Aus der Klinik und Poliklinik für kleine Haustiere
des Fachbereichs Veterinärmedizin
der Freien Universität Berlin

Patellar luxation and concomitant cranial cruciate ligament rupture in small breed dogs

Inaugural-Dissertation
zur Erlangung des Grades eines
Doktors der Veterinärmedizin
an der Freien Universität Berlin

vorgelegt von
Mario Candela Andrade
Tierarzt aus Ceuta (Spanien)

Berlin 2019
Journal-Nr.: 4132

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Index

Abbreviations

AT – Anteversion

CFI – Capsular and fascial imbrication technique

CCL – Cranial cruciate ligament

CCLR – Cranial cruciate ligament rupture

CCT – Cranial tibial thrust

CKCS – Cavalier King Charles Spaniel

CT – Computer tomography

CDT – Cranial drawer test

Jack R. Terrier – Jack Russell Terrier

MPL – Medial patellar luxation

LPL – Lateral patellar luxation

MRI – Magnetic resonance imaging

Min – Minimum

Max – Maximum

OT – Fascia over the top technique

PL – Patellar luxation

Q-angle – Quadriceps angle

SD – Standard deviation

TT – Tibial tuberosity transposition

TPA – Tibial plateau angle

TPLO - Tibial plateau levelling osteotomy

WHWT – West Highland White Terrier

York. Terrier – Yorkshire Terrier

1. Introduction

On the one hand, patellar luxation (PL) is one of the most common pathologies affecting the stifle joint in toy breeds. On the other hand, cranial cruciate ligament rupture (CCLR) is the most common disease affecting the stifle joints in dogs (WITSBERGER et al. 2008), which may be caused by patellar luxation. While many studies have been conducted on patellar luxation and cranial cruciate ligament rupture, studies of dogs suffering from a combination of both pathologies and focus on the high incidence in toy breeds are lacking. To date, few authors have correlated patellar luxation with concomitant cranial cruciate ligament rupture (CCLR). PIERMATTEI (1997) proposed that 15-20% of dogs with patellar luxation could acquire a secondary cranial cruciate ligament rupture. A more recent study by GIBBONS et al. (2006) found that 14% of large dogs with patellar luxation had concomitant CCLR. In addition, CAMPBELL et al. (2010) found that 40% of small breed dogs found with patellar luxation also suffered from CCLR at the time of diagnosis. Moreover, the study revealed a correlation between high grades of luxation (grade IV) and concomitant CCLR.

PL is a common orthopaedic problem in toy and miniature breed dogs, with a complex and poorly understood pathogenesis, which is often complicated by CCLR. To contribute to a better understanding, the present study aimed to evaluate:

- Frequency of concomitant CCLR in a group of small-breed dogs with PL
- Correlations between the grade of PL and concomitant CCRL
- Efficacy of different surgical combinations (“Tibial tuberosity transposition”, “Wedge resection osteotomy” and “Capsular fascial imbrication” or “Fascia over the top” technique) to treat both PL and CCLR

2. Anatomy and biomechanics of the canine stifle joint

2.1 Functional anatomy of the canine stifle joint

The stifle joint consists of three interrelated joints: the femorotibial, the femoropatellar and the proximal tibiofibular joint (ROBINS 1990). It can hinge, glide and rotate around its axis through the integration of muscles, ligaments, joint capsule and menisci through the condylar surface geometry of femur and tibia (ROBINS 1990). It is important to understand that the femoral condyles roll and slide on the tibial table and that the joint allows for cranial and caudal displacement, compression and distraction, internal and external rotation, varus and valgus angulation, as well as lateral and medial translation (ARNOCZKY and MARSHALL 1977). Furthermore, abduction and adduction, as well as rotation, are possible to a small extent (BUDRAS 1996) due to the articulating bones and limited displaceability of the menisci (NICKEL et al. 1992).

2.2 Patella and quadriceps muscle group

The patella is the largest sesamoid bone in the body and situated within the tendon of the quadriceps femoris muscle (ROBINS 1990). Both femoral condyles are separated by the intercondylar fossa (FITCH et al. 1995). In healthy dogs, the depth of the femoral trochlea is approximately half of the thickness of the patella (ROUSCH 1993; SLOCUM and SLOCUM 1993; COSTANTINESCU and TOMLINSON 1994). The patella articulation with the femoral trochlea is created by the convex caudal part, which is covered by hyaline cartilage and conforms to the shape of the femoral trochlea. Fibres of the quadriceps tendon and the fascia lata (ROBINS 1990) cover the cranial part. The medial and lateral parapatellar fibrocartilages articulate with the ridges of the femoral trochlea, thereby preventing luxation and providing a greater surface area for protection and bearing of the tendon (ROBINS 1990). Physiologically, the parapatellar cartilages insert into the femoral fascia (CARPENTER 2000). The suprapatellar fibrocartilage plays a role in repositioning the patella into the trochlear groove after maximal flexion (DRAHN 1925). Generally, the patella is held in the femoral trochlea by the thick lateral femoral fascia, or fascia lata, and the thinner medial femoral fascia. The comparatively delicate medial and lateral femoropatellar ligaments aid this function (EVANS and DE LAHUNTA 2013). These narrow bands of loose fibres partially blend with the overlying femoral fascia. While the lateral femoropatellar ligament runs from the lateral side of the patella to the lateral fabella and inserts into the lateral head of the gastrocnemius muscle, the smaller medial ligament blends into the periosteum of the medial epicondyle of the femur.

It has been postulated that weakness or absence of the lateral parapatellar fibrocartilage could be a cause of medial patellar luxation in dogs (MORITZ 1960).

The muscles that primarily allow extension and flexion of the stifle joint are the quadriceps and popliteus muscles, respectively (KOENIG and LIEBLICH 2014; NICKEL et al. 2001). The quadriceps muscle is subdivided into four parts: rectus femoris, vastus lateralis, vastus medialis and vastus intermedius (ROBINS 1990; EVANS and DE LAHUNTA 2013). It covers the cranial, medial and lateral aspects of the femur, as well as holds the patella within. The rectus femoris muscle originates from the tuberosity of the rectus femoris on the ileum, ends in a strong tendon that holds the patella and continues to the tibial tuberosity (ROBINS 1990; EVANS and DE LAHUNTA 2013). Finally, it ends in the patellar ligament (FREWEIN and VOLLMERHAUS 1994; NAV 2012). The rectus femoris fuses with the vastus lateralis and inserts on the base of the patella. The vastus medialis also merges with the rectus femoris tendon, just proximal to the base of the patella, while the tendon of insertion of the vastus intermedius creates an aponeurosis with the vastus medialis (EVANS and DE LAHUNTA 2013).

2.3 Cranial cruciate ligament

The cranial cruciate ligament (CCL) (Lig. cruciatum craniale) originates from the condylar fossa on the caudomedial aspect of the lateral femoral condyle (DYCE et al. 1952; LOEFLLER 1964; MÜELLER 1969; ARNOCZKY and MARSCHALL 1977; HEFFRON and CAMPBELL 1978; ARNOCZKY 1988 and 1993; WEISS 1990), reaches across the intercondyloid fossa diagonally and inserts at the cranial intercondyloid area of the tibia (ARNOCZKY and MARSHALL 1977; LOEFFLER 1964; HEFFRON and CAMPBELL 1978; ARNOCZKY 1988 and 1993). The ligament widens distally and runs out fan-shaped (SONNENSCHEIN 1951; ZAHM 1964). It is rotated on its own longitudinal axis, resulting in lateral pull on the cranial fibres and caudal pull on the medial fibres (SONNENSCHEIN 1951; LOEFFLER 1964; GEYER 1966; ARNOCZKY 1988 and 1993; ROBIN 1990; WEISS 1990). Many authors differentiate the cranial cruciate ligament into two portions: the craniomedial portion, which is taut during all phases of the gait, and the caudolateral portion, which is only taut during extension of the stifle (LOEFFLER 1964; MÜELLER 1969; ARNOCZKY and MARSCHALL 1977; HEFFRON and CAMPBELL 1978; BRUNNBERG 1989A; ROBINS 1990). Fibres that form the craniomedial portion arise from the cranioproximal aspect of the femoral attachment and end in the craniomedial aspect of the tibial attachment. The remaining bulk is known as the caudolateral portion (ARNOCZKY 1993). Both strength and texture of the CCL were found to be influenced by increasing age (ZAHM 1964; VASSEUR et al.1985; REESE 1995).

The CCL is covered by folds of synovial membrane, which are supplied with blood from branches of the medial and lateral genicular arteries, derived from the popliteal artery, cranially and from a direct branch of the descending genicular artery, caudally (ARNOCZKY and MARSHALL 1977; SLOCUM and DEVINE 1983). The mid-section of the ligament has a poorer blood supply than the proximal and distal ends (VASSEUR 2003; PALMISANO et al. 2000). The main functions of the CCL include: prevention of cranial displacement of the tibia in relation to the femur (ARNOCZKY and MARSCHALL 1977; HEFFRON and CAMPBELL 1978; ROBINS 1990), limiting rotational mobility of the stifle joint, preventing excessive internal rotation as well as limiting stretching and hyperextension of the stifle joint (DYCE et al.1952; ARNOCZKY and MARSCHALL 1977; ROBINS 1990).

2.4 Caudal cruciate ligament

The caudal cruciate ligament (Lig. cruciatum caudale) originates from the condylar fossa located at the proximal aspect of the cranial outlet of the intercondylar notch on the lateral side of the medial femoral condyle. It inserts on the medial aspect of the popliteal notch of the tibia. The caudal cruciate ligament prevents caudal movement of the tibia towards the femur. Moreover, in combination with the cranial cruciate ligament, it prevents extreme internal rotation of the tibia (ARNOCZKY and MARSHALL 1977; ARNOCZKY 1988).

2.5 Collateral ligaments

The medial collateral ligament is a strong ligament that extends from the medial femur epicondyle to the medial border of the tibia, about 2 cm distal to the medial tibial condyle. It is connected to the joint capsule and the medial meniscus. The lateral collateral ligament crosses the joint cavity, passing through the tendon of origin of the popliteus muscle and ends on the head of the fibula distally, leaving new fibres going to the adjacent condyle of the tibia (EVANS and DE LAHUNTA 2013). While it is connected to the joint capsule, it shares no connection with the lateral meniscus (VASSEUR and ARNOCZKY 1981).

2.6 Menisci

The lateral and medial menisci are semilunar discs of fibrocartilage with thin, concave, axial borders and thick, convex, abaxial borders (SLOCUM and DEVINE 1993; ROBINS 1990). They lie between the articulating surfaces of the femur and tibia in the stifle joint (KÖENIG and LIEBICH 2014). In cross section, they appear wedge shaped. The lateral meniscus is slightly thicker and forms a slightly greater arc than the medial one (ARNOCZKY 1993; ROBINS 1990; EVANS and DE LAHUNTA 2013). The menisci are covered by synovial membrane. The medial meniscus retains its attachment to the joint capsule, while the lateral meniscus does not (EVANS and DE LAHUNTA 2013). Meniscal ligaments attach the menisci to tibia and femur (EVANS and DE LAHUNTA 2013). The femoral ligament of the lateral meniscus (Lig. meniscofemorale), which originates in the lateral meniscus, is the only femoral attachment of the menisci. It passes from the caudal axial angle of the lateral meniscus dorsally to the part of the medial femoral condyle that faces the intercondyloid area (EVANS and DE LAHUNTA 2013; NICKEL et al. 2001). The menisci have several functions including the protection of the opposing articular surfaces and increasing stability of the stifle through increased depth of the articular surface of the proximal tibia. Basically, the menisci counteract the incongruence between the adjacent articular surfaces of femur and tibia. Moreover, they aid in joint lubrication (ROBINS 1990; FREWEIN and VOLLMERHAUS 1994; KÖENIG and LIEBICH 2014). While the lack of structural attachment allows for movement in the lateral meniscus, thereby enabling greater movement in the lateral femoral condyle during flexion and extension, the connections to the medial collateral ligament and the joint capsule result in limited flexibility in the medial meniscus (ARNOCZKY 1993). Consequently, the medial meniscus is more likely to be damaged due to trauma or joint instability (PAATSAMA 1952; LOEFFLER 1964).

2.7 Biomechanics of the stifle joint

In dogs, the caudal angle of the stifle joint should not exceed 150° (DYCE 1991). The range of movement in flexion and extension varies between 90° and 130°. Abduction and adduction, as well as rotation, are limited to a maximum of 20° (VOLLMERHAUS 1994). In the average dog, 60% of body weight is held by the fore limbs and 40% by the hindlimbs (BUDSBERG et al. 1987; UNKEL-MOHRMANN 1999), although variations have been observed in different breeds (HULSE and HYMAN 1993; OFF 1997). Boxers, Whippets, Greyhounds and Borzois carry 70-80% of their body weight in their forelimbs, while other breeds like German Shepherds, Dobermans, Rottweilers or Airedale Terriers vary between 58-69% (OFF and MATIS 1997). The amplitude of movement in the knee during flexion and extension lies around 140° in dogs (LEIGHTON 1966), though breed variations of up to 10° have been described (LOTT 1988). Muscles, ligaments and tendons protect the stifle joint against damage through abnormal movements. (HENSCHEL et al. 1981). A stable movement of the stifle joint requires a balance of forces between the quadriceps femoris and the antagonistic ischiocrural musculature as well as the ligaments. A loss of balance between the forces will lead to abnormal joint movement (BARRATTA et al. 1988). In the standing phase, the stifle joint is flexed. At the beginning of the swing phase, the flexion turns into stretching and reaches its maximum point at the end of this phase (UNKEL-MOHRMANN 1999). During extension, muscles contract and the patella slides along the proximal trochlea. In the state of maximal stretching, the patella is unsupported at the proximal end of the femoral trochlea. The pulling direction during the contraction of the extensor muscles corresponds to a vertical axis, which runs longitudinally through the middle of femur and tibia. This means that the patella follows this imaginary axis with its sliding movement. By flexing the hip joint, the limbs are guided forward, and the patella, patellar tendon, trochlea, and tibial tuberosity should follow a straight line (SCHAEFER 1981). Stability between patella and femoral trochlea is a prerequisite for the efficacy of the quadriceps femoris and the patellar tendon. The stability of the patella is ensured by a combination of different effective forces that control the femorotibial rotation in the axial direction. These include the axis of the quadriceps femoris muscle and the patellar tendon, the muscular strength of the fascia, the shape of the femoral trochlea and the integrity of both patellar retinacula (KRAUS 2006). The cruciate ligaments and the patellar ligament are the primary restraints for the normal degree of craniocaudal movement. CCL prevents cranial displacement, as it is taut in extension and lax in flexion (RIEGERT 2004). Throughout extension and flexion, the joint rotation centre moves cranial and caudal, respectively (IRELAND et al. 1986), while the femoral condyles rotate on the meniscal surface (DYCE et al. 1952; ARNOCZKY 1980; STONE et al. 1980). When the stifle is flexed, the femoral origin of the fibres of the caudolateral portion of the CCL are brought closer to the tibia, thereby relaxing the fibres, whereas the attachment of the craniomedial portion moves caudodistal and remains taut. During extension, both portions are taut. As a result, the distance between the femoral and the tibial attachments of the craniomedial ligament remain unaffected (and taut) during flexion (ARNOCZKY 1993). Because of this, the ligament provides a primary check against hyperextension of the stifle. The joint capsule, lateral and medial menisci, collateral ligaments, dynamic muscle forces and the shape of the femoral and tibial articulating surfaces supply a secondary constraint for craniocaudal movement. The semimembranosus and semitendinosus muscles stabilize through a caudally directed pull of the proximal tibia (KANNO et al. 2012). However, these secondary constraints are insufficient, and instability appears in lack of an intact cranial cruciate ligament (ARNOCZKY 1993).

A rotation of the tibia relative to the femur takes place in a longitudinal direction and mainly occurs during phases of joint flexion. The external rotation is limited to a few degrees for both flexion and extension, while the internal rotation is hardly possible when the joint is extended. ARNOCZKY and MARSCHALL (1977) indicated that the internal rotation of the tibia with respect to the femur in a 90° bending position is possible to about 19°, while a maximum of 8° tibial external rotation may be achieved. Physiologically stretched stifles allow for an internal tibial rotation of 6° and an external rotation of 5°. Alteration of the axial stifle joint rotation, such as valgus and varus deformities, increase compression and friction to the joint surface. In certain types of movements where the rotation centre between femur and tibia is not in a parallel line to the articulation point, resulting in the motion vector not running tangential to the joint surface, meniscal damage can be caused (FRANKEL et al.1971; WALKER and HAJEK 1972; ARNOCZKY et al. 1977).

3. Pathophysiology

The patellofemoral joint enables mechanical efficacy of the quadriceps muscle group (VASSEUR 1993), as it makes the extensor function easier, centralizes the forces of the quadriceps muscle (Figure 1) and its cartilage cover provides a smooth gliding mechanism for the quadriceps muscle. As a result, the stifle joint is stabilized (VASSEUR 1993). Currently, two hypotheses regarding the correlation of patellar luxation and CCLR are being debated; however, both are yet to be proven.

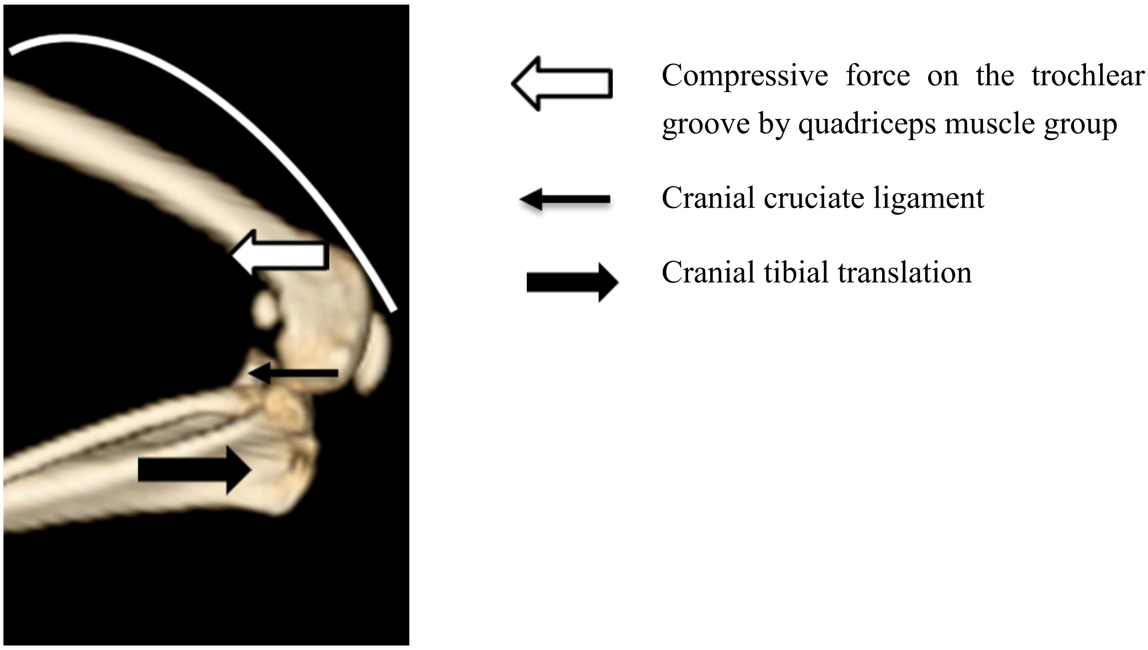


Figure 1. Lateral view of the stifle joint of a 3-year-old male poodle without patellar luxation, modified from a 3D computer tomography image. During joint flexion, compressive force exerted by the patella in the trochlear groove could support the cranial cruciate ligament (CCL) against the cranial tibial translation (CTT).

3.1 Theory I

The first theory is based on an increase of forces during flexion of the stifle joint and consequent geometric forces in the femoropatellar joint, as illustrated in Figure 2. These forces act between the quadriceps muscle group and the patellar ligament. In a physiological motion, they are perpendicular to the joint surfaces and directed caudally to maintain the patella in equilibrium (CAMPBELL et al. 2010). After a patellar luxation, there is a lack of joint compressive force on the trochlear groove (A), while the cranial tibial translation persists and increases stress on the CCL, possibly causing its rupture. Dogs with medial patellar luxation (MPL) are prone to secondary CCLR (MOORE and READ 1996), because the caudally directed vector force of the patellofemoral joint (exerted through the patella and the quadriceps muscle group, compressing the trochlear groove) fails, while the cranially directed sheer force of the cranial tibial translation increases the strain on the CCL (B). Consequently, the CCL may be predisposed to rupture (BRINKER 1990; CAMPBELL et al. 2010).

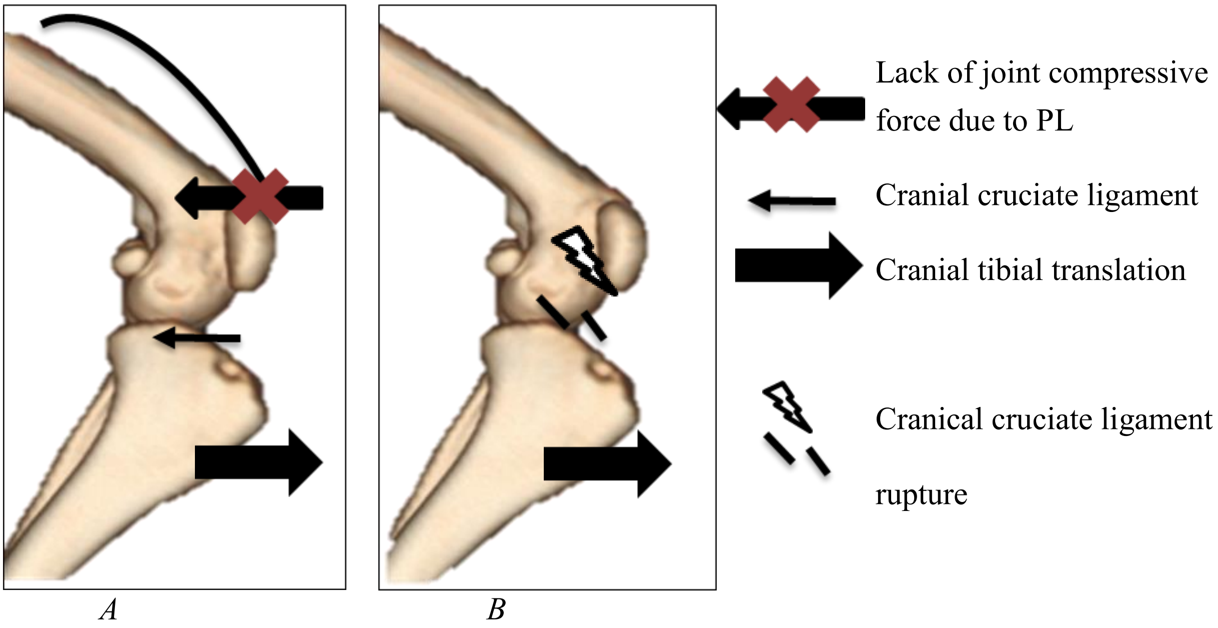


Figure 2. Mediolateral view of the stiflte joint of a 3-year-old male poodle with medial patellar luxation grade III, modified from a 3D computer tomography image. (A) Mediolateral view of a stifle joint with medial patellar luxation. Due to the patellar luxation, the caudally directed joint compressive force on the trochlear groove is no longer exerted. (B) Same illustration. Cranial tibial translation increases further stress on the CCL. This increased stress could cause the rupture of the ligament.

3.2 Theory II

The second theory proposes that patellar luxation is a direct consequence of the cruciate ligament rupture (Figure 3). When the ligament ruptures (3B), the lack of constraints of internal rotation of the tibia could lead to patellar luxation or increase the degree of a pre-existing patellar luxation (3C) (KAISER et al. 2001). This additional stress, combined with the normal degenerative process of these structures with age, could account for the findings of CCLR in older dogs suffering from patellar luxation (ALAM et al. 2007). Studies that found an association between patellar luxation and CCLR proposed a combination of factors as causative. They theorized that internal rotation of the tibia, quadriceps muscle-patella-patellar tendon-mechanism deviation, cartilage erosion and degenerative joint disease could create an environment in the stifle joint that promoted CCL degeneration, and ultimately, CCLR. (ARNOCZKY and MARSHALL 1977; MOORE and READ 1995; PIERMATTEI 1997).

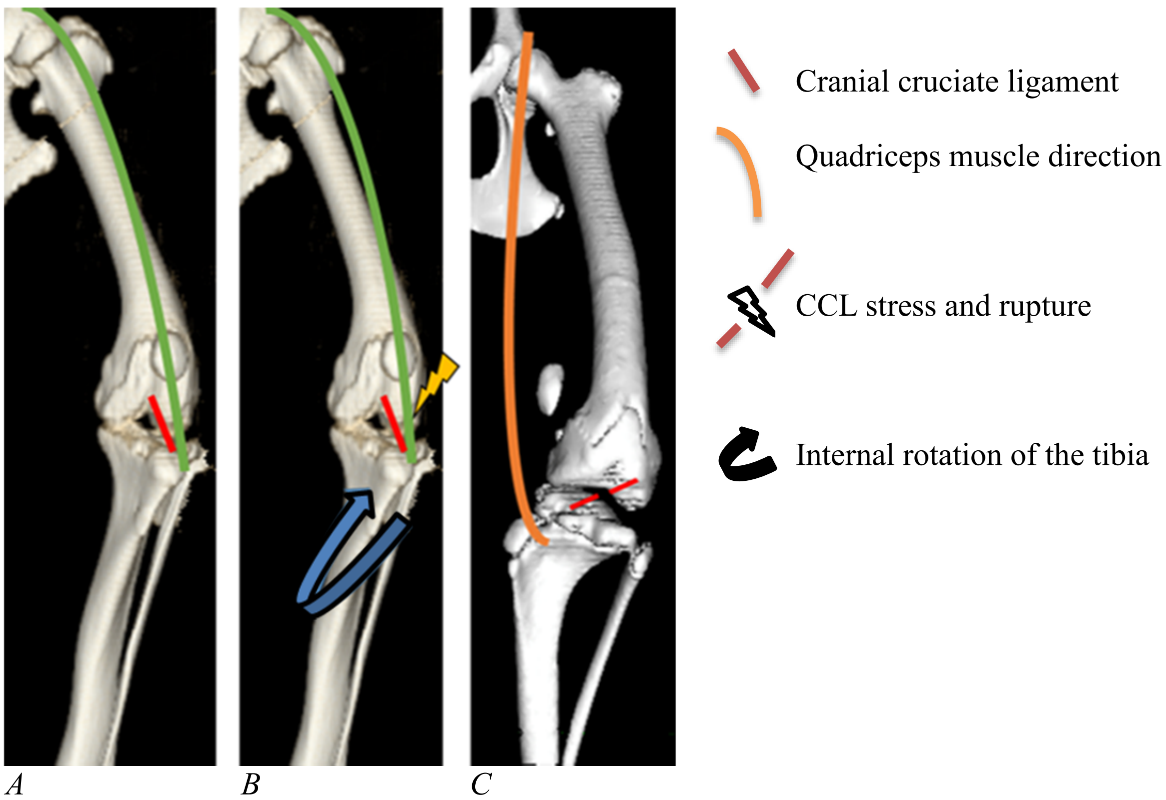


Figure 3. Illustration of events according of the second theory. (A) Shows healthy stifle joint, with no patellar luxation or mild grades (I-II) of luxation. (B) Shows the rupture of the cranial cruciate ligament. (C) Shows a stifle joint post- rupture with an internal rotation of the tibia could lead into a patellar luxation or increase pre-existing patellar luxation. Images were adapted from 3D computer tomography images.

4. Patellar luxation

Patellar luxation is not just a simple surgical disease but has rather been characterized as an anatomic anomaly of the entire pelvic limb (HARRISON 1975; ROUSH 1993). The correct alignment of the stifle joint is essential for the efficacy of the extensor mechanism, which relies on the quadriceps muscle group, the patella and the tibial tuberosity working together (HULSE 1981; L'EPLATTENIER and MONTAVON 2002). The causes of patellar luxation have been associated with many factors. However, a complete understanding is yet to be achieved. Patellar luxations are categorized into congenital and acquired luxations, in which the patella can luxate medially, laterally or in both directions. (REIF 2012; SCHULZ 2009)

4.1 Patellar luxation types: acquired and congenital

Acquired patellar luxations are either traumatically induced or occur as a result of stifle joint diseases, such as malformations or femoral luxations (KODITUWAKKU 1962; HARRISON 1975; SCHMIDTKE 1981; BRINKER et al. 1993). Traumatic patellar luxations generally have sudden onset clinical signs and may occur in any breed at any age. Affected dogs suffer from a moderate degree of pain and may experience secondary joint capsule rupture, fracture of the tibial crest apophysis, patellar fracture, as well as rupture of the cranial cruciate ligament and patellar ligament (BRUNNBERG 1992). In these cases, the femoral trochlea has usually developed correctly (KASA et al. 2001). In human medicine, acquired patellar luxations are known as exogenous patellar luxation (JANSSEN 1978).

In cases of congenital patellar luxation, dogs show lameness due to instability when the patella has slipped out of place, but usually do not experience pain (DEANGELIS 1971). Congenital patellar luxation can be intermittent or stationary. For those stationary, there is often a formation of a pseudotrochlea (GUENGO and BARDET 1996). Over time, the patellar luxation causes erosion of the cartilage on the condylar ridge, thereby causing pain. As a result, lameness becomes more evident and persistent (DEANGELIS and HOHN 1970).

Lateral patellar luxations (LPL) are generally uncommon. About half of these cases occur in medium to large breed dogs suffering from “genu valgum” or hip dysplasia (DEANGELIS 1971). Some authors consider PL to be a breeding problem and consequently recommend excluding affected individuals from breeding programs (KODITUWAKKU 1962; PRIESTER 1972; BRINKER et al. 2006). In most PL cases, the patella luxates medially. The paw is rotated inward, while the patella is fixed on the medial side and can be difficult to locate due to its small size. In radiographs, a lateral bowing of the distal femur can be seen, with a valgus or medial bowing of the proximal tibia, resulting in what is called a "shallow s-shaped curve" of the femur and tibia (DEANGELIS and HOHN 1970). A combination of lateral and medial ipsilateral patellar luxations is possible (OLMSTEAD 1981; BRINKER et al. 2006).

Congenital patellar luxation has a high incidence in miniature and toy breeds, which has been associated with underlying soft tissue and bone abnormalities (ORMROD 1966; UBERREITER 1966; FRITZ 1989; HAYES et al. 1994; KAISER 1999; KASA et al. 2001 and MEYER 2001). Even if the patellar luxation is not manifest at birth, potential deformities can develop as the dog grows older and ultimately cause this pathology (MATIS et al. 1993). However, in many cases, patellar luxation is not accompanied by skeletal deformities. This led BRINKER et al. (2006) to propose a laxity of the muscle group and patellar ligament to be causative. Furthermore, MOSTAFA et al. (2008) associated MPL with a relatively long patellar ligament and patella alta, in medium to large breed dogs, while lateral patellar luxation was theorized to be associated with a relatively long proximal tibia and patella baja.

4.2 Statistical analysis of patellar luxation

A predisposition for patellar luxation has been found in many breeds, such as Chihuahua, Pomeranian, Miniature Poodle, Boston Terrier, Bichon Frise and Yorkshire Terrier (PRIESTER 1972; KODITUWAKKU 1962; PUTNAM 1968; CAMPBELL and POND 1972; TROTTER 1980; HAYES et al. 1994; DENNY 1996; ALAM et al. 2007; OBOLADZE 2010; NILSSON et al. 2018). It is known that small-breed dogs have a higher risk to be affected by (medial) patellar luxation compared to large-breed dogs (PRIESTER 1972; TROTTER 1980; ALAM et al. 2007; O'NEIL et al. 2016). Moreover, the condition is even more common in toy breeds (KODITUWAKKU 1962; LOEFFLER 1964; ÜBERREITER 1966; SINGLETON 1969; RODENBECK 1971; SCHÄFER 1982; HOFFMANN 1983; NUNAMAKER 1985; MÜLLER and REINHARD 1986; SCHIMKE and PAATSAMA 1986; FRITZ 1989; HULSE 1993; MEYER 2001). Various studies found that 90% of MPL cases occurred in small breed dogs (KODITUWAKKU 1962; DEANGELIS and HOHN 1970; FRITZ 1989; KAISER 1999; MEYER 2001). In the case of HAYES et al. (1994), as many as 98% of MPL cases were found in small breed dogs. In addition, they found both stifle joints to be affected (UBERREITER 1966; FRITZ 1989; KAISER 1999; KASA et al. 2001; MEYER 2001) in up to 50% of cases (TROTTER 1980; HAYES et al. 1994; ALAM et al. 2007).

In previous studies, LPL was found in 5-25% of cases (KODITUWAKKU 1962; ENDRES 1977; HULSE 1981; HOFFMANN 1983; BOSIO 2017).

Furthermore, studies showed that less than 10% of LPL cases occurred in small breed dogs (KALFF et al. 2014), while 19-33% of cases occurred in medium and large breed dogs (HAYES et al. 1994; SHAVER et al. 2014).

Right and left hindlimbs appear to be equally affected by patellar luxations (ALAM et al. 2007). The sex distribution of patellar luxation revealed a female predisposition (ALBRECHT 1999; OBOLADZE 2010), which was particularly evident in small breeds with sex ratios between 1:1.86 (male:female) and 1:1.5 (PRIESTER 1972; HULSE 1981; HAYES et al. 1994; VASSEUR 2003; ALAM 2007). In contrast to this, the sex distribution for large breed dogs was found to be 1.8:1 (male:female) (GIBBONS et al. 2006; REMEDIOS et al. 1992).

A study by CAMPBELL et al. (2010) found a correlation between MPL and concomitant CCLR. Around 40% of the patellar luxation cases showed concomitant CCLR. Furthermore, almost 50% of the patellar luxation grade IV cases had concomitant CCLR. In addition, bilateral MPL was found in 76% of cases. The mean age at which dogs with concomitant CCLR were identified (7.8 years) was significantly higher than the mean age of dogs in which MPL alone was identified (3 years). It was hypothesized that this could be due to the progression of skeletal deformities with age, which could increase overall pathological changes in a stifle joint and the grade of luxation. Chihuahuas and Yorkshire Terriers were the most common breeds found in this study.

4.3 Pathophysiology of medial patellar luxation

Although the pathogenesis of congenital patellar luxation is not yet fully understood, a number of soft tissue, bone and skeletal abnormalities appear to be associated with many cases (ORMROD 1966; HULSE 1981). The following abnormalities are known to be associated with a medial displacement of the extensor mechanism: coxa vara, medial displacement of the quadriceps muscle group, lateral torsion of the distal femur, shallow trochlear groove, dysplasia of the femoral epiphysis, rotational instability of the stifle joint and tibial deformity (HULSE 1981; KINSCHER 2007). Varus deformities of the femur and malpositions of the tibia or a combination of both can cause pathological external rotation of the distal femur, possibly causing MPL (PETAZZONI 2011).

4.3.1 Malalignment of the quadriceps muscle group

Many studies have postulated that deviation of the quadriceps muscle could cause congenital PL. If the tendon of the quadriceps femoris is malaligned to the femoral trochlea, unphysiological movement could lead to PL (SINGLETON 1957; KODITUWAKKU 1962; REX 1963; RUDY 1965; HERRON 1969; DE ANGELIS and HOHN 1970; WHITTICK 1974; SCHEBITZ and BRASS 1975). A study by ÜBERREITER (1966) proposed a complex malformation with hypoplastic development of different parts of the skeleton, patella and the muscles as causative. For correct skeletal development, both lateral and medial forces must be exerted on the growth plate of the distal femur by the quadriceps. Unequal forces can cause dysplasia and potentially result in PL (HULSE 1981). Vastus lateralis produces a proximal lateral force on the patella, while vastus medialis exerts a proximomedial force (HULSE 1981). In the latter case, the lateral soft tissue supporting the stifle joint is stretched, exerting a lateral torsion force on the distal femoral growth plate and thereby causing lateral torsion of the femur. At the same time, the trochlea is displaced laterally to the line of contraction of the quadriceps, whereas the compensatory internal rotation of the limb would simultaneously cause medial displacement of the quadriceps muscle group (HULSE 1993).

It has been indicated that the angular and torsional abnormalities occur secondary to abnormal forces directed against the growing physis and that these forces originate from the medial displacement of the quadriceps muscle group (ARKIN and KATZ 1956). When PL is persistent and upholds abnormal forces over time, the deformities worsen. Hence, they could be correlated to the grade of luxation.

PUTNAM (1968) performed an experimental study on Poodles with PL to test a proposed connection between the appearances of coxa vara due to a reduced angle of anteversion of the femoral neck. An enhanced adduction of the limbs resulted in abnormal forces in the epiphysis of the femoral head. It was hypothesized that the reduced anteversion caused external rotation of the hip, with a compensatory internal rotation of the distal limb to place the paw properly (PUTNAM 1968). In human orthopaedics, the deviation of the quadriceps direction is defined as the Q-angle. It measures the direction of force of the quadriceps muscle group, the patella and the patellar ligament (BRATTSTRÖM 1964). The course of the rectus femoris muscle and the patellar ligament are the baseline for measuring the Q-angle in the extended limb (GOLDER et al. 2011). Measurements of the Q-angle in dogs were performed with diagnostic radiological and magnetic resonance imaging (MRI) (KAISER et al. 2001; PALMER 2011).

4.3.2 Hypoplasia of the femoral trochlear groove and angular deformations

The patella articulates within the trochlear groove, which is limited by the trochlear ridges. It contributes to the anterior and rotational stability of the joint and indirectly provides nutrition for the articular cartilage. The straight patellar tendon and the anatomic situation of the tibial crest are important for the extensor mechanism (HULSE 1981). Previous studies have theorized that hypoplasia of the trochlear groove caused patellar luxation (KODITUWAKKU 1962; KNIGHT 1963; PEARSON and RAMSEY 1963; LOEFFLER 1964; HENSCHEL et al. 1981). However, later studies contradicted this theory, proposing hypoplasia to be a secondary effect, rather than a cause of PL (SHUTTLEWORTH 1935; PUTNAM 1968; SINGLETON 1969; LEIGHTON 1970; DEANGELIS 1971; HUTTER et al. 1983; DÄMMRICH et al. 1993). With a medial displacement of the quadriceps muscle group, the medial pressure results in a small hypoplastic medial femoral condyle, whereas a decreased lateral pressure results in an elongated lateral femoral condyle. At the same time, these abnormal forces cause the tibial growth plate to react with a varus deformity of the proximal tibia and a medial torsion of the proximal tibia (HULSE 1981). A shallow trochlear groove is a result of the same process. While HULSE (1981) proposed that the right amount of pressure exerted by the patella was necessary for a physiological development of trochlea groove depth, HENSCHEL et al. (1981) postulated that the groove depth was genetically predetermined and developed independent of patella pressure. Furthermore, KODITUWAKKU (1981) proposed a congenital cause, theorizing that a recessive gene caused trochlear hypoplasia.

4.3.3 Osteological conformation

The anteversion angle (AT-angle) is defined as the angle in the transverse plane, formed by an imaginary line passing through the femoral neck and the tangent running caudal to the femoral condyle. It has been suggested that changes in the AT-angle of the femoral neck could lead to patellar instability (CAMPBELL 1972; HULSE 1981). Although a study by PUTNAM (1968) described these findings in dogs with patellar instability, a later study failed to confirm this theory (KAISER et al. 2001). More recently, LÖER (1999) hypothesized that genetic defects were a probable cause, since torsional defects of the femur were only found in a minority of cases. The study initially hypothesized that a torsional defect predisposed to a medial patellar luxation. However, this turned out to be a consequence of the patellar luxation. Since an internal rotation in the femorotibial joint was a dominant finding in their patient population, the study proposed that medial patellar luxation could be caused by hypoplasia of the vastus lateralis (LÖER 1999). KAISER et al. (2001) found that the AT-angles to be reduced in dogs with patellar instability, even to the point of retroversion in some. However, the study did not find a significant correlation between MR-AT angle and clinical signs of patella instability.

Other authors have suggested that the origin of these pathological changes lies in the conformation of the pelvis. In a radiographical study of 100 Papillon dogs (WEBER 1992), approximately half of the group had PL grade I or II. However, no significant difference regarding the angles of anteversion and inclination of the femur neck were found compared to healthy dogs. Interestingly, there was a significant difference in weight and size among the sample group, which correlated to the pathology. The study demonstrated that lighter and smaller dogs had a higher prevalence of the disease. Moreover, morphometric analysis of the pelvis revealed that the origin of the cranial head of the sartorius muscle was located significantly more medial in dogs with PL. As a result, the pelvis conformation changed and showed an increased medial contraction of the muscle and a subconsequent medial displacement of the patella (L'EPLATTENIER and MONTAVON 2002). Those who have successfully treated the luxation through a transplantation of the cranial head of the sartorius muscle have supported this theory (HORNE 1979).

Coxa vara is an anatomical condition thought to be associated with MPL (BRINKER et al. 2006). However, a recent study found coxa valga significantly associated with MPL in small-breed dogs, which contradicts this theory (BOUND et al. 2009). In addition, a recent CT study performed by YASUKAWA et al. (2016) found that there was no correlation between the occurrence of coxa vara and different grades of MPL. Furthermore, SOPARAT et al. (2009) failed to find a significant correlation between coxa vara or coxa valga and MPL in Pomeranian dogs. Instead, the study found that the distal femoral varus angle, the anatomical lateral distal femoral angle and the mechanical lateral distal femoral angle were significantly different, indicating a distal femoral varus deformation in dogs with MPL grade III (SOPARAT et al. 2009).

A medial displacement of the tibial tuberosity, a medial torsion of the proximal tibial part with or without lateral torsion of the distal tibia, which may result in an outward position of the tarsus, can be found in MPL patients (BONATH and PRIEUR 1998; FITZPATRICK et al. 2012; LÖER 1999; SCHULZ 2009). Moreover, the medial displacement of the tibial tuberosity has been found to predispose for MPL (APELT et al. 2005; SINGLETON 1969; SWIDERSKI and PALMER 2007; TOWLE et al 2005). However, it is questionable whether the medialization of the tibial plateau is a varus angulation in relation to the proximal tibial half to the distal tibial half, or a medial displacement of the entire tibia by a femorotibial rotation. Both options could coexist (BARNES et al. 2014).A CT-study of MPL found hypoplasia of the patella and in contrast with previous studies, patella alta was not found to correlate with the severity grade of MPL. (YASUWAKA 2016). According to OLIMPO (2015), femoral varus angulation, medial displacement of the tibial tuberosity and internal torsion of the proximal tibia were confirmed associates of MPL.

4.3.4 Estradiol levels

GUSTAFSSON et al. (1969) proposed an alternative theory in an experimental study. The study found that the condyles of the femoropatellar joint were lower in puppies that had been administered estradiol than in the control group. Moreover, observed changes in the test group included PL, coxa vara, increased angle of anteversion of the femoral neck and dorsal bowing of the femoral shaft. Finally, the results of this study indicated that low femoral condyles and a shallow patellar groove are primary causes of PL. The study concluded that increased estradiol levels could start a vicious circle, thereby leading to more pronounced deformities of the femur and a more severe PL (GUSTAFSSON et al. 1969).

4.4 Clinical presentation and diagnosis of patellar luxation

4.4.1 Clinical signs and grades of patellar luxation

Clinical signs of patellar luxation usually include either stiffness of the stifle joint, permanent flexion or the incapability of complete stretching, although some patients show no clinical signs (MATIS 2005). In a standing position, the hindlimb typically appears “bow-legged”, with an internal rotation of the knee joint and an external rotation of the foot (MATIS 2005).

In order to assess the grade of luxation and thereby assess the need for therapeutic intervention, the PUTNAM classification is used (PUTNAM 1968). Grade I and grade II represent reoccurring luxations, while grade III and IV represent persistent luxations (ROUSH 1993). The PUTNAM classification system was later modified by SINGLETON (1969), who included the assessment of the correlation between the degree of luxation and the degree of rotation of the tibial tuberosity in relation to length of the limb axis. According to this system, grade I represents a slight deviation of the tibial tuberosity, grade II stands for a deviation of up to 30°, grade III shows deviation degree of 30° to 60° and grade IV is characterized by a deviation of 60° to 90°. The classification system was updated by MATIS (2005):

Table 1. Patellar luxation classification according to clinical signs and anatomical changes (MATIS 2005).

Grade I	The patella temporarily luxates during limb extension but is repositioned during flexion. Patients often lack clinical signs and are predisposed to joint capsule rupture.
Grade II	Rotation of the tibial tuberosity of up to 30°. During extension, a more persistent luxation can be produced. The patella slides back into the trochlea during maximum flexion. Prognosis depends on the frequency in which luxation occurs. The more often the patella is luxated, the more cartilage erosion occurs and the likelier gonotrochleosis develops.
Grade III	Rotation of the tibial tuberosity is between 30° until 60°. Clinically, a temporary stationary luxation occurs. The patella is luxated during flexion and may be repositioned during extension. Gonotrocleosis is common, due to the lack of cranial stability, the strong tibial rotation and a secondary CCLR predisposition. Trochlear hypoplasia is another common finding.
Grade IV	Rotation of the tibial tuberosity is between 60° and 90°. The patella is permanently luxated throughout flexion and extension. If this luxation is found in young dogs, it is likely accompanied by shallow trochlear ridges. The quadriceps extension function is lost in these animals. The animal either does not use the limb or moves with a half-bended extremity.

The clinical signs associated with patellar luxation depend on the degree and duration of the luxation. They may include intermittent or consistent hindlimb lameness, conformational defects like genu vara, femoral or tibial bowing, pain and reluctance to move (ROUSH 1993). Owners often report a reluctancy to jump onto objects and notice intermittent lameness or unusual movements, such as “skipping”. A lameness pattern, in which the dog uses the affected limb normally, picks it up for some steps, then stretches it out and continues walking normally again, has also been described. These lamenesses can occur unilaterally or bilaterally and can cause weight to be shifted to the front limbs (ROUSH 1993; L'EPLATTENIER and MONTAVON 2002).

4.4.2 Diagnosing medial patellar luxation

Medial patellar luxation should be diagnosed based on clinical signs, such as type and grade of lameness, and further specified by the grade of luxation through an orthopaedic examination and diagnostic imaging, such as radiographs, computer tomography or magnetic resonance imaging. The degree of lameness has been described to correlate with the presence of retropatellar chondromalacia, rather than the degree of luxation, which is why the diagnosis should be supported by continuative diagnostics (L'EPLATTENIER and MONTAVON 2002). During gait analysis, both lameness and skeletal anomalies should be examined (KOWALESKI et al. 2012). Assessment of behavior and postural reactions in a proximal environment is recommended (MATIS 2005). Clinical signs are known to vary according to the age of patients. Moreover, age and weight gain cause additional risk of CCLR and increase erosion of the articular cartilage (L'EPLATTENIER and MONTAVON 2002).

The examination should be performed both in standing and lateral recumbency. The patella can be located by following the patellar ligament proximally, starting at the tibial tuberosity (ROUSH 1993; L'EPLATTENIER and MONTAVON 2002). In obese animals, the patella can be difficult to palpate, however, the patellar ligament can be used to deduce the position of the patella (ROUSH 1993). The physiological retention of the patella to the trochlear groove under flexion, extension, abduction, adduction, endo- and exorotation is tested with and without pressure, created by placing a thumb on the patella (BRUNNBERG et al. 2014). Pathological findings include pain caused by pressure on the patella, crepitation, drawer movement, muscle atrophy and assimetry (L'EPLATTENIER and MONTAVON 2002). A minimal medial deviation of the patella position may be physiological in healthy knee joints (MATIS 2005). Depending on the position in which the examination was performed (standing or lateral recumbency), the luxation grade found in the same patient may vary (WEBER 1992). To standardize findings, a simpler classification system was proposed by KOCH et al. (1998).

To specify palpation findings, radiographical findings can be used to determine the degrees of limb deformity and osteoarthritis in the stifle (L'EPLATTENIER and MONTAVON 2002). Moreover, the depth of the trochlea groove can be indirectly determined by applying the DIMA-technique (geometric direct enlargement) to latero-medial images (MEYER 2001). In obese patients, radiographic imaging may be necessary to confirm a patellar luxation (ROUSH 1993). The depth of the femoral trochlea groove can be determined with a skyline view radiographic image (KEALY 1979), however surgical exploration and direct observation are the most precise diagnostic method (ROUSH 1993). In addition, radiographic imaging is an affordable method to evaluate femoral varus or torsion in dogs. However, the evaluation of pelvic limb angles is limited compared to CT diagnostic imaging (ŽILINČÍK 2018; PHETKAEW et al. 2018). Three-dimensional CT imaging has proven clear advantages over bi-planar radiographs in pre-operative planning of PL therapy in dogs (LÖER 1999; APELT et al. 2005; APER et al. 2005; KOWALESKI 2006; DUDLEY et al. 2006; FITZPATRICK et al. 2012), since it can be used to precisely calculate femoral and tibial torsion angles (PHETKAEW et al. 2018).

After diagnostic imaging, the Q-angle (see 4.3.1) can be measured to quantify the degree of patellar luxation (PINNA 2017). The physiological angle of 10° was determined in a study by BEHRENDT (2006). In cases of grade I patellar luxation, the average angle was found to be 12.2°. At grade II, the average angle was found to be 24.3°. At grade III, the average angle was found to be 36.6°, while an average angle of 19.3° was found in cases with concomitant CCLR , due to the internal rotation after failure of the ligament. The study did not include dogs with grade IV luxation (KAISER et al. 2001). The measuring of Q-angles was proven to be a precise diagnostic method for patellar luxation. Moreover, the results reproducable and independent from patient positioning in CT studies (SCHMITZ 2016).

5. Cranial cruciate ligament rupture

CCLR is the most common orthopaedic condition in the sfitle joint diagnosed in adult dogs (PAATSAMA 1952; BRADEN 1980; BRUNNBERG 1989A). Although aetiology and pathomechanismn for CCLR have been described and discussed in numerous articles, to date, some aspects remain unclear. The pathology is considered a multifactorial event (BRUNNBERG 1989B; DE ROOSTER et al. 1994), which can only be evaluated based on a thorough understanding of biomechanics and anatomy of the stifle joint, patient conformation and gait analysis (JERRAM and WALKER 2003). Moreover, even though cranial cruciate ligament surgeries account for 3% of all surgeries in dogs (MUELLER 1969), standard protocols are yet to be established.

Breed predisposition has been named in many studies, for almost 70 breeds in total. This predisposition has also been seen to correlate with the increased presence or temporary popularity of breeds in certain regions (BRUNNBERG 1990). Apart from a genetic predisposition (WHITEHAIR and VASSEUR 1993), obesity, trauma, and anatomical malformations, such as stenotic intercondylar femur fossa, abnormal hindlimb conformations and the tibial plateau condition have been discussed as causes of the disease (VASSEUR and BERRY 1992; VASSEUR 2002; INAUEN et al. 2009).

5.1 Trauma

Rupture of the ligament following trauma has been described by many authors (WESTHEUS 1961; LOEFFLER 1964; LAMPADIUS 1964; DIETZ and SCHMIDT 1968 and HOHN 1974) and observed in 5-35% of the CCLR cases (PAATSAMA 1952; GEYER 1966; KÜPPER 1971; GAMBARDELLA et al. 1981; SMITH and TORG 1985; HOFER 1990; SCHAEFER 1991; TIMMERMANN 1995; REESE 1995). Moreover, hyperextension and excessive internal rotation of the stifle during partial flexion have been proven to cause CCLR (PAATSAMA 1952; DIETZ and SCHMIDT 1968; HOHN and NEWTON 1975; ARNOCZKY and MARSHALL 1977; HULSE and SHIRES 1986; BRUNNBERG 1987).

Physiologically, the tibia is compressed by weight bearing force on femur and hock as well as the muscle contraction of the muscles extending the stifle (quadriceps muscle group) and the hock (gastrocnemius muscle). The contact point between the femur and the tibia lies cranial to an imaginary line drawn between the centres of motion of hock and stifle, producing a cranially directed force (cranial tibial thrust) (SLOCUM and DEVINE 1993). Thereby, these forces prevent unphysiological movement.

A study by JOHNSON and JOHNSON (1993) proposed that unphysiological movement, such as a dog's attempt to free itself after getting their foot caught in a fence or hole, could result in traumatic CCLR.

CCLR may have immediate or delayed onset after traumatic events during which the ligament is overstressed. The elasticity of a ligament allows it to undergo temporary deformation during stress and return to normal size and shape once the stress stops. If the stress is too high, the ligament becomes permanently deformed, causing a loss in functionality and elasticity. This effect can cumulate under repetitive stress, resulting in functional failure and ligament rupture. (SLOCUM and DEVINE 1993).

5.2 Degeneration and age

Some authors found CCLR to occur spontaneously in the absence of a traumatic event. Therefore, they proposed a connection to aging and chronic degenerative processes of the ligament (PAATSAMA 1952; ZAHM 1964; GEYER 1966; TIGARI 1977; ARNOCZKY and MARSHALL 1981; MOORE and READ 1996; VASSEUR 2003). Degeneration of the ligament is known to weaken the ligament and can ultimately lead to a rupture. Interestingly, this has more commonly been observed in the cranial cruciate ligament, than in the caudal one (ZAHM 1964; PEARSON 1971; NOYES et al. 1974, 1980; VASSEUR et al. 1985). A histological study by VASSEUR et al. (1985) divided a sample group according to bodyweight. Dogs under 15 kilograms were defined as small, while dogs over 15 kilograms were defined as large. The study found that by 5 years of age, large dogs had suffered a loss of fibroblasts, metaplasia of the remaining fibroblasts to chondrocytes, a loss of collagen fibre structure and a loss of primary collagen bundles. Furthermore, they found that these degenerative processes progressed with increasing age. In small dogs, the degeneration appeared at a later age and was found to be less severe overall. In addition, the caudal cruciate ligament underwent similar changes to a milder degree, while collateral ligaments only showed minimal degeneration. The greatest degeneration was found around the point of contact between the cranial and caudal cruciate ligament, which was marked by angiodegeneration.

A study by ZAHM (1964) proposed that the loss of elasticity observed in aging dogs was due to hyalinization and deposition of calcium salts, which resulted in circumferential changes. In addition, HULSE (1994) theorized that CCLR was a secondary effect of enzymatic degeneration of the ligament through primary osteoarthritis in the stifle joint. Furthermore, PAATSAMA (1952) demonstrated that the midsection of the CCL was the most common site of ligament rupture in dogs, the site at which both cruciate ligaments twist on each other during flexion and extension, which was later confirmed by other authors (TIGARI 1977; ZAHM 1964). They theorized that this was due to the friction and strong forces acting on this area of the ligaments. In a later study, REESE (1995) observed that this part of the ligament often showed structural changes. Moreover, NEURATH et al. (1994) suggested that the poor healing of the CCL resulted from diminished function of structurally altered intraligamentous fibroblasts. Tearing of the synovial sheath surrounding the ligament during CCLR causes a severing of the blood supply of the torn ends of the ligament. In addition, a study by DOVERSPIKE et al. (1993) reported that 37% of dogs with unilateral CCLR returned with a contralateral CCLR after an average time of 17 months. The author argued that since it was reasonable to assume equal stress on both cranial cruciate ligaments, the occurrence of bilateral CCLR supported the theory of ligament degeneration as primary cause of rupture. Recent studies found that 22-55% of dogs with an initial diagnosis of unilateral CCLR were diagnosed with contralateral CCLR between 10 and 17 months after the initial CCLR occurred (CABRERA 2008; BUOTE 2009; MUIR 2011; DOVERSPIKE et al. 1993).

A study by LOEFFLER (1964) reported that CCLR was more common in dogs between the ages of two and three years, as well as between 5 and 6 years of age. PAATSAMA (1952) and GEYER (1966) reported that most CCLRs occurred between the ages of 6 and 9 years, while HOHN and NEWTON (1975) observed that the rupture was more common in animals older than 5 years of age and GAMBARDELLA et al. (1981) found the highest numbers in dogs over 6 years. Later studies by ELKINS et al. (1991), METELMANN et al. (1995), INNES AND BARR (1998), ALT (2000) and MAGER (2000) found that most CCLR cases occurred in dogs between the ages of 5 and 7 years. Other studies found the highest frequency of CCLR cases in dogs between 7 and 10 years of age (WHITEHAIR et al. 1993; ALAM et al. 2007; WITSBERGER et al. 2008), while SCHNELL (1986) proposed that in larger breeds, 70% of ruptures occurred before the age of 6 years, while only 19% of CCLR in small breed dogs occurred at that age. A recent study by MANCHI (2011) reported that most small breed dogs suffering from CCLR were diagnosed between 9 and 10 years of age. These findings indicate that CCLR tends to occur at a later age in small breed dogs.

5.3 Anatomical malformations

In small breed dogs, genu varum is a common anatomical malformation. It leads to an internal rotation of the tibia, cranial displacement of the tibia relative to the femur and hyperextension of the stifle, which exerts extra strain on the CCL during motion. The constant stress weakens the ligament and provokes rupture (JERRAM and WALKER 2003). A study by SLOCUM

(1993) proposed a direct relationship between the tibial plateau angle (TPA) and the magnitude of the cranial tibial thrust. The contact point between femur and tibia lies cranial to an imaginary line between the centres of motion of the hock and stifle, known as the cranial tibial thrust. It is actively counteracted by the hamstring and the biceps femoris muscle, and passively restrained by the CCL. The magnitude of this cranial thrust could vary with the slope of the tibial plateau (SLOCUM and DEVINE 1993). This theory was supported by findings of READ and ROBINS (1982), SELMI and PADHILA FILHO (2001), MORRIS and LIPOWITZ (2001), MACIAS et al. (2002) ROONEY et al. (2002) and KYLLAR (2018). All authors concluded that a greater inclination of the tibial plateau made the CCL vulnerable to rupture. In addition, a recent study found that TPAs were higher in spayed females and castrated males, compared to intact male dogs (SU 2015). Moreover, a study by VEDRINE et al. (2008) found that breed variations in TPAs needed to be considered during examination of CCL pathologies. However, other authors failed to find a correlation between TPA and CCLR in dogs (EL FAKHARANI 1997; REIF and PROBST 2003; CABRERA et al. 2008; WILKE 2002; BUOTE 2009). Furthermore, some authors have argued that intercondylar notch stenosis could exacerbate the degenerative process, predisposing to early CCLR (FITCH et al. 1995; AIKEN et al. 1995; COMERFORD et al. 2006; KYLLAR 2018).

5.4 Immune-mediated degeneration

Some authors believe that osteoarthritis of the stifle, due to immune-mediated degeneration or genetic factors, is the main cause of CCL damage (WHITEHAIR et al. 1993; MOORE and READ 1996; VASSEUR 2003). Other authors have questioned this theory, since only one stifle joint and in most cases, only the cranial cruciate ligament is affected (JERRAM and WALKER 2003). While a hostile intraarticular environment, due to various immune-mediated arthropathies, has proven to cause degeneration of the intraarticular ligaments, these usually appear bilaterally. On the one hand, an author that found anticollagen antibodies in serum and synovia of CCLR patients theorized that the pathology has an immunologic component (NIERBAUER 1987). On the other hand, a later study argued that the immunopathological arthritis was a secondary consequence of CCLR (REESE 1995). Endogenous proteases such as cathepsin K and tartrate-resistant acid-phosphatase were isolated from the synovial membrane of most of a group of patients with CCLR, indicating an autoimmune response (MUIR et al. 2005). However, in a study on Labrador and Golden Retrievers, the hypothesis of induced CCL degeneration was refuted (CLEMENTS et al. 2011).

5.5 Breed, sex, weight and sedentary lifestyle

Physical stimuli are required to maintain the balance in continuous biochemical turnover processes. A lack can result in divergent responses from joint and periarticular tissues. While the periarticular tissues stiffen, the ligaments and their insertions to the bone weaken considerably (NOYES 1977; LARSEN et al. 1987; VAN C. MOW 2011). NOYES et al. (1974) study on CCLs in primates found increased incidence of femoral avulsions after immobilization periods, while the percentage of ruptures in the ligament substance had decreased. In a later study, NOYES (1977) analysed the insertions sites of the ligaments. While no histological evidence of changes to the insertion sites were found, pronounced bone resorption was observed in the tibial insertion of the medial collateral ligament. These findings led the author to conclude that a sedentary lifestyle could predispose ligaments to rupture.

Obesity has been reported as a nutritional disorder in dogs with a general prevalence of 28% (MASON 1970; EDNEY et al. 1986; LUND et al. 1999). It has been proven to cause additional mechanical stress on joints, thereby promoting degeneration and ligament rupture (PAATSAMA 1952; LAMPADIUS 1964; HOHN and NEWTON 1975; ARNOCZKY 1980; VASSEUR 1984; RAHLSF and FEHR 1986; DOVERSPIKE et al. 1993; DUVAL 1999; JOSHUA 1970; KEALY 1997). Overweight, relative to joint size, could explain why larger breeds suffer from ligament rupture more often (SHIRES et al. 1984). Moreover, obesity has been discussed as a risk factor for development and progression of osteoarthritis in dogs (JOSHUA 1970).

Although numerous authors have discussed sex predispositions for CCLR in dogs, their findings have varied considerably. Some authors found that surgically sterilized dogs had a higher prevalence of CCLR (WHITEHAIR et al. 1993; DUVAL et al. 1999; WITSBERGER et al. 2008). WHITEHAIR et al. (1993) found a weak connection between spayed females and CCLR within his patient group. In addition, a recent study by BELANGER (2017) found neutering to be significantly associated with an increased risk of CCLR in both male and female dogs. A study by GAMBARDELLA et al. (1981) found a higher prevalence in male dogs. However, a study by BRUNNBERG (1990) concluded that CCLR could affect any dog, regardless of breed, age, limb side and sex. In addition, various other studies found no sex predilection in CCLR patients (PAATSAMA 1952; DEANGELIS 1961; SINGLETON 1969; POND and CAMPBELL 1972; HOHN and NEWTON 1975; HUTTER et al. 1983; SCHAEFER 1983; SCHNELL 1986; BRUNNBERG 1987 and 1990; KAISER 1999; ALT 2000).

Furthermore, many authors have discussed breed predispositions for CCLR. Several authors proposed that among small breed dogs, Poodles had a predisposition to cruciate ligament rupture (PUNZET and WALDE 1974; GAMBARDELLA et al. 1981; SHIRES et al. 1984; SCHNELL et al. 1984; BRUNNBERG 1990; MAGER 2000). Finally, a study by WILKE et al. (2006) indicated that 26% of CCLR cases could be attributed a genetic factor, while the remaining 73% were linked to environmental factors.

5.6 Clinical signs and diagnostic methods

The postural reaction is of interest in all orthopaedic diseases. In CCLR cases, typical signs include refusing to sit on the affected limb, thereby avoiding joint flexion (MATIS 2005). Pain caused by ligament rupture is caused by acute inflammation and hemarthrosis, and results in lameness. Depending on the degree of injury, the lameness might be intermittent or persistent, and weight bearing or not weight bearing (SANDMAN and HARARI 2001). As the initial inflammation decreases within weeks after the injury, the stifle stabilizes slightly due to the thickening of periarticular tissue. Consequently, the lameness may improve temporarily. During this period, the dog may show short, intermittent periods of increases lameness due to inflammation caused by the remaining joint instability. This period of improvement gives way to a gradual or sudden decline in limb use (MOORE and READ 1996). Meniscal damage as well as a partial or complete rupture of a ligament can cause this sudden onset of lameness. Moreover, the instability in the joint results in osteoarthritis over time (JOHNSON and JOHNSON 1993). Furthermore, an audible and palpable click is often present during flexion and extension of the stifle, which is associated with displacement of the caudal horn of the medial meniscus (ROBINS 1990; ARNOCZKY 1993). To assess indirect signs such as thigh muscle atrophy, pain, joint effusion, periarticular swelling, asymmetry and cranial displacement of the tibial crest, both hindlimbs should be palpated simultaneously, while the dog is standing (PAATSAMA 1952; JOHNSON and JOHNSON 1993).

In addition, a cranial-drawer-test and a tibial-compression-test should be performed, since positive results have been proven pathognomonic for CCLR (BRUNNBERG 1989b). For the cranial drawer test, the dog is positioned in lateral recumbence with the affected limb uppermost. The tibia is then moved in a cranial direction relative to the femur, while the femur is fixated. Cranial movement and an increased internal rotation are regarded positive test results and pathognomonic signs of cruciate ligament rupture (CARLIN 1926; MOORE and READ 1996). In cases when this procedure is too painful or the muscle tension is too high, sedation might be necessary (LOEFFLER 1964; BRADEN 1980). CAROBBI and NESS (2009) found that patient sedation significantly increased both the sensitivity and the specificity of the test. Chronic processes in the knee joint can alter results of the cranial drawer test (LAMPADIUS 1964; PUNZET and WALDE 1974; DIETZ et al. 1980). Test responses vary in cases of partial CCLR. If the craniolateral portion of the CCL is ruptured, a positive cranial-drawer test will be found during extension and flexion, resulting from craniomedial portion distension in both positions. However, if the craniomedial portion is ruptured, the cranial-drawer test will only be positive during flexion, when the craniolateral portion is relaxed (TARVIN and ARNOCZKY 1981). In order to differentiate between a partial and complete anterior cruciate ligament rupture, the drawer test should be performed on both extended and slightly flexed knee joint (TOBIAS and JOHNSTON 2011). The tibial compression test attempts to demonstrate cranial drawer movement by tibial-femoral compression, which is created by muscle forces during flexion of the hock. The dog should be positioned in lateral recumbency with the affected limb uppermost. The tibial compression test has been found to be less painful than the cranial drawer test (HENDERSON and MILTON 1978).

To confirm the diagnosis and eliminate differential diagnoses, mediolateral and craniocaudal radiographs of the stifle should be made (JERRAM and WALKER 2003). Indirect radiographical signs like muscle atrophy of the thigh, joint effusion, periarticular swelling, loss of intrapatellar fat pad shadow and periarticular osteophyte formation are often seen in CCLR patients and support the diagnosis (BRUNNBERG 1989B). Over time, the injured joint develops osteophytes, which first appear on the distal patella and proximal aspect of the femoral trochlear ridges. At later stages, they often develop on the fabellae, femoral and tibial condyles, fibular head, and the intercondylar aspects of tibia and femur (ELKINS et al. 1991). In addition to or instead of radiographs, MRI may provide additional diagnostic information. According to recent studies, it has become an increasingly important diagnostic tool in diagnosing cruciate ligament rupture (BANKFIELD and MORRISON 2000; OHLERT et al. 2001; FOLATIN et al. 2004; KONAR 2005 A and B).

Furthermore, arthroscopy has proven useful due to its diagnostic sensitivity in cruciate ligament rupture, particularly in cases of partial ruptures, (FEHR et al. 1996) with the added benefit of combining diagnostic and treatment procedures, for example through a partial meniscectomy (POZZI et al. 2008; ERTELT and FEHR 2009; TOBIAS and JOHNSTON 2011). Due to the anatomical localization and interference through the retropatellar fat pad, ultrasonographic examination methods are not reliable diagnostic methods in CCLR cases (POULSEN-NAUTRUP and TOBIAS 1998; SEONG et al. 2005).

5.7 Correlation between meniscal disease, arthrosis and CCLR

Secondary meniscal injuries are the most common pathology that accompanies CCLR and were found in up to 70% of CCLR cases (MAHN et al. 2005; THIEMANN et al. 2006; PAATSAMA 1952; HOHN 1974). Cranial movement of the tibia with respect to the femur often leads to impingement of the caudal horn of the medial meniscus (SLOCUM and DEVINE 1984), which can result in meniscal lesions. Various studies found concomitant medial meniscus lesions in 45.5% - 74% of CCLR cases (FLO 1978; FLO and DEYOUNG 1978; GAMBARDELLA et al. 1981; SCHNELL 1986; SCHÄFER 1991). Over time, CCLR causes irreversible, degenerative osteoarthritis in the stifle joint (AU et al. 2010).

MRI has proven to aid a reliable diagnosis of meniscal lesions in dogs with CCLR with high sensitivity (OLIVE et al. 2014), especially in larger breeds (BLOND et al. 2008). In contrast to this, a multicentric study by BÖTTCHER et al. (2012) found that MRI sensitivity and specificity, for meniscal lesion diagnosis was 0.64 and 0.69, respectively. Consequently, they concluded that MRI was not suitable for a reliable diagnosis. POZZI et al. (2008) showed that over 90% of meniscal lesions in CCLR cases could be diagnosed through an arthroscopic examination. Moreover, BÖTTCHER et al. (2009) found that accuracy of arthroscopic diagnoses could be even more reliable through percutaneous extraarticular attachment of a knee joint distractor, thereby creating a better overview of the knee joint.

5.8 Patellar luxation and concomitant CCLR in small breed dogs

Cranial instability of the stifle joint still appears after patellar luxation correction (DEANGELIS and HOHN 1970) and this could result from previous degenerative changes secondary to the PL, natural progressive degenerative changes (VASSEUR et al. 1985) or new stresses applied to the CCL secondary to PL repair (WILLAUER and VASSEUR 1987). Degeneration of the CCL was usually apparent microscopically in large dogs by 5 years of age, which correlates to the increased frequency of naturally occurring CCLR at that age. The study indicated that increasing body size might be a factor that could exacerbate the degeneration of the CCL. Histopathologic changes were present in the CCL of dogs weighing 15 kg or more by 5 years of age, and degenerative disease in the CCL of these larger dogs progressed over time (VASSEUR et al. 1985). VASSEUR et al. (1985), showed that smaller dogs experienced CCL rupture at an older age, compared to large dogs (117 months vs 58 months respectively). In small dogs (<15kg), the CCLs were different in that degeneration was generally less severe and late onset compared to large dogs. Ligament degeneration in large dogs was earlier onset and progressed more rapidly. While small breeds like Poodles are generally kept as pets and therefore are much less likely to stress their joints in the manner as an active 35 kg Labrador retriever. Moreover, small dogs have a decreased maximum stress and strain energy compared to large dogs. Factors like body size and conformation likely modify the amount of stress to the CCL, which could affect the age at which a rupture occurs (VASSEUR et al.1985).

ZAHM (1964) proposed that signs of degeneration in the cranial cruciate ligament only appeared to take place in small breed dogs of 7 years and older. Whether this is due to body size and conformation differences or whether ligament fibres degenerate slower due to other reasons remains unclear. Moreover, the influence of PL and consequent instability in the knee joint on CCLR remains controversial. Some studies have suggested that patients suffering from MPL have an excessively large mechanical proximal tibial angle. These results support studies that found a caudal deformity of the proximal tibia in toy and small breed dogs (MACIAS and MCKEE 2002), which has been associated with an increased risk of CCLR.

6. Surgical treatment for PL and concomitant CCLR

All surgical methods should aim to restore functional stabilization of the stifle joint (POMPLUN 1989; ELKINS et al. 1991; MOORE and READ 1995). The first method for CCLR treatment was described by PAATSAMA (1952) and consisted of restabilising the joint by replacing the ligament with a strip of fascia lata. Various authors, such as VAUGHAN (1963), SINGLETON (1969) and ORMROD (1963), later modified this technique. The "Fascia lata overlap" procedure helped correct the unphysiological medial pull exerted by the quadriceps femoris muscle by adding pressure to the patella as well as dorsally, along the lateral aspect of the thigh (FLO and BRINKER 1970). BRUNNBERG (1987) confirmed that over time, numerous authors have described over 100 methods (STRANDE 1964; DICKISON and NUNAMAKER 1977; ARNOCZKY et al. 1979; SCHAWALDER 1981; PIERMATTEI and MOORE 1981; HULSE et al. 1980; PICHLER et al. 1982; ELD and LONG 1983; BRUNNBERG et al. 1985), including the posterior development of biomechanical and or dynamic corrective osteotomies (SLOCUM and SLOCUM 1993; MONTAVON et al. 2002; ETCHEPAREBORDE et al. 2011). Surgical treatment procedures are divided into intracapsular and extracapsular techniques. While extracapsular techniques, such as extracapsular suture repair, tibial plateau levelling osteotomy or tibial tuberosity advancement are recommended in most cases, intracapsular techniques may be considered for acute injury in large breed dogs (CHAUVET et al. 1996; TEPIC and MONTAVON 2002; HILDRETH et al. 2006). Extracapsular techniques, such as remodelling osteotomies, have been found to achieve good to very good results (LAZAR et al. 2005; AU et al. 2010; COOK et al. 2010; SNOW et al. 2010; BODDEKER et al. 2012; CHRISTOPHER et al. 2013). Despite low complication rates described for these techniques (CASALE and MCCARTHY 2009 ; COOK et al. 2010), most of which were found in heavy and young dogs (CASALE and MCCARTHY 2009), post-operative instability due to loosening and tearing of the suture material has been described by a recent study (BÖTTCHER et al. 2010). In most cases, a combination of "Trochlear wedge recession" (WR) or "Tibial tuberosity transposition" (TT) with a "Joint imbrication capsulectomy" is sufficient to correct PL. Generally, surgical corrections of PL cases with grade I, II or III are successful (WANGDEE et al. 2013), whereas the surgical correction of a grade IV PL carries a guarded prognosis in young dogs (ROUSH 1993). A recent study found an overall success rate of 93% in grade IV MPL cases (DUNLAP 2014).

Complication rates of surgical treatments of PL are generally low and include reluxation as well as implant-associated failure (DI DONA 2018). CASHMORE et al. (2014) found that grade I luxations had a significantly lower prevalence of major complications compared to other grades. In addition, a recent study found an association between corrective osteotomies and major complications (HANS 2016). In PL cases with concomitant CCLR, a combination of TT, for the treatment of PL, with a TPLO (LEONARD et al. 2016) or new techniques such as the "Tibial tuberosity transposition-advancement" (YEADON 2011) or the modified "Tibial plateau levelling osteotomy" (LANGEBACH 2010), showed successful results. Moreover, FAURON et al. (2017) proposed that stifles stabilized through TT were more likely to suffer a poor clinical outcome than those treated with a "Tibial tuberosity transposition and advancement".

Multiple studies have described a correlation between body weight and a higher risk of post-surgical complications and reluxation (ARTHURS and LANGLEY-HOBBS 2006; GIBBONS et al. 2006; CASHMORE et al. 2014; BOSIO 2017). Hence, weight reduction is recommended in addition to surgical treatment. In cases of lameness due to hip osteoarthritis, studies found that a weight loss of 11-18% of the initial body weight significantly decreased the severity of hind-limb lameness (IMPELLIZERI et al. 2000). In addition to weight reduction in overweight patients, physiotherapy to regain quadriceps muscle function plays an important role in the outcome of patients. A recent study suggested that the reactivation of the quadriceps muscle group through physiotherapy could act as a CCL agonist in dogs with low TPA, thereby increasing surgical success rates (RAMIREZ et al. 2015). No significant correlation between femoral varus angulation and post-surgical complications were found (PERRY 2017).

6.1 "Trochlear wedge recession"

The "Trochlear wedge recession" technique (WR) creates an osteochondral wedge from the original trochlear sulcus (SLOCUM and SLOCUM 1993). While the osteochondral wedge provides a living surface of cartilage and a living support for the patella, the geometry of creating a triangular wedge by removing bone at the kerf produces a smaller wedge, which fits the cavity (SLOCUM et al. 1982; BOONE et al. 1983; SLOCUM and DEVINE 1985; SLOCUM and SLOCUM 1993). The "Trochlear block recession" is a modified technique (TALCOTT et al. 2000). Sulcoplastic techniques can produce arthrosis because of the replacement of resected hyaline cartilages for fibro cartilaginous connective tissue (MOORE and BANKS 1989). WR is the method of choice since the contact of the patella with hyaline cartilage is maintained and degenerative joint reactions are reduced (SLOCUM et al. 1982; BOONE et al. 1983; SLOCUM and DEVINE 1985; SLOCUM and SLOCUM 1993). Modified WR with proximal excisional trochleoplasty might be performed to prevent the reluxation, especially in cases with PL associated with patella alta (TOWLE et al. 2005).

6.2 "Tibial tuberosity transposition"

TT was first described by PEZOLI and BIGNOZZI (1954) and more disclosed by SINGLETON (1969). This technique is recommended in case of non-physiological deviation of the patellar ligament insertion or pronounced tibial rotation (RICHARDS 1975; HULSE 1981; HULSE and SHIRES 1993) where the direction of the deviated patellar ligament will be corrected to avoid further PL. Preservation of this distal thin strip of the patellar ligament is important (VIERHELLER 1959) to protect the transplanted tuberosity from being pulled too far proximally, in case the fixation of the transplant fails. The osteotomised bone piece is then fixed with a lag screw or two Kirschner wires (BRINKER et al. 2006; SCHULZ 2009). With this surgical method, the tibial tuberosity is shifted into an unnatural position. The rotational stability is not corrected, but merely fixated and the biomechanics do not improve. For this reason, this technique cannot prevent periarticular arthrosis in dogs or humans (CROSBY and INSALL 1976; KUMMEL 1981; MUELLER 1985; FRITZ 1989; MATIS and FRITZ 1990; ROY et al. 1992; VON WERTHERN et al. 1997). SCHMÖKEL and MONTAVON (1993) combined the lateral displacement with a cranialisation of the tibial tuberosity to reduce the intraarticular pressure in the stifle joint and to prevent the risk of patellar chondromalacia. The increased internal rotation of the tibia is strengthened by the tuberosity transposition (NUNAMAKER 1985). To compensate for the inward rotation, NUNAMAKER (1985) recommends a cranial transposition of the fibula. WILLAUER and VASSEUR (1987) described the transposition of the tibial tuberosity with a distalisation to improve the leverage effect. This way, the intraarticular pressure in the stifle joint and cartilage stress can be reduced. FRITZ (1989) concluded that the best results are obtained when WR is performed in combination with a TT, while LINNEY (2011) proposed that trochlear groove deepening procedures are not always necessary and patients that undergo this technique should be carefully selected.

6.3 Surgical techniques for cranial cruciate ligament deficiency

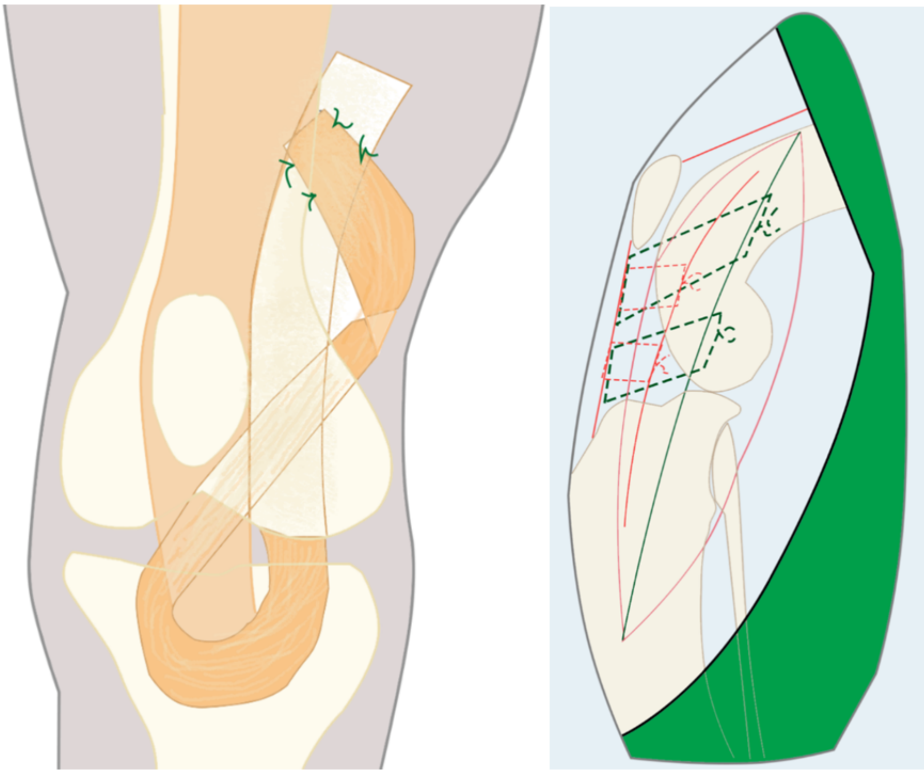
6.3.1 Intracapsular – "Over-the-top graft"

PAATSAMA (1952) introduced this technique, which was originally developed for humans, into veterinary medicine. A strip of fascia lata and fascia genu are obtained. These are then drawn through a drill-hole in the articular canal between the medial tibial condyle and the lateral femoral condyle. Finally, the fascia strip is sutured to the lower part of the patellar ligament (Fig.4A). This technique was later modified by BRASS 1955; SINGLETON 1963;

ARNOCZKY 1979; HULSE et al. 1983; RAHLFS and FEHR 1986; BRUNNBERG et al. 1985; SCHAEFER et al. 1991; TIMMERMANN 1995; TIMMERMANN et al. 1996). BRUNNBERG et al. (1985) described another modification, in which a distal fascia band is fixed to the tibial tuberosity, included the lateral distal third of the patellar ligament, and passed around the patellar ligament, continuing intraarticularlary to the intercondylar groove. The study demonstrated successful functional results in 82% of 447 surgical patients (505 stifle joints), although only 12 of the stifle joints progressed without osteoarthrosis (BRUNNBERG et al. 1992).

6.3.2. Extracapsular – "Capsular fascial imbrication" (CFI)

Extracapsular techniques provide joint stability by altering the extraarticular structures. They produce a thickening of the periarticular tissues after the surgical procedure (FOX and BANE 1986). The imbrication techniques require less time and are easier to perform, compared to other methods (DEANGELIS and LAU 1970). Two sutures are placed from the lateral fabellopatellar fibrocartilage, joint capsule and fascia lata to the insertion of the patellar ligament, using a vertical mattress suture pattern (Fig.4, B). External rotation of the pes must be applied manually during this procedure, in order to increase the external rotation of the tibia (ALLGOEWER et al. 2000; ALT 2000). This technique has shown successful functional results in 93% of cases (ALLGOEWER et al. 2000). However, BERGER (2015) found that TPLO was superior to CFI in the treatment of CCLR in small breed dogs.



A *B*

Figure 4. Illustration of the surgical techniques applied to correct CCLR, modified from (A) Modified "Fascia over the top" (BRUNNBERG 1985), (B) "Capsular and fascial imbrication" technique (ALLGOEWER et al. 2000).

7. Materials and methods

To investigate the relationship between patellar luxation (PL) and cranial cruciate ligament rupture (CCLR) in toy and small breed dogs, this retrospective study analysed cases of patellar luxation lameness in toy and small breed dogs. Between 2004 and 2016, a total of 233 cases were presented to the small animal teaching hospital of the Freie Universität Berlin, Germany.

Apart from patellar luxation, the presence of CCLR was registered in this patient population. In addition, the efficacy of surgical treatment was evaluated in cases of PL and concomitant CCLR.

7.1 Study and patients

Between 2004 and 2016, a total of 233 small and toy breed dogs were presented for examination and treatment of lameness due to PL. The American Kennel Club (2014) standards were used to categorize the breeds of patients.

From the total of 233 recorded cases, two groups of patients were selected for comparison, of which 81 patients, with 130 affected stifle joints, met the inclusion criteria. 26 patients (33 affected stifle joints) diagnosed with PL and CCLR were selected for the test sample. 55 patients (97 affected stifle joints) diagnosed with PL that showed no evidence of CCLR were selected as the control group (Table 2).

Table 2. Number of cases selected for the PL and the PL+CCLR groups from all PL cases found in toy and small breed dogs between 2004 and 2016.

233 toy and small breed dogs *Presented for patellar luxation or patellar luxation and CCLR* *between 2004 and 2016*	
⇩ *81 toy and small breed dogs met the inclusion criteria.* *130 affected stifle joints were divided in two groups:*	
⇩ PL group –55 dogs *97 stifle joints with patellar luxation*	⇩ PL+CCLR group – 26 dogs *33 stifle joints with patellar luxation* *and cranial cruciate ligament rupture*

Cases were selected based on presence and expression of the following inclusion criteria:

1- Age

2- Breed

3- Sex

4- Weight

5- Affected limb: right, left, both

6- Direction of luxation: medial, lateral, bidirectional

7- Grade of patellar luxation: I, II, III, IV

8- Presence of CCLR

9- Difference in grade of patellar luxation between stifles

10- Combination of surgical techniques

11- Post-operative complications: none, minor, major, catastrophic

12- Meniscal disease at the time of surgery

13- Clinical outcome (post-surgery lameness score)

14- Owner questionnaire (post-surgery)

15- Unilateral or bilateral patellar luxation

16- Unilateral or bilateral cranial cruciate ligament rupture

17- Overweight according to AMERICAN KENNEL CLUB CLUB STANDARDS 2014

18- Time between first and second CCLR (in bilateral CCLR cases)

19- Time of follow-up

7.2 Clinical examination

To eliminate other causes, all patients presented or referred with acute or chronic hindlimb lameness underwent a standard procedure of examination. The examination started with a classic anamnesis to assess patient history and signalement, after which a general examination was performed. This was followed by an orthopaedic examination, which focused on:

1. Adspecting locomotion while standing, walking and trotting on level floors and stairs
2. Palpation and comparison of both hindlimbs
3. Determination and grading of patellar luxation according to the standard operating procedure issued by the Verband Deutsches Hundewesen (Table 3)
4. Stifle instability assessed through a cranial drawer test (CDT) (Fig. 5, A-C)

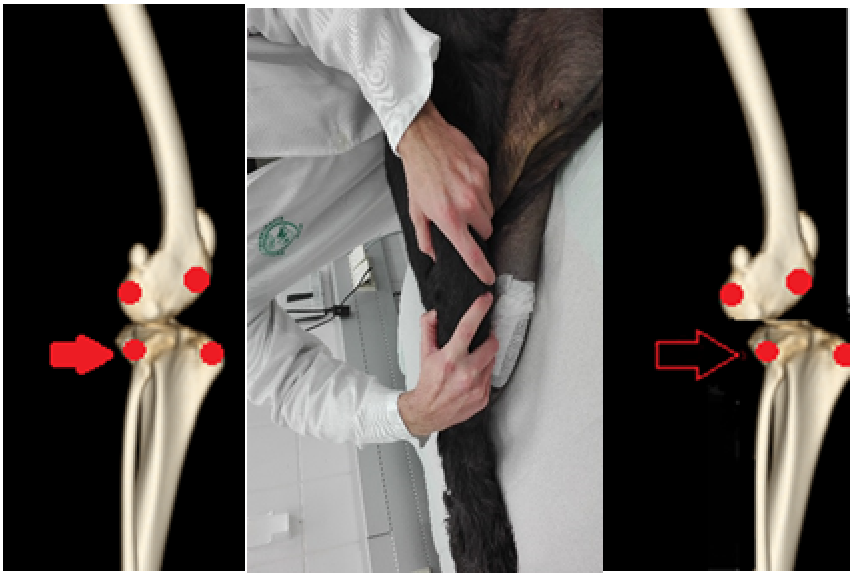


Figure 5. A B C

Figure 5. 5A-C. Illustration of the cranial drawer test. (A) Shows the anatomical pressure points in rest, while (B) illustrates the positioning of the patient and the examiner during the test. (C) Shows the relative movement expected in a CCLR positive test.

For the CDT, the patient was restrained in lateral recumbency, with the limb in question facing up. The examiner was positioned caudal to the limb. One hand firmly grasped the prominent bone features of the lateral fabella, placing the index finger on the cranial aspect of the patella and the thumb on the lateral fabella, caudal to the femur. The other hand firmly held the tibia, with the index finger placed around the cranial aspect of the proximal tibial crest and the thumb holding the fibular head. To test for CCLR, the examiner attempted to displace the tibia cranially, relative to the femur. The test was considered positive, if displacement was possible. However, a negative test does not rule out partial CCLR and other CCL pathologies.

Table 3. Standard examination procedure for patellar luxation issued by Verband Deutsches Hundewesen (https://shop.vdh.de/index.php?id=artikel_51)

1.Adspection in motion						
Lameness:	no:	yes:	right:	left:	permanent:	intermittent:

2-Adspection in standing				
Axial deviation	no:	yes:	right:	left:

3- Palpation (standing)	Right stifle				Left stifle			
Patella in situ	no:	yes:			no:	yes:		
Luxating patella	no:	yes:	>lat.	med.	no:	yes:	>lat	med.

4- Palpation (laying)	Right stifle				Left stifle			
Patella in situ	yes:	no:	>lat.	med.	yes:	no:	>lat.	med.
Luxating patella	no:	yes: with:	>lat.	med. without rotation:	no:	yes: with:	>lat.	med. without rotation:
P. luxates when tibial rotation	no:	yes:	>lat.	med.	no:	yes:	>lat.	med.
Crepitation:	no:	yes:			no:	yes:		
Deviation tibial tuberosity:	no:	yes:			no:	yes:		

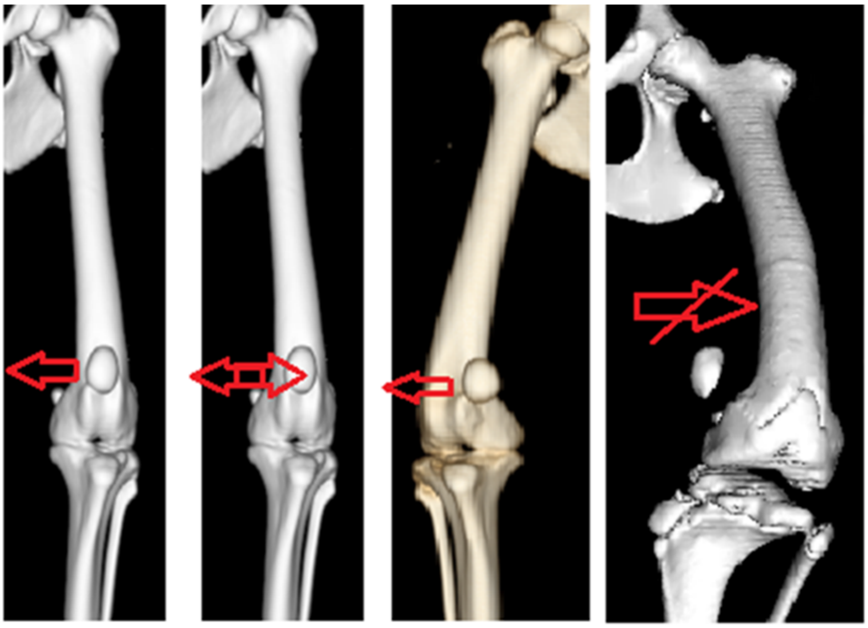
5- Evaluation

Grade I : In flexion and extension the patella can be luxated through medial / lateral pressure, returning back to the trochlea when released

Grade II : The patella can be luxated through lateral / medial pressure or by extension of the stifle through the examiner or the animal itself. The patella remains medially / laterally luxated and jumps by pressure from medial/ lateral or by active flexion or extension

Grade III : The patella is luxated medially / laterally. It can be brought into its normal position in the trochlear groove with medial / lateral pressure. Releasing pressure on the patella results in a re-luxation of the patella

Grade IV : The patella is permanently medially / laterally luxated. Reposition is not possible.



A B C D

Figure 6A-D. Illustration of the different patellar luxation grades by a 3D computer tomography reconstruction of femur, patella and proximal tibia. Arrows indicate the direction of patella movement under pressure.

(A) Frontal view of femur, patella and proximal tibia in a 2-year-old male poodle. In grade I luxations, the patella can be medially luxated by manual manipulation and returns to its physiological position without manual assistance.

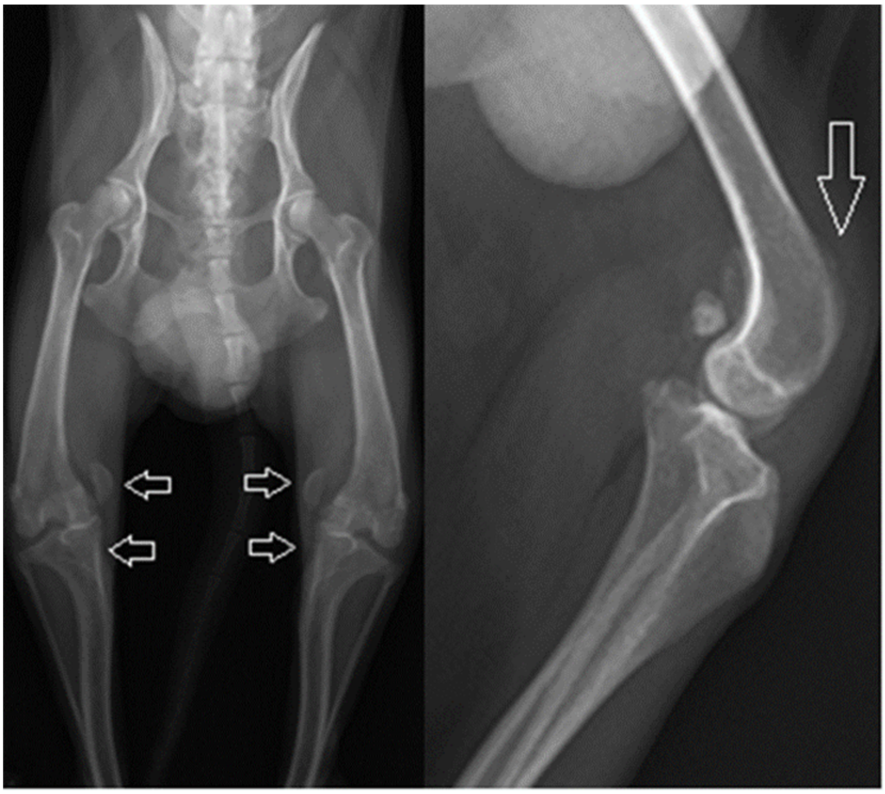
(B) Frontal view of femur, patella and proximal tibia in a 2-year-old male poodle. In grade II luxations, the patella can be luxated through lateral pressure or by extension of the stifle and remains luxated until repositioned through flexion or extension.

(C) Frontomedial view of femur, patella and proximal tibia in a 7-year-old female crossbreed with patellar luxation grade III. In grade III luxations, the patella is permanently luxated and can be temporarily repositioned through manual lateral pressure.

(D) Frontal view of femur, patella and proximal tibia in a 7-year-old male crossbreed with patellar luxation grade IV. In grade IV luxations, manual repositioning of the permanently luxated patella is impossible. In addition, lateral deviation of the distal femur, hypoplasia of the patella, trochlear groove and medial deviation of the proximal tibia occur.

7.3 Radiological examination

If the orthopaedic examination showed evidence of patellar luxation or cruciate ligament rupture, three radiographs were made to secure the diagnosis and rule out other stifle pathologies (Fig. 7). A ventro-dorsal radiograph of the hip with a craniocaudal view of both femurs and stifle joints as well as medio-lateral radiographs of both stifle joints were taken. Patients were not sedated or anaesthetized for radiographical imaging. Aside from anatomical correctness and symmetry, the examination of the radiographs included assessing indirect signs such as muscle atrophy of the thigh, joint effusion, periarticular swelling, loss of infrapatellar fat pad shadow and periarticular osteophyte formation.



A *B*

Fig. 7A-B Illustration of radiographical diagnostic imaging technique performed on patients with clinical signs of patellar luxation. (A) Shows a dorso-ventral radiograph of hip, femur, stifle joint and proximal tibia in a 7-year-old crossbreed male dog with bilateral patellar luxation grade IV. Findings include distal femoral lateral bowing, medial shift of the patellae, as well as medial deviation of the proximal tibia, indicated by white arrows. (B) Shows a medio-lateral radiograph of the left stifle joint of in an intact 7-year-old crossbreed male dog with bilateral patellar luxation grade IV. Findings include a medially luxated patella (partially overlapped by the femur) and poor development of the trochlear groove, indicated by the white arrow.

7.4 Surgery

7.4.1 Surgical procedures

In cases diagnosed with patellar luxation and concomitant CCLR, treatment options were discussed with owners. If the owner elected surgery, a venous catheter was placed in one of the cephalic veins.

All patients were treated with a standard anaesthesia protocol. Midazolam 0,5 mg/kg (Ratiopharm, Ulm, Germany) was administered as premedication and 0,2mg/kg L-Polamivet (Intervet, Unterschleissheim, Germany) and 4 mg/kg Narcofol (CP-Pharma, Burgdorf, Germany) were used for induction, followed by intubation. The affected stifles were clipped and aseptically prepared for surgery. Anaesthesia was maintained through isoflurane.

Within the PL+CCLR group, 30 stifle joints were treated surgically. “Trochlear-wedge-recession-osteotomy” (WR) was performed in all cases. Of those, 28 stifle joints were also treated with a “Tibial-tuberosity-transposition” (TT). To treat the concomitant CCLR, a “Fascia-over-the-top-technique” (OT) was performed on 14 stifles, while 16 stifles were treated with the “Capsular-and-fascial-imbrication-technique” (CFI) (Fig.8, Diagram 2).

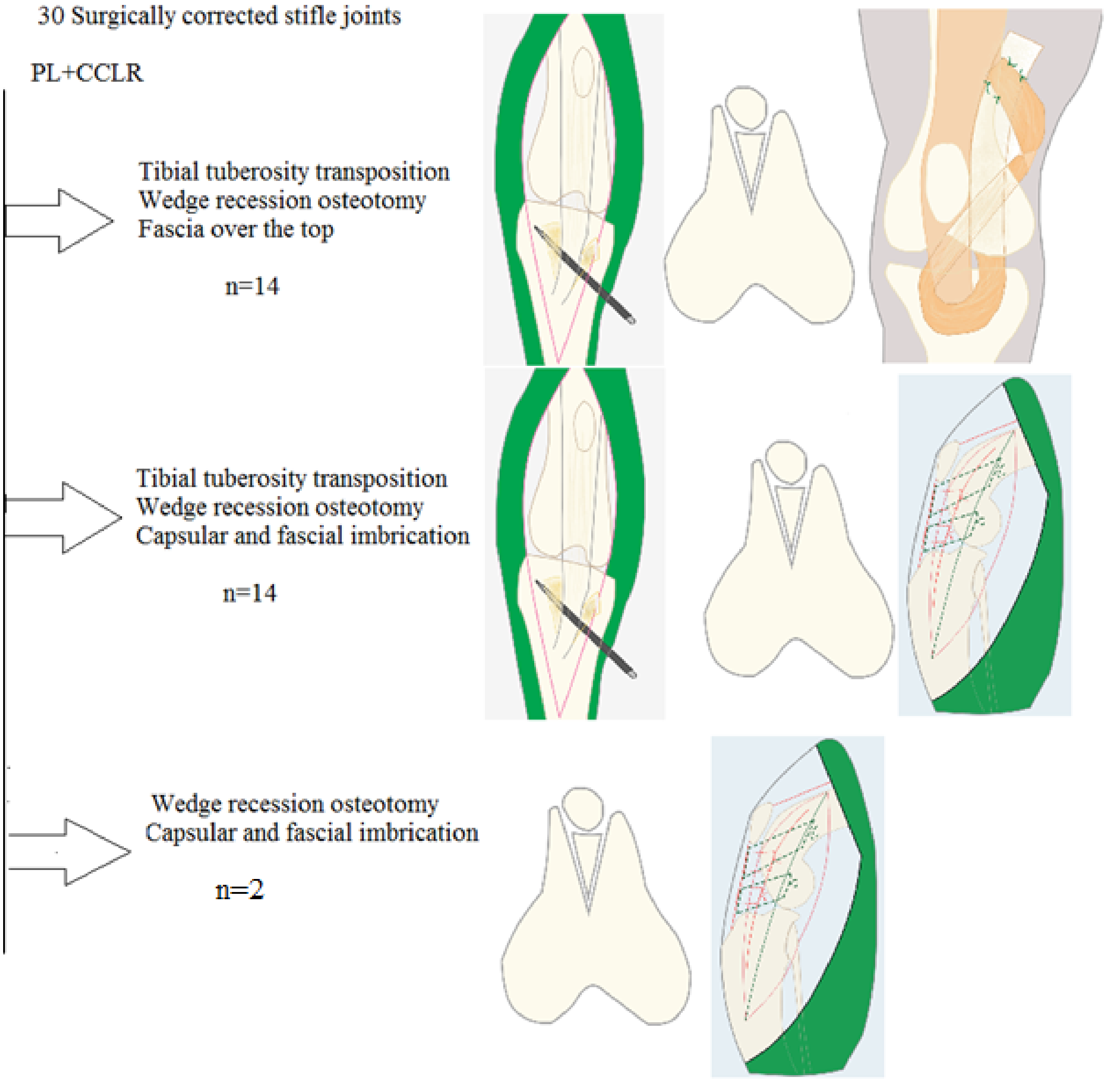


Figure 8. Illustration of the three combinations of surgical techniques used on stifles with PL and CCLR. Modified illustrations from: BRINKER, PIERMATTEI and FLO (1990), BRUNNBERG et al. (1985), ALLGOEWER et al. (2000).

After performing the chosen procedures and closing the incisions, the corrective effect was verified through postoperative radiographs. Postoperatively, all surgically treated stifle joints were stabilized through a Robert-Jones-bandage. Wounds were inspected two days post-surgery. All patients received standard pain treatment, which consisted of 0.1 mg/kg meloxicam (Metacam®, Boehringer Ingelheim Vetmedica GmbH, Germany) once daily and 22.5 mg/kg cephalexin (Albrecht GmbH, Germany), administered orally twice daily for 7 days. Patients were discharged after surgery and instructed to present to their referring veterinarian as well as the surgeon for follow-up examinations. Weight reduction and physiotherapy of the quadriceps muscle group was recommended to all patients. Compliance with post-operative care instructions varied. Three final follow-up examinations of lameness and general condition were performed at 3-6 months, 6-12 months and over 12 months post-surgery. Lameness was examined according to a standardized protocol (Table 4). Owners were contacted via telephone and asked to participate in a short questionnaire with the help of the referring veterinarian.

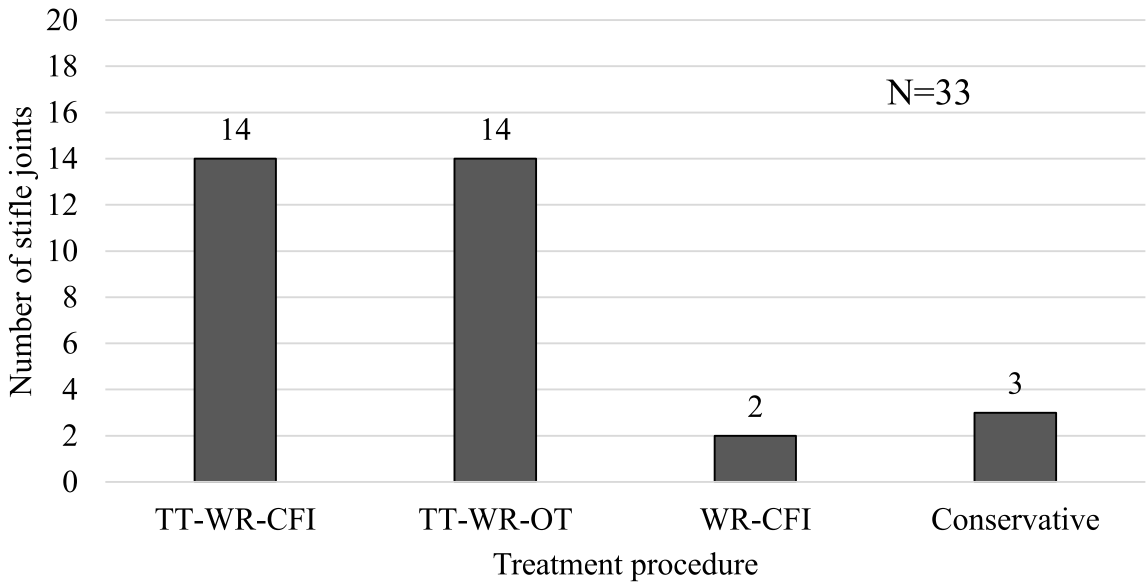


Diagram 2. Illustration of the four different procedures used to treat stifle joints diagnosed with PL and CCLR (N=33).

Abbreviations: TT= "Tibial tuberosity transposition", WR: "Wedge recession osteotomy", OT: "Fascia over the top" technique, CFI: "Capsular and fascial imbrication" technique.

7.4.2 Complications

Post-operative outcomes were categorized into four groups: no complications, minor complications, major complications and catastrophic complications. Minor complications were treated conservatively, while major complications needed additional surgery. Complications that did not improve after secondary surgery or resulted in elective euthanasia were considered catastrophic.

7.4.3 Follow-up examinations and outcomes

The efficacy of chosen surgical approaches was assessed through follow-up examinations and owner questionnaires. The follow-up examinations were performed by the treating surgeon and assessed lameness, pain and patellar luxation. Lameness was recorded on a score from 0-5, with 0 standing for “no visible lameness” and 5 for “extreme lameness / non weight-bearing limb” (Table 4). Pain was assessed during flexion and extension of the stifle joint. Patellar luxation was examined through palpation and manual manipulation. Quadriceps muscle development was assessed through palpation. Skipping and limb loading were examined through adspection and palpation. The outcomes were classified into four categories: excellent, good, fair and poor.

An outcome was considered “excellent”, if no lameness (0/5), no skipping, no pain, complete physiological limb loading, a free range of movement and good regain of quadriceps musculature were evident.

An outcome was considered “good”, if infrequent skipping occurred and all other excellent criteria were met.

An outcome was considered “fair”, if infrequent skipping and quadriceps muscle atrophy were present, but all other excellent criteria were met.

An outcome was considered “poor”, if skipping and quadriceps muscle atrophy were present, limb loading was incomplete and lameness of 2/5 or higher was present.

Results from owner questionnaire were classified according to the same criteria.

Table 4. Lameness score used to assess clinical outcomes (Monk et al. 2006).

	Lameness score (walking)
Grade 0	No lameness detected at the walk
Grade I	Intermittent lameness at the walk with some steps that are fully weight bearing
Grade II	Constant use of the affected limb at the walk with mild lameness
Grade III	Constant, partially weight bearing use of the affected limb and obvious lameness
Grade IV	Intermittent non-weight-bearing lameness at a walk
Grade V	Non-weight-bearing lameness at the walk

7.5 Statistical analysis

Statistical analysis of the collected data included descriptive statistics, calculation of means and standard deviations. The Chi-squared test for independence was applied to assess correlations between two variables. Due to the small samples size, Fisher’s exact test was used as an alternative to the Chi-squared test, when appropriate. In addition, a Mann-Whitney-U-Test was applied to analyse rank correlations in nonparametric variables. Significance was determined as $p<0.05$ (FIELDS 2013) (SPSS Statistics, Version 22, IBM, USA).

8. Results

A total of 233 small and toy breed dogs were presented for examination and treatment of lameness due to PL. Of those patients, 52 (23%) suffered both from PL and CCLR, while 181 (77%) were only diagnosed with patellar luxation (Diagram 1).

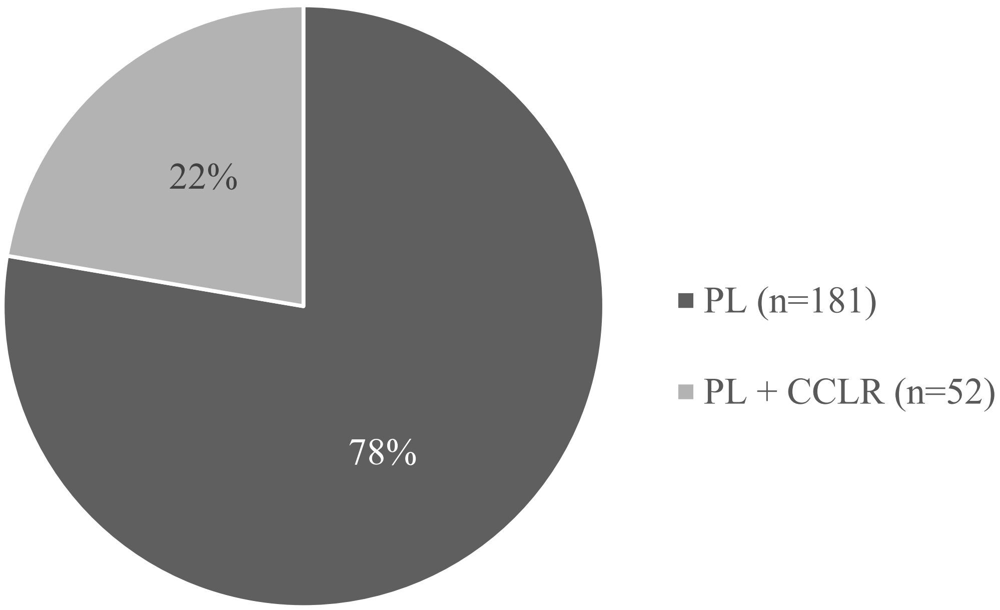


Diagram 1. Frequency and distribution of concomitant cranial cruciate ligament rupture in cases of patellar luxation in small and toy breed dogs, presented to the small animal teaching hospital of the Freie Universität Berlin between 2004 and 2016.

8.1 Breeds

20 different breeds were recorded among the patients included in this study (Diagram 3). In the PL group, Yorkshire Terriers (36.4%), Poodles (10.9%), West Highland White Terrier (9.1%) and crossbreeds (9.1%) were the most common breeds (Tab. 5). Breed distribution within the PL+CCLR group revealed that Yorkshire Terriers (30.8%), Maltese (23.1%), Chihuahuas and Cairn Terriers (7.7%) were the most common breeds in this group (Tab. 6)

Table 5. Breed distribution among patients in the PL group.

Breed	Number	Percent (%)
Yorkshire Terrier	20	36.4
Poodle	6	10.9
Crossbreed	5	9.1
West Highland White Terrier	5	9.1
Chihuahua	3	5.5
Jack Russell Terrier	2	3.6
Terrier	2	3.6
Papillon	2	3.6
Fox Terrier	2	3.6
Cavalier King Charles Spaniel	1	1.8
Tibet Terrier	1	1.8
Boston Terrier	1	1.8
Spitz	1	1.8
Havaneser	1	1.8
Pug	1	1.8
Shih Tzu	1	1.8
Maltese	1	1.8
n=55		

Table 6. Breed distribution among patients in the PL+CCLR group.

Breed	Number	Percent (%)
Yorkshire Terrier	8	30,8
Maltese	6	23.1
Cairn Terrier	2	7.7
Crossbreed	2	7.7
Chihuahua	2	7.7
Poodle	1	3.8
West Highland White Terrier	1	3.8
Jack Russell Terrier	1	3.8
Shih Tzu	1	3.8
Bolonka Zwetna	1	3.8
Biewer Terrier	1	3.8
n=26		

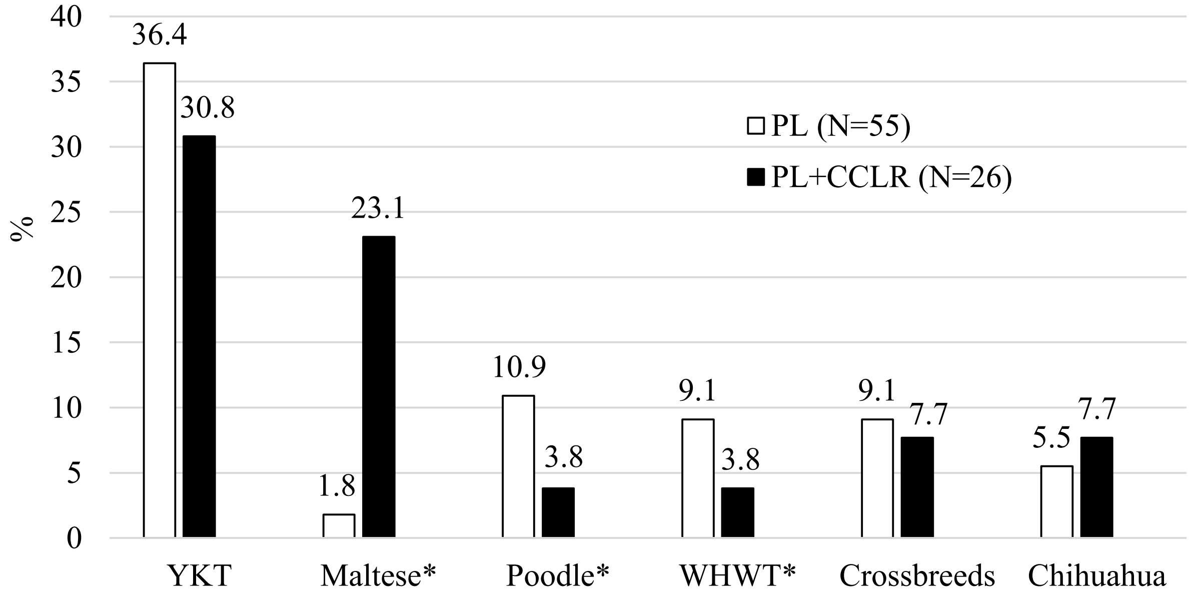


Diagram 3. Breed distribution among dogs in the PL group and the PL+CCLR group. Abbreviations: YKT=Yorkshire Terrier; WHWT= West Highland White Terrier.

** = Statistic significance for Maltese, Poodle and West Highland White Terrier was $p<0.001$, $p=0.420$ and $p=0.658$, respectively.*

A correlation between concomitant CCLR and in PL patient's breed found that the Maltese breed was significantly correlated to concomitant CCLR ($p<0.001$). Poodles ($p=0.420$) and West Highland White Terriers ($p=0.658$) were negatively correlated. All other breeds did not show statistically significant predispositions for PL and CCLR (Tab. 7).

Table 7 illustrates the breed predisposition for PL and CCLR found in Maltese dogs.

Fisher's exact test: p-value= 0,001			PL		Total
			No CCLR	CCLR	
Breed	Maltese	Number (n)	2	7	9
		%	22.2%	77.8%	100%
	Other breeds	Number (n)	95	26	121
		%	78.5%	21.5%	100%
Total		Number (N)	97	33	130
		%	74.6%	25.4%	100%

8.2 Sex

The PL group consisted of 72.8% sexually intact patients, of which 36.4% (n=20) were female and 36.4% (n=20) were male, as well as 27.2% (n=15) neutered patients, of which 12.7% (n=7) were spayed females and 14.5% (n=8) were castrated males (Diagram 4). The PL+CCLR group consisted of 53.9% (n=14) sexually intact patients, of which 38.5% were intact females (n=10) and 15.4% were intact males (n=4), as well as 46.1% neutered patients (n=12), of which 19.2% were spayed females (n=5) and 26.9% were castrated males (n=7) (Diagram 5). Fisher's exact test revealed no statistical correlation between sex and CCLR (p=0.182).

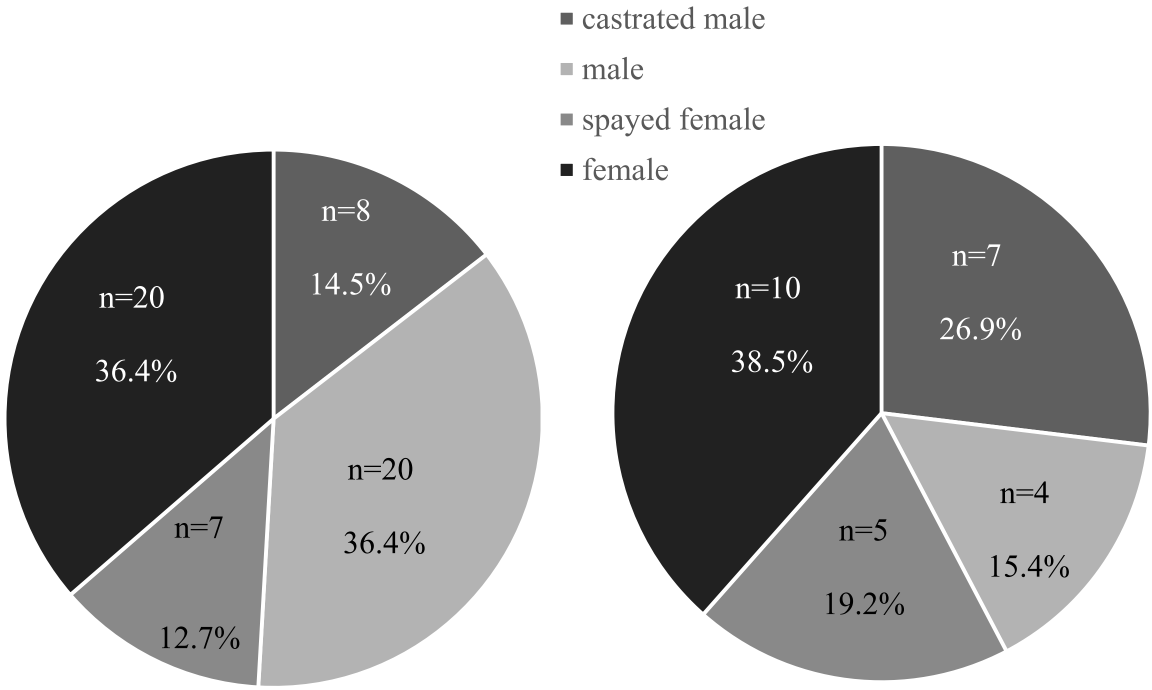


Diagram 4 PL group (n=55) *Diagram 5 PL+CCLR group (n=26)*

Diagrams 4 and 5. Illustration of sex distribution in the PL and PL+CCLR group, respectively.

8.3 Weight – overweight

In the PL group, the average weight was 5.07 kg, while the average weight in the PL+CCLR patients was 5.61 kg. Comparing both groups, 57.7% of the dogs of the PL+ CCLR group were overweight (Diagram 7), in contrast to the PL group with only 18.2% of overweight patients (Diagram 6). The Chi-squared test found that the correlation between overweight and concomitant CCLR was significant ($p<0.001$).

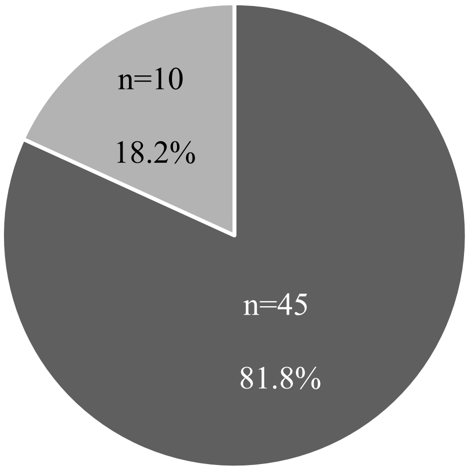


Diagram 6 PL group (n=55)

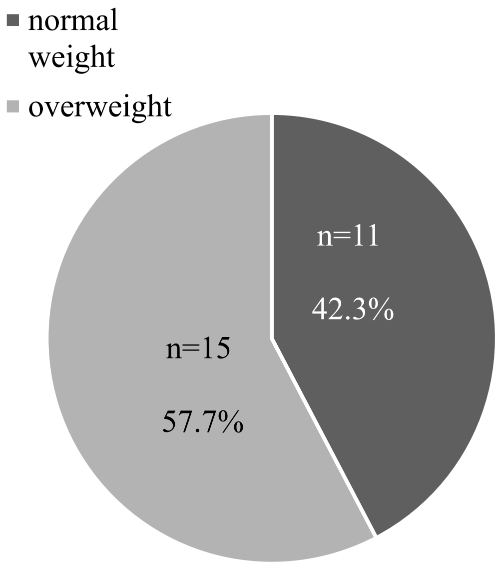


Diagram 7 PL+CCLR group (n=26)

Diagrams 6 and 7. Overweight distribution in the PL and PL+CCLR groups, respectively.

8.4 Age

In the PL group, age ranged from 12 to 188 months (m=63.93 months or 5.26 years). In contrast to this, age ranged from 42 to 154 months (m=88.77 months or 7.33 years) in the PL+CCLR group. The Mann-Whitney-U-Test found a significant correlation between concomitant CCLR and older age (p=0.002) (Tab. 8).

Table 8. Age of patients in the PL and PL+CCLR groups. Abbreviations- SD: standard deviation, MED: median, MIN: minimum, MAX: maximum

Mann Whitney U Test p = 0.002			Groups	
		Total	PL	PL+CCLR
Age in months (M)	MEAN	71.9	63.93	88.77
	SD	41.47	43.97	29.83
	MED	68	54	84
	N	81	55	26
	MIN	12	12	42
	MAX	188	188	154

8.5 Patellar luxation

8.5.1 Type and direction

In both groups, 23.1% of the dogs were presented with unilateral patellar luxation (n=13 in the PL and n= 6 in the PL+CCLR). Bilateral patellar luxation was found in 76.9% of the dogs of both groups (n=42 in the PL and n=20 in the PL+CCLR) (Diagram 8).

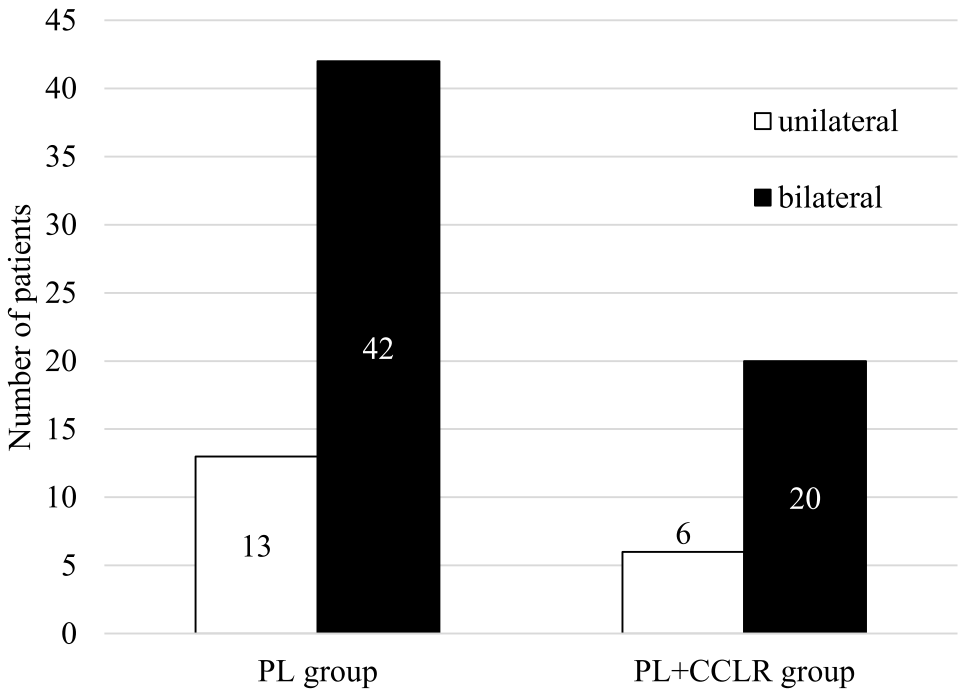


Diagram 8. Distribution of unilateral and bilateral patellar luxations in patients in the PL and the PL+CCLR groups.

In the PL group, 83.47% (n=81) of stifle joints were diagnosed with medial patellar luxation, while 9.2% (n=9) were diagnosed with lateral patellar luxation and 7.2% (n=7) of stifle joints were diagnosed with bidirectional patellar luxation. In contrast to this, in the PL+CCLR group, 100% of stifle joints were diagnosed with medial patellar luxation (Diagram 9). No significant correlation between MPL and concomitant CCLR was found (p=0.34).

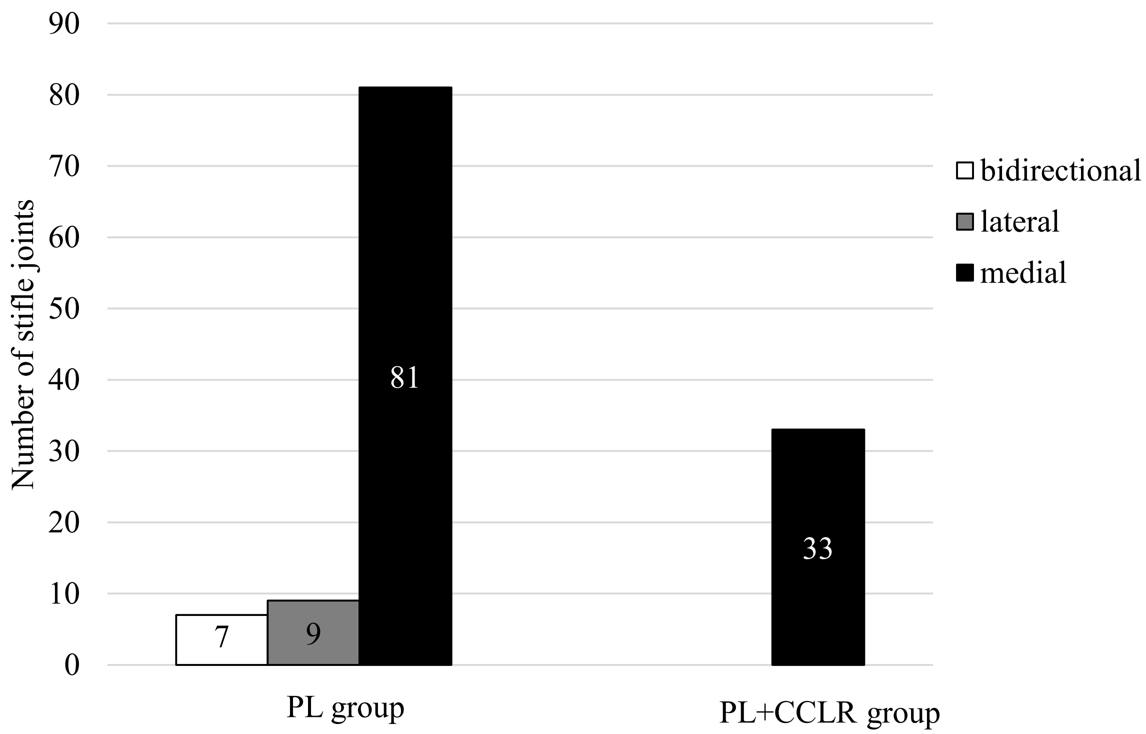


Diagram 9. Distribution of medial, lateral and bidirectional patellar luxations in the PL and the PL+CCLR groups (N=130).

8.5.2 Grade and affected side

Grade I was diagnosed in 24.7% of stifles in the PL group (n=24) and in 18.2% of stifles in the PL+CCLR group (n=6). Grade II was diagnosed in 37.1% (n=36) of stifles in the PL group and in 36.4% (n=12) of stifles in the PL+CCLR group. Grade III was seen in 23.7% (n=23) of cases in PL group and 36.4% (n=12) in the PL+CCLR group. Grade IV was found in 7.2% of the cases (n=7) in the PL group and 9.1% of cases (n=3) in the PL+CCLR group. Other medial and lateral luxation grades amounted to 7.2% (n=7) in the PL group (Diagram 10).

No significant differences in the distribution of patellar luxation grades (I, II, III and IV) were found between the PL group and PL+CCLR group (Table 9).

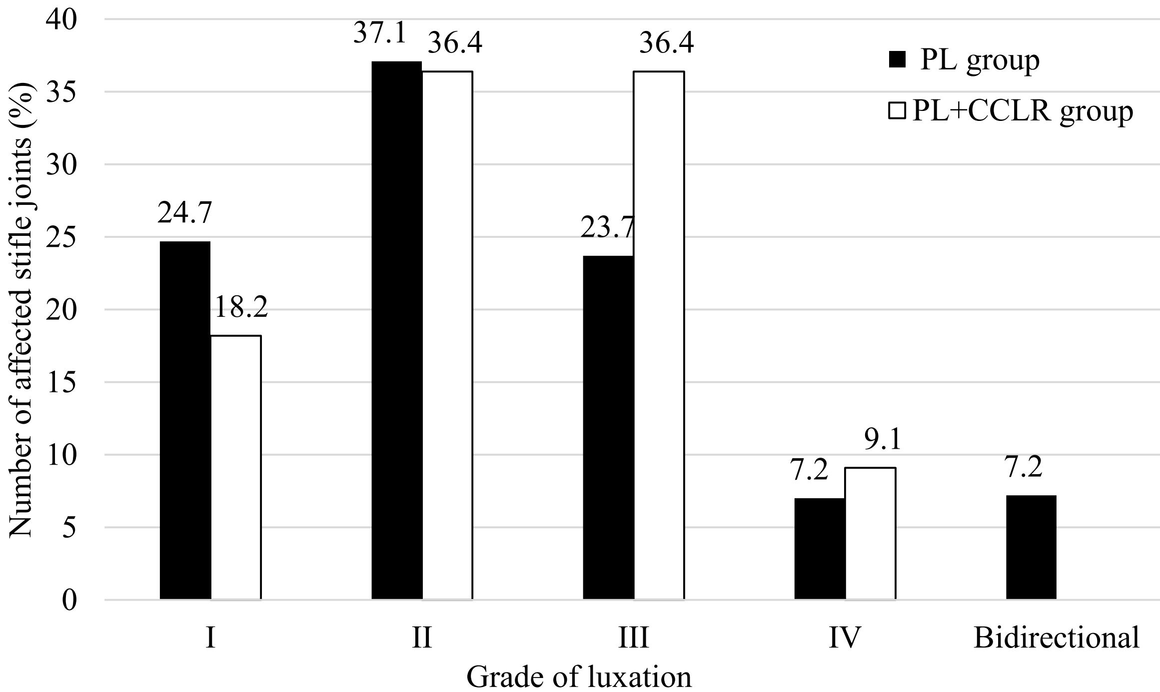


Diagram 10. Distribution of luxation grades in affected stifle joints (N=130) in the PL group (n=97) and the PL+CCLR group (n=33).

The mean patellar luxation grade was slightly higher in the PL+CCLR group (2.36), compared to the PL group (2.12). According to the Mann-Whitney-U test, the correlation between concomitant CCLR and patellar luxation grade was not statistically significant (p=0.165) (Table 9).

Table 9. Mean grade of luxation, minimal, maximal and for grades of patellar luxation in the PL and PL+CCLR groups

Mann-Whitney-U test p = 0.165		Group	
	Total	PL	PL+CCLR
Mean grade of luxation	2.18	2.12	2.36
N	130	97	33
MIN	1	1	1
MAX	4	4	4

In the PL+CCLR group, 46.2% (n=12) of patients showed an identical luxation grade in both affected stifles. In 26.9% (n=7) the grades between the luxated patellae differed by one grade. In 23.1% of patients (n=6), the grades between the luxated patellae differed by two grades, while the grade of luxation differed by three degrees in 3.8% (n=1) (Diagram 11). Mean grade of luxation was 0.85 grades higher in the limb affected by CCLR than in the contralateral one. According to the Mann-Whitney-U-Test, the correlation between higher grades of luxation and concomitant CCLR was not significant (p=0.165).

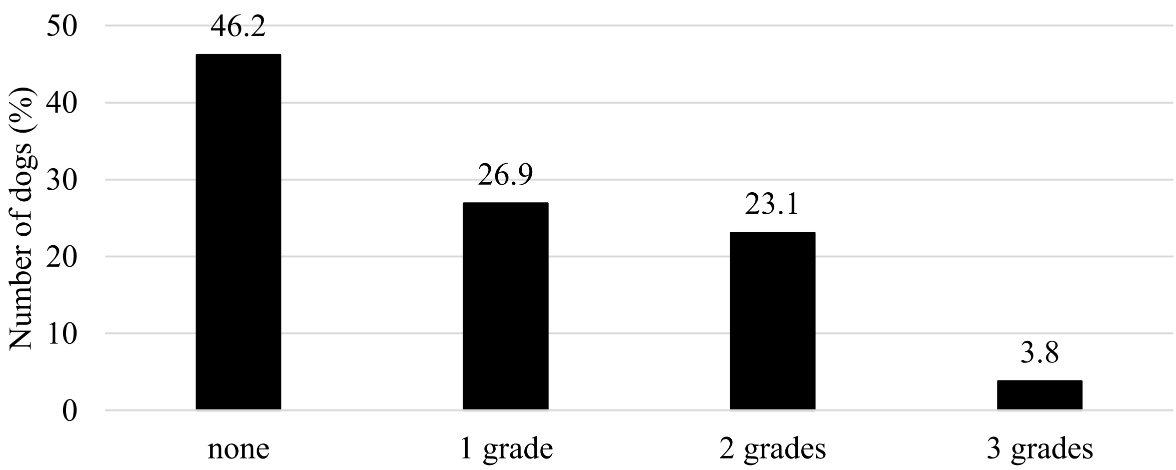


Diagram 11. Differences in luxation grades found in patients with bilateral patellar luxations in the PL+CCLR group (n=26).

In the PL group, 51.55% (n=50) of patellar luxations occurred in the left stifle joint, while 48.4% (n=47) occurred in the right stifle. In the PL+CCLR group, 42.4% (n=14) of patellar luxations occurred in the left stifle joint, while 57.6% (n=19) occurred in the right stifle joint. (Diagram 12). Fischer's exact test showed no significant correlation between concomitant CCLR and the affected limb side (p=0.320).

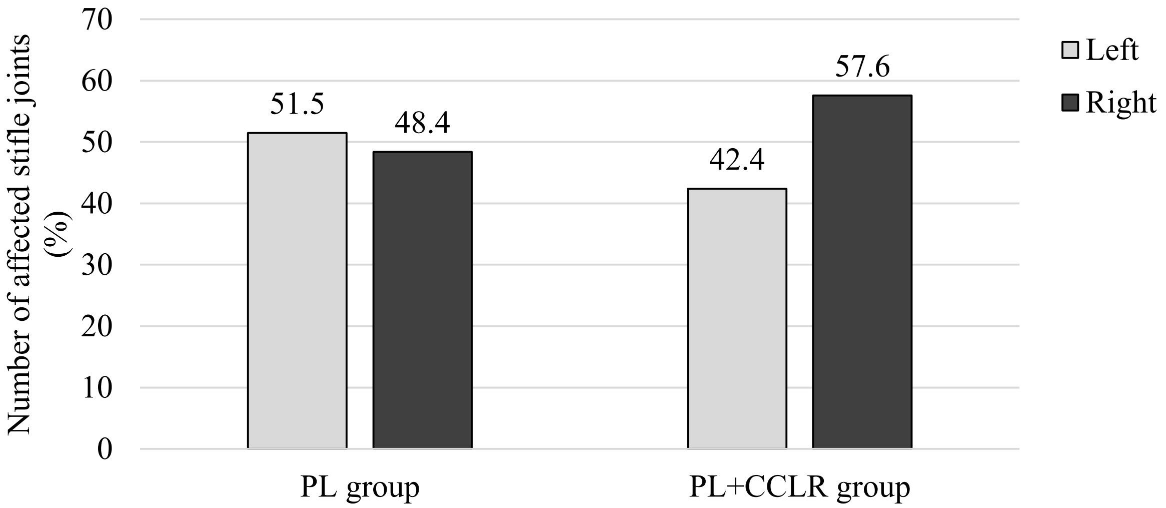


Diagram 12. Distribution of patellar luxations in left and right stifle joints in the PL (n=97) and PL+CCLR groups (n=33)

8.6 Weight – overweight – castration

Combining all patients from the PL and the PL+CCLR groups (n=81), 66.6% (n=54) were sexually intact, while 33.3% (n=27) were neutered. Among the castrated dogs (n=27), 48.1% (n=13) were overweight, compared to 22.1% (n=12) overweight dogs among the sexually intact patients. Among the castrated dogs (n=27), 51.9% (n=14) showed a normal weight, compared to 77.8% (n=42) among the sexually intact patients (Diagrams 13 and 14). The Chi-squared test revealed a significant correlation between neutering and overweight (p=0.023).

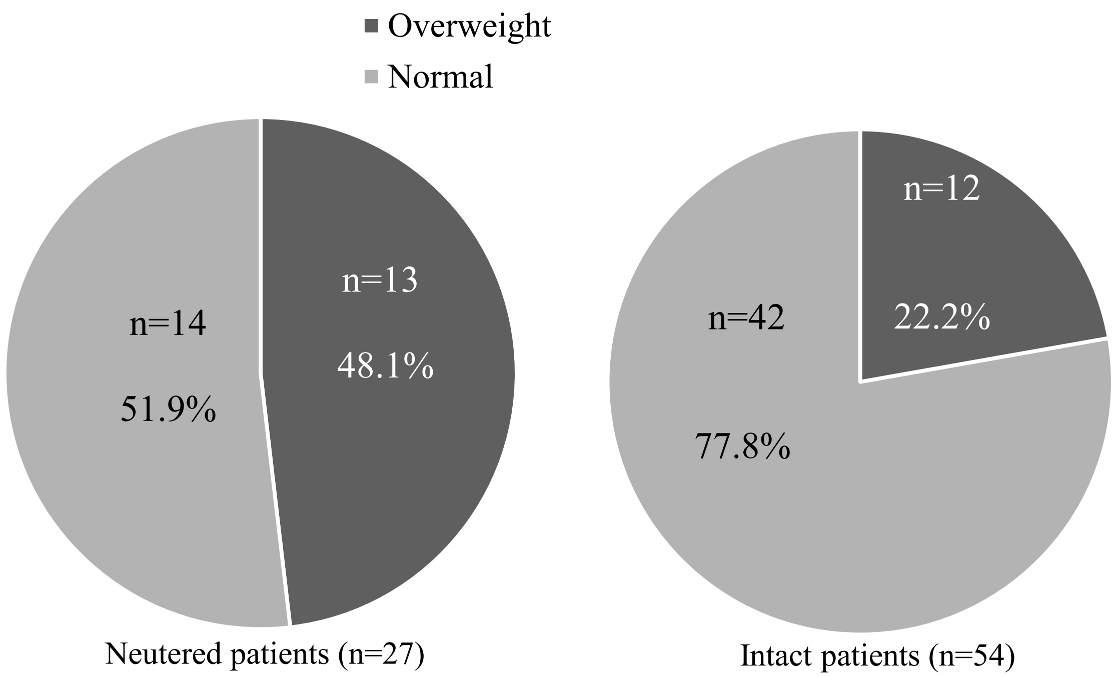


Diagram 13 *Diagram 14*

Diagrams 13 and 14. Overweight distribution among neutered and intact patients respectively, combined from the PL and the PL+CCLR groups (N=81).

8.7 Cranial cruciate ligament rupture

8.7.1. Unilateral and bilateral

In the PL+CCLR group, 30.8% (n=8) of patients were found with bilateral CCLR, while 69.2% (n=18) showed unilateral CCLR at the time of diagnosis. A contralateral patellar luxation was found in 87.5% (n=7) of patients with bilateral CCLR (Diagram 15).

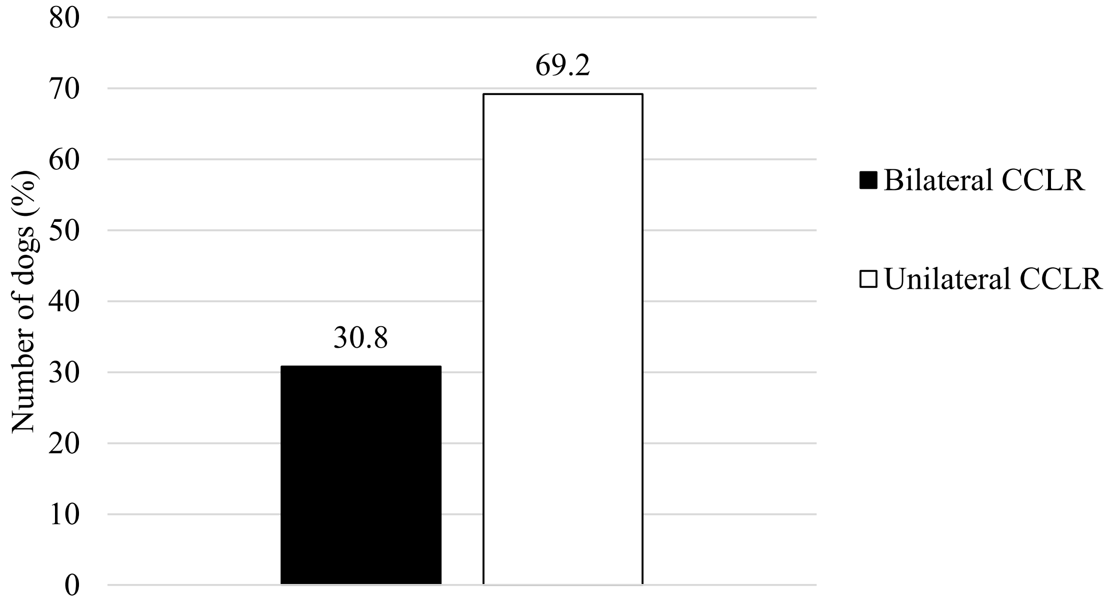


Diagram 15. Prevalence of bilateral CCLR in the PL+CCLR group (n=26).

8.7.2 Timing of bilateral rupture

In the PL+CCLR group, patients with bilateral patellar luxation were divided into groups, according to the timespan between the first and the second CCLR. In 37.5% (n=3) of patients, bilateral CCLR was found during the initial examination. In the remaining patients, the second CCLR was diagnosed 8 (n=1), 10 (n=1), 11 (n=1), 12 (n=1), and 24 (n=1) months after the initial diagnosis, respectively (Diagram 16). Patients with bilateral CCLR were diagnosed with the second CCLR at a mean time of 13 months after the initical CCLR diagnosis.

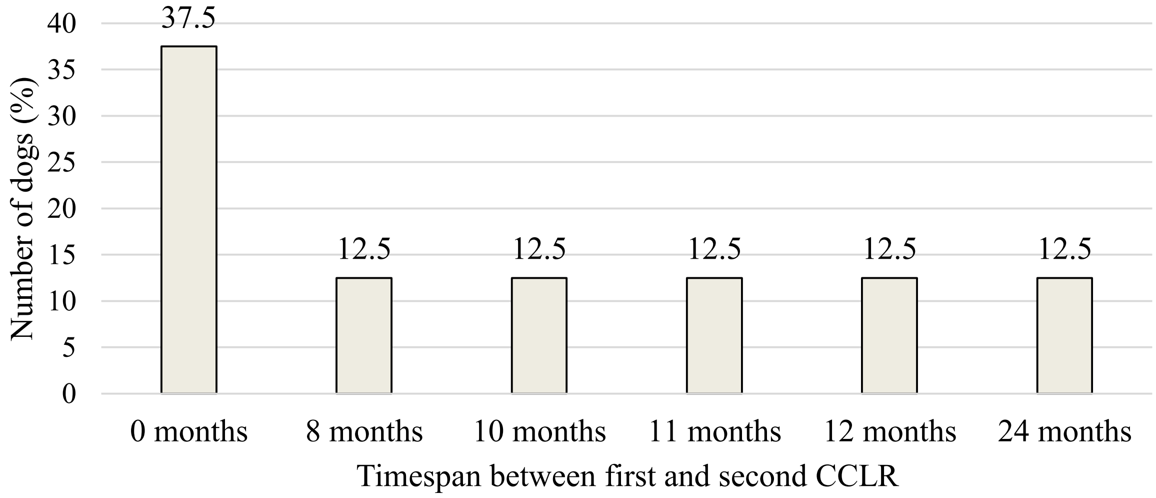


Diagram 16. Differences in timespan between the first and the second CCLR found in patients with bilateral CCLR in the PL+CCLR group (n=8).

8.8 Meniscal disease

In the PL+CCLR group, 9.1% (n=3) of affected stifle joints showed meniscal disease at the time of diagnosis, while no signs of meniscal disease were found in 90.9% (n=30) (Diagram 17).

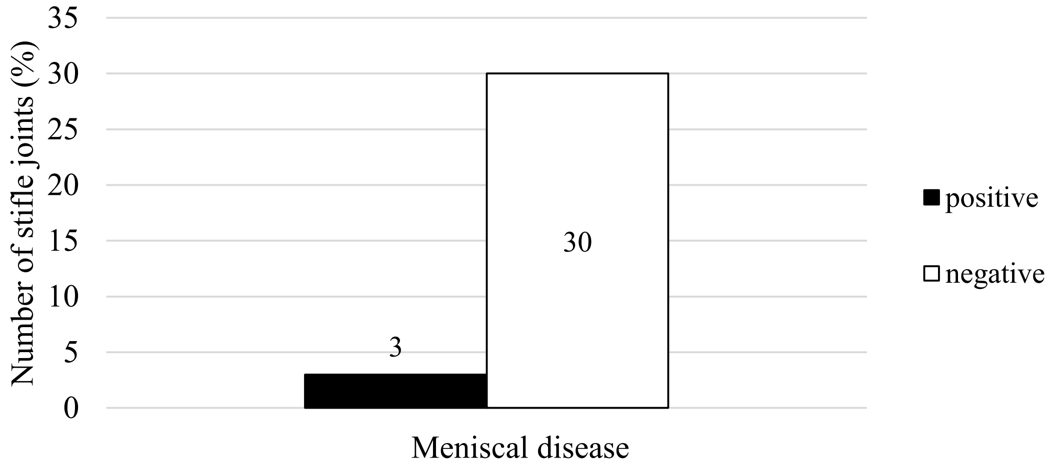


Diagram 17. Distribution of meniscal disease in affected stifle joints in the PL+CCLR group (N=33).

In the PL+CCLR group, the mean grade of patellar luxation was slightly lower in stifle joints diagnosed with meniscal disease (2.33) compared to those without meniscal disease (2.37). The Mann-Whitney-U-Test found no significant correlation between the mean grade of luxation and meniscal disease (p=1.00) (Table 10).

Table 10. Differences in luxation grades in stifle joints with meniscal disease compared to stifle joints without meniscal disease in the PL+CCLR group (n=33).

Mann Whitney U test p=1.000			Meniscal disease	
		Total	yes	no
	MEAN	2.36	2.33	2.37
	SD	0.9	0.58	0.93
	MED	2	2	2
	N	33	3	30
	MIN	1	2	1
	MAX	4	3	4

8.9 Follow-up

In the PL+CCLR group (n=33), 90.9% (n=30) of affected stifle joints were corrected surgically. Owners were asked to return for follow-up examinations with the veterinary surgeon after post-surgical healing was completed. Follow-up examinations were performed between 3 and more than 12 months post-surgery. In 60% of cases (n=18), the examination was performed more than 12 months after surgical treatment, while 20% of cases (n=6) were presented for the examination between 6 and 12 months and another 20% of cases (n=6) were examined between 3 and 6 months post-surgery (Table 11). In addition to enabling clinical follow-up examinations by the veterinary surgeon, owners were asked to evaluate the outcome of their dog by participating in a standardized questionnaire.

Table 11. Time at which veterinary surgeons performed post-operative follow-up examinations

			Total
Time of follow-up in months	>12 M	%	60
		n	18
	6-12 M	%	20
		n	6
	3-6 M	%	20
		n	6
	Total	%	100
		N	30

8.9.1 Clinical examinations

46.6% (n=14) of surgically treated stifle joints in the PL+CCLR group were corrected with a combination of "Tibial tuberosity transposition" technique (TT), "Wedge recession osteotomy" technique (WR) and "Fascia over the top" technique (OT). The clinical follow-up examinations revealed that 92.8% (n=13) had an excellent outcome (one needing revision surgery), while 7.2% (n=1) had a poor outcome (Diagram 18). 46.6% (n=14) of surgically treated stifle joints in the PL+CCLR group were corrected with a combination of TT, WR and "Fascial capsular-imbrication" technique (CFI). The clinical follow-up examinations revealed that 85.7% (n=12) had an excellent outcome, while 14.2% (n=2) showed a poor outcome (1 despite revision surgery) (Diagram 19). 6.8% (n=2) of surgically treated stifle joints in the PL+CCLR group were corrected with a combination of WR and CFI. The clinical follow-up examinations revealed that 100% (n=2) had an excellent outcome (Diagram 20).

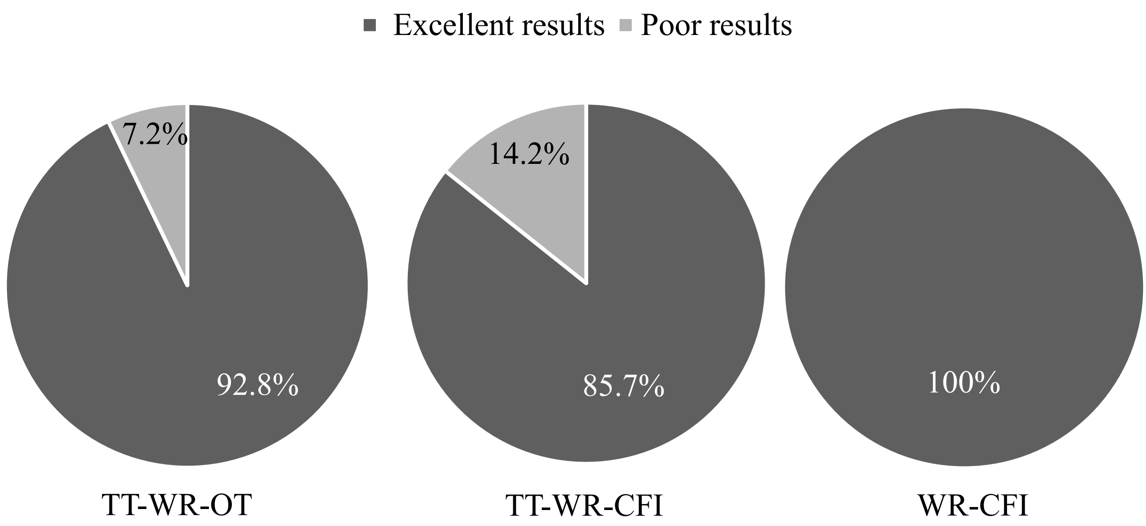


Diagram 18 *Diagram 19* *Diagram 20*

Diagrams 18, 19, and 20. Post-surgical outcomes in patients treated with different combinations of surgical techniques.

Diagram 18. (TT-WR-OT) Patients treated with "Tibial tuberosity transposition", "Wedge recession osteotomy" and "Fascia over the top" technique.

Diagram 19. (TT-WR-CFI) Patients treated with "Tibial tuberosity transposition", "Wedge recession osteotomy" and "Capsular and fascial imbrication" technique.

Diagram 20. (WR-CFI) Patients treated with "Wedge recession osteotomy" and "Capsular and fascial imbrication" technique.

In sum, the clinical follow-up revealed that 90% (n=27) of surgically treated stifle joints in the PL+CCLR group had an excellent outcome, while 10% (n=3) had a poor outcome. The Chi-squared test showed that there was no significant correlation (p=1.000) between post-operative outcome and choice of surgical techniques.

8.9.2 Owner questionnaires

46.6% (n=14) of surgically treated stifle joints in the PL+CCLR group were corrected with a combination of "Tibial tuberosity transposition" technique (TT), "Wedge recession osteotomy "technique (WR) and "Fascia over the top" technique (OT). The owner questionnaires revealed that 92.8% (n=13) of owners evaluated the post-operative outcome of their dog as excellent, while 7.2% (n=1) evaluated the outcome as poor (Diagram 21).

46.6% (n=14) of surgically treated stifle joints in the PL+CCLR group were corrected with a combination of TT, WR and "Fascial capsular imbrication" technique (CFI). The owner questionnaires revealed that 85.7% (n=12) of owners evaluated the post-operative outcome of their dog as excellent, while 14.3% (n=2) evaluated the outcome as poor (Diagram 22)

6.8% (n=2) of surgically treated stifle joints in the PL+CCLR group were corrected with a combination of WR and CFI. The owner questionnaires revealed that 100% (n=2) of owners evaluated the post-operative outcome of their dog as excellent (Diagram 23)

In sum, owners' follow-up questionnaires revealed that 90% (n=27) of surgically treated stifle joints in the PL+CCLR group had an excellent outcome, while 10% (n=3) had a poor outcome. The Chi-squared-test showed that there was no significant correlation (p=1.000) between evaluation of post-operative outcome by owners and choice of surgical techniques.

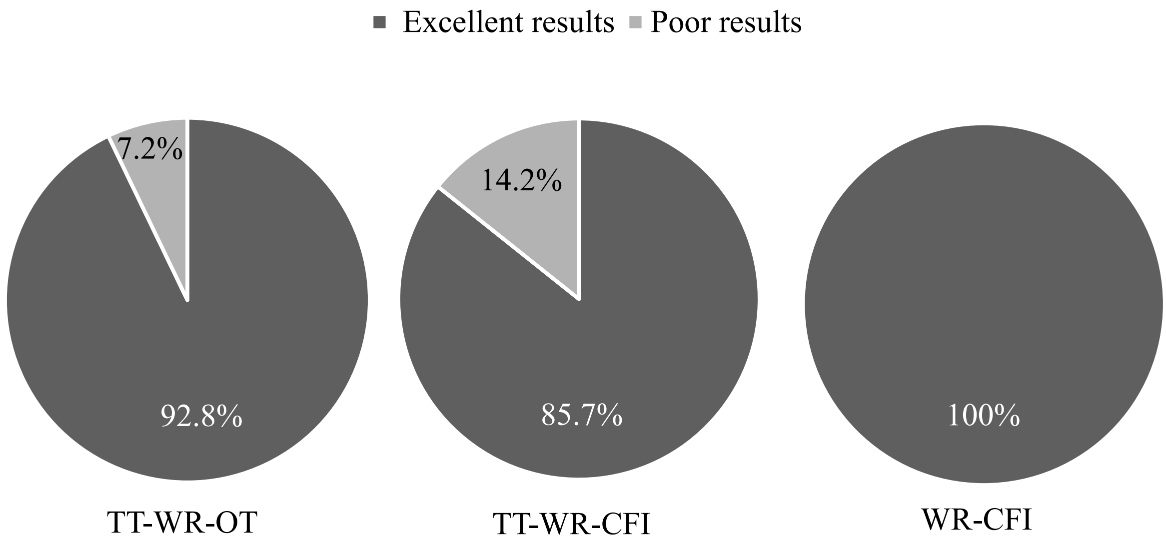


Diagram 21 *Diagram 22* *Diagram 23*

Diagrams 21, 22 and 23 show evaluation of post-operative outcome by owners in patients treated with different surgical techniques.

Diagram 21. (TT-WR-OT) Patients treated with "Tibial tuberosity transposition", "Wedge recession osteotomy" and "Fascia over the top" technique.

Diagram 22. (TT-WR-CFI) Patients treated with "Tibial tuberosity transposition", "Wedge recession osteotomy" and "Capsular and fascial imbrication" technique.

Diagram 23. (WR-CFI) Patients treated with "Wedge recession osteotomy" and "Capsular and fascial imbrication" technique.

8.10 Complications

83.3% (n=25) of surgically treated stifle joints had no post-operative complications. 3.3% (n=1) of surgically treated stifle joint showed minor complications, while 6.6% (n=2) developed major complications. 6.6% (n=2) of surgically treated stifle joints, of the same patient, showed catastrophic complications (Diagram 21).

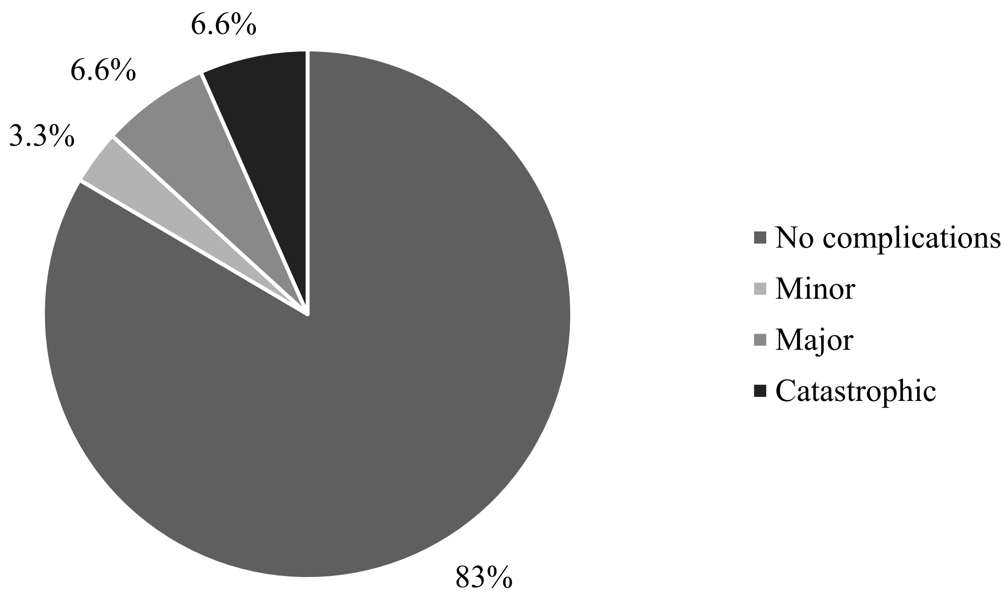


Diagram 24. Illustration of post-operative complications found in surgically treated stifle joints in the PL+CCLR group (n=30).

9. Discussion

Patellar luxation and cranial cruciate ligament rupture are the most common pathologies found in canine stifle joints. Moreover, they are common diseases in small breed dogs that often occur in combination. Patellar luxation has been associated with bone deformations and soft tissue changes. However, the aetiology remains controversial to date. While both diseases have been studied separately, few studies have focused on the combination of these pathologies.

The purpose of this study was to identify contributing factors, as well as outcomes in patients with PL and concomitant CCLR. A similar study conducted by CAMPBELL et al. (2010) determined frequency of CCLR in a larger sample of small breed dogs with PL and correlations between CCLR and PL grade IV, while treatment procedures and outcomes were not assessed. In addition to assessing the frequency of CCLR in our study population of small breed dogs with PL and investigating the suggested correlation between higher grades of luxation and CCLR, this present study's goal was to evaluate patient outcomes. Since patients included in this study were treated with different combinations of commonly used surgical techniques, the efficacy of surgical choices was also analysed. Several modified remodelling osteotomies for simultaneous treatment of PL and CCLR have been established (LANGEBACH and MARCELLIN-LITTLE 2010; YEADON et al. 2011; LEONARD et al. 2016) over the past decade. Yet, the combination of much more commonly used techniques like a "Wedge recession osteotomy" (WR) and/or "Tibial tuberosity transposition" (TT) for PL with traditional methods to treat concomitant CCLR such as the intra-articular reconstruction ("Fascia over the top technique") (BRUNNBERG et al. 1985) or extra-articular stabilisation ("Capsular and fascial imbrication technique") (ALLGOEWER et al. 2001) has not been studied to date. Two groups of patients were included in this study. The PL+CCLR group consisted of 33 stifle joints with patellar luxation and concomitant CCLR, found in 26 patients, while the PL group consisted of 97 stifle joints with patellar luxation without CCLR, in 55 patients.

Origins and correlating factors of the pathological combination remain controversial. While some suggest that PL is a contributing factor to cranial cruciate ligament rupture (CCLR), others have hypothesized that CCLR is a contributing factor to PL. Further authors have noted that the theories do not contradict each other and could both be valid. On the one hand, studies have hypothesized that patellar luxation leads to instability in the stifle joint, due to a lack of a caudal vector exerted by the patella in the trochlear groove, which could lead to further stress and ultimately CCLR (PIERMATTEI 1997; VASSEUR 2003; ARTHURS and LANGLEY-HOBBS 2007).

On the other hand, studies have shown that CCLR leads to an increased internal rotation of the tibia, which in turn increases the Q-angle and could thereby increase the probability of a medial patellar luxation (KAISER et al. 2001). Since neither theory has been proven to date, further studies are needed to gain a full understanding of the pathological processes.

9.1 Study and patients

9.1.1 Frequency of PL and CCLR in this study's population

In the present study, 23% of the small breed dogs presented for treatment of patellar luxation had a concomitant CCLR rupture at the time of diagnosis. While CAMPBELL et al. (2010) found a frequency of 40% of concomitant CCLR in a group of small breed dogs with PL, results of this present study are in the line of the reports of PIERMATTEI (1997), which confirmed concurrent CCLR in 15-20% of the stifles of middle-aged and older dogs with patellar luxation. Frequency reports differ for large breed dogs with only 13% of the cases reparted to have PL and CCLR (GIBBONS 2006). The differences between PL and CCLR occurrence in small and large breed dogs could be related to breeding effects.

9.1.2 Breeds

Combining both groups, 20 different breeds were found in patients suffering from patellar luxation with and without CCLR. In this present study, Yorkshire Terriers were the most common breed both in the PL and the PL+CCLR group, accounting for 36.4% and 30.8% of patients, respectively. Moreover, Poodles, West Highland White Terriers, Crossbreeds and Chihuahuas were also common breeds seen in the PL group. In addition, Maltese dogs were the second most common breed found in the PL+CCLR group, accounting for 23.1% of patients.

The high number of Yorkshire Terriers observed in both groups support the findings of previous studies, in which this breed was found to be commonly affected by PL and/or CCLR (CAMPBELL et al. 2010). In contrast to LAFOND (2002), our findings suggest that Maltese dogs do not have an increased risk for PL. However, we found that Maltese dogs suffering from PL were significantly more likely to develop concomitant CCLR. In opposition to this, West Highland White Terriers and Poodles with PL showed a significant negative correlation to concomitant CCLR. Moreover, in contrast to CAMPBELL et al. (2010), Chihuahuas were not a common breed in the PL+CCLR group. Since both Yorkshire Terriers and Maltese dogs are popular breeds in the patient population of our hospital, this may limit our findings.

In previous studies, breed predispositions for patellar luxation were reported for Boston Terriers, Chihuahuas, Pomeranians, Miniature Poodles, Bichon Frises and Yorkshire Terriers (PRIESTER 1972; KODITUWAKKU 1962; PUTNAM 1968; CAMPBELL and POND 1972; TROTTER 1980; HAYES BOUDRIEAU et al. 1994; DENNY 1996; ALAM et al. 2007; OBOLADZE 2010). Moreover, breed has been identified as a risk factor for CCLR (WITSBERGER 2008). Two recent studies found breed predispositions for CCLR in Yorkshire Terriers and West Highland White Terriers (MANCHI 2011; ADAMS et al. 2011). In addition, various authors have proposed that within small breed dogs, Poodles have a predisposition for cruciate ligament rupture (PUNZET and WALDE 1974; GAMBARDELLA et al. 1981; SHIRES et al. 1984; SCHNELL et al. 1984; BRUNNBERG 1990; MAGER 2000). In a recent study, Yorkshire Terriers and Chihuahuas were common breeds among patients with PL and concomitant CCLR (CAMPBELL et al. 2010). However, a study by WITSBERGER (2008) did not find Yorkshire Terriers and Maltese dogs to have an increased risk of CCLR, compared to other breeds. Breed predispositions for CCLR have been described in many articles for almost 70 breeds and were found to correlate to the temporary popularity and regional presence of breeds (BRUNNBERG 1990).

9.1.3 Sex

In this study, the sex ratio (male to female) was found to be 1:1 in dogs with patellar luxation only, which contrasts with findings of previous studies. For dogs with PL and concomitant CCLR, a sex ratio of 1:1.3 was seen, which is in line with recent findings. In addition, a higher number of female dogs and neutered male dogs were found among patients suffering from both PL and concomitant CCLR. However, a statistically significant correlation between sex and PL+CCLR was not evident. Since the percentage of neutered males and females was higher in the PL+CCLR group, this may account for some of our findings.

In previous studies, sex distribution (male to female) among dogs with patellar luxation and cranial cruciate ligament rupture was reported as 1:1.3 (CAMPBELL et al. 2010). Moreover, similar findings have been reported in previous studies on dogs suffering from patellar luxation only, where ratios of around 1:1.5 (PRIESTER 1972; BOUDRIEAU et al. 1994; HULSE 1993; HAYES 1994; VASSEUR 2003) and 1:1.86 (ALAM 2007) were found. In contrast, studies of patellar luxation in large breed dogs found sex ratios of 1.8:1 (REMEDIOS et al. 1992; GIBBONS et al. 2006).

Sex predispositions for PL and CCLR have been controversial findings in previous studies. GUSTAFSSON (1969), PRIESTER (1972) and HAYES et al. (1994) hypothesized that female dogs are more predisposed to PL. GUSTAFSSON (1969) theorized that higher estradiol levels in puppies could negatively influence bone development, causing the femoropatellar condyles to lower, which could predispose to patellar luxation. To date, this theory has not been validated. While some authors did not find predispositions for a cruciate ligament rupture (PAATSAMA 1952; POND and CAMPBELL 1972; HOHN and NEWTON 1975; SCHNELL 1986; BRUNNBERG 1987, 1990; ALT 2000), GAMBARDELLA et al. (1981) found a predisposition among male patients. In addition, neutered dogs have been reported to have an increased risk of CCLR compared to sexually intact patients (WHITEHAIR et al. 1993; DUVAL et al. 1999; WITSBERGER et al. 2008). Finally, BRUNNBERG (1990) proposed that cruciate ligament rupture could affect every dog, regardless of breed, age, limb side and sex.

9.1.4 Weight – overweight – castration

A combination of a surgical treatment, to correct patellar luxation and cranial cruciate ligament rupture, in combination with a weight loss program and physical therapy was expected to achieve the most successful patient outcomes. The results show a significant correlation between overweight and concomitant CCLR. In addition, a significant correlation between overweight and neutering was observed, which has been described in previous studies (MCGREEVY 2005). The average weight found in patients of the PL+CCLR group (m=5.61kg) was higher than in the PL group (m=5.07kg). Moreover, according to the AMERICAN KENNEL CLUB STANDARDS (2014), more than half (57.7%) of the dogs in the PL+CCLR group were overweight, while just 18.7% of patients in the PL group were overweight. Studies of standard canine populations have reported that 28% of dogs were overweight (MASON 1970; EDNEY et al. 1986; LUND et al. 1999). Evidence from numerous studies suggests that overweight can cause additional mechanical stress on joints, thereby promoting degeneration, as well as ligament rupture (PAATSAMA 1952; LAMPADIUS 1964; HOHN and NEWTON 1975; ARNOCZKY 1980; VASSEUR 1984; DOVERSPIKE et al. 1993; DUVAL 1999; JOSHUA 1970; KEALY 1997). SHIRES et al. (1984) proposed that this could explain higher prevalence of ligament rupture in heavier breeds. Previous and current findings suggest that overweight could be a risk factor for developing concomitant CCLR in dogs with patellar luxation. When overweight increases mechanical stress in the absence of the joint compressive force of the patella in the trochlear groove, the stress on the cranial cruciate ligament is increased, since it is the main force counteracting the cranial tibial translation during locomotion. This additional stress could cause the cranial cruciate ligament to rupture. Furthermore, obesity has been reported as a risk factor for the development and progression of osteoarthritis in dogs (JOSHUA 1970). Moreover, caloric restriction combined with intensive physical therapy has proven to facilitate weight loss and improve mobility as well as reactivate the quadriceps muscle group in overweight dogs with osteoarthritis (MLACNIK et al. 2006; RAMIREZ et al. 2015). Hence, weight loss and physiotherapy should be recommended as post-surgical treatment for all patients suffering from patellar luxation with or without concomitant CCLR.

9.1.5 Age

This study found that patients in the PL and PL+CCLR were diagnosed at an average of 5.25 and 7.33 years of age, respectively (PL: m=63.93 months; PL+CCLR: m=88.77 months). The correlation between concomitant CCLR and older age was significant (p=0.002), which is in line with previous findings.

CAMPBELL et al. (2010) found that on average, CCLR in small breed dogs with PL occurred at 7.8 years of age, while the average age at the time of diagnosis for MPL was 3.0 years. In addition, other authors reported that most patients with CCLR were diagnosed between 6 and 9 years of age (PAATSAMA 1952; GEYER 1966), 5 and 6 years (LOEFFLER 1964) and 5 and 7 (ELKINS et al. 1991; METELMANN et al. 1995; INNES and BARR 1998; ALT 2000 and MAGER 2000). Moreover, further studies found that most patients diagnosed with CCLR were older than 5 years (HOHN and NEWTON 1975) or older than 6 years (GAMBARDELLA et al. 1981). Finally, CCL injury appeared most frequently from 7 to 10 years of age (WHITEHAIR et al. 1993; ALAM et al. 2007; WITSBERGER et al.2008).

SCHNELL (1986) proposed that in large dogs, 70% of the ruptures occurred in patients younger than 6 years of age, while in small breed dogs only 19% of cases were found that age group. In addition, studies have observed that signs of degeneration of the cranial cruciate ligament were found several years later in small breed dogs, compared to large breed dogs (VASSEUR et al. 1985; ZAHM 1964). While ZAHM (1964), found degeneration of the CCL in small breed dogs aged 7 years or older, MANCHI (2011) observed that CCLR only occurred in small breed dogs aged 9-10 years old.

The findings in this study support previous reports of middle-aged and older dogs suffering from patellar luxation to be at increased risk for concomitant CCLR. However, patellar luxation may not be the only significant risk factor for CCLR. Since degeneration of the CCL was found in small breed dogs aged 7 years and older and the average age of dogs with PL + CCLR in this, study was 7.33 years, ligament degeneration could be an additional risk factor for CCLR in small breed dogs.

9.2 Type, grade and direction of patellar luxation

In this study, bilateral patellar luxation was equally prevalent in 77% of patients in both groups, which is higher than described in previous studies. Previous studies of patients suffering from PL and concomitant CCLR found that bilateral PL was prevalent in 50-65% of cases, respectively (TROTTER 1980; HAYES et al. 1994; ALAM et al. 2007; CAMPBELL et al. 2010). A higher prevalence of CCLR in dogs with bilateral patellar luxation could indicate that dogs with unilateral patellar luxation have a decreased risk of CCLR. Furthermore, it is possible that dogs with unilateral patellar luxation compensate the injury by loading more weight onto the healthy limb. Consequently, the ligament stress on the joint suffering from PL could be reduced, thereby resulting in a decreased risk for CCLR.

54% of dogs with bilateral patellar luxation had a higher patellar luxation grade in the stifle joint with CCLR, or the first limb affected by CCLR, which was lower than expected. The mean luxation grade was 0.85 grades higher in stifle joints suffering from CCLR. CAMPBELL et al. (2010) found a higher patellar luxation grade in the stifle joint or the first limb affected by CCLR 76% of dogs with bilateral patellar luxation had. Subjectiveness of PL grading must be considered when evaluating the impact of PL grades. Studies have shown that different veterinarians (WEBER 1992) can diagnose the same patient with different PL grades. Nevertheless, the findings could imply that higher grades of PL increase ligament stress and ultimately lead to ligament rupture. Moreover, higher grades of PL found in cases with CCLR could be due to other reasons. Firstly, an increased cranial tibial translation could reduce the contact force of the patellofemoral joint by increasing the angle between the patellar ligament and the quadriceps tendon, consequently resulting in patellar laxity (CAMPBELL et al. 2010). Secondly, the absence of internal rotation restraints (CCL) could result in an increased Q-angle. Moreover, the positioning of the patient during the examination could further increase the Q-angle (KAISER et al. 2001).

Initially, it was expected that patellar luxation led to increased stress on the CCL and that a higher grade of luxation would correlate to a higher prevalence of concomitant CCLR. However, the differences in median luxation grades seen between the patient groups in this study were not statistically significant (p=0.165). Mean luxation grades in the PL and the PL+CCLR group were found at 2,12 and 2,36, respectively. While, grade III was seen more often in the PL+CCLR group compared to the PL group, grade IV was only found in 9.1% of PL+CCLR cases. On the one hand, dogs with high grades of luxation likely show acute lameness early on, in which case they are more likely to be treated surgically. Consequently, they could be less likely to suffer from CCLR, since the PL risk factor was eliminated. On the other hand, dogs suffering from patellar luxation grades II and III could easily be overlooked by owners, which could result in delayed medical treatment. If the patellar luxation remains surgically untreated, the CCL could be subjected to increased levels of stress. However, the subjectiveness of patellar luxation grading could also lead to fewer diagnoses of high PL grades. CAMPBELL et al. (2010) found CCLR in 50% of patients with grade IV patellar luxation. The lack of significant correlation found in our study supports a hypothesis based on the study by WILLAUER and VASSEUR (1987), which found CCLR in dogs with surgically corrected PL, indicating that CCLR could be caused by other factors. Further studies are warranted to investigate the effect of CCLR on the Q-angle and determine the influence of PL grades on concomitant CCLR.

Previous findings led us to expect that MPL in combination with medial internal rotation of the tibia could stress the ligament and promote its rupture. Preventing excessive internal rotation between femur and tibia is an important function of the CCL (DYCE et al. 1952; ARNOCZKY and MARSCHALL 1977; ROBINS 1990). Moreover, anatomical abnormalities derived from MPL, such as internal torsion of the tibia, varus angulation and medial displacement of the tibial tuberosity, which in turn exert excessive forces on the CCL and could lead to its rupture. However, no statistically significant correlation between MPL and CCLR was found compared to lateral and bidirectional luxations. Medial patellar luxation was found in all cases in the PL+CCLR group and in 82.5% in the PL group, while merely 10.3% suffered from LPL and 7.2% were diagnosed with MPL and LPL. These findings support previous reports of MPL in around 90% of PL cases (KODITUWAKKU 1962; DEANGELIS and HOHN 1970; FRITZ 1989; KAISER 1999; MEYER 2001) and even 98% of cases, in small breed dogs (HAYES et al. 1994). Although no significant correlation between MPL and CCLR was found, which could be due to the modest sample size, it is possible that in lateral patellar luxations, lateral displacement of the tibial tuberosity, external rotation of the tibia and valgus angulation do not exert additional forces against the cranial cruciate ligament, since the stifle joint is externally rotated and are therefore less likely to occur in combination with CCLR. This could explain why none of the stifle joints in the PL+CCLR group suffered from LPL.

Further biomechanical studies are warranted to gain a better understanding of the effects of anatomical changes derived from medial and lateral patellar luxations on the CCL.

9.3 Cranial cruciate ligament rupture

Almost 31% of patients in the PL+CCLR group were diagnosed with bilateral CCLR, which is in line with previous findings. DOVERSPIKE et al. (1993) found that 37% of patients with unilateral CCLR were diagnosed with contralateral CCLR within an average time of 17 months after the initial diagnosis. Other studies showed that 22-55% of patients with an initial diagnosis of unilateral CCLR were diagnosed with contralateral CCLR after a median time of 10 and 17 months (CABRERA 2008; BUOTE 2009; MUIR 2011).

In this study, patients with bilateral CCLR were diagnosed with the second CCLR at a mean time of 13 months after the initial CCLR diagnosis. In 7 out of 8 cases, bilateral patellar luxation was present. These findings concur with previous studies. None of the patients suffering from bilateral PL and CCLR had surgical correction of the PL before the second CCLR occurred. Bilateral ruptures seem to be highly prevalent in small breed dogs with CCLR.

Surgical correction of the patellar luxation could avoid or delay (the second) CCLR. Nevertheless, some studies have indicated that CCLR may occur despite surgical correction of PL (WILLAUER and VASSEUR 1987). Further studies should explore other risk factors involved in CCLR.

9.4 Meniscal disease and patellar luxation

During surgical inspection, meniscal lesions were found in around 9% of the cases, which was lower than to be expected based on previous reports. Other studies found concomitant medial meniscal lesions in 45.4% (SCHNELL 1986), 48% (FLO 1975), 53% (FLO and DEYOUNG 1978), 57% (SCHÄEFER 1991) and even 74% (GAMBARDELLA et al. 1981) of cases. No significant correlation between patellar luxation grade and meniscal damage was found. The mean patellar luxation grade between dogs with and without meniscal disease was not significantly different. Hence, higher grades of luxation did not prove to cause an increased prevalence of meniscal lesions (p=1.000). These findings suggest that meniscal lesions are not common complications in small breed dogs with patellar luxation. However, further studies are warranted.

9.5 Surgical correction, follow-up and outcome

In this study, 30 stifles were surgically treated to correct both PL and CCLR. 14 stifles were treated with a combination of a “Tibial tuberosity transposition” technique (TT), “Wedge recession osteotomy” (WR) and “Fascia over the top” technique (OT). 14 stifles were treated with a combination of TT-WR and “Capsular and fascial imbrication” technique (CFI). In addition, 2 stifle joints were treated with a combination of WR and CFI.

Follow-up examinations with the treating surgeon were conducted between 3-6 and 6-12 months post-surgery in 20% of affected stifle joints each. In 60% of stifle joints, the follow-up was conducted more than 12 months post-surgery. Efficacy of surgical techniques was assessed by the clinical outcome determined in the follow-up examination as well as the outcome according to the owner questionnaire, answered with the help of the referring veterinarian.

According to the clinical follow-up examination, 90% of patients had an excellent outcome, while 10% of patients had a poor outcome. Owner questionnaires revealed the same results regarding the post-surgical outcomes of patients. No significant correlation was found between post-surgical outcomes and different combinations of surgical techniques, which was expected.

The excellent surgical results found in this study are in line with previous studies that found surgical correction of patellar luxations generally had a high success rate (WANGDEE et al. 2013, DUNLAP 2014). 82% of 447 dogs (505 stifle joints) suffering from patellar luxation treated with an “Over the top” technique where successful, while merely 12 stifle joints progressed without osteoarthrosis (BRUNNBERG et al.1992). In cases treated with a “Capsular and fascial imbrication” technique, 93% of surgeries were considered successful (ALLGOEWER et al. 2000).

9.6 Limitations of the study

Limitations of this study are related to its retrospective nature. Cases were recorded between 2004 and 2016. The analysed data was subject to the accuracy of medical records, which was limited by the subjectiveness of PL grading and owner´s compliance throughout treatment.

Breed distributions in the present study could be impacted by regional popularity of certain breeds and the specific features of the clinic. Breed distribution might not be representative of a standard population within the region or the country.

In addition, the results of owner questionnaires may be subject to the opinion of the referring veterinarian. Moreover, the significance of our findings could be affected by the modest sample size.

9.7 Conclusions

Patellar luxation could be a risk factor for CCLR in almost 25% of small breed dogs with patellar luxation. Maltese dogs suffering from a patellar luxation are predisposed to develop a cranial cruciate ligament rupture. Although previous studies found predispositions for patellar luxation and concomitant CCLR in Yorkshire Terriers and Chihuahuas (CAMPBELL et al. 2010), this study did not show predispositions for those breeds.

Overweight was proven a risk factor for concomitant CCLR in dogs suffering from a patellar luxation. Therefore, weight loss should be recommended to patients with patellar luxation, in order to avoid additional stress on the cranial cruciate ligament. We found a correlation between castration and overweight. In addition, there was a higher number of female dogs in the PL+CCLR group, compared to the PL group.

Post-surgical physiotherapy was recommended for each patient, to increase the joint compressive force of the patella in the trochlear groove and to improve the extensor mechanism. A combination of weight loss and physiotherapy are important factors in achieving excellent results.

Middle-aged and toy and small breed older dogs were found to be at increased risk for concomitant CCLR. The mean age of patients in the PL+CCLR group was 7.36 years at the time of diagnosis. Since previous studies on small breed dogs found that degeneration of the cranial cruciate ligament commonly occurs in dogs aged seven years and older (VASSEUR et al. 1985; ZAHM 1964), degeneration could be a factor into the development of CCLR.

In contrast to previous studies (CAMPBELL et al. 2010), higher grades of patellar luxation (grade IV) did not correlate to CCLR. Moreover, the mean patellar luxation grade in the PL+CCLR group was 2.36. However, it is not possible to draw conclusions regarding the causal effect of patellar luxation grade and the development of concomitant CCLR.

While previous studies found a correlation between meniscal lesions and CCLR, this study did not find a correlation. Moreover, meniscal lesions did not seem to be common complications in small breed dogs suffering from patellar luxation.

A combination of “Wedge recession osteotomy”, with a “Tibial tuberosity transposition” and “Fascia over the top technique” or “Capsular and fascial imbrication” technique seemed to be good surgical approaches to treat both pathologies (PL+CCLR).

In 90% of followed-up surgical cases (27/30), the result was excellent. There was no significant difference in outcome between different surgical combinations.

In sum, CCLR appears to have a multifactorial pathogenesis. Our findings indicate that patellar luxation might not be the main risk factor for cranial cruciate ligament rupture. The fact that higher grades of luxation and CCLR were not correlated suggests that patellar luxation alone does not trigger CCLR. However, in combination with breed predisposition, overweight, medially directed patellar luxation, degeneration and age, patellar luxation likely contributes to the pathology.

To assess the role of PL as a possible trigger factor of CCLR in small breed dogs, future studies should compare surgically treated patellar luxation cases and cases of patella luxations with concomitant CCLR to a healthy control group. Thereby, differences in CCLR prevalence in patients with and without patellar luxation could be analysed more reliably. It would be interesting to see, if small breed dogs without patellar luxation and with a surgically corrected PL show a similar mean incidence of CCLR over time. Previous studies on all sizes of dogs found that patients with surgically corrected PL developed CCLR later in life (WILLAUER and VASSEUR 1987). 52 stifle joints included in the study showed 2 CCL deficiencies at the time of the third follow-up examination. However, the findings are limited by the short follow-up time and indicate that the development of CCLR was associated with factors other than PL.

Finally, there is a need to assess frequency of PL in a group of dogs with CCLR. Internal rotation of the tibia related to the femur after CCLR could lead to the development of a medial patellar luxation (KAISER et al. 2001). The present study did not assess this possibility. It is possible that the patella is easier to be luxated in small breed dogs due to quadriceps muscle laxity and patellar ligament weakness. Moreover, in combination with the internal rotation that occurs due to CCLR, this could lead to false positive PL results in dogs with CCLR. Nevertheless, future studies should consider this line of inquiry.

10. Summary

Patellar luxation and concomitant cranial cruciate ligament rupture in small breed dogs

10.1 Background

Patellar luxation and cranial cruciate ligament rupture are the most common pathologies affecting the stifle joint in toy and small breed dogs. Many studies involving patellar luxation or cranial cruciate ligament rupture have been performed but few focused on frequency and treatment of both pathologies together in toy and small breed dogs. The purpose of this study was to assess frequency of CCLR in a group of toy and small breed dogs with PL, risk factors, treatment options and outcome after surgical correction.

10.2 Material and methods

Between 2004 and 2016, 233 small and toy breed dogs underwent surgery for patellar luxation in the small animal teaching hospital of the Freie Universität, Berlin. 52 dogs (23%) had a concomitant cranial cruciate ligament rupture at the time of diagnosis. Two groups of dogs had appropriate medical records and met the inclusion criteria. The first group included 55 dogs (97 stifles) with patellar luxation only (PL group), while the second group included 26 dogs (33 stifles) with patellar luxation and cranial cruciate ligament rupture (PL+CCLR group), serving as the test sample.

10.3 Results

23% of the dogs with patellar luxation suffered from CCLR. Overweight and increasing age were identified as risk factors for developing CCLR in patients with patellar luxation. In our study population, Maltese dogs were more likely to be affected by both pathologies together. Higher grades of patellar luxation were not in correlation to CCLR. The combination of a “Trochlear wedge recession osteotomy” with a “Tibial tuberosity transposition” and a “Fascia over the top” technique or a “Capsular and fascial imbrication” technique was performed to treat both pathologies in affected stifles (n=28). In 2 cases, a “Tibial tuberosity transposition” was not necessary. 90% of surgically corrected stifles had an excellent functional outcome.

10.4 Conclusions

The pathophysiology of patellar luxation and cranial cruciate ligament rupture could be the result of a multifactorial complex. A combination of factors such as increasing age, degeneration of the ligament, overweight, medial direction of luxation and breed could be factors in the pathophysiology. Further studies are warranted.

11. Zusammenfassung

Patellaluxation und Ruptur des vorderen Kreuzbandes bei Hunden kleinwüchsiger Rassen

11.1 Hintergrund

Patellaluxation (PL) und Ruptur des vorderen Kreuzbandes (KBR) sind die häufigsten Pathologien des Kniegelenkes bei Hunden kleinwüchsiger Rassen. Es gibt viele Studien zur Patellaluxation oder Kreuzbandruptur, aber nur wenige davon untersuchen die Kombination der beiden Pathologien. Diese ist besonders bei kleinen Hunden ein häufiger Befund. Ziel dieser Studie war es die Häufigkeit von KBR von Hunden kleinwüchsiger Rassen in der Studienpopulation, Risikofaktoren, Behandlungsmethoden und die Ergebnisse nach chirurgischer Behandlung zu evaluieren.

11.2 Material und Methoden

In der Zeit von 2004 bis 2016 wurden in der Klinik für Kleine Haustiere der Freien Universität Berlin 233 Hunde kleinwüchsiger Rassen wegen einer Patellaluxation operiert. Durch die klinische Untersuchung wurde bei 52 Hunden (23%) zusätzlich eine Ruptur des vorderen Kreuzbandes festgestellt. Zwei Gruppen erfüllten die Einschlusskriterien. Die erste Gruppe bestand aus 55 Hunden (97 Kniegelenken) mit Patellaluxation (PL Gruppe), während die zweite Gruppe aus 26 Hunden (33 Kniegelenke) mit Patellaluxation und einer Ruptur des vorderen Kreuzbandes (PL+CCLR Gruppe) bestand.

11.3 Ergebnisse

23% der Hunde mit Patellaluxation litten zugleich auch an einem Kreuzbandriss. Übergewicht und zunehmendes Alter wurden bei Patienten mit Patellaluxation als Risikofaktoren für KBR identifiziert. In dieser Studie waren Malteser die einzige Rasse, die für PL und KBR prädisponiert war. Höhere Grade von PL standen nicht in Bezug zur KBR. Die Kombination von “Trochleakeilvertiefung” mit einer “Transposition der Tuberositas tibiae” und einer "Fascia Over the top” oder “Kapsel und Faszienraffung”- Technik wurden durchgeführt, um Kniegelenke (n=28) mit beiden Pathologien zu behandeln. Bei zwei Fällen war eine “Transposition der Tuberositas tibiae” nicht erforderlich. 90% der chirurgischen Kniegelenkskorrekturen erbrachten ein hervorragendes Resultat.

11.4 Fazit

Als Resultat der Pathophysiologie von PL und KBR kommt ein multifaktorieller Komplex in Frage. Eine Kombination von Faktoren wie zunehmendes Alter, Degeneration des Ligamentes, Übergewicht, Luxation in mediale Richtung sowie die Rasse könnten für die Pathogenese ausschlaggebend sein. Weitere Studien sind notwendig.

12. Appendix

Table 12. Patellar luxation group

Limb side	Age in months	Breed	Sex ♂♀	Weight (kg)	PL direction	PL grade (1-4)	Over-weight (+/-)
1 Left	32	Havanese	♂	5.3	Medial	2	-
Right	32	Havanese	♂	5.3	Lateral	2	-
2 Left	25	Shih Tzu	♂	5	Medial	3	-
Right	25	Shih Tzu	♂	5	Medial	3	-
3 Left	16	Pug	♀	8.2	Medial	3	-
Right	16	Pug	♀	8.2	Medial	3	-
4 Left	69	Terrier	♂	9.5	Medial	1	-
Right	69	Terrier	♂	9.5	-	-	-
5 Left	25	York. Terrier	♂	3	Medial	3	-
Right	25	York. Terrier	♂	3	Medial	2	-
6 Left	21	Papillon	♀	2.5	Medial	3	-
Right	21	Papillon	♀	2.5	Medial	2	-
7 Left	76	Chihuahua	♀	1.8	Medial	3	-
Right	76	Chihuahua	♀	1.8	-	-	-
8 Left	85	York. Terrier	♂	3.2	Med/Lat	1+2	-
Right	85	York. Terrier	♂	3.2	Med/Lat	1+2	-
9 Left	115	Poodle	♀	5	Medial	3	-
Right	115	Poodle	♀	5	Medial	3	-
10 Right	78	York. Terrier	♂̶	3	Lateral	2	-
11 Left	71	York. Terrier	♂	3.4	Medial	2	-
Right	71	York. Terrier	♂	3.4	Medial	2	-
12 Left	52	York. Terrier	♂̶	7	Medial	1	+
Right	52	York. Terrier	♂̶	7	Medial	2	+
13 Left	71	York. Terrier	♀	1.9	Medial	3	-
Right	71	York. Terrier	♀	1.9	Lateral	3	-
14 Left	84	Foxterrier	♀̸	10.5	Lateral	4	+
Right	84	Foxterrier	♀̸	10.5	Lateral	4	+

Limb side		Age in months	Breed	Sex ♂♀	Weight (kg)	PL direction	PL grade (1-4)	Over-weight (+/-)
15	Left	23	Jack R. Terrier	♂	6.2	Medial	2	-
	Right	23	Jack R. Terrier	♂	6.2	Medial	2	-
16	Left	82	York. Terrier	♀̸	2.5	Med/Lat	2+1	-
	Right	82	York. Terrier	♀̸	2.5	Med/Lat	2+2	-
17	Left	41	York. Terrier	♀	4.2	Lateral	2	+
	Right	41	York. Terrier	♀	4.2	Lateral	2	+
18	Left	26	York. Terrier	♀	1.7	Medial	3	-
	Right	26	York. Terrier	♀	1.7	Medial	3	-
19	Left	17	CKCS	♂	7.6	Medial	2	-
	Right	17	CKCS	♂	7.6	Medial	2	-
20	Left	53	Crossbreed	♂̶	9.5	Lateral	4	-
	Right	53	Crossbreed	♂̶	9.5	-	-	-
21	Left	26	Chihuahua	♀	3	Medial	2	-
	Right	26	Chihuahua	♀	3	Medial	2	-
22	Right	104	WHWT	♂	9	Medial	1	-
23	Left	95	York. Terrier	♀	5	-	-	+
	Right	95	York. Terrier	♀	5	Medial	1	+
24	Left	44	Crossbreed	♂	6	Medial	3	-
	Right	44	Crossbreed	♂	6	Medial	2	-
25	Left	140	Poodle	♀̸	4	Medial	1	-
	Right	140	Poodle	♀̸	4	Lateral	2	-
26	Left	78	York. Terrier	♀	2.9	Medial	3	-
	Right	78	York. Terrier	♀	2.9	-	-	-
27	Left	53	Tibet Terrier	♀	9	Medial	2	-
	Right	53	Tibet Terrier	♀	9	Medial	2	-
28	Left	12	York. Terrier	♂̶	3.2	Medial	2	-
	Right	12	York. Terrier	♂̶	3.2	Medial	2	-
29	Left	30	Boston Terrier	♂	6.9	Medial	2	-
	Right	30	Boston Terrier	♂	6.9	Medial	1	-

Limb side	Age in months	Breed	Sex ♂♀	Weight (kg)	PL direction	PL grade (1-4)	Over-weight (+/-)
30 Left	38	Terrier	♂̶	6.5	Med/Lat	1+1	-
Right	38	Terrier	♂̶	6.5	Medial	1	-
31 Left	19	Crossbreed	♂̶	8	Medial	4	-
Right	19	Crossbreed	♂̶	8	Medial	2	-
32 Left	116	WHWT	♂	9.3	Medial	2	-
33 Left	188	York. Terrier	♀	2.3	Medial	2	-
Right	188	York. Terrier	♀	2.3	Medial	3	-
34 Left	48	York. Terrier	♂	2.2	Medial	4	-
34 Right	48	York. Terrier	♂	2.2	Medial	2	-
35 Left	55	Spitz	♀	4.7	Medial	3	-
Right	55	Spitz	♀	4.7	-	-	-
36 Left	103	York. Terrier	♂	3.6	-	-	+
Right	103	York. Terrier	♂	3.6	Medial	1	+
37 Left	66	Crossbreed	♀̸	6	-	-	-
Right	66	Crossbreed	♀̸	6	Medial	2	-
38 Left	132	WHWT	♀̸	7.2	Med/Lat	2+1	-
Right	132	WHWT	♀̸	7.2	Med/Lat	2+1	-
39 Left	24	Crossbreed	♂	6.5	Medial	2	-
Right	24	Crossbreed	♂	6.5	-	-	-
40 Left	138	Chihuahua	♀	2.9	Medial	3	-
Right	138	Chihuahua	♀	2.9	Medial	2	-
41 Left	67	Poodle	♀	5	Medial	1	+
Right	67	Poodle	♀	5	-	-	+
42 Left	153	York. Terrier	♂	3.8	Medial	3	+
Right	153	York. Terrier	♂	3.8	Medial	2	+
43 Left	16	York. Terrier	♀	1.7	Medial	2	-
Right	16	York. Terrier	♀	1.7	Medial	2	-
44 Left	119	York. Terrier	♂	2.4	Lateral	I	-
Right	119	York. Terrier	♂	2.4	Medial	I	-

Limb side		Age in months	Breed	Sex ♂♀	Weight (kg)	PL direction	PL grade (1-4)	Over-weight (+/-)
45	**Left**	**25**	**Maltese**	♀	**2.6**	**Medial**	**2**	-
	Right	**25**	**Maltese**	♀	**2.6**	**Medial**	**2**	-
46	**Left**	**38**	**WHWT**	⚲	**8**	**Medial**	**1**	-
	Right	**38**	**WHWT**	⚲	**8**	**Medial**	**1**	-
47	**Left**	**13**	**Poodle**	♀	**4.5**	**Medial**	**1**	-
	Right	**13**	**Poodle**	♀	**4.5**	-	-	-
48	**Left**	**57**	**Foxterrier**	⚴	**9**	**Medial**	**3**	+
	Right	**57**	**Foxterrier**	⚴	**9**	**Medial**	**3**	+
49	**Left**	**54**	**York. Terrier**	⚴	**5**	**Medial**	**4**	+
	Right	**54**	**York. Terrier**	⚴	**5**	**Medial**	**2**	+
50	**Left**	**31**	**Papillon**	♂	**4.2**	**Medial**	**1**	-
	Right	**31**	**Papillon**	♂	**4.2**	**Medial**	**1**	-
51	**Left**	**12**	**WHWT**	♂	**6.5**	**Medial**	**1**	-
	Right	**12**	**WHWT**	♂	**6.5**	**Medial**	**2**	-
52	**Left**	**120**	**Poodle**	♀	**6.7**	**Medial**	**1**	+
	Right	**120**	**Poodle**	♀	**6.7**	**Medial**	**2**	+
53	**Left**	**56**	**Poodle**	♂	**4.5**	**Medial**	**1**	-
	Right	**56**	**Poodle**	♂	**4.5**	**Medial**	**1**	-
54	**Left**	**20**	**York. Terrier**	♀	**2.5**	**Medial**	**3**	-
	Right	**20**	**York. Terrier**	♀	**2.5**	**Medial**	**4**	-
55	**Left**	**164**	**York. Terrier**	⚲	**3.4**	**Medial**	**1**	-
	Right	**164**	**York. Terrier**	⚲	**3.4**	**Medial**	**1**	-

Abbreviations Table 12 - PL group:

♂-male; ♀-female; ⚲-Spayed female, ⚴-Neutered male; Med - medial patellar luxation, Lat- Lateral patellar luxation. York. Terrier - Yorkshire Terrier; WHWT - West Highland White Terrier; CKCS – Cavalier King Charles Spaniel; Jack R. Terrier - Jack Russell Terrier

Table 13. PL+CCLR group

Limb side	Age in months	Breed	Sex ♂♀	Weight (kg)	PL direction	PL grade (1-4)
1 Left	**91**	**Maltese**	♂	**5.3**	**Medial**	**2**
2 Left	**125**	**York. Terrier**	♂̶	**3.3**	**Medial**	**3**
3 Left	**84**	**Maltese**	♂	**6**	**Medial**	**2**
Right	**84**	**Maltese**	♂	**6**	**Medial**	**4**
4 Left	**52**	**Maltese**	♀̸	**4.2**	**Medial**	**3**
Right	**52**	**Maltese**	♀̸	**4.2**	**Medial**	**3**
5 Left	**154**	**WHWT**	♀	**9**	**Medial**	**2**
Right	**154**	**WHWT**	♀	**9**	**Medial**	**2**
6 Left	**45**	**Cairn Terrier**	♂̶	**10**	**Medial**	**1**
Right	**45**	**Cairn Terrier**	♂̶	**10**	**Medial**	**1**
7 Left	**84**	**Crossbreed**	♂̶	**8**	**Medial**	**3**
Right	**84**	**Crossbreed**	♂̶	**8**	**Medial**	**3**
8 Left	**68**	**York. Terrier**	♀	**2.9**	**Medial**	**3**
Right	**68**	**York. Terrier**	♀	**2.9**	**Medial**	**3**
9 Left	**104**	**Maltese**	♀	**3.5**	**Medial**	**2**
Right	**116**	**Maltese**	♀	**3.5**	**Medial**	**3**
10 Left	**58**	**Crossbreed**	♀̸	**6.5**	**Medial**	**3**
Right	**82**	**Crossbreed**	♀̸	**6.5**	**Medial**	**3**
11 Left	**117**	**Cairn Terrier**	♂	**13,5**	**Medial**	**2**
12 Right	**84**	**Poodle**	♀	**4.5**	**Medial**	**4**
Left	**90**	**Poodle**	♀	**4.5**	**Medial**	**2**
13 Right	**84**	**Jack R. Terrier**	♀	**6**	**Medial**	**1**
14 Left	**132**	**York. Terrier**	♀̸	**3.4**	**-**	**-**
Right	**140**	**York. Terrier**	♀̸	**3.4**	**Medial**	**1**
15 Left	**56**	**Shih Tzu**	♂̶	**9**	**Medial**	**1**
16 Left	**115**	**York. Terrier**	♂̶	**5.4**	**Medial**	**2**
Right	**126**	**York. Terrier**	♂̶	**5.4**	**Medial**	**2**
17 Left	**42**	**Chihuahua**	♂	**5**	**Medial**	**2**

Limb side	Age in months	Breed	Sex ♂♀	Weight (kg)	PL direction	PL Grade (1-4)
17 Right	**51**	**Chihuahua**	♂	**5**	**Medial**	**3**
18 Left	**61**	**York. Terrier**	♀	**2.7**	**Medial**	**2**
Right	**78**	**York. Terrier**	♀	**2.7**	**Medial**	**4**
19 Left	**116**	**Bolonka Zwetna**	♀̸	**6**	**Medial**	**2**
Right	**116**	**Bolonka Zwetna**	♀̸	**6**	**Medial**	**2**
20 Left	**105**	**York. Terrier**	♂̶	**4**	**Medial**	**3**
Right	**105**	**York. Terrier**	♂̶	**4**	**Medial**	**3**
21 Right	**55**	**Maltese**	♀	**3.8**	**Medial**	**1**
22 Left	**80**	**Biewer Terrier**	♂̶	**3.5**	**Medial**	**3**
Right	**80**	**Biewer Terrier**	♂̶	**3.5**	**Medial**	**3**
23 Left	**96**	**York. Terrier**	♀	**3.2**	**Medial**	**2**
Right	**96**	**York. Terrier**	♀	**3.2**	**Medial**	**3**
24 Left	**82**	**Chihuahua**	♀	**2.8**	**Medial**	**2**
Right	**82**	**Chihuahua**	♀	**2.8**	**Medial**	**2**
25 Left	**132**	**Maltese**	♀	**6.7**	**Medial**	**3**
Right	**135**	**Maltese**	♀	**6.7**	**Medial**	**3**
26 Left	**66**	**York. Terrier**	♀̸	**7.7**	**Medial**	**2**
Right	**66**	**York. Terrier**	♀̸	**7.7**	**Medial**	**1**

Abbreviations Table 13:

♂-male; ♀-female; ♀̸-Spayed female, ♂̶-Neutered male; York. Terrier- Yorkshire Terrier, Jack. R. Terrier- Jack Russell Terrier

Table 14. PL+CCLR Group

Case limb side	CCLR (+)	Difference of luxation between stifles	Meniscal Disease (+)	Outcome according to owner question-naires	Result Post-surgery (Lameness Score)	Surgical combination
1 Left	+	**1**	**-**	**Excellent**	**0**	**TT-WR-OT**
2 Left	+	**3**	**-**	**Poor**	**2**	**TT-WR-CFI**
3 Left	**-**	**2**	**-**	**-**	**-**	**No surgery**
Right	+	**2**	**-**	**Excellent**	**0**	**TT-WR-CFI**
4 Left	**-**	**0**	**-**	**-**	**-**	**No surgery**
Right	+	**0**	**-**	**Excellent**	**0**	**TT-WR-CFI**
5 Left	+	**0**	**-**	**Excellent**	**0**	**TT-WR-OT**
Right	+	**0**	**-**	**-**	-	**No surgery**
6 Left	+	**0**	**-**	**-**	**-**	**No surgery**
Right	+	**0**	**-**	**Excellent**	**0**	**TT-WR-CFI**
7 Left	+	**0**	**-**	**-**	**-**	**No surgery**
Right	+	**0**	+	**Excellent**	**0**	**TT-WR-CFI**
8 Left	+	**0**	**-**	**-**	**-**	**No Surgery**
Right	+	**0**	**-**	**Excellent**	**0**	**TT-WR-OT**
9 Left	+	**1**	**-**	**Excellent**	**0**	**TT-WR-CFI**
Right	+	**1**	**-**	**Excellent**	**0**	**TT-WR-OT**
10 Left	+	**0**	**-**	**Excellent**	**0**	**TT-WR-CFI**
Right	+	**0**	**-**	**Excellent**	**0**	**TT-WR-OT**
11 Left	+	**2**	+	**Excellent**	**0**	**TT-WR-CFI**
12 Left	+	**2**	+	**Poor**	**2**	**TT-WR-CFI**
Right	+	**2**	**-**	**Poor**	**2**	**TT-WR-OT**
13 Right	+	**1**	**-**	**Excellent**	**0**	**WR-CFI**
14 Left	+	**1**	**-**	**Excellent**	**0**	**CFI**
Right	+	**1**	**-**	**Excellent**	**0**	**TT-WR-OT**
15 Left	+	**1**	**-**	**Excellent**	**0**	**TT-WR-CFI**
16 Left	+	**0**	**-**	**Excellent**	**0**	**TT-WR-CFI**
Right	+	**0**	**-**	**Excellent**	**0**	**TT-WR-CFI**
17 Left	+	**1**	**-**	**Excellent**	**0**	**TT-WR-OT**
Right	**-**	**1**	**-**	**Excellent**	**0**	**TT-WR**

Limb side	CCLR (+)	Difference of luxation	Meniscal disease	Outcome according to owner question-naires	Results Post-surgery (Lameness score)	Surgical combination
18 Left	**-**	**2**	**-**	**Excellent**	**0**	**TT-WR**
18 Right	+	**2**	**-**	**Excellent**	**0**	**TT-WR-CFI**
19 Left	**-**	**0**	**-**	**-**	**-**	**No surgery**
Right	+	**0**	**-**	**Excellent**	**0**	**TT-WR-OT**
20 Left	+	**0**	**-**	**Excellent**	**0**	**TT-WR-OT**
Right	**-**	**0**	**-**	**-**	**-**	**No surgery**
21 Right	+	**2**	**-**	**Excellent**	**0**	**WR-CFI**
22 Left	**-**		**-**	**-**	**-**	**No surgery**
Right	+	**0**	**-**	**Excellent**	**0**	**TT-WR-OT**
23 Left	**-**		**-**	**-**	**-**	**No surgery**
Right	+	**1**	**-**	**Excellent**	**0**	**TT-WR-OT**
24 Left	**-**	**0**	**-**	**-**	**-**	**No surgery**
Right	+	**0**	**-**	**Excellent**	**0**	**TT-WR-OT**
25 Left	+	**0**	**-**	**Excellent**	**0**	**TT-WR-CFI**
Right	**-**		**-**	**Excellent**	**0**	**TT-WR**
26 Left	+	**1**	**-**	**Excellent**	**0**	**TT-WR-OT**
Right	**-**	**1**	**-**	**-**	**-**	**No surgery**

Abbreviations Table 14:

+, yes; -, no; TT – "Tibial tuberosity transposition"; WR – "Wedge recesstion osteotomy"

OT – "Fascia over the top" technique

Table 15. PL+CCLR Group

Limb side	Complications	Uni/Bi CCLR	Uni/Bi PL	Overweight (+)
1 Left	**-**	**Unilateral**	**Unilateral**	+
2 Left	**Major complication**	**Unilateral**	**Unilateral**	+
3 Right	**-**	**Bilateral**	**Unilateral**	+
4 Right	**-**	**Bilateral**	**Unilateral**	+
5 Left	**-**	**Bilateral**	**Bilateral**	**-**
6 Right	**-**	**Bilateral**	**Bilateral**	+
7 Right	**-**	**Bilateral**	**Bilateral**	+
8 Right	**-**	**Bilateral**	**Unilateral**	**-**
9 Left	**Minor complication**	**Bilateral**	**Unilateral**	+
9 Right	**-**	**Bilateral**	**Unilateral**	+
10 Left	**-**	**Bilateral**	**Bilateral**	**-**
10 Right	**-**	**Bilateral**	**Bilateral**	**-**
11 Left	**-**	**Unilateral**	**Unilateral**	+
12 Left	**No improvement, Euthanasia**	**Bilateral**	**Bilateral**	**-**
Right	**No improvement, Euthanasia**	**Bilateral**	**Bilateral**	**-**
13 Right	**-**	**Unilateral**	**Unilateral**	**-**
14 Right	**-**	**Bilateral**	**Unilateral**	+
15 Left	**-**	**Unilateral**	**Unilateral**	+
16 Left	**-**	**Bilateral**	**Bilateral**	+
16 Right	**-**	**Bilateral**	**Bilateral**	
17 Left	**-**	**Unilateral**	**Bilateral**	+
18 Right	**-**	**Bilateral**	**Unilateral**	**-**
19 Right	**-**	**Bilateral**	**Unilateral**	+

Limb side	Complications	Uni/Bi CCLR	Uni/Bi PL	Overweight (+)
20 Left	-	Bilateral	Unilateral	+
21 Right	-	Bilateral	Unilateral	-
22 Right	-	Bilateral	Unilateral	-
23 Right	-	Bilateral	Unilateral	-
24 Right	-	Bilateral	Unilateral	-
25 Left	-	Bilateral	Unilateral	+
26 Left	Major complication	Bilateral	Unilateral	-

Abbreviations Table 15*:*

Uni – Unilateral, Bi – Bilateral, CCLR – Cranial cruciate ligament rupture,

PL - Patellar luxation, - No complications, + Overweight

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Patellar luxation and concomitant cranial cruciate ligament rupture in small breed dogs

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15. Declaration of Authorship

I hereby declare that the thesis submitted is my own unaided work. All direct or indirect sources used are acknowledged as references.

Selbständigkeitserklärung

Hiermit bestätige ich, dass ich die vorligende Arbeit selbständig angefertig habe. Ich versichere, dass ich ausschließlich die angegebenen Quellen und Hilfen Anspruch genommen habe.

Berlin, den 19.06.2019

Mario Candela Andrade

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