by our veterinarian: orthopaedic examination, PVF and IMP of force platform analysis, radiological examination of the stifle and of the stifle and hip combined and conclusive assessment. The proportion of observations in which an individual physiotherapeutic evaluation method and the clinical evaluation method used by a veterinarian agreed was calculated as follows: (agreeing observations / all observations)*100. Similar proportions were calculated again, but now agreement was also granted for observations where the physiotherapeutic evaluation method under evaluation resulted in an “asymptomatic” finding and the clinical evaluation method used by a veterinarian resulted in a “symptomatic” finding, due to the difference in the number of groups in which the variables were assigned by different methods. This is referred to as the adjusted proportion of agreement. As a result, 18 different ranking lists were constructed, three for each comparative evaluation method. The three rankings within a comparative method were then summed to place the evaluation methods into a total rank order. Finally, these six ranking numbers were summed. A final ranking list was then constructed based on these sums; the first evaluation method on the list was considered to be the most congruent. Sensitivities against each method used by a veterinarian were calculated.
4.6.2. STUDY II

The repeatability of the bathroom scale measurements was calculated using a one-way analysis of variance model, with the dog used as the sole explanatory factor. The intra- and intergroup mean squares were used to calculate an estimate of the repeatability of the measurement. In addition, limbs of the dogs with OA were divided into affected and unaffected limb groups, in which repeatability was re-calculated by group.

Congruity between the SWB measured with bathroom scales and the other evaluation methods was examined by calculating pair-wise proportions of agreement and their 95% confidence intervals for the physiotherapeutic evaluation methods and clinical evaluation methods used by a veterinarian; results were calculated separately for each outcome class and OA severity classification. The overall congruity between the methods was assessed with Cohen’s Kappa coefficient. When the agreement and Kappa were evaluated, a range of less than zero to zero was considered to have less than chance agreement, 0.01–0.20 slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement and 0.81–0.99 almost perfect agreement (Viera et al. 2005).

4.6.3. STUDY III

The FCSI score difference between surgically treated CCL dogs and control dogs was analysed with one-way analysis of variance (ANOVA). The internal consistency between the eight evaluation methods of the FCSI score was assessed using Cronbach’s alpha. In addition, a principal components analysis (PCA) with varimax rotation was conducted to describe the structure of the testing battery.

When calculating sensitivities and specificities, the results of the test were handled as presented in Table 3. Based on the initial data, the sensitivity was then calculated as follows: \( A / (A+C) \), and specificity: \( D / (B+D) \).

Table 3. Method of calculating sensitivity and specificity.

<table>
<thead>
<tr>
<th>Test</th>
<th>Group</th>
<th>Healthy</th>
<th>Affected</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td></td>
<td>A</td>
<td>B</td>
<td>A+B</td>
</tr>
<tr>
<td>Negative</td>
<td></td>
<td>C</td>
<td>D</td>
<td>C+D</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>A+C</td>
<td>B+D</td>
<td></td>
</tr>
</tbody>
</table>
4.6.4. STUDY IV

To investigate responsiveness, the differences in FCSI total score between the three groups (STIF, OTHER, CTRL) were assessed using a linear mixed effects model for repeated measures, with group, visit and the interaction term between group and visit as fixed effects and dog as a random effect. Between- and within-group comparisons were estimated from this model using contrasts.

Reliability and differences between the three testers were evaluated in three ways. First, to validate the primary group comparisons a similar linear mixed effects model was fitted as above for the full data, supplemented with the fixed effect of the tester; an insignificant tester effect indicated that there was no bias introduced to the group comparisons due to the tester evaluating the dog. Second, using only the data where two parallel ratings were made, an ANOVA was fitted, where the sole fixed effect was the difference between the two testers for the same dog/visit. Third, a random effects model was fitted to estimate the variance component related to the tester. The model included the dog as a random effect and the group as a fixed effect (to avoid overestimation of the variation between dogs). The variance components related to dogs and testers were estimated from the model, and the proportions of total variation were calculated for the components, i.e. intraclass correlation coefficients (ICCs) were obtained.
5. RESULTS

5.1. ANIMALS

In Studies I-III, the CCL-treated group consisted of 15 Labrador Retrievers, 6 Rottweilers, 3 Golden Retrievers, 3 mixed breed dogs, 2 Bernese Mountain Dogs, 2 Newfoundland Dogs, 2 Nova Scotia Duck Tolling Retrievers and one each of the following: Black Russian Terrier, Bordeaux Dog, Bullmastiff, Collie, Dalmatian Dog, Doberman Pinscher, Giant Schnauzer, Karelian Bear Dog, Pointer and Short-Haired German Pointer. Of the dogs, 19 were males and 24 females. Their mean ± SD age was 83.8 ± 30.2 months, and their mean ± SD body weight was 37.6 ± 9.4 kg. In this group, the youngest age was 38.8 months and the oldest 145.8 months. The lowest weight was 17.5 kg and the highest 60 kg.

The control group (I–III) comprised 12 Labrador Retrievers and 9 Rottweilers, of which 7 were males and 14 females. The mean ± SD age and body weight were 38.5 ± 19.4 months and 35.5 ± 8.3 kg, respectively. The youngest age was 13.2 months and the oldest 71 months. The lowest weight was 23 kg and the highest 53 kg.

The difference between ages of the study group and the control group (I-III) was highly significant ($P < 0.0001$), with control dogs being younger. There was no significant difference between the groups’ weights or genders. Three dogs in the study group had undergone neither platform analysis nor radiographs (I-III). All dogs in the surgically treated CCL deficiency group were confirmed to have at least grade 1 OA changes in one or more of either the stifle or hip joint (II). Two dogs did not tolerate manual evaluation of weight bearing, and two dogs did not have their SWB measured on bathroom scales (I-III). Of the tested dogs, two performed the runs over the force plate at 1.72–2.10 m/s, and all of the rest at 2.10–2.50 m/s (I-III).

In Study IV, the STIF group consisted of 27 dogs, of which 25 completed the 2nd test and 18 the 3rd. The group included 2 Bichon Havannaises, 2 Golden Retrievers, 2 Jack Russell Terriers and one each of the following: Afghan Hound, American Akita, American Staffordshire Terrier, Bernese Mountain Dog, Border Collie, Boxer, Griffon Bruxellois, Finnish Lapphund, French Bulldog, German Wirehaired Pointer, Glenn of Imaal terrier, Kleinspitz, Lagotto Romagnolo, Norfolk Terrier, Miniature Poodle, Mixed breed dog, Parson Russell Terrier, Petit Brabancon, Portuguese Podengo, Russian Toy Terrier, Samoyed and Short-Haired Chihuahua.
The mean age of the dogs was 5.7 ± 2.9 years and the mean weight 16.0 ± 14.3 kg. The youngest age was 13 months and the oldest 128 months. The lowest weight was 2.7 kg and the highest 40.6 kg. Seventeen dogs were male and 12 female.

In the second study group (OTHER), 17 dogs started the study and 11 completed the 2nd and 3rd tests. The group comprised 3 Border Collies, 2 Labrador Retrievers, 3 mixed breed dogs and one of each of the following: Australian Shepherd, Doberman, Cavalier King Charles Spaniel, Norwich Terrier, Nova Scotia Duck Tolling Retriever, Pumi, Spanish Water Dog and Staffordshire Bull Terrier. Their mean age was 5.2 ± 3.2 years and mean weight 21.5 ± 9.1 kg. In this group, the youngest age was 9 months and the oldest 138 months. The lowest weight was 6.5 kg and the highest 44.7 kg. Eight of the dogs were male and 9 female.

Sixteen dogs were enrolled in the CTRL group, but 5 of them were excluded due to findings in preliminary examinations. This group comprised 2 Border Collies, 2 mixed breed dogs and one of each of the following: Chinese Crested Dog, Cocker Spaniel, Golden Retriever, Lapponian Herder, Mudi, Polish Hound and Rough Collie. Their mean age was 5.2 ± 3.2 years and mean weight 21.5 ± 9.1 kg. The youngest age was 12 months and the oldest 94 months. The lowest weight was 9.2 kg and the highest 29.8 kg. Eight of the dogs were male and 9 female. No significant difference existed between the weight, age or gender of the three groups.

5.2. RANKING AND CONCURRENT VALIDITY OF INDIVIDUAL PHYSIOTHERAPEUTIC EVALUATION METHODS (I)

The sensitivities and ranking of the physiotherapeutic evaluation methods are presented in Table 4 in descending order. Evaluations of muscle asymmetry between hindlimbs and sitting position symmetry were clearly the strongest methods, ranking consistently highest, and also having the highest sensitivities (mean 82.3% and 66.5%, respectively) against the evaluation methods used by a veterinarian.
5. RESULTS

Table 4. Physiotherapeutic evaluation methods in rank order and the sensitivity of each physiotherapeutic method against the evaluation methods used by the veterinarian.

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Method</th>
<th>Orthopaedic examination</th>
<th>Conclusive assessment</th>
<th>Stifle radiographs</th>
<th>Stifle/hip radiographs</th>
<th>PVF</th>
<th>IMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Evaluation of atrophy</td>
<td>1. 80.5%</td>
<td>1. 81.6%</td>
<td>1. 82.1%</td>
<td>3. 82.1%</td>
<td>6. 80.0%</td>
<td>6. 87.5%</td>
</tr>
<tr>
<td>2.</td>
<td>Sitting position</td>
<td>2. 70.0%</td>
<td>2. 67.6%</td>
<td>2. 68.4%</td>
<td>1. 68.4%</td>
<td>12. 68.4%</td>
<td>11. 56.3%</td>
</tr>
<tr>
<td>3.</td>
<td>qmSWB</td>
<td>6. 39.0%</td>
<td>6. 38.5%</td>
<td>8. 40.0%</td>
<td>7. 40.0%</td>
<td>2. 40.0%</td>
<td>1. 50.0%</td>
</tr>
<tr>
<td>4.</td>
<td>Stifle flexion</td>
<td>8. 43.9%</td>
<td>7. 43.6%</td>
<td>4. 42.5%</td>
<td>4. 42.5%</td>
<td>4. 50.0%</td>
<td>8. 43.8%</td>
</tr>
<tr>
<td>5.</td>
<td>Lying position</td>
<td>3. 47.5%</td>
<td>3. 51.4%</td>
<td>6. 47.4%</td>
<td>6. 47.4%</td>
<td>11. 47.4%</td>
<td>10. 43.8%</td>
</tr>
<tr>
<td>6.</td>
<td>Thrust from sitting</td>
<td>5. 65.0%</td>
<td>5. 64.9%</td>
<td>5. 68.4%</td>
<td>5. 68.4%</td>
<td>10. 63.2%</td>
<td>9. 62.5%</td>
</tr>
<tr>
<td>7.</td>
<td>Stifle extension</td>
<td>4. 63.4%</td>
<td>8. 64.1%</td>
<td>3. 62.5%</td>
<td>2. 62.5%</td>
<td>13. 65.0%</td>
<td>14. 68.8%</td>
</tr>
<tr>
<td>8.</td>
<td>meSWB</td>
<td>9. 65.8%</td>
<td>10. 65.7%</td>
<td>10. 66.7%</td>
<td>10. 66.7%</td>
<td>3. 64.7%</td>
<td>3. 85.7%</td>
</tr>
<tr>
<td>9.</td>
<td>Thrust from lying</td>
<td>7. 62.5%</td>
<td>4. 62.2%</td>
<td>7. 60.5%</td>
<td>8. 60.5%</td>
<td>9. 57.9%</td>
<td>13. 62.5%</td>
</tr>
<tr>
<td>10.</td>
<td>Stairs</td>
<td>12. 41.7%</td>
<td>11. 41.7%</td>
<td>13. 41.7%</td>
<td>12. 41.7%</td>
<td>1. 52.6%</td>
<td>2. 50.0%</td>
</tr>
<tr>
<td>11.</td>
<td>Diagonal movement</td>
<td>11. 30.2%</td>
<td>12. 27.5%</td>
<td>12. 29.3%</td>
<td>13. 29.3%</td>
<td>5. 15.0%</td>
<td>4. 23.5%</td>
</tr>
<tr>
<td>12.</td>
<td>Tarsus extension</td>
<td>14. 36.6%</td>
<td>14. 35.9%</td>
<td>11. 35.0%</td>
<td>11. 35.0%</td>
<td>7. 40.0%</td>
<td>5. 37.5%</td>
</tr>
<tr>
<td>13.</td>
<td>Tarsus flexion</td>
<td>10. 43.9%</td>
<td>9. 43.6%</td>
<td>9. 42.5%</td>
<td>9. 42.5%</td>
<td>14. 50.0%</td>
<td>12. 43.8%</td>
</tr>
<tr>
<td>14.</td>
<td>Lameness evaluation</td>
<td>13. 50.0%</td>
<td>13. 48.7%</td>
<td>14. 51.3%</td>
<td>14. 51.3%</td>
<td>8. 52.6%</td>
<td>7. 56.3%</td>
</tr>
</tbody>
</table>

Abbreviations: manual evaluation of static weight bearing (meSWB), quantitative measurement of static weight bearing (qmSWB), peak vertical force (PVF) and vertical impulse (IMP).
Table 5a. Association between physiotherapeutic evaluation methods and force platform, based on three statistical approaches.

<table>
<thead>
<tr>
<th>Physiotherapy method</th>
<th>Force platform</th>
<th>Peak vertical force</th>
<th>Vertical impulse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fisher’s exact Test</td>
<td>Proportion of agreement (%)</td>
</tr>
<tr>
<td>Lameness evaluation</td>
<td>0.607</td>
<td>42.5</td>
<td>67.5</td>
</tr>
<tr>
<td>Diagonal movement</td>
<td>0.142</td>
<td>32.5</td>
<td>75.0</td>
</tr>
<tr>
<td>Sitting position</td>
<td>0.858</td>
<td>40.5</td>
<td>56.8</td>
</tr>
<tr>
<td>Thrust from sitting</td>
<td>0.386</td>
<td>37.8</td>
<td>56.8</td>
</tr>
<tr>
<td>Lying position</td>
<td>0.898</td>
<td>37.8</td>
<td>64.9</td>
</tr>
<tr>
<td>Thrust from lying</td>
<td>0.407</td>
<td>37.8</td>
<td>59.5</td>
</tr>
<tr>
<td>Stairs</td>
<td>0.042*</td>
<td>55.3</td>
<td>81.6</td>
</tr>
<tr>
<td>Evaluation of atrophy</td>
<td>0.018*</td>
<td>42.1</td>
<td>52.6</td>
</tr>
<tr>
<td>meSWB</td>
<td>0.002*</td>
<td>48.6</td>
<td>65.7</td>
</tr>
<tr>
<td>qmSWB</td>
<td>0.082</td>
<td>51.3</td>
<td>82.1</td>
</tr>
<tr>
<td>Stifle flexion</td>
<td>0.598</td>
<td>46.2</td>
<td>71.8</td>
</tr>
<tr>
<td>Stifle extension</td>
<td>0.499</td>
<td>33.3</td>
<td>59.0</td>
</tr>
<tr>
<td>Tarsus flexion</td>
<td>0.477</td>
<td>20.5</td>
<td>56.4</td>
</tr>
<tr>
<td>Tarsus extension</td>
<td>0.216</td>
<td>35.9</td>
<td>71.8</td>
</tr>
</tbody>
</table>

Significant associations are indicated with an asterisk (*). Abbreviations: manual evaluation of static weight bearing (meSWB) and quantitative measurement of static weight bearing (qmSWB). The physiotherapeutic evaluation methods are numbered as in Appendix 1. N = 38–43.
5. RESULTS

Table 5b. Association between physiotherapeutic evaluation methods and clinical methods used by a veterinarian, based on three statistical approaches.

<table>
<thead>
<tr>
<th>Physiotherapy method</th>
<th>Clinical Method</th>
<th>Orthopaedic examination</th>
<th>Conclusive assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fisher’s exact Test p-value</td>
<td>Proportion of agreement (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fisher’s exact Test p-value</td>
<td>Proportion of agreement (%)</td>
</tr>
<tr>
<td>Lameness evaluation</td>
<td>0.865</td>
<td>20.9</td>
<td>86.0</td>
</tr>
<tr>
<td>Diagonal movement</td>
<td>0.761</td>
<td>20.9</td>
<td>90.7</td>
</tr>
<tr>
<td>Sitting position</td>
<td>0.003*</td>
<td>42.5</td>
<td>97.5</td>
</tr>
<tr>
<td>Thrust from sitting</td>
<td>0.154</td>
<td>57.5</td>
<td>92.5</td>
</tr>
<tr>
<td>Lying position</td>
<td>0.013*</td>
<td>32.5</td>
<td>100</td>
</tr>
<tr>
<td>Thrust from lying</td>
<td>0.107</td>
<td>55.0</td>
<td>92.5</td>
</tr>
<tr>
<td>Stairs</td>
<td>0.286</td>
<td>15.4</td>
<td>89.7</td>
</tr>
<tr>
<td>Evaluation of atrophy</td>
<td>0.001*</td>
<td>78.0</td>
<td>97.6</td>
</tr>
<tr>
<td>meSWB</td>
<td>0.207</td>
<td>55.3</td>
<td>89.5</td>
</tr>
<tr>
<td>qmSWB</td>
<td>0.149</td>
<td>36.6</td>
<td>97.6</td>
</tr>
<tr>
<td>Stifle flexion</td>
<td>0.052</td>
<td>22.0</td>
<td>97.6</td>
</tr>
<tr>
<td>Stifle extension</td>
<td>0.004*</td>
<td>34.1</td>
<td>92.7</td>
</tr>
<tr>
<td>Tarsus flexion</td>
<td>0.028*</td>
<td>51.2</td>
<td>80.5</td>
</tr>
<tr>
<td>Tarsus extension</td>
<td>0.308</td>
<td>12.2</td>
<td>85.4</td>
</tr>
</tbody>
</table>

Significant associations are indicated with an asterisk (*). Abbreviations: manual evaluation of static weight bearing (meSWB) and quantitative measurement of static weight bearing (qmSWB). The physiotherapeutic evaluation methods are numbered as in Appendix 1. N = 38–43.
Table 5c. Association between physiotherapeutic evaluation methods and radiological methods, based on three statistical approaches.

<table>
<thead>
<tr>
<th>Physiotherapy method</th>
<th>Radiological Method</th>
<th>Stifle radiographs</th>
<th>Stifle + hip radiographs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fisher’s exact Test p-value</td>
<td>Proportion of agreement (%)</td>
<td>Adjusted proportion of agreement (%)</td>
</tr>
<tr>
<td>Lameness evaluation</td>
<td>0.920</td>
<td>19.0</td>
<td>83.3</td>
</tr>
<tr>
<td>Diagonal movement</td>
<td>0.664</td>
<td>21.4</td>
<td>90.5</td>
</tr>
<tr>
<td>Sitting position</td>
<td>0.001*</td>
<td>48.7</td>
<td>94.9</td>
</tr>
<tr>
<td>Thrust from sitting</td>
<td>0.025*</td>
<td>61.5</td>
<td>92.3</td>
</tr>
<tr>
<td>Lying position</td>
<td>0.006*</td>
<td>35.9</td>
<td>94.9</td>
</tr>
<tr>
<td>Thrust from lying</td>
<td>0.025*</td>
<td>53.8</td>
<td>92.3</td>
</tr>
<tr>
<td>Stairs</td>
<td>0.190</td>
<td>15.8</td>
<td>86.8</td>
</tr>
<tr>
<td>Evaluation of atrophy</td>
<td>0.001*</td>
<td>75.0</td>
<td>94.9</td>
</tr>
<tr>
<td>meSWB</td>
<td>0.176</td>
<td>54.1</td>
<td>86.5</td>
</tr>
<tr>
<td>qmSWB</td>
<td>0.411</td>
<td>36.6</td>
<td>95.1</td>
</tr>
<tr>
<td>Stifle flexion</td>
<td>0.004*</td>
<td>26.8</td>
<td>97.6</td>
</tr>
<tr>
<td>Stifle extension</td>
<td>0.004*</td>
<td>36.6</td>
<td>95.1</td>
</tr>
<tr>
<td>Tarsus flexion</td>
<td>0.213</td>
<td>39.0</td>
<td>92.7</td>
</tr>
<tr>
<td>Tarsus extension</td>
<td>0.093</td>
<td>7.3</td>
<td>92.7</td>
</tr>
</tbody>
</table>

Significant associations are indicated with an asterisk (*). Abbreviations: manual evaluation of static weight bearing (meSWB) and quantitative measurement of static weight bearing (qmSWB). The physiotherapeutic evaluation methods are numbered as in Appendix 1. N = 38–43.
5. RESULTS

5.3. REPEATABILITY AND CONGRUITY OF BATHROOM SCALES (II)

The repeatability of the SWB measurements with bathroom scales was 76% for all surgically treated CCL dogs and 61% for control group dogs. The overall repeatability was 66% in the right hindlimb and 56% in the left hindlimb of control dogs. The overall repeatability for OA dogs was 79%, and 81% in the affected limb and 70% in the unaffected limb. According to the conclusive assessment of OA dogs, the repeatability of the measurement was 74% and 83% for dogs with unilaterally and bilaterally affected hindlimbs, respectively.

The Kappa values between SWB measured with bathroom scales and force platform analysis within the severe and the not-severe OA groups were as follows: 0.52 and 0.12 between SWB and the force plate IMP, indicating a moderate and slight agreement, and 0.38 and 0.03 between SWB and force plate PVF, indicating a fair and nearly no agreement, respectively.

Regarding various physiotherapeutic evaluation methods, the sensitivity of evaluation of atrophy ranged between 80% and 87.5% when tested against any of the clinical evaluation methods used by a veterinarian. Sensitivity of sitting position ranged between 67.6% and 70.0%, except when compared with the IMP, where the sensitivity was 56.3%. Manual evaluation of SWB had a sensitivity ranging from 64.7% to 85.7%. Thrust from a lying position had a sensitivity ranging between 60.5% and 62.5% with all clinical evaluation methods used by a veterinarian, except PVF, where the sensitivity was 57.9%. Stifle extension and thrust from a sitting position had sensitivities of 62.5–68.8% and 62.5–68.4%, respectively. In Study II, with a set limit for normal difference in SWB (3.3% ± 2.7%), the sensitivity and specificity of SWB measurements using bathroom scales was 39% and 85%, respectively.

5.4. STRUCTURING THE TESTING BATTERY (III, IV)

Eight items were selected since they all had a sensitivity over 60% compared with the other clinical evaluation methods, and they all systematically and overall ranked in the better half of the ranking order. Although belonging to the group of higher ranked methods, the manual evaluation of SWB was left out of the items chosen for the testing battery, as the measurement of SWB with bathroom scales proved to be a better method (II).

Each item was given a score. All individual scores were summed for each hindlimb, resulting in a final score of 0 to 21 per hindlimb. The final sum of scores was divided by the number of evaluations done and multiplied by 100 (Sum of ((Item1+Item2+... Item8)/number of evaluations conducted)*100), resulting in
a total score from 0 to 262.5, rounded up to 263 for user convenience. With this method, a dog could be evaluated even if it was unable to perform all tests. In some of the items, both hindlimbs might get a score, although the test would focus on scoring primarily only one hindlimb, the weaker one. In this index, 0 indicated a perfect result and 263 the worst possible result.

Based on principal component analysis, the physiotherapeutic evaluation method items were divided into two main components, termed “functional” and “passive” components. Naming of the components was based on the fact that in the functional one the dog was actively involved in the performance of the item, whereas in the passive one the dog had no effect on the measurement result. Evaluation of sitting and lying positions, thrust from sitting and lying positions, muscle mass asymmetry and measurement of SWB were functional components, while measurement of stifle PROM was a passive component. Cronbach’s alpha for the internal reliability of the total FCSI score was 0.727, for the functional component 0.746 and for the passive component 0.394.

Sensitivity and specificity of the dichotomized FCSI score were evaluated. Compared with the conclusive assessment, these were 90% and 90.5%, with the orthopaedic examination 88.4% and 90.5%, with the IMP 76.2% and 45% and with the PVF 75% and 46%, respectively. Sensitivity relative to stifle radiographs and to stifle and hip radiographs together was 87.8%. Specificity relative to radiographs could not be calculated, as the healthy dogs were not radiographed (III).

The final scores of the FCSI were dichotomized into two classes based on the results of a ROC analysis (Figure 2): “adequate” and “compromised” performance levels, with a cut-off value of 60 (III). Based on the STIF dogs’ baseline results, another cut-off was set at 120 to differentiate the “severely compromised” performance level from the “compromised” and “adequate” levels (IV). The cut-offs in relation to the second study population are presented in Figure 3 (IV).

The cut-off at 60 had a sensitivity of 88.4% and specificity of 90.5% when dogs with surgically treated CCL were compared with control dogs. In Study IV, the cut-off at 120 had a sensitivity of 82.8% and specificity of 89.3% when the STIF group was compared with the other two groups (OTHER and CTRL).
5. RESULTS

**Figure 2.** ROC analysis defining the cut-off between “adequate” and “challenged” performance levels.

**Figure 3.** Scatter plot figure presenting the cut-off values for the Finnish Canine Stifle Index (FCSI) total score.
5.5. RESPONSIVENESS AND INTER-TESTER RELIABILITY OF THE TESTING BATTERY (III, IV)

From the FCSI score range of 0-263, the mean (±SD) for dogs with surgically treated CCL was 105 (±43) (95% confidence interval (CI) 92.9-116.1) and for control dogs 20 (±27) (95% CI 3.6-36.9). The difference between the two groups was significant (P < 0.001) (III).

In Study IV, a significant difference (P < 0.001) was seen in the FCSI score between the STIF, OTHER and CTRL groups at baseline. The mean FCSI scores in the three groups at baseline were as follows: STIF 154.7 (± 60.9), OTHER 59.4 (± 54.3) and CTRL 17.0 (±22.9). In addition, the change in mean total score between baseline and the 6- and 10-week test was biggest in the STIF group, from 48.8 (± 44.6) to 93.3 (± 62). In the OTHER group, the corresponding change was from 26.1 (± 38.1) to 29.5 (± 39.6) and in CTRL group from 3.3 (± 13.9) to 11.7 (± 21.0). Only the STIF group showed a significant (P < 0.001) change at both 6 and 10 weeks. The mean scores of the three groups on the three testing occasions are presented in Figure 4.

No significant differences were observed between the testers’ results in any of the groups (P = 0.736). The random effects model showed that the proportion of total variance due to variation between dogs (within each problem group) was 78.4% and due to variation between testers 21.6% (i.e. ICC = 0.784) (IV).

![Mean Total FCSI score (+StdErr) by group and week](image)

**Figure 4.** Mean total score of the Finnish Canine Stifle Index (FCSI) in the three groups.
6. DISCUSSION

The main aim of this thesis was to develop the first physiotherapeutic testing battery for dogs with stifle dysfunction that also takes into consideration the overall functionality of the dog. This testing battery provides animal physiotherapists with a new method for measuring and quantifying the effects of therapy and recording the progress of the rehabilitation process. Until now, testing batteries in animal physiotherapy have been non-existent, although these batteries are an important part of the evaluation process in various patient groups in human physiotherapy (Finch et al. 2002).

The development process of the testing battery here can be divided into three phases. The first is the preparatory phase in which the physiotherapeutic evaluation methods used in daily clinical practice in evaluating dogs with stifle dysfunction were investigated for their suitability (I, II). The second is the actual testing battery development phase in which the best physiotherapeutic evaluation methods were chosen to form the testing battery (III). In the third phase, the confirmatory phase, the testing battery was further evaluated for its psychometric properties (IV).

6.1. PREPARATORY PHASE

Optimally, when an evaluation method is validated, it is done against a valid method that measures the same thing (Fritz et al. 2001, Horner et al. 2006). As the method developed in this thesis is the first of its kind, no comparative methods were available. We therefore decided to use several evaluation methods that are commonly used by veterinarians.

Selection of the 14 physiotherapeutic evaluation methods to be studied for their validity and put into ranking order was based on clinical experience and previous literature regarding methods most commonly used with canine stifle dysfunction patients (Schäfer et al. 2000, Monk et al. 2006, Mostafa et al. 2009). The top three methods were the evaluation of atrophy, the evaluation of symmetry in a sitting position and the measurement of static weight bearing. The nineth task marked a transition in the ranking order. All methods ranking below the nineth task had consistently low congruity.

A conclusive assessment was designed for the purposes of this thesis. It combines a clinical examination performed by a veterinarian, diagnostic imaging and force platform analysis results. The conclusive assessment was considered to resemble most closely the multifaceted and functional approach of the testing battery.
Although all veterinarians do not have access to a force platform, it is nevertheless the golden standard of lameness evaluation in research (Evans et al. 2005) and was therefore included in the conclusive assessment. We expected that the agreement between force platform analysis and the physiotherapeutic evaluation methods would be weak, as the force platform measured PVF and IMP during movement (trot, in this case) (Mölsä et al. 2014), and none of the physiotherapeutic methods measure GRF. When looking at the ranking order of the physiotherapeutic evaluation methods according to the force platform, it was clearly in contradiction to the ranking order set by the other methods used by a veterinarian (Table 4). Accordingly, when sensitivity and specificity of the total score of the FCSI were compared with the force platform results, the sensitivity was only moderate (75.6%) and the specificity low (45.5%). The radiological evaluation was also included in the conclusive evaluation. Although radiological findings do not necessarily correlate with clinical signs (Hielm-Björkman et al. 2006), radiography is an important method for diagnosing orthopaedic problems in dogs (Barr et al. 2006). However, when looking at the sensitivities between all physiotherapeutic evaluation methods and the methods used by the veterinarian, they were quite different. Thus, the selection of the methods used to validate the physiotherapeutic evaluation methods and later the testing battery was considered justified and reasonable.

One challenge of the thesis was the different categorizing of dogs used in Studies I and II. In some items and evaluation methods, based on findings the dogs were categorized into three groups and in others into four (Table 2). This discrepancy arose because in some items bilateral problems were recognized, and in others only unilateral ones. Obviously, some dogs may have been symmetrical due to bilateral problems or alternatively due to having no problems at all. The categories with three options did not differentiate these two situations. In statistical analysis, agreement in observations was allowed when the four-category result was bilaterally problematic and the three-category result was either a left- or a right hindlimb problem. This way, the problem limbs were found, which was considered to be sufficient.

6.2. DEVELOPMENT PHASE OF A TESTING BATTERY

Based on the ranking order, the eight best physiotherapeutic evaluation methods were selected as items in the testing battery, and according to the principal component analysis, two components, “functional” and “passive”, were defined. Through these components, the testing battery aims at taking into account various aspects affecting the overall functionality of the dog. The items of the testing battery target the most common physiotherapeutic problems defined in stifle patients: decreased ROM, SWB and muscle mass in the dysfunctional limb (Monk et al.
There are similarities in item selection of the testing battery developed here and the batteries used in humans. Atrophy and PROM (Lysholm et al. 1982, Insall et al. 1989), as well as squatting or bending of the knee (Lequesne et al. 1987, Noyes et al. 1989, Lequesne et al. 1991, 1997, Barber-Westin et al. 1999, Frohm et al. 2012), corresponding to sitting and lying positions in the dog, are noteworthy.

The FCSI total score yields a numerical value describing the performance level of the dog in the testing battery. However, to give meaning to the numbers and to add a qualitative aspect to the results, two cut-off values were defined. The cut-offs inform the therapist and owner of what the total score means clinically, revealing whether there is a need for further rehabilitation or whether the performance level is sufficient. Although there is a lot of manoeuvrability within the categories (adequate, compromised, severely compromised) generated by the cut-offs, they still make the interpretation of the total score more perceivable than mere numbers would have done. Similar definitions, albeit with a varying number of cut-offs, have been used in testing batteries for human knee patients (Lysholm et al. 1982, Lequesne et al. 1987, 1991, 1997).

In Studies I and II, the study group consisted of dogs with unilaterally surgically treated stifle. This led us to plan the grading of some of the physiotherapeutic evaluation methods to be selective between two limbs, with the main aim being that the method would recognize and select the dysfunctional limb from the two. As the thesis evolved to generating a testing battery, we noted the problem of two types of grading; deficits in flexion and extension can be graded separately for both limbs, whereas the other evaluation methods (sitting and lying position symmetry, symmetry of thrust in getting up from these positions, evaluation of atrophy and measurement of static weight bearing) only separate the “better” from the “worse” functional limb. Hence, the testing battery generated here is aimed at dogs with unilateral stifle problems. Although some of the items may give a notable result to both limbs, others will not, and therefore, only the “worse” limb will receive a full evaluation. Testing batteries that evaluate unilateral dysfunction also exist in human medicine (Lysholm et al. 1982, Insall et al. 1989).

In this thesis, the items that were high in ranking order have been weighed in the testing battery to reflect their importance. For example, the evaluation of muscle symmetry is scored either 0 in case of no atrophy or 2 in case of atrophy. Two points instead of 1 weighs the importance of the item relative to the others, as atrophy was ranked the best of the methods selected to the testing battery.

Based on Cronbach’s alpha, the internal reliability is good for the total FCSI score, 0.727, and for the functional component, 0.746 (Nunnally 1978). Surprisingly, for the passive component, it was inadequate, 0.394. This finding supports the FCSI testing battery being a measurement method aimed at evaluating the functional status of patients. The testing battery is thus far the only method designed to evaluate
the overall functionality of dogs with stifle dysfunction, and therefore, should be considered an irreplaceable part of the clinical examination of these dogs.

6.3. CONFIRMATORY PHASE

In the first cohort, the dogs were medium-sized, and thus, the question arose of whether the testing battery would be applicable only for medium-sized dogs. Hence, the second cohort, used to test the responsiveness and reliability of the testing battery, was rather heterogenic. This was deliberate, as the aim was to determine whether the testing battery would work with dogs of all sizes, breeds and structures. The results showed that despite the dogs’ heterogeneity the testing battery worked as intended.

If sensitivity of a testing battery is high, it ascertains that the patient receives sufficient therapy. On the other hand, if the testing battery assesses the patient to be at a lower functional level than is really the case this will result in excessive costs for the owner due to continued unnecessary therapy. When studied separately, the individual eight items eventually chosen for the testing battery had sensitivities varying from low (38.5%) to high (87.5%). Nevertheless, when the items were combined as a testing battery and the testing battery’s mean total score was examined against radiological evaluation, orthopaedic examination and the conclusive assessment, the sensitivity and specificity of the battery were quite similar and high; the mean sensitivity was 88.7% and the mean specificity 90.5%.

There was a significant 85/263 point difference in the FCSI scores between dogs with a surgically treated CCL (105 ± 43) and control dogs (20 ± 27) (III). Also, between the STIF groups the FCSI total score (154.7 ± 60.9) was even higher at baseline (over 138 points) than the CTRL groups (17.0 ± 22.9) (IV). A major influencing factor between the studies may be that in the first cohort (I-III) the dysfunctional dogs had all had their CCL surgically repaired over a year ago, whereas in the second cohort (IV) some of the dogs were still in an acute phase, e.g. surgical repair of the CCL being done only 2 weeks earlier. Therefore, the signs of dysfunction may have been more exaggerated, and this can be seen in the total FCSI score in Study IV. It should, however, be noted that in the stifle group neither a ceiling effect nor a floor effect was seen, which supports the range in scoring being adequate for the patients. This is in accordance with information published previously on a human knee testing battery (Barber-Westin et al. 1999).

The testing battery was intended to enable appropriate follow-up of rehabilitation of stifle patients. It was therefore important to verify that it has a sufficient responsiveness. The main criteria for responsiveness have been defined by Lohr et al. (2002). Firstly, it should be shown that there is evidence of changes in the scores
of the measure. Secondly, longitudinal data comparing a group that is expected to change with a group that is expected to remain stable are needed. And thirdly, there should be a population in which responsiveness has been tested, including the time intervals between the assessments, interventions or measures involved in evaluating change, in addition to populations assumed to be stable. The criteria are all fulfilled in Study IV; the most obvious and significant (P < 0.001) change in FCSI total score was seen in dogs in the STIF group (48.8 ± 44.6 to 93.3 ± 62) between baseline and 6 and 10 weeks, respectively, in comparison with dogs in the CTRL (3.3 ± 13.9 to 11.7 ± 21.0) group.

Regarding the effect of physiotherapy, it should be noted that dogs in both STIF and OTHER groups received physiotherapy (IV). The effect of various therapy protocols was not studied in this thesis. However, although a change was seen in both groups (STIF 93.3 (± 62) and OTHER 29.5 (± 39.6)), it was clearly more evident in the STIF group. This is indicative of the testing battery’s ability to discriminate stifle dysfunction from other dysfunctions, despite physiotherapy received.

Various types of stifle dysfunction patients were included in study groups, some acute, other chronic. In addition, some were treated conservatively, others surgically. Schedules for rehabilitation processes cannot be given, but they are not actually needed, as therapy continues as long as there is clinically a need for it. Hence, the results of the stifle patients might have improved had the last testing been conducted later. Previous studies have used follow-up periods of 6 weeks or 6 months to evaluate the outcome of rehabilitation in CCL patients (Marsolais et al. 2002, Monk et al. 2006, Jerre 2009). In this thesis, the test period lasted 10 weeks from either the surgical treatment or the initial contact to physiotherapy if there was no surgical treatment involved (IV). The testing battery (I-III) was performed on dogs that had been surgically treated for CCL rupture at least one year before the testing time. The FCSI total score (105 ± 43) was, however, quite similar to the score of dogs with only a 10-week follow-up (IV) (93.3 ± 62). This suggests that the testing schedule used here was sufficient. The total score of the FCSI should decrease within a reasonable time of rehabilitation or in relation to the dysfunction or disease in question. In case of unexplained plateauing or an increase in the total score without a good reason, the therapist should react accordingly.

The FCSI testing battery contains several subjective items such as evaluation of sitting position, lying position, symmetry of thrust from those positions and symmetry of muscle mass between limbs. Similar subjective evaluation methods are used in many of the human testing batteries (Lequesne et al. 1987, Noyes et al. 1989, Lequesne et al. 1991, 1997 Barber-Westin et al. 1999). Despite the subjective elements, the inter-class correlation of 0.784 indicated an excellent inter-tester reliability (Fleiss 1986). The fact that one of the testers was less experienced than the other two had no effect on the inter-rater reliability. Neither did the level of
familiarity with the FCSI, as one of the testers was more familiar with the testing battery than the other two. The most important factor in performing a testing battery is a standardized way of conducting it (Lysholm et al. 1982, Insall et al. 1989). Therefore, before commencing the study, all testers were familiarized with the testing battery, and throughout the study period they had access to the written instructions for the testing battery, described in Appendix 1. This means that the testing battery can be used as a multicentred communication tool between, for example, the therapist in the referring acute facility and the therapist continuing therapy locally, and vice versa. In addition, although initially designed as a testing battery performed by a physiotherapist, the total score (0-263) and classifications (adequate, compromised, severely compromised) provided by the two cut-offs are also informative to the veterinarian surgeon treating the patient.

In this thesis, emphasis was placed not only on providing and validating a measurement method but also on defining the clinical relevance of the results gained when using the FCSI to evaluate overall functional level or bathroom scales to measure SWB. Many evaluation methods, especially in small animal orthopaedics, produce a quantitative result (Jaeger et al. 2002, Mostafa et al. 2009), but interpretation of the clinical relevance of the result to the patient (Horner et al. 2006) is subjective and, while not defined, also important. The FCSI is provided with two cut-offs to clarify the clinical relevance of the total score result; the result indicates an adequate, compromised or severely compromised performance level. In addition, the bathroom scales are equipped with information of what can be considered the limit to normal variation of SWB between hindlimbs (6%). We are unaware of similar threshold values being reported for any other quadrupedal species.

6.4. LIMITATIONS

The group sizes as well as the similar demographics of the three groups were ideal at the beginning of the study (IV); however, nine dogs did not complete the study. Although this is not desirable, it is understandable considering that this was a clinical study and the study groups consisted of real patients.

Three of the four studies comprising this thesis used the same study group of surgically treated CCL patients and control group dogs for the following purposes: to define normal variation of static weight bearing, to define various ranges of ROM, to rank and validate physiotherapeutic evaluation methods and to validate the testing battery against other evaluation methods used by a veterinarian. However, all of these sections were separate and independent from each other and are therefore acceptable.
Certain items in the testing battery have weaknesses. For example, weight bearing is measured only between hindlimbs, and not between all four limbs. However, the method of four bathroom scales, one under each limb, was tested prior to commencing the actual study. It was found to be highly difficult and in some cases impossible to perform in the setting and with the dogs available at the time, and therefore, the decision was made to concentrate on merely the hindlimbs. This has also been the set-up in previously published studies of bathroom scales used as measurement tools for dogs’ SWB (Meadows et al. 1990, Aro et al. 1991). Computerized platforms are also available that enable the measurement of weight distribution between all four limbs simultaneously (Phelps et al. 2007, Millis et al. 2012); however, the cost of such equipment is high and would limit the use of the testing battery in a clinical environment.
7. CONCLUSIONS

1. Congruity between fourteen physiotherapeutic evaluation methods commonly used in dogs with stifle dysfunction and six evaluation methods used by a veterinarian was evaluated. At least one and up to six significant associations were observed between the methods. Based on these, a ranking order for the physiotherapeutic evaluation methods was set. In addition, the sensitivities of the physiotherapeutic methods were determined, which ranged from 15% to 87.5%, i.e. from very low to very high.

2. Clinically normal variation, 3.3% ± 2.7%, of weight bearing between the hindlimbs in a static state, measured with bathroom scales, was presented. The overall repeatability for static weight bearing difference between the hindlimbs of dogs with OA in their stifles was 79%, which can be considered good.

3. The testing battery, FCSI, comprised the eight best ranked items. Based on principal component analysis, the items were divided into two components: “functional” and “passive”. The FCSI had a total score of 0-263, with a higher score indicating a higher level of dysfunction. Cronbach’s alpha for the internal reliability of the total FCSI score was 0.727, which can be considered good. When studied against the veterinarian-performed conclusive assessment, the sensitivity and specificity of the FCSI total score were very high, 90% and 90.5%, respectively. Two cut-off scores were set, 60 and 120, to separate “adequate”, “compromised” and “severely compromised” performances based on a sensitivity of 88.4% and 82.8% and a specificity of 90.5% and 89.3%, respectively.

4. Responsiveness of the testing battery was considered good, as the dogs with stifle dysfunction showed a significant decrease in FCSI total score at each testing time relative to the control groups. The inter-tester reliability was excellent (ICC 0.784), with no significant differences between the three testers.
8. APPENDICES

8.1. FINNISH CANINE STIFLE INDEX, FCSI: THE EVALUATION PROTOCOL

For each item, the handler of the dog, usually the owner, is given standardized instructions. The tests are always performed in the same environment. In case of disturbance (e.g. reaction to other dogs, misbehaviour), the handler is asked to repeat the item as many times as necessary. Assistive aids, such as treats or toys, are used to motivate the dogs to perform tasks, if needed.

Visual evaluation of functional active range of motion: sitting position and symmetry of the thrust from sitting position

The dog is led over a 20-m distance and asked to sit and sit-to-move 3 times within equal distances. Any functional limitation or compensation of the sitting position, such as external rotation, abduction, and limited flexion of the hindlimbs, is noted. Observed weakness or asymmetry in thrust of hindlimbs from the ground is noted.
Visual evaluation of functional active range of motion: lying position and symmetry of thrust from lying position
This is done using a similar protocol as the above items.

Evaluation of symmetry of muscle mass
While the dog is standing in a balanced, square position, the symmetry of thigh musculature between the hindlimbs is manually evaluated. In case of asymmetry, the weaker limb is noted.

Symmetry of static weight bearing between hindlimbs
SWB is measured with the hindlimbs placed on two identical bathroom scales. The handler holds the dog from the front, keeping it in a straight, square-standing position, and is instructed not to provide any manual support for the dog. The examiner is situated behind the dog, placing the hindlimbs symmetrically onto the scales, recording the measurements for both limbs. At least three measurements should be taken; the mean is calculated and used.
Passive range of motion: stifle flexion and extension

The PROM of stifle joints is measured using a universal goniometer, with the dog lying on its side. Joints proximal to the one being measured are positioned so that the least amount of muscular restriction affects the joint being measured.

Measurement procedure follows standard joint measurement protocols, where the universal goniometer (UG) is placed lateral to the stifle joint, and the axis of the UG is placed over the axis of the movement of the joint. The stationary arm of the UG lies parallel to the femur, pointing towards the greater trochanter of the femur. The movable arm of the UG lies parallel to the tibia, pointing towards the lateral malleolus of the fibula.

Three measurements of maximal flexion and extension of the stifles are taken, and the mean value is used. The PROM in extension and flexion is followed through until the last possible end of PROM is met at the furthest possible full fifth degree, limited by either active resistance of the dog, pain, or palpable end-feel. Possible deviant findings in end-feels and limiting factors are recorded.
### 8.2. FINNSH CANINE STIFLE INDEX, FCSI: THE SCORING SYSTEM

<table>
<thead>
<tr>
<th>FINNSH CANINE STIFLE INDEX</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual evaluation of functional active range of motion: Sitting position</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Possible compensations detected:</td>
<td></td>
<td></td>
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<tr>
<td>- decreased flexion in stifle and/or tarsus</td>
<td></td>
<td></td>
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<tr>
<td>- external rotation of limb</td>
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<td></td>
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<tr>
<td>- abduction of limb</td>
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<td></td>
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<tr>
<td>- sitting on either hip</td>
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</tr>
<tr>
<td>- other severe compensations (any type of deviation from normal symmetrical positions of an animal due to pain or mechanical restrictions in the musculoskeletal system)</td>
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<tr>
<td>0 = No compensations detected</td>
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<td></td>
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<tr>
<td>1 = One of the above-mentioned compensations detected</td>
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<td></td>
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<tr>
<td>2 = Two of the above-mentioned compensations detected</td>
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<tr>
<td>3 = Three or more of the above-mentioned compensations detected</td>
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<tr>
<td><strong>Symmetry of thrust from sitting position</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 = Adequate symmetrical thrust (both limbs scored as 0)</td>
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<tr>
<td>2 = Asymmetry of thrust (weaker limb scored as 2, contralateral as 0)</td>
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<tr>
<td><strong>Visual evaluation of functional active range of motion: Lying position</strong></td>
<td></td>
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<tr>
<td>Possible compensations detected:</td>
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<tr>
<td>- decreased flexion in stifle and/or tarsus</td>
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<tr>
<td>- external rotation of limb</td>
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<td>- abduction of limb</td>
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<tr>
<td>- sitting on either hip</td>
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<tr>
<td>- other severe compensations (any type of deviation from normal symmetrical positions of an animal due to pain or mechanical restrictions in the musculoskeletal system)</td>
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<tr>
<td>0 = No compensations detected</td>
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<tr>
<td>1 = One of the above-mentioned compensations detected</td>
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<tr>
<td>2 = Two of the above-mentioned compensations detected</td>
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<td></td>
</tr>
<tr>
<td>3 = Three or more of the above-mentioned compensations detected</td>
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<td></td>
</tr>
<tr>
<td><strong>Symmetry of the thrust from lying position</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 = Adequate symmetrical thrust (both limbs scored as 0)</td>
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<tr>
<td>2 = Asymmetry of thrust (weaker limb scored as 2, contralateral as 0)</td>
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<tr>
<td><strong>Symmetry of muscle mass</strong></td>
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<tr>
<td>0 = Adequate symmetrical muscle mass (both limbs scored as 0)</td>
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<tr>
<td>2 = Asymmetry of muscle mass (weaker limb scored as 2, contralateral as 0)</td>
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<td></td>
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<tr>
<td><strong>Symmetry of static weight bearing between hindlimbs</strong></td>
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<tr>
<td>SWB result in kilograms (mean of three measurements):</td>
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<tr>
<td>Body weight of dog</td>
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<tr>
<td>% Difference between hindlimbs: (SWB left – SWB right)/body weight*100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 = Less than 6% difference between hindlimbs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 = 6.8–7.7% difference between hindlimbs (weaker limb scored as 1, contralateral as 0)</td>
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<tr>
<td>2 = 8.8–11.5% difference between hindlimbs (weaker limb scored as 2, contralateral as 0)</td>
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<tr>
<td>3 = Over 11.5% difference between hindlimbs (weaker limb scored as 3, contralateral as 0)</td>
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<tr>
<td><strong>Passive range of motion: Stifle flexion</strong></td>
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<tr>
<td>Result in degrees (mean of three measurements):</td>
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<tr>
<td>0 = Less than 51.7°</td>
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<td></td>
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<tr>
<td>1 = 51.7°–57.9°</td>
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<tr>
<td>2 = 57.9°–64.2°</td>
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<td></td>
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<tr>
<td>3 = Over 64.2°</td>
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<tr>
<td><strong>Passive range of motion: Stifle extension</strong></td>
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<tr>
<td>Result in degrees (mean of three measurements):</td>
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<tr>
<td>0 = Over 147.7°</td>
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<td></td>
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<tr>
<td>1 = 140.5°–147.7°</td>
<td></td>
<td></td>
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<tr>
<td>2 = 133.3°–140.5°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 = Less than 133.3°</td>
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<td></td>
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<tr>
<td><strong>Amount of items performed (max. 8)</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>FCSI SCORE</strong> (sum of item scores / amount of items * 100)</td>
<td></td>
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</tr>
</tbody>
</table>

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