Department and Clinic of Surgery and Ophthalmology
University of Veterinary Medicine, Budapest

CANINE TOTAL HIP REPLACEMENT: STATE OF THE ART

By
Calvin Tanios

Supervisors:

Dr. Bence Sebesztha DVM
Department and Clinic of Surgery and Ophthalmology, Hungary

Dr. Chadi Eid, DVM, PhD
DVM, PhD, Orthopedic Surgeon at Ortovet, Italy

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Abstract

This thesis investigates the current state of canine total hip replacement (THR) by comparing three different systems: the Biomedtrix BFX & CFX systems, the Zurich system, and the Helica System. The focus of the thesis is on the Biomedtrix systems, its advantages and disadvantages in comparison to the other two systems, and on the BFX cementless system in the cases studied. The study begins with a comprehensive review of the current state of THR in canine, including the history, techniques, materials, and outcomes of the surgery. The research then proceeds to compare the three different systems of THR based on a comprehensive literature review. The thesis then focuses on the Biomedtrix system and provides an in-depth analysis of its advantages and disadvantages, including case studies of canines that underwent THR with the BFX Biomedtrix system. The cases analyzed in this thesis show that the Biomedtrix system provides good stability and range of motion, a quick recovery time, and similar outcomes to the literature. However, the system is also associated with potential drawbacks, such as implant migration and the need for special instrumentation and a high learning curve for surgeons. Overall, this thesis provides valuable insights for veterinary surgeons in selecting the most appropriate implant system for their patients.

Ez a dolgozat a kutyák teljes csípőprotézisének (THR) jelenlegi állapotát vizsgálja, három különböző rendszer összehasonlításával: a Biomedtrix BFX & CFX rendszerek, a Zurich rendszer és a Helica rendszer. A dolgozat fókusza a Biomedtrix rendszereken, azok előnyein és hátrányain a másik két rendszerhez képest, valamint a vizsgált esetekben a BFX cementmentes rendszeren van. A tanulmány átfogó felülvizsgálattal kezdődik a jelenlegi állapotról a canine THR-ben, beleértve a sebészeti beavatkozás történetét, technikáját, anyagait és eredményeit. A kutatás ezután összehasonlítja a három különböző THR rendszert részletes irodalmi áttekintés alapján. A dolgozat aztán a Biomedtrix rendszerre fókuszál és részletes elemzést nyújt az előnyeiről és hátrányairól, beleértve azokat a kutyákat is, akik THR-en estek át a BFX Biomedtrix rendszerrel. A dolgozatban elemzett esetek azt mutatják, hogy a Biomedtrix rendszer jó stabilitást és mozgástartományt biztosít, gyors gyógyulási időt és hasonló eredményeket a szakirodalomhoz képest. Azonban a rendszer potenciális hátrányokkal is járhat, mint például az implantátum migrációja és a speciális eszközök és magas tanulási görbe szükségessége a sebészek számára. Összességében ez a dolgozat

értékes betekintést nyújt az állatorvosoknak a legmegfelelőbb implantátum rendszer kiválasztásában a betegeik számára.

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Glossary

Abbreviations list

Figure (fig.)

Polymethyl methacrylate (PMMA)

Ultra-high molecular weight polyethylene (UHMWPE)

Total hip replacement (THR)

Cemented fixation (CFX)

Biologic fixation (BFX)

Porous coated anatomic (PCA)

Polyether ether ketone (PEEK)

Titanium (Ti)

Titanium Nitride (TiN)

Cobalt Chrome (CoCr)

Highly cross-linked polyethylene and vitamin E (Poly-XVE)

Cell blood count (CBC)

Electron beam melting (EBM)

Canal flare index (CFI)

Femoral head and neck ostectomy (FHNO)

Femoral head ostectomy (FHO)

Osteoarthritis (OA)

Triple pelvic osteotomy (TPO)

Dorsal acetabular rim (DAR)

Capital physeal fracture (CPF)

Avascular necrosis (AVN)

Distraction index (DI)

Computed tomography (CT)

Pulmonary embolism (PE)

Versus (vs)

Not applicable (NA)

Ventrodorsal (VD)

1. Introduction

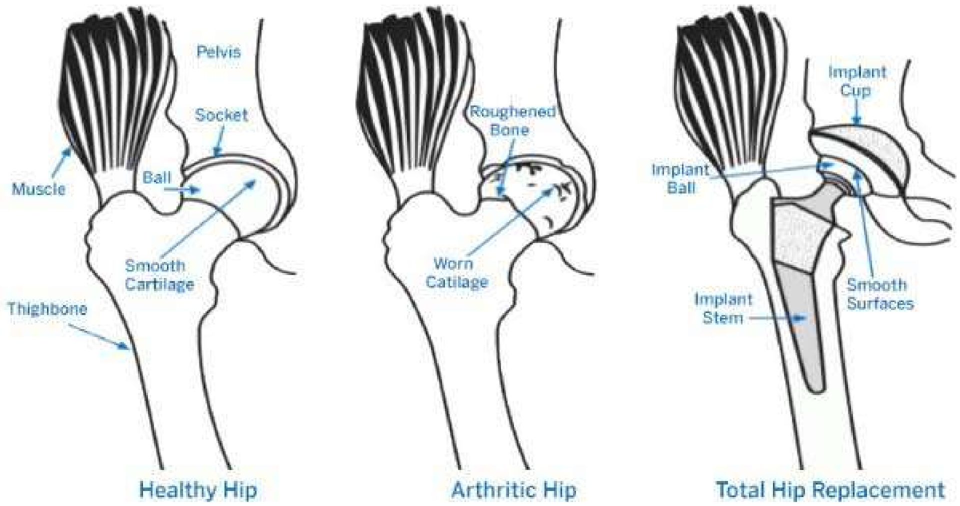

Figure 1- Demonstration of a healthy hip, an arthritic hip and a hip after total hip replacement (266).

The hip joint is one of the most crucial joints in the body of a dog, providing stability, support, and mobility. Canine hip problems, such as hip dysplasia, osteoarthritis, and hip fractures, can cause severe pain and discomfort, and can limit the dog's ability to move and perform daily activities. Total hip replacement (THR) is a surgical procedure that has been increasingly used in veterinary medicine to treat hip problems in dogs. This procedure involves the removal of the diseased or damaged hip joint and replacement with a prosthetic implant, which provides stability, pain relief, and improved mobility.

The hip joint is a ball and socket joint, consisting of the femoral head and the acetabulum. The femoral head is the ball-shaped end of the femur, while the acetabulum is the socket-shaped cavity in the pelvis that receives the femoral head. The joint is surrounded by a capsule, ligaments, and muscles that provide stability and support. The joint surfaces are covered with articular cartilage, which allows smooth and pain-free movement. The *ligamentum transversum acetabuli* and *lig capitis ossis femoris* will be replaced by a mechanical prothesis.

The hip joint is subjected to a range of biomechanical forces during normal movement and activities, including compression, tension, shear, and torsion. These forces are distributed across the joint surfaces, the surrounding soft tissues, and the prosthetic implant in THR. The prosthetic implant should be designed to mimic the natural joint mechanics and distribute the forces evenly to prevent implant failure, loosening, and other complications. Dogs that undergo THR can return to their normal activities, such as running, jumping, and playing, without pain or discomfort. Moreover, THR can prevent the progression of hip problems, such as osteoarthritis, and improve the long-term prognosis.

Total hip replacement is a surgical intervention that is considered when conservative treatments for hip problems, such as medication, physical therapy, and lifestyle modifications, have failed to provide adequate pain relief and improvement in mobility. Moreover, surgeries involving replaced joints are now faced with a higher demand from patients and their owners. They seek not only pain relief, but also the ability to perform athletic activities and increased longevity, challenging the surgeons and implants to provide pain-free function and restore normal biomechanics and kinematics to the affected joint. Over the years, there have been improvements in patient selection, pre- and post-surgical care, surgical techniques, and treatment or prevention of complications. However, it was only recently that there have been advancements in prostheses and instrumentation. With the availability of modern surgical techniques and a modular prosthesis with improved instrumentation, veterinary surgeons now have access to "state-of-the-art" implants and instruments. The new prostheses are easier to implant, provide greater flexibility to the surgeon during surgery, and improved outcomes are expected. From those newest developments, the Biomedtrix, the Zurich and the Helica system are all available THR systems and will be discussed in the following work.

The aim of this thesis is to evaluate the effectiveness and safety of different total hip replacement systems in canine patients with hip problems. The thesis will describe the principles of canine THR as well as the surgical procedure of one of the most used systems, the Universal hip system of the Biomedtrix and review the current literature on the different THR systems available for dogs, the various complications encountered during this surgical procedure and their respective systems. The thesis will also present a clinical study comparing the outcomes of different THR patients, using the Biomedtrix BFX cementless press-fit implants, in terms of pain relief, functional improvement, complications, and implant survival thanks to Doctor Chadi Eid, who gave me the opportunity to observe this procedure and to access some of his suitable cementless THR cases. The results of this thesis will contribute to the knowledge base on the use of THR in canine medicine, more specifically the Biomedtrix systems, and help guide through the various THR systems available for different patients demands.

While working and conducting research at the OrtoVet clinic in Italy on total hip replacement in canine medicine, I encountered the question of whether THR is the most effective solution for addressing hip problems. Additionally, the inquiry arose as to whether an ideal THR system exists that can consistently produce optimal outcomes across all cases, as well as what the long-term outcomes are for THR in canine patients, the advantages and disadvantages of various THR systems. These questions highlight the need for further research and evaluation of the use of THR in dogs and emphasize the importance of selecting the most appropriate THR system for each patient.

2. History of Canine Total Hip Replacement

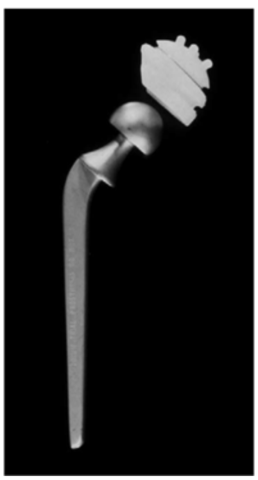

Figure 2- The Richards II canine total hip prosthesis. (Image courtesy of David DeYoung) (21)

Figure 3- The Gorman total hip prosthesis was used in canine patients as a model for human total hip replacement. (Image courtesy of David DeYoung) (21)

For decades, the dog has served as a model for human total hip replacement. This was first documented in 1957 by Gorman, who implanted a cementless stainless steel prosthesis in over 50 dogs (1). The acetabular component was secured using toggle bolts and the femoral component was simply inserted into the femur without fixation as seen in figure 3, though the first-generation stem was fixed to the medullary canal. The femoral head was held in place by a retaining rim to prevent dislocation. Gorman reported generally positive results from this procedure. One of the most noteworthy applications of the canine model for human total hip replacement was the use of Robodoc, an industrial robot adapted for surgical use in 1992 (2). The purpose of this study was to assess the impact of robotic preparation of the femoral canal on implant-bone contact and the incidence of intraoperative cracks or fissures, compared to hand broaching for a cementless total hip prosthesis. The study included 25 canine patients who underwent robotic femoral canal preparation and 15 patients who underwent manual preparation. The outcome showed that robotic preparation resulted in better implant-bone contact and no fissures or cracks.

The Richard II (fig.2) cemented system became the sole commercially available option for canine total hip replacement from 1974 to 1990 (3). In the late 1970s, modifications were made to the implant to reduce the risk of luxation, ensure more consistent placement of the acetabular component, and minimize damage to the femoral component during preparation. These modifications included a cutaway in the acetabular component, changes to the design of the femoral component, and the introduction of a femoral trial prosthesis. Numerous reviews were conducted during this time, with generally positive results. The most comprehensive review was conducted by Olmstead, who analyzed 221 total hip replacements over a 5-year period (4). At the end of the study, 91% of the patients were reported to have satisfactory function, with owners reporting improved activity levels, muscle mass, and relief from pain. The overall complication rate was 20%, with 58% of cases with complications ultimately resolving favorably (4). Studies were also conducted to continue to improve the cemented total hip replacement system, such as Gitelis, who studied the effects of weight-bearing on the bone-cement interface in cemented total hips in two groups of six dogs (5), and Dowd, who investigated the role of implant motion, titanium alloy, cobalt-chrome alloy, and polyethylene particles in the development of osteolysis and aseptic loosening (6).

The BioMedtrix CFX system was commercially introduced in June 1990 and marked a significant change in total hip replacement development (7). The most notable change in this modular system was the two-piece design of the femoral component, consisting of a stem and a head connected through a locking taper mechanism, offering three different neck lengths per stem. The new system also came with new instrumentation, such as power reaming of the femur and acetabulum, to improve accuracy and simplify the procedure. In 2004, a study by Liska reported on 730 consecutive total hip replacements using the BioMedtrix CFX system, with an average follow-up of 3.9 years (8). The procedure was considered successful in 96% of cases, and the study was considered the most comprehensive to date. It allowed for a direct comparison of the rate of complications (8). Initially, femoral implants were made of stainless steel, but newer generations utilized titanium alloys as mentioned in figure 7, which are resistant to corrosion and highly biocompatible. However, titanium alloys, when used as a cemented stem, are more susceptible to severe abrasive corrosion compared to stainless steel or cobalt-chrome alloys (9), resulting in aseptic loosening (10). The CFX system and its surgical procedure are described later in Chapter 4.

Techniques for total hip replacements without cement have been developed due to ongoing problems with irreversible infections and aseptic loosening associated with cementing techniques (11) (12). Studies by Skurla and Edwards have shown that most instances of aseptic loosening occurred at the cement-implant interface, and were more prevalent when the distal tip of the femoral component was in contact with the cortical endosteum (13) (14).

The PCA Canine Total Hip system by Howmedica was used clinically, but not produced commercially for the veterinary market. However, this system was considered the precursor to the BioMedtrix BFX system. DeYoung provided information on the implant design and surgical technique for the PCA system, and a preliminary study of 60 experimental hips showed an overall success rate of 98% (12). Marcellin-Little reported on 50 consecutive total hip replacements in 41 dogs, with a mean follow-up of 63 months, 74% of which had normal function, 3 luxations and others had unrelated issues leading to abnormal hind limb gait (11). Significant work in the area of cementless canine THR was carried out at the North Carolina State University College of Veterinary Medicine from 1986 to 1992, using the Canine PCA Total Hip System by Howmedica, which was highly successful in both research and clinical applications, though it was never commercially available (15) (12) (11).

Another rising Cementless system, The Zurich Total Hip Replacement system was developed at the University of Zurich in the late 1990s (16). It features a unique locking screw implantation system for application designed to minimize complications from subsidence and micromotion, as well as reduce stress shielding of the bone, and a micro interlock bone on-growth for stability of the femoral component. The acetabular component uses a press-fit stabilization followed by bone in-growth through a porous design (17). There have been several publications on the surgical technique and outcomes for the Zurich THR (18) (19) (20). Over time, improvements have been made to earlier generations of the Zurich THR, such as the use of polyether ether ketone (PEEK) instead of UHMWPE, and a proprietary cup inlay geometry to reduce wear and ongoing generations are presented to the market (16). The design of the prosthesis is mentioned further in Chapter 4.

Emerging from the PCA system, the BioMedtrix BFX press-fit system was introduced in 2003. Osseointegration of patient bone into and/or onto the implant surface is required for cementless implants, the initial implant stability is accomplished by press-fit. Its design was to be compatible with the BioMedtrix CFX system. Later in 2007, the BFX and CFX total hip systems were merged to create the Universal Total Hip System (Fig.12) with a standardized surgical approach. The many newer developments presented by BioMedtrix included micro and nano implants and customized femoral stems. The Biomedtrix system and its developments are discussed later in detail as my thesis and my personal experience focus on this system. Many other systems are available in the market, such as the Zurich system and the Helica Innoplant system which will be shortly mentioned in chapter 4.

Despite the remarkable advancements made in the field of total hip replacement for companion animals, further practice and evaluation are always improving outcomes. The potential for improvement in the field of total hip replacement is promising, particularly when combining knowledge from human and veterinary medicine. Currently, cementless hip systems are widely considered for many patients. However, the advantages of cemented prostheses should not be overlooked. The decision-making for selecting the optimal system for each THR patient can result in impressive outcomes when the right system is selected for the patient or for his revision. Therefore, the surgeon's expertise is necessary for the decision making of THR candidates and this proves once more the advantages of having a variety of systems that could answer the different demands of different patients. In the following, the indications for the use of THR are explained with the knowledge of their different diagnostic methods available nowadays (21).

3. Indications and contraindications for Canine Total Hip Replacement

3.1 Indications

In dogs, the primary reason for performing THR is to relieve pain resulting from osteoarthritis (OA) caused by hip dysplasia (22) (23) (24). However, non-septic OA caused by various factors, such as trauma, development, acquisition, or idiopathic reasons, can also be indications for the surgery and are described in the following. Not all dogs experiencing hip pain require immediate THR, but those with coxofemoral OA, with or without clinical signs, can be potential candidates for the procedure. Surgery may be delayed until pain management is partially effective and/or clinical signs worsen, or until non-surgical pain management combined with ideal body condition score of 4 or 5 out of 9 (25) and exercise resolves the symptoms (26). To maintain the quality of life and function of the patient, several other factors need to be considered, including the assessment of muscle mass, weight shifting, and the owner's feedback on the success or failure of previous treatments (non-surgical or surgical) (27) (28). In cases where previous hip surgeries such as triple pelvic osteotomy (TPO), femoral head and neck ostectomy (FHNO) (29), dorsal acetabular rim (DAR) arthroplasty, and toggle pin procedure have failed, THR may still be an option to revise the previous surgery or to revise a THR performed with an alternate system (30) (24) (16) (20). Age is also an important consideration, and surgery should be delayed until the acetabular growth plates are closed, except for young dogs with severe coxofemoral subluxation or developmental luxation (31). In cases where concurrent orthopedic and neurological diseases are present, this may lead one to incorrectly attribute the severity of the clinical signs to the hip joint. Therefore, a thorough physical examination and neurological evaluation must be conducted to identify or rule out any coexisting conditions during the planning process.

On the other hand, if financial constraints make THR surgery impossible, femoral head ostectomy (FHO) may be considered in selected cases. Nevertheless, an FHO carries several risks, including the possibility of not achieving acceptable pain relief and restoring function in all breed sizes (32). It can also disrupt the normal hip biomechanics, resulting in limb leg length discrepancy and unpredictable pain relief, and may require prolonged rehabilitation (33). It is possible to revise a painful FHO to a THR (34) (35), but an FHO should never be advised as an interim procedure. The indications for hip replacement remain generally the same, irrespective of the method of implant fixation or the type of hip system chosen. Some of the important indications described in many reports are represented in the following.

3.1.1 Hip Dysplasia

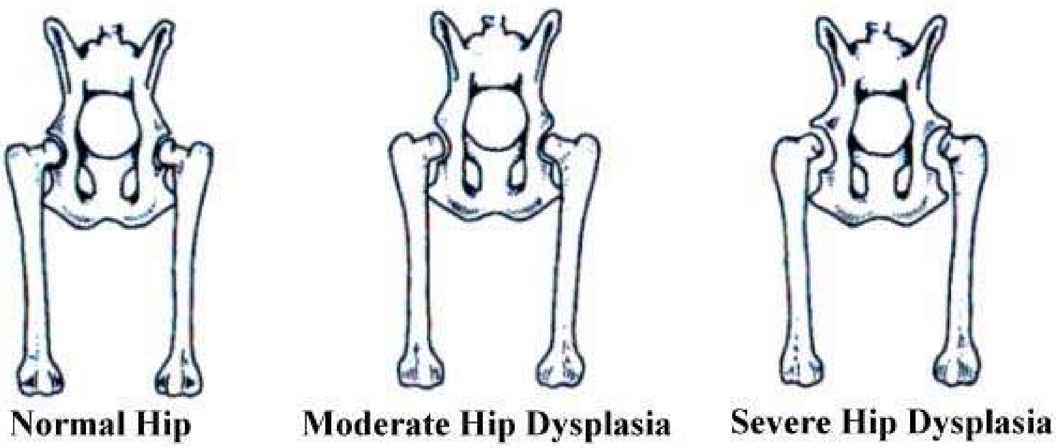

Figure 4- Normal hip vs hip dysplasia at different grades. (267)

Hip dysplasia is a frequently occurring musculoskeletal condition among medium to large breed dogs (36) (37). It is a developmental and biomechanical disease of the coxofemoral joints that causes secondary inflammation and osteoarthritis due to hip joint laxity, leading to hind limb lameness and pain (38). The precise mechanism behind the development of hip dysplasia remains unclear, but it is thought that both genetic and environmental factors contribute to the onset of the disease (39) (40).

Typically, affected young dogs exhibit hip pain, difficulty in lying down or rising, a bunny-hopping gait, and difficulty climbing stairs or jumping, with clinical signs typically diagnosed between 4 to 12 months of age (41) (42) (43). Hip dysplasia is propagated in young dogs by the stretching of the joint capsule and an increase in synovial fluid volume, which allows the hip to subluxate during the swing phase of the gait cycle (44). As the subluxation of the hip continues, the joint capsule stretches further, the synovial fluid volume increases, and the sensitivity of the mechanoreceptors decreases. This results in muscle-assisted hip reduction occurring later in the swing phase, which causes traumatic reduction of the hip upon foot placement, leading to the propagation of articular microfractures, deformation of the acetabulum and femoral head, and the development of osteoarthritis (36). In adult dogs, the signs of hip dysplasia are typically associated with osteoarthritic changes rather than laxity and subluxation. Adult dogs with chronic hip dysplasia typically have a stiff gait, difficulty rising, and chronic pain (38).

Clinical tests that provide information about the hip joint have been recommended for a long time (45). These tests can be divided into two categories: tests that assess hip joint laxity, mainly for use in young animals (such as the Ortolani, Barlow, and Bardens tests) (46) (47) (48), these tests are typically performed on animals under sedation or anesthesia (45), and tests that detect signs of osteoarthritis such as palpation and range of motion tests.

The positive Ortolani test involves abducting a subluxated hip until a palpable and/or audible reduction of the hip is noted. It is performed while the dog is in lateral or dorsal recumbency. However, this test may lack sensitivity in puppies around 8 weeks of age, but is more sensitive in young dogs older than 4 months (49) (50). The Barlow test involves adducting the hip while applying a distoproximal force, which can sense acute proximal displacement of the hip with palpable loss of stability. This can also be performed in dorsal or lateral recumbency. Whereas the Bardens test, which was described by a veterinarian in the late 1960s, involves applying a mediolateral force to the proximal femur with one hand while quantifying lateral movement of the greater trochanter with the other. This test is performed in lateral recumbency and is recommended for evaluating hip joint laxity in puppies at 6-8 weeks of age (51). Although Barden's original work considered this test diagnostic for early hip dysplasia, other researchers have failed to replicate these findings and consider it a subjective test (50) (49). In addition, subluxation tests may become less productive as dysplasia progresses (52). Patients with advanced osteoarthritis may exhibit not only hip pain, but also crepitus on palpation of the hip, decreased coxofemoral range of motion due to osteophytes, capsular fibrosis, subluxation or fixed luxation (53), and muscle atrophy of the affected limb.

The diagnosis of hip dysplasia involves the identification of joint laxity or indications of osteoarthritis on radiographs, with the former being a key risk factor for the development of the latter (54). Radiography has been utilized for diagnosing hip dysplasia ever since its initial reporting in 1935 (55). There are various radiographic projections available for evaluating and screening patients, with the most frequently reported techniques including hip-extended radiography, Norberg angle, distraction-stress radiographs, and the dorsal acetabular rim (DAR) view.

The most usual radiographic projection for assessing canine hips is the hip-extended ventrodorsal radiograph. However, achieving the correct position for this view can be challenging and may require the use of heavy sedation or general anesthesia. To obtain the correct positioning, the animal is placed in dorsal recumbency, and the hind limbs are extended caudally while slightly rotating the femurs internally. The radiograph should show a symmetrical pelvis, fully extended and parallel femurs, and patellae centered within the femoral trochlea (56). One of its advantages is its ability to detect signs of osteoarthritis in the joint. Evidence of coxofemoral degenerative changes associated with hip dysplasia include periarticular osteophytes around the femur, flattening of the femoral head, subchondral sclerosis of the craniodorsal aspect of the acetabulum, and remodeling of the acetabulum into a dish-like shape, as well as the formation of osteophytes at the cranial and caudal poles of the acetabulum (57). It is commonly used as a screening tool by organizations like the Orthopedic Foundation for Animals (OFA), Federation Cynologique Internationale, and the British Veterinary Association/Kennel Club. If there are no radiographic signs of OA, joint subluxation on the hip-extended radiograph is considered a diagnostic sign of hip dysplasia (58) (59). However, the hip-extended radiograph may not always accurately show joint subluxation due to the tightening of the joint capsule as the limbs are extended, causing the femoral heads to sit deeper within the acetabula (60) (61). The degree of subluxation can be evaluated subjectively or quantified using techniques like the Norberg angle.

To determine the level of hip laxity, the Norberg angle is measured by calculating the angle between two lines. One line connects the center of the femoral head between the left and right hips, while the other line connects the center of the femoral head with the lateral tip of the cranial acetabular rim (59). A larger angle indicates a more congruent hip joint and a deeper acetabulum, while a smaller angle suggests increasing degrees of subluxation. Typically, a Norberg angle greater than 105° is considered normal, while angles less than 105° suggest hip laxity (62). However, it's important to note that slight rotation of the pelvis during the radiograph can significantly impact the Norberg angle's accuracy. This can cause one hip joint's congruency to be overestimated while underestimating the other hip joint (63). Additionally, breed variations can affect the Norberg angle, making the use of a strict reference value inappropriate for detecting dysplastic hips (64).

Figure 5- Pennhip technique. (268)

Distraction stress radiographs are procedures used to assess functional laxity in dogs while they are ambulating. PennHip, Dorsolateral Subluxation Measurement, and the Fluckiger Subluxation Index are the most often used distraction stress radiography procedures (65).

A typical hip-extended radiograph, a neutral stance-phase compression radiograph, and a neutral stance-phase distraction radiograph are all taken for PennHip (66). During early screening (as early as 4 months), a distraction radiograph is produced using a specific device called a distractor, and it enables for the computation of a Distraction Index (DI), which measures the degree of femoral head separation from the acetabulum. A DI score of 0 shows that there is no subluxation, whereas a value of 1 indicates that the joint is totally luxated (67). Compression radiographs are used to assess joint congruency (68), whereas hip-extended radiographs are utilized to diagnose osteoarthritis in the coxofemoral joints. The capacity of the PennHip approach to anticipate the development of OA in dogs as young as 16 weeks of age is a considerable benefit (69) (70) (71). Nevertheless, veterinarians must attend a training course for certification in order to take and submit radiographs, and major drawbacks include numerous radiographic views and physical restraint (72). The

PennHip approach has had little popularity in Europe, but it remains a good tool for assessing functional laxity in dogs and forecasting the onset of osteoarthritis.

Slocum and Devine described the Dorsal Acetabular Rim View for the first time in 1990 (73). This radiographic image is utilized to examine the dorsal side of the acetabular rim, which is the portion of the acetabulum that absorbs the majority of the stress from femoral head subluxation during ambulation (74) (75) (76) (77). The dog is positioned in sternal recumbency, with the hind limbs drawn cranially and kept close to the animal's torso. To offer more pelvic rotation, a spacer might be put beneath the tarsi. The iliac wings, iliac body, acetabulum, and tuber ischii are superimposed on the radiograph, providing an unobstructed view of the dorsal acetabulum (78). According to reports, the DAR view is beneficial for documenting the degree of joint injury as the acetabular rim develops from sharply pointed in the normal dog to more rounded and blunted with joint disease (79). The DAR radiographic view, on the other hand, is not generally employed since diagnostic quality pictures can be difficult to generate, and the research has little clinical usefulness when compared to other diagnostic procedures such as joint palpation or DI calculations (80).

3.1.2 Avascular Necrosis of the femoral head- Perthes' disease

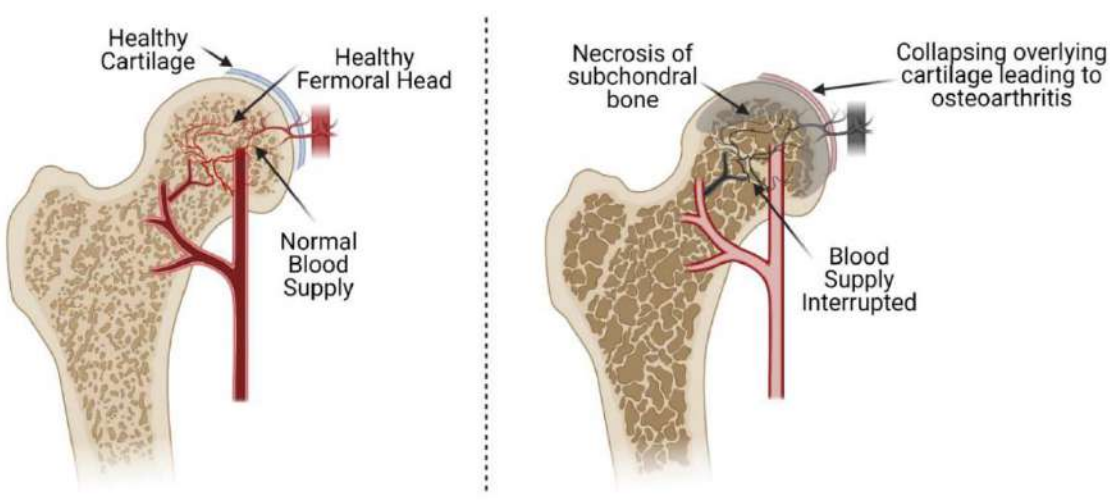

Figure 6- Avascular necrosis of the femoral head. (269)

Avascular necrosis (AVN) of the femoral head, which is also referred to as Legg-Calve-Perthes disease, aseptic necrosis of the femoral head, coxa plana, and osteonecrosis, is a developmental condition that often affects small breed dogs. In one report, hip luxation, avascular necrosis, and capital physeal fractures were the indications for 23%, 26%, and 17% of 66 small-breed THRs, respectively (81). The manifestation of clinical symptoms typically occurs around 6-7 months of age (82) (83) (84), and bilateral involvement is observed in 12-16% of cases (85) (86) (87) (83). The etiology of AVN remains elusive; however, several theories have been suggested, including infection, trauma, anatomical configuration (88), genetic factors (89) (90), hormonal imbalances (91) (92), infarction, obstruction of venous drainage of the femoral head and neck (93) (94), and deficiency in blood clotting factors (95). In the Manchester Terrier, AVN has been reported as an autosomal recessive trait (96).

Despite the lack of clarity regarding the cause of AVN, its pathophysiology has been well described. The compromised blood supply leads to ischemia and subsequent necrosis of the femoral head (97) (98), which is repaired by fibrovascular tissue starting at the periphery of the femoral head (99). Repeated forces on the necrotic bone cause clefts and fissures in the articular cartilage, followed by collapse of subchondral trabeculae and flattening of the femoral head (100) (101). This ultimately leads to articular incongruency and coxofemoral joint osteoarthritis. Radiographic signs typically demonstrate a decreased radiopacity in the femoral head and neck, leading to infarction and fissures meaning a deformed head and neck which eventually gets absorbed.

According to many reports, using THR as a treatment for capital femoral physeal fractures and avascular necrosis of the femoral head was successful (102) (103) (104).

3.1.3 Capital femoral physeal fracture

Femoral capital physeal fracture (CPF) is a commonly diagnosed condition in both dogs and cats. While it is typically associated with a traumatic event, it can also occur spontaneously as a result of a multicentric chondrocyte disorder causing physeal dysplasia (105) (106) (107). This condition is believed to be a precursor to slipped capital femoral epiphysis in children (108) (109), and the same pathogenesis has been recently described in dogs (110). The femoral proximal epiphysis is located within the joint and is reliant on a unique blood supply. When deciding on a treatment for

CPF, it's important to take into account the likely root cause and the level of vascular disturbance to the physeal plate and epiphysis. The ultimate aim of CPF treatment is to create a joint that is free of pain and has normal function for the patient's entire life, while minimizing the chances of developing OA and/or avascular necrosis. Non-surgical therapies have a foreseeable outcome of producing pseudoarthrosis, a mal/non-union, and/or OA (111).

3.1.4 Luxation

Hip luxation is responsible for around 90% of all luxations in dogs (112). There are two types of luxations, chronic and nonreducible. In cases of acute luxation, closed reduction may be attempted, and if unsuccessful, open reduction with joint stabilization is recommended for dogs with normal hip conformation (112). However, for dogs with chronic luxation, hip dysplasia, osteoarthritis, or irreparable articular fractures, open reduction and joint stabilization are not recommended. In these cases, total hip replacement is the preferred treatment option (113). While femoral head and neck ostectomy may be a potential alternative for owners with financial constraints, it is not the best option (114). The most common reason for total hip replacement in dogs is clinical disability caused by hip dysplasia with secondary osteoarthritis (115). In less frequent cases, complete hip luxation can occur in dogs as a result of hip dysplasia.

3.1.5 Complex Fractures

Dogs can experience irreparable fractures of the acetabulum, femoral head and/or neck most of the time as a result of a traumatic event. These types of fractures can have significant consequences since they directly impact the hip joint. If left untreated, fractures of the acetabulum that affect the weightbearing portion can alter the way the joint is aligned and cause degenerative joint disease, leading to posttraumatic arthrosis. In dogs, the acetabular structure is affected in 14% to 43% of cases (116). Following femoral neck fractures, osteonecrosis of the femoral head can be a severe and frequent complication, despite the understanding of the fragile blood supply to the femoral head (117).

3.1.6 Unsuccessful hip surgeries

Numerous surgical procedures that were previously mentioned as alternatives to total hip replacement have been reported to have a low positive outcome compared to THR. Total hip replacement offers the veterinarian and the pet owner the choice to restore the function and biomechanics of the dog's hip. Several common surgeries, such as FHO, TPO, DAR arthroplasty, and toggle pin stabilization, can be corrected through THR. Moreover, nowadays revision of a total hip replacement using an alternative system is widely practiced and will be discussed later (118) (119) (120) (121).

3.2 Contraindications

In small breeds and cats, hip pathology often coincides with orthopedic issues such as medial patella luxation or cranial cruciate ligament rupture (122). Proper diagnosis is crucial in cases where both hip and knee problems are suspected, with priority given to the knee problem. Before performing total hip replacement, serious medical conditions like immunosuppression, diabetes mellitus, Cushing's disease, and generalized immune-mediated polyarthropathy should be evaluated, as they may pose a significant risk to the patient (123). Additionally, predisposed breeds should be tested for von Willebrand factor deficiency. THR is contraindicated in cases of septic arthritis, as well as hindquarter or generalized dermatitis, otitis externa, urinary tract infection, and periodontal disease. While neoplasia may be a relative contraindication, it may be possible to use a custom-made prosthesis in selected cases. However, caution is necessary when considering THR in such patients. Therefore, thoughtful preoperative assessment and counseling of the owner is recommended before undergoing THR surgery, even after treating these or similar diseases.

4. Description of different THR systems, their surgical techniques and material

Hip System	Femoral stem material, manufacturing, bone ingrowth surface	Femoral Head (and neck)	Acetabular cup/shell/insert/liner material, manufacturing, bone ingrowth surface	Major complication(s)
Richard II	Cemented, fixed-head, stainless steel femoral component (21)	NA	Polyethylene acetabular cup in three sizes (21)	Acetabular or femoral loosening or both. Other: failure of the femoral component via bending or breakage at the stem–neck angle and luxation. (21)
Modular cemented Biomedtrix CFX	1st stainless steel then titanium alloy in five sizes. Later CoCr, Machine taper, hand finish stem. Micro/Nano: Wrought CoCr, machined CoCr cement fixation surface: Bead blast, Matte finish (21)	Head: CoCr in three sizes. (21)	-Cup: UHMWPE, machined polyethylene, -Cement fixation surface: Radial and circumferential grooves. (21)	Aseptic loosening. (21) Other complications like craniodorsal and ventral luxation, infection, femur fracture, sciatic neuropraxia, PE, incision granuloma, medullary infarction and osteosarcoma according to Liska study (2004) discussed later. (8)
PCA press-fit with porous bone ingrowth.	Cast CoCr alloy in 4 sizes, with porous coating at the proximal 1/3 of the stem. (21)	The modular femoral head with 2 femoral neck lengths. (21)	-Cast CoCr alloy with a backing of 3 layers of beads. -UHMWPE insert with 2 depths. (21)	3 luxation and the remainder with unrelated problems causing abnormal hind limb gait according to Marcelin little et al. (23)
Helica Innoplant	Ti alloy, machined Ti, sand-blasted and macro thread. (21)	1st gen: 316L stainless steel, machined, with TiN coating, plasma steam. (21)	-Shell: Ti Alloy, machined Ti, sand-blasted and macro thread, -insert: UHMWPE, tampered. (21)	Aseptic loosening. (124)
Zurich Cementless anchored to the femur with locking screws and acetabular press-fit.	-Ti alloy, machined Ti, Micropeened, Plasma sprayed -Screws: Ti alloy, machined Ti, TiN coating. (21)	Head and neck: Ti alloy, machined Ti, Amorphous diamond-like coating. (21)	Shell: CP titanium, Grade 4, machined Ti, plasma sprayed Liner: UHMWPE, machined polyethylene. (21)	Luxation, fracture, and cup loosening within 6 months of surgery. Stem loosening, cup loosening, and implant breakage, occur later. (125)

Biomedtrix BFX press-fit allowing porous ingrowth.	-CoCr, Cast CoCr machine taper, hand finish, Sintered CoCr beads. -Ti alloy, machined Ti, plasma-sprayed Ti particles. (21)	Wrought CoCr, Machined CoCr from wrought bar stock. (21)	-Shell: Ti alloy, machined Ti, Sintered Ti beads -Insert: UHMWPE, machined polyethylene. (21)	Postoperative subsidence or migration of the stem potentially leading to luxations, fractures, or misaligned implants. (21)

Figure 7- Implant materials, manufacturing methods, and specifications for veterinary total hip replacement prostheses by historical order with the most major complication(s) in each system.

TiN is a hard ceramic coating to improve smoothness and wear performance. Product prior to 2010 had a TiN coating. Whereas, amorphous diamond-like coating is a hard coating to improve smoothness and wear performance.

Over time, various THR systems have been introduced to the field of veterinary medicine. These include the Cemented (CFX) and Cementless (BFX) Biomedtrix systems, the HELICA system (Innoplant), and the Zurich cementless system and are currently available commercially (124). This thesis will focus mainly on the Biomedtrix systems and specifically the BFX press-fit method in its case studies. In a wider version, Cemented THR systems use PMMA as a connection between the implant and the bone to provide both short-term and long-term stability. Cementless systems, on the other hand, achieve short-term stability through methods such as press-fit, locking screw fixation, or screw-in implants and long-term stability through bone ingrowth (125) (21). The selection between a cemented or cementless system is often dependent on the specific case, however, due to complications that can arise from aseptic loosening of cemented implants, cementless systems are now more commonly used (126) (127).

4.1 Preoperative planning for canine THR

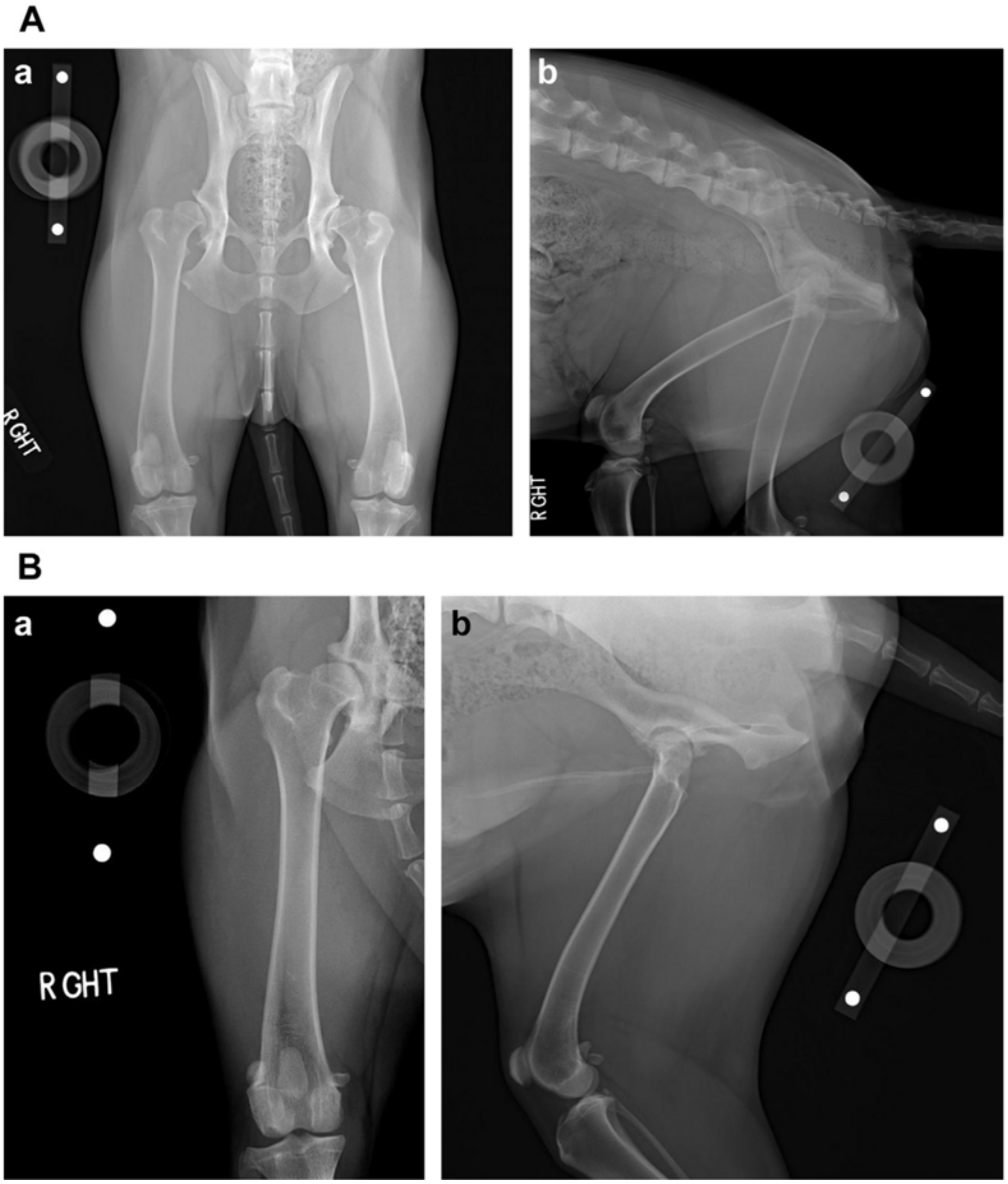

Figure 8- (A) Preoperative radiographic pelvis. Ventrodorsal (VD) and lateral radiographs of the pelvis are obtained preoperatively. A 10 cm magnification marker is placed at the area of interest, parallel with the level of the bone for templating. The VD view (a) is used determine appropriate cup size. The walking lateral view (b) gives an indication of femoral head position relative to the acetabulum. (B) Preoperative radiographic femur images. Fully extended craniocaudal (a) and true open leg lateral (b) views of the femur are obtained to be able to accurately template the size of the femur. The magnification marker is placed at the level of the proximal one-third of the femur. Implant sizing is performed and evaluation of the central axis of the femur in both planes is determined. (131)

It is crucial to assess the eligibility of candidates for THR procedure based on a range of factors to achieve satisfactory outcome. These include the age of the patient as mentioned earlier (128), a thorough history, severity of symptoms and radiographic findings, physical examination, and orthopedic and neurological examination of both hindlimbs. It is important to evaluate the dog's neurological status, as deficits can often be mistaken for gait abnormalities due to hip conditions. Other factors considered include the presence of other orthopedic diseases, comorbidities, breed and temperament, expected patient performance, financial constraints of the client, skill of the surgeon, and internal fixation implants available (129).

Once the patient's profile fits the procedure's requirements, preoperative planning starts with conducting a physical examination and laboratory examination such as serum chemistry, CBC count, urinalysis, and urine or blood culture to ensure a good general health (130). It is then of utmost importance to accurately evaluate the coxofemoral joint through radiography, regardless of the type of total hip replacement system being used (21). The current technique for preoperative planning and implant selection involves obtaining four radiographic views of the pelvis and femur, which are then corrected for magnification. These views are used to superimpose implant templates using either acetate overlays or digital templating programs (131). The size of the acetabular cup and femoral stem are then determined and a smaller implant of each size is prepared. The standard procedure for templating acetabular components involves using an extended ventrodorsal view of the pelvis with the magnification marker placed at the level of the acetabulum. The shape of the pelvis and the positioning of the femur relative to the acetabulum are evaluated using a lateral view of the pelvis. To accurately determine the size of the femoral stem, craniocaudal and open leg lateral or mediolateral views of the femur are taken. The magnification marker is positioned in the proximal one-third of the femur, in line with the level of the bone and parallel to the radiographic beam and plate. This also allows for clear assessment of the implant-bone and cement-bone interfaces (21).

Implant sizing is performed using either calibrated acetate overlays or digital templates. The recommended size of a femoral implant, based on work with the Canine PCA cementless system, is one that fills approximately 85% of the femur to minimize the risk of subsidence post-operatively (132). To determine the size of the CFX femoral component, the templates are superimposed over craniocaudal (Fig.8 (a)) and lateral (Fig.8 (b)) radiographic views. The largest CFX stem that allows for adequate space for a cement mantle in the medullary canal of the femoral diaphysis is selected. The BFX stem is chosen to fill the endosteal space of the metaphysis and diaphysis on both craniocaudal and lateral radiographic views. In narrow "champagne fluted" femurs, the diaphysis may be the limiting factor in determining the size. The same radiographic views are used to determine the size of a screw fixation stem. The size of the acetabular component should match the cranial-to-caudal width of the acetabulum, with the medial pole of the implant reaching or nearly reaching the medial acetabular wall. The next size template is superimposed over the acetabulum. Knowledge of magnification and the accurate size of the bone is crucial in selecting the appropriate implant that fills the confines of the proximal femoral metaphysis and diaphysis and the cranial-to-caudal width of the acetabulum. This is especially important in cementless implants, where the templating process forms the basis of surgical decision-making and planning (21).

However, this method has a limitation in that the three-dimensional structures of the hip are viewed and measured in two dimensions on radiographs. While radiographs are sufficient for preoperative planning with enough precision and experience, other advanced imaging modalities such as computed tomography (CT) provide higher-detail images in multiple sections and can be reformatted into three-dimensional representations, improving implant size and orientation accuracy (133). But radiographs stay the least expensive and the most accessible in veterinary clinics with a sufficient image. A large part of a THR outcome counts on those preoperative radiographs, therefore a clean work at this stage is necessary and inaccurately positioned radiographs and magnification markers can distort the representation of the bone, potentially affecting the surgical procedure and leading to operative and postoperative complications. The same radiographic protocol is followed for postoperative and serial radiographic follow-up.

4.2 Biomedtrix systems

4.2.1 Cemented vs Cementless

The cemented CFX system consists of a two-piece design of the femoral component, a stem and a head, and an UHMWPE cup with different sizes (40). The material and manufacturing methods of each is mentioned in figure 7 for further information. The advantage of cemented THRs is immediate implant stabilization in the bone during surgery, allowing patients to return to an active lifestyle, free of pain with a recovery time of 6 to 8 weeks. The cohesive PMMA, which plays the role of a grout between the bone and the implant, is used for short and long-term fixation of cemented implants (40). However, as mentioned earlier in the history, aseptic implant loosening became a significant issue despite improvements in surgical and cementing techniques. The mechanical properties of PMMA, and therefore the cement-bone and cement-implant interfaces, are influenced by several factors (134) (135).

To strengthen implant-cement mechanics, implant design has been evolving. The cobalt-chrome femoral stem is sand-blasted or bead-blasted or priorly coated with PMMA (136) and grooves are inserted into the acetabular cup also expanding the surface area of the cement-implant interface; the cup is made of UHMWPE with a marking wire around the periphery (21).

To strengthen the bone-cement interface, the amount of fat and blood that comes into contact with the cement is minimized (40) and additional options aroused to avoid some common complications during cemented THR such as the pressurization and centrifugation of the cement before application (21). The stem centralizer features 1 mm flanges that prevent direct contact between the stem's edge and the outer bone layer, and allow for the cement to surround the stem tip between it and the outer bone layer (131). It has been proposed that direct contact between the stem tip and the cortical wall increases the risk of aseptic loosening in cemented femoral implants (13). Furthermore, a pliable plastic plug representing a femoral cement restrictor, previously made of PMMA, may be used for patients within a range of implant sizes. Like its name, the restrictor contains the cement in the proximal region of the femur, to improve cement pressurization within the canal (131) (21).

The first generation of cementing techniques packed with hands had poor manipulation properties and insufficient interdigitation at the cement-bone interface, contributing to aseptic loosening (137). The second generation, using an intramedullary plug and cement gun, improved uniform penetration and distribution of the cement. Whereas the third generation, utilizing centrifugation and vacuum mixing, further strengthened the cement mantle by reducing air inclusion during preparation, and improved its tensile and fatigue properties in various mechanical studies (138). Modified third-generation techniques, such as slow vacuum mixing, can be performed with commercially available equipment but comes with a high cost. Mixing antibiotics with PMMA has also been evaluated in clinical studies, despite potentially reducing some mechanical properties (139).

Furthermore, postoperatively, the bone-cement interface may be jeopardized right away due to factors such as polymerization of the cement, heat damage, the drilling process, or harmful effects of local monomers, as stated by Mann et al. (140). In an ideal scenario, the bond between the cement and bone can remain unimpaired for a long time without any negative biological reactions. However, in reality, several factors can compromise the conditions of the bond. The mechanism responsible for loosening is believed to be complex, involving multiple factors (21).

The most comprehensive data on the CFX procedure and patient outcomes comes from the 2004 Liska study of 730 CFX THRs as mentioned in the history earlier. These studies found high success rates, but also reported similar complications such as dislocation, infection, femoral fracture, sciatic nerve neuropraxia, and most importantly, aseptic loosening (141). As a result of the high incidence of loosening, the development of implant systems without cement has been a significant motivation (126) (127).

Hence the release of the BioMedtrix BFX THR system in 2003 (131). The titanium acetabular cup with a high molecular weight polyethylene liner, the prosthetic head from wrought cobalt-chromium polished to a very smooth finish to reduce polyethylene wear, and the variable femoral stem make up the cementless press-fit system (21). A press-fit mechanism is used in this system to initially fixate the implants by creating friction between the bone and the implants. Osteointegration is therefore necessary for these implants to remain stable over time (127). It's believed that cementless implants initially experience tissue ingrowth similar to secondary bone healing, changing to bone ingrowth once a stable implant-tissue interface forms. While less stable initially compared to cemented implants, cementless fixation offers potential benefits such as a bone-implant interface stabilized by vital tissues, potentially reducing risks of infection and aseptic loosening (131).

Press-fit is achieved after bone preparation with acetabular reamers and femur broaches. The precise match of implant and bone geometry plus design features maintain implant position and promote tissue ingrowth for stability. In cementless hip replacement, the preparation of the bone determines the exact positioning and stability of the implants press-fitted (131). On the other hand, in a cemented surgery, the bone is prepared in a way that helps the surgeon position the implant accurately within the cement mantle. Compared to cement fixation, press-fit stems require more precision in fitting the femoral canal and positioning the femoral stem (21). The surgical procedure of both CFX and BFX Biomedtrix systems are further described in the following.

As we mentioned above, the conventional press-fit stem relies on close contact with the bone for initial stability, which makes it less versatile in patient selection than a cemented or cementless screw fixation stem. In some cases, a cemented stem may be preferred for patients with large size or "stovepipe" shaped femurs, poor bone quality, or advanced age; as well as in small dogs and cats, cement fixation allows for flexibility in implant sizes for both the cup and stem (21) (142). Conversely, for younger patients with a flared proximal metaphyseal region of the femur, a press-fit cementless stem may be the better choice and, in most cases, a press-fit acetabular cup is preferred over a cemented cup, regardless of the type of stem fixation used (21). Furthermore, juggling between the cemented and cementless implants can answer many revisions, per example a failed cemented stem can be replaced with a cementless stem; a better alternative to recementing the femoral component. The reverse can also be true, where a cementless stem fails to press-fit and a cemented stem may be the safest option for revision (21). The choice between a cemented or cementless system typically depends on the specific case, but currently, the cementless total hip replacement (THR) system is more frequently used due to the risk of aseptic loosening associated with cemented implants (40) (137).

Given all the reasons mentioned above, Biomedtrix has continued to develop their options by introducing a Universal system to the market, where implants can be mixed, including one cemented and another cementless, to create a hybrid system. They have also created many customized press-fit femoral stems, as well as micro and nano systems to meet the demands of smaller breeds and cats and patients with special femoral shape. These developments will be further described in the following.

4.2.2 Advancements in Biomedtrix Stems

Figure 10- Biomedtrix- bfx EBM titanium stem. (143)

Figure 9- Biomedtrix- bfx collared femoral stem titanium. (271)

Figure 11- Biomedtrix- bfx EBM lateral bolt stem. (272)

The BFX electron beam melting titanium (EBM) Stem, available for standard and large breeds, was introduced commercially in 2010, improving the technology for biological fixation. Plasma spray and beaded coating were used for press-fit stability with titanium and cobalt chrome femoral stems respectively, but the BFX EBM Stem, made from biocompatible wrought titanium alloy, contains a porous surface created via the EBM process instead of spray or coating, increasing friction and the resistance to subsidence in the first two postoperative months. Moreover, cranial and caudal holes exist for a better stem insertion. All those characteristics make EBM biocompatible with optimal mechanical properties (143) (144).

BioMedtrix BFX Stems aim to secure permanent osteointegration within 6 to 8 weeks after Total Hip Replacement surgery. However, certain factors such as weak cancellous bone, improper stem size, broaching method and proximal femoral bone shape can raise the risk of complications. Despite efforts to minimize these challenges through careful surgery and patient adherence to post-op care, some stems may still sink in the femoral canal. To address this, BioMedtrix has created custom BFX femoral components to boost stability and protect against subsidence, especially in larger breeds, including the collared EBM titanium BFX stem and the Lateral Bolt EBM Titanium BFX stem. These designs have been proven successful by multiple surgeons and clinics, with minor changes to surgical technique needed (131).

The BFX Collared Stem, also available for standard and large breeds, is designed to resist subsidence and support bone growth during the early postoperative period. This stem is ideal for large breeds like German Shepherds, and breeds with low canal flare index (CFI), or stove-pipe femoral shape. Although the collar was originally created for low CFI animals, it can be used regardless of CFI, as long as proper technique is used. The collar should be proximomedial, near the calcar bone at the femoral neck resection to ensure a proper press-fit. The collar should be positioned within 2 to 3 mm of the osteotomy cut during stem placement for the best results. If minor subsidence occurs, the collar will rest on the bone and prevent further implant movement into the medullary canal. However, proper press-fit is still crucial for success. If resistance to broaching and impaction is insufficient, indicating inadequate press fit, the collar will not prevent significant subsidence or rotation and the implant may move into the medullary canal through the cancellous bone. To be effective, the collar should be positioned over the cortical bone (145) (144) (131).

The lateral bolt stem can be utilized for the same patient populations as the collared stem, including those with stove-pipe femoral anatomy. It offers a solution for cases where a BFX Collared Stem cannot be used due to the absence of calcar bone. It may also be useful in cases where there are concerns about stem position changes post-operation despite perceived adequate press-fit during broaching. However, the lateral bolt stem will not prevent stem implant position changes in cases where press-fit is not achieved or in instances of poor bone quality or insufficient bone resistance during broaching. Patients with thin femoral cortex walls may also not be suitable candidates for the lateral bolt stem. The lateral bolt BFX stem, in sizes for standard and large breeds, adds a fourth component to the modular Universal THR system. A stabilizing bolt is inserted into the femoral stem to enhance stability against subsidence and rotation during early bone ingrowth after THR. The stem design allows for a screw-in straight bolt to be inserted from the lateral cortex of the femur into the lateral aspect of the stem. Placement of the femoral component is done using standard Universal THR techniques and is positioned to the desired level in the bone. Before preparing the bone for the lateral bolt, a trial reduction of the hip is performed to confirm proper hip reduction at the level of the stem (144) (131).

The process of installing the lateral bolt BFX stem begins by orienting a drill bit and a guide pin through the central canal of the femoral neck and stem. The drill bit and pin are then powered through to exit on the lateral side of the femur, near the greater trochanter. A cannulated drill bit is used to create a tunnel from the lateral cortex of the femur to the insertion site for the bolt on the edge of the stem. A depth gauge is used to determine the length of the bolt needed to fill the distance between the lateral cortex of the femur and the lateral edge of the stem. An additional 2 to 3 mm is added to this measurement to choose the correct size bolt. The bolt is then inserted and tightened into the stem with screws. The bolt has an extra locking mechanism for the stem and prevents subsidence and rotation. However, adequate bone quality and a secure press-fit are still necessary for the implant to be successful. Surgeons have reported high satisfaction with the lateral bolt stem, especially for larger patients and for patients with stove-pipe femoral morphology where there is a risk of implant movement early in the recovery process (131) (144).

Newer developments continue to emerge in the field, and one such development is the Centerline Stem, which is now available as part of the Universal Hip System. This innovative stem makes use of the true femoral neck centerline, resulting in reduced bending and improved calcar loading following a Total Hip Replacement. Patients who are eligible for this unique stem are the same as those who are eligible for previously mentioned stems. The Centerline Stem is designed to achieve press-fit stabilization using a femoral preparation and stem insertion technique that is similar to the standard BFX EBM Stem, but with a higher, adjusted neck resection and lateral exposure preparation. Additionally, in addition to the Universal Hip Basic Preparation instrument set, a supplementary instrument set is required for the Centerline system (146) (144).

Moreover, nowadays Poly-XVE (highly cross-linked polyethylene and vitamin E stabilization) constitutes all Biomedtrix THR polyethylene articular surfaces, providing a long-term resistance, a stable vitamin E leading to a minimum of reduction to mechanical resilience, and therefore preventing bone resorption and implant loosening (147) (144).

It is evident that numerous exceptions arise during the THR procedure, which have spurred the development of newer inventions and more tailored options. Thus, there is no flawless system that can accommodate all patients, and meticulous individualization of preoperative planning is necessary to address each patient's unique case and choose the right system for it.

4.2.3 Hybrid – Universal hip system

Figure 12- Biomedtrix- The Universal hip system- Interchangeable implants. (270)

When one implant is cemented and the other is press-fit, hybrid fixation is achieved. The BFX and CFX total hip systems were merged in 2007 to create the Universal total hip system, which standardized the sizes to blend the two systems. The implants in each system are interchangeable and prepared to a single surgical preparation, using a common set of equipment, enabling greater variety in total hip replacement clinical alternatives. Both applications employ the same fundamental surgical processes and are both compatible with the common femoral head, giving the surgeon the choice of press-fitting or cementing into the same acetabular or femoral preparation and a consistent surgical technique. The approach in this surgical technique is to prepare the acetabulum and femoral canal using the same precise technique needed for BFX cementless implants. If a CFX cemented implant is planned, the preparation is adjusted at the end of the BFX preparation process. The mantle for cement in the femur is created by simply reducing the size of the CFX stem from the BFX preparation. In the acetabulum, the CFX cup is also smaller than the BFX preparation, creating room for a cement mantle (21) (131). The surgical procedure is described further in the following.

The choice of CFX or BFX implants is best decided prior to surgery and is determined by various factors, including the surgeon's expertise and training, patient characteristics such as size and weight, coxofemoral joint conditions, bone quality, femoral shape, and whether it's a primary or revision surgery. The use of cement in THR implant fixation can address bone quality issues or provide a safer option when a cementless implant may not be suitable for press-fit. Furthermore, postoperative subsidence or migration of a cementless femoral stem can occur, potentially leading to problems such as luxations, fractures, or misaligned implants. This requires complex revision surgeries. On the other hand, cemented stems are more prone for aseptic loosening, leading to the use of a cementless stem. Hence, the decision on using cemented or cementless implants and the surgical technique used is critical to avoid these complications (21).

It's impossible for one total hip replacement system to fulfill the requirements of every potential THR patient. When implant systems are compatible and compatible surgical techniques are utilized, it benefits both the performing surgeon and the receiving patient.

4.2.4 Micro and Nano THR –

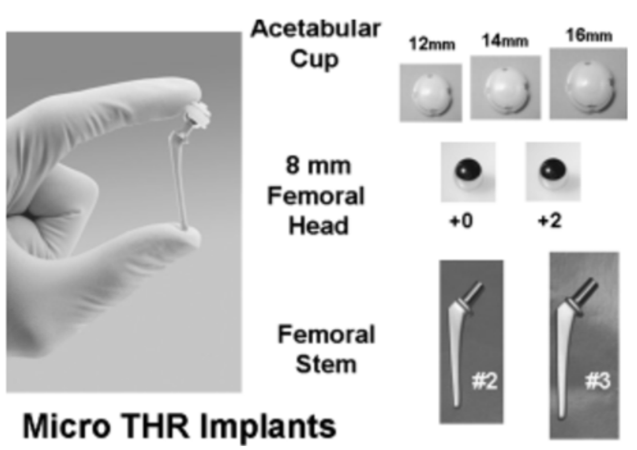

Figure 14- The modular micro total hip replacement prosthesis includes different sizes of an acetabular cup, femoral head, and femoral stem. (35)

Figure 13- (B) Relative size of NanoTHR implants. (148)

Small dogs and cats can suffer from hip joint problems similar to larger patients, such as avascular necrosis, degenerative osteoarthritis, femoral head and neck fractures, and coxofemoral subluxations and luxations, leading to pain and hind limb dysfunction. To address these issues, the

Micro THR system was introduced in 2005 for pets weighing less than 12 kg and the Nano THR system followed in 2010. These procedures can restore normal hip biomechanics and function for pets weighing from 2 kg to 12 kg (131). The system was designed to offer a superior alternative to femoral head ostectomy with a greater range of motion, increased function, and pain-free joints (35).

The Micro THR system consists of a 3-component modular system, a cup, a tapered and collared femoral stem and a femoral head of small sizes. The components are interchangeable and sized based on the patient's anatomy seen on radiographs. Nowadays, femoral heads, CFX or BFX acetabular cups, and monoblock or modular CFX femoral Stems are available. The Nano THR system is designed for the smallest canine weighing between 2 to 5 kg. It features a 6mm fixed femoral head mounted on a monoblock collared femoral stem and a 10mm UHMWPE cup that is a smaller version of the CFX cup (148). The femoral stem comes in 3 sizes (10mm, 12mm, and 14mm) based on neck length. Due to the small size of the implants and patients, bone cement is required for stabilization (149).

The surgical procedure for small cemented implant placement is similar to larger breeds CFX THR, with manual manipulation of surgical tools instead of power (21). The femoral excision is carried out using a powered sagittal saw and guided by the femoral neck excision guide to establish the correct angle (129). Acetabular preparation is done with solid fixed reamers on a shaft used in a Jacobs chuck and a high-speed burr, while the femoral canal is opened using a cutting awl and tapered reamer by hand to avoid fractures (131). The MicroTHR instrumentation set includes additional the fluted femoral reamer. Other instruments used to perform MicroTHR, but not included in the set, are also utilized (150). A cement restrictor is not used in the femoral canal. For a Micro THR, a modular femoral head is chosen based on trial reduction and joint tightness, while for a Nano THR, trial stems with fixed femoral heads of different lengths are used to determine the correct size for cementing. Proper bony landmark attention and matching the implant with the patient's acetabular axis and anatomy are crucial for best outcome (131).

Liska study conducted on 66 dogs undergoing Micro THR, found that 91% had excellent outcomes, while 9% experienced failures, including 6% due to unmanageable luxation and 3% due to being undersized for the prosthesis, a common recognized cause of luxation, resulting in explantation (35). The Micro THR procedure, outcomes, and complications were comparable to those in larger dogs undergoing THR, excluding the use of specialized instruments in smaller animals (35). Whereas for the Nano THR procedure, the most frequently reported complication was postoperative femoral fracture, which occurred in 3 out of 12 patients in a study. One case of medial acetabular displacement was also reported. Despite this 33% complication rate, all patients were expected to return to a good to excellent level of function by 12 weeks post-surgery, either through revision surgery for fracture fixation or through a conservative treatment plan for cup displacement (148).

Investigators reported that early technical surgical errors due to the small size of the patients were the cause of postoperative complications. However, with increased surgeon experience and advancements in surgical instruments and techniques, the outcome of these THR cases is expected to improve (35).

4.2.5 Surgical technique for Biomedtrix total hip replacement - Universal hip system

Figure 15- The Biomedtrix positioning board for a dog undergoing Biomedtrix BFX total hip replacement.

To perform a Biomedtrix THR procedure, patients are positioned into lateral recumbency, with the hemipelvi in a sagittal plane. To secure this position, a device like the BioMedtrix positioning board or a vacuum-assisted moldable bag is used because accurate acetabular preparation and implant placement require the patient to remain stable and properly positioned in the pelvis (28). A craniolateral approach is made to the coxofemoral joint, the hip is luxated, the femur is rotated 90 degrees externally, and the arthritic femoral head is exposed (151). The neck-cutting guide is positioned along the cranial portion of the femoral neck. When putting a collared CFX femoral stem, the cut angle is critical because it determines the position of the stem within the medullary canal when the collar meets the bone edge during final implant seating. The final neck cut should be a few millimeters above the lesser trochanter level (21). A high neck incision that maintains cortical and cancellous bone proximally may contribute to improved initial cementless femoral implant stability and torsional resistance during osseointegration (152).

The initial preparation for implant sites is done using a technique specifically for placing press-fit BFX implants. Should it later be decided to use a CFX implant instead, slight adjustments to the bone bed will be necessary for the cemented acetabular component, but the femoral canal will already have been prepared to accept a cemented stem (21). As mentioned earlier, the Micro Hip method resembles CFX system but has variations in instruments due to the smaller patient size (131).

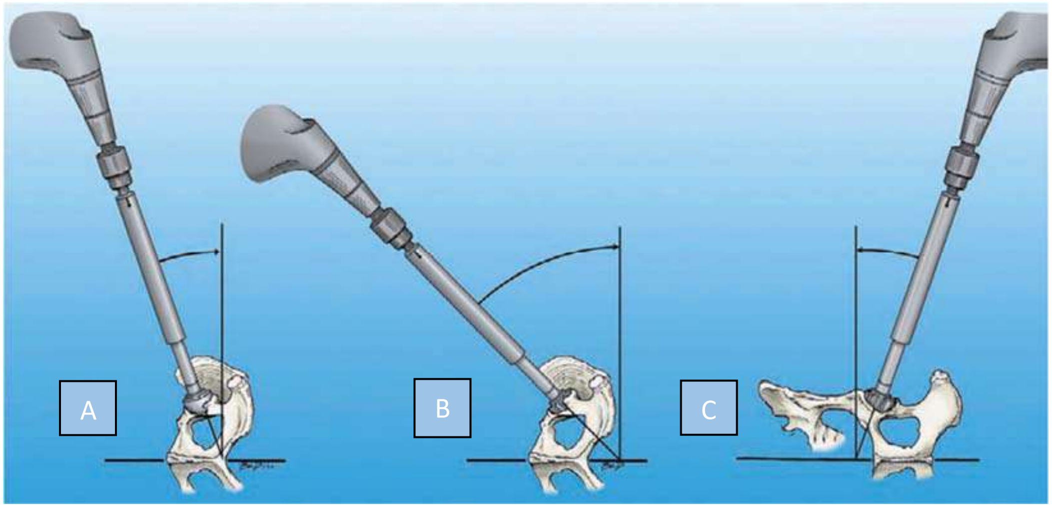

Figure 16 - (A) Starter acetabular reamer - (B), (C) Finishing acetabular reamer in two positions (21).

*Acetabular reaming is initiated using the starter reamer positioned approximately 15–20 degrees ventral to perpendicular to minimize dorsal migration and minimize removal of the acetabular rim (A).
*Once the depth of the hemispherical bone bed has been established, the finishing reamer is used to create a press-fit and set the orientation of the cup. The finishing reamer is aligned with the anatomical axis of the acetabulum at approximately 45 degrees ventral to perpendicular (B) and in 20 degrees of retroversion (C). (21)

The acetabulum is first prepared in two steps reaming process to deepen and widen the often severely remodeled and arthritic acetabulum. It is therefore, surgically exposed using Meyerding and Hohman retractors around the acetabular rim and on the proximal femur (131). The placement of the ventral transverse acetabular ligament reveals the true acetabulum and not a pseudo-acetabulum from the existing hip dysplasia. Reaming is required in this area to give the most accessible bone material for implant site as well as to provide a solid interference fit between the bone and the BFX cup at its cranial and caudal poles. For optimum bone ingrowth, the ideal prepared bone bed exposes healthy, bleeding cancellous bone cranially, dorsally, and caudally inside the acetabulum. The starter reamers are odd numbered (19, 21, 23, 25, 27, 29, 31, 33mm) and the finishing reamers are even-numbered sizes (20, 22, 24, 26, 28, 30, 32, 34mm). The first process is to use a cheese “grater-type” reamer, 1mm smaller than the intended BFX cup, to remove subchondral and cancellous bone, and to achieve the proper depth and width for the preparation. The finishing reamer, more precise, is then used as trial sizing, to fine-tune the surface and width of the bone bed ensuring a proper fit for the BFX cup, therefore 1mm bigger than the intended CFX cup for cement mantle space. To achieve proper anatomic alignment in a press-fit cup placement, it is important to pay close attention to the reaming process. Instrumentation is utilized to guarantee correct orientation and alignment in relation to cup retroversion and closure angles. Additionally, minimizing movement during reaming is crucial in ensuring the accuracy of the final bone bed size (21).

The BFX cup features a hemisphere shape, except for the last 3mm of the edge, where it becomes cylindrical to fit the interference at the cranial and caudal poles of the implant, meaning to seated to its full depth (21). The metal-backed shell provides extra support to the UHMWPE liner, allowing for less coverage of the dorsal boney area to achieve stability. This design of the BFX cup, along with the need for less pelvic bone, makes it versatile and the preferred option compared to a cemented CFX cup in most surgical situations (153). The surgeon can decide, only in specific cases like small pelvis, inadequate acetabular development, or severe dorsal rim loss, to remove the medial acetabular wall cautiously to seat the BFX cup and engage cranial and caudal poles while preserving bone and pelvis stability (154). A particular size BFX acetabular implant's reamer is used for trial sizing due to matching depth and width profiles. To confirm the desired cup positioning and the fit with the prepared bone bed, we use a trial CFX acetabular cup one size smaller than intended BFX size after final bone bed preparation. For cementless biological fixation, the cup implant is then inserted. A major advantage of using a cementless BFX cup is the ability to make slight repositioning adjustments with an offset cup positioner head or fully remove and reinsert it. The implant is finally impacted using an impactor instrument and mallet until press-fitted (21).

In uncommon cases where a CFX cup is preferred, modifications are made to the prepared acetabular bed to create defects for the cohesive cement intrusion and anchoring. With a drill bit or a small curette, three small keyholes are created in the cancellous bone at the cranial, dorsal, and caudal aspects of the acetabular rim to allow the cement to penetrate the bone, thereby increasing the shear strength at the bone-cement interface (155). A crucial step is to thoroughly clean and dry the bed unlike BFX applications where the implant does not require complete cessation of bleeding in the bone site, in fact, the formation of a blood clot serves as the initial step for fibrous tissue to grow and eventually lead to bone formation in that case (21). Cement application is then followed by fitting of the CFX cup onto the cup positioner handle with the central cup positioner head as with the BFX cup, but seated by hand rather than impacted with the mallet in the correct angles. The CFX cup is one size smaller than the corresponding size of the Universal finishing reamer (21).

The femur is then prepared by initial reaming process followed by the use of sequential femoral broaches to expand the canal to the size needed. A technique commonly used for either a BFX or CFX stem is employed until the final implant selection is determined. The optimal alignment of an implant should align with the long axis of the femur in both cranial-caudal and medial-lateral directions.

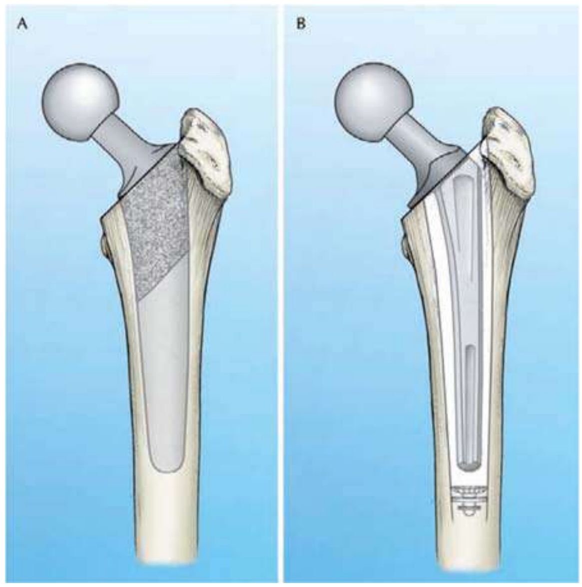

Figure 17- A) BFX stem press-fit into the femoral canal following preparation using the broaches. (B) A CFX stem surrounded by bone cement. The distal flow of bone cement is limited by a cement restrictor placed distal to the stem tip. (Image courtesy of BioMedtrix, Boonton, NJ) (21)

The ideal way to enter the femoral canal is by going through the trochanteric fossa along the long axis of the femur using an intramedullary pin for a good alignment. To prevent valgus-varus deviation, pins should be aimed towards the center of the patella. For proper cranial-caudal alignment, the pin should follow the long axis of the proximal femur, as determined during templating with a lateral radiographic view. In normal femoral anatomy, the pin should be slightly above the patella. In case of a downward-angled femoral shaft, the pin should be aimed higher, above the patella. These guidelines apply to all instruments used during the preparation of the femoral canal. The opening is then expanded through the remaining caudal wall of the femoral neck using a drill bit, tapered power reamers, and larger BFX femoral broaches until the desired size is reached for the BFX stem, and each numbered broach corresponds to a specific BFX stem size. The opening in the caudal neck must be placed to guide the broach into the canal in a neutral or slightly anteverted position, not excessively anteverted or retroverted. The broaching technique must be precise because it affects stem alignment and position and the surgeon is required a serious learning curve for it. The final broach is used to test the size and fit of the stem. The final stem size is determined through a combination of preoperative templating and in-operation resistance change during sequential broaching. The last 5-10mm of broaching should be met with resistance to achieve proper seating, with a sound pitch change indicating the correct fit. The femoral preparation for a cementless BFX stem is evaluated using visual, auditory, and touch senses. If excessive resistance is felt, it may indicate the broach is too large or misaligned, potentially leading to fracture. If resistance is lacking, it may indicate a lack of cancellous bone quality and the stem should not be placed. The drive length should be roughly two-thirds to half the length of the beaded section of the stem. If so, the stem is then impacted to the desired depth with an impactor instrument and mallet, ensuring that the final resting position is at the same level or within a few millimeters of the level achieved with the final broach. If stem extraction is necessary during surgery, the surgeon secures the stem extractor to the stem and removes it using a slotted mallet against an impaction block. If resistance occurs, a Vise-Grip can be used (21).

However, when traditional press-fit methods are not feasible or a patient's condition requires the use of cemented implant, a CFX stem is cemented in place. Before that, trials of the stem are used to practice positioning within the femoral canal, ensure proper angles of the neck cut and collar, check for proper axial placement, and test for hip reduction. This helps prevent issues with final implant placement, such as improper hip reduction where a modification to the level of the femoral neck cut is necessary to decrease the length of the femur and decrease the tension during hip reduction. A femoral cement restrictor made of polyethylene may be used for patients with implant sizes for standard and large breeds. The CFX stem is typically 1-2 sizes smaller than the final BFX broach used for canal preparation to allow at least a 2 to 4 mm of cement space and a premade centralizer can be placed on the stem tip. It is important to take precautions to prevent contamination of the stem. The femoral canal is cleaned before cement infusion, as well as the stem before insertion (21). Research has revealed that if the stem is wet or contaminated with marrow or fat, the bonding strength between the stem and cement can decrease by more than 80% (156). The CFX stem is inserted into the cement-filled canal until the collar of the prosthesis reaches the cut in the femoral neck, keeping the implant steady until the cement sets.

After placement of the femoral and acetabular implants, trial femoral heads are used to evaluate the tension of the hip joint during reduction. The alignment of the femoral stem's anteversion with the acetabular retroversion is also evaluated while the leg is held in a neutral walking position.

Additionally, potential impingement areas across the joint during range of motion are identified, particularly during external rotation and adduction of the hip, to prevent postoperative hip luxation issues. The length of the femoral neck is adjusted by selecting the appropriate head size until the correct level of tension with full range of motion is achieved. The trial head is then removed and replaced with a metal chrome-cobalt head. The final femoral head is highly polished to minimize surface defects that could cause abnormal wear on the polyethylene cup surface. Care is taken to prevent the newly placed femoral head from coming into contact with any abrasive surfaces during placement or hip reduction, to avoid accidental surface scratches. Once the final hip reduction and assessment are completed, the joint capsule and the soft tissues supporting the hip are closed, in sequential layers (21).

4.3 Zurich system - Locking screws

Figure 20- (A) Revision cup. Outside (left) and inside view of the shell (centre) and inside view of the cup (right). (162)

Figure 19- Initial drilling with implanted femoral stem and proper position of jig. (130)

Figure 18- Fifth-generation Zurich THR femoral and acetabular implants. (130)

The Zurich Cementless THR (manufactured by Kyon in Zurich, Switzerland) was developed at the University of Zurich in the late 1990s as mentioned in the history chapter (157). The unique aspect of this system is that the femoral stem is anchored to the endosteal surface of the medial femoral cortex with locking-screw fixation for primary stability (157), which is eventually strengthened through bone ingrowth to a porous titanium plasma-sprayed coating surface (158). The key feature of this prosthesis is the locking screw anchorage of the stem, avoiding the coupling effect of the medial and lateral cortices and approximating the stress distribution of the proximal femur, ultimately enabling bone remodeling around the screws. The locking screw technology eliminates the risk of micromotion in the femoral component. Whereas the Zurich acetabular component uses both initial press-fit stabilization and long-term stabilization through bone in-growth, facilitated by its porous design which enables fluid convection and osseointegration over time (157) (159) (160).

Despite the common steps of procedures for hip replacement, differences in implant design and fixation techniques exist and might impact the results. The Zurich Cementless system, first prepares the femur before proceeding to acetabular preparation and implantation. The preparation of the acetabulum is the most challenging aspect of the procedure, as well as careful positioning of the stem, drilling access and screw holes in the medial cortex of the femur, which are then secured with screws. The recommended order for screw placement is 3, 1, 2, 4, 5, and the most proximal hole should now be filled with a bicortical screw to reduce the risk of avulsion from the medial cortex before osseointegration, particularly in larger breeds. One advantage of the Zurich stem is that it is not a collared prosthesis and does not require full seating. However, it must be inserted deep enough so that the proximal screw hole is at least one screw hole diameter distal to the osteotomy. If the press-fit is lost in case of repositioning, several options are available, including increasing the cup size (if possible), using the Zurich Cementless revision cup, cementing a Zurich cup, or using a custom femoral head with a CFX or BFX Biomedtrix cup (21). The different material and manufacturing of the Zurich hip components are mentioned in figure 7 for further information.

Complications vary in type and frequency depending on the time elapsed since the surgery. Generally, luxation, fracture, and early cup loosening tend to occur within the first 6 months after surgery, which is considered the short term. On the other hand, other complications such as stem loosening, late cup loosening, and implant breakage tend to happen on the long term (161). As we can see in figure 20, improvements have been made to its implants over the time to address problems such as luxation, and to increase press-fit of the cup and reinforce the stem. The cementless prosthesis has undergone modifications to its cup, including a flattened pole and the addition of three parallel ridges along the periphery of the shell, a double shell to enhance osseointegration of the cup and amorphous diamond-like carbon coating of the head to reduce friction and particle formation and create a smooth hard, bearing surface. The polyethylene liner has been extended to better balance the center of motion, resulting in a 100° head coverage. The peg has been redesigned to avoid stress failure and the stem has undergone shot-peening to increase its resistance, resulting in a significant decrease in complications compared to the first generation of the prosthesis (160) (157) (18). Additionally, the surface of the stem and cup has been modified with hydroxyapatite, promoting rapid bone integration (161). The system is available in a variety of stem and cup sizes.

The Zurich Cementless prosthesis has been implanted in a big number of dogs, various models have been introduced to the market in recent years and the developments continue to meet the demands of many patients. Diverse options including a dual mobility cup for a better rotation of the hip and an acetabular revision cup available from the Kyon system as the figure 18 displays (162). This system has been proven to be a successful treatment option for various orthopedic conditions in canine hip joints. The success of the outcome depends on the surgeon's experience and proper case selection. The complication rates are comparable to other THR systems, and the majority of complications can be revised successfully (130).

4.4 Innoplant Helica system – Screw-in implants

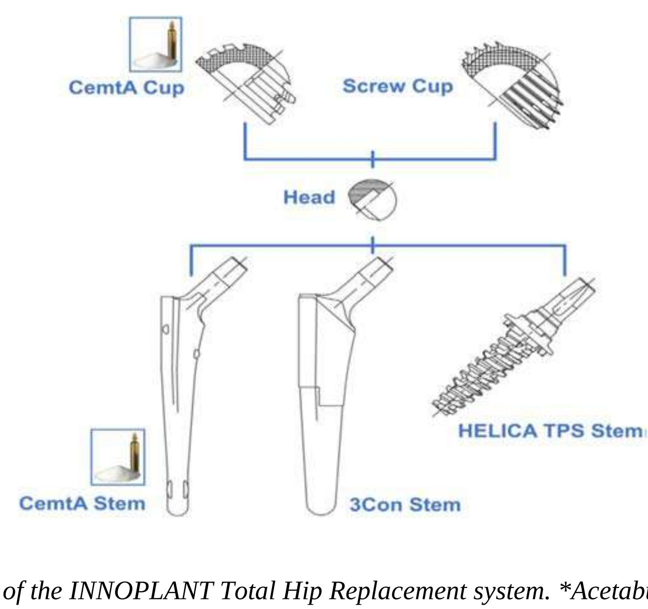

*Figure 21 - Components of the INNOPLANT Total Hip Replacement system. *Acetabular cups: CemtA Cup and Screw Cup. *Three different femoral stem options: CemtA Stem, 3Con Stem, and HELICA TPS stem. (Courtesy of INNOPLANT Veterinary, Hannover, Germany.) (128)*

The screw-in components, previously referred to as the HELICA Canine Cementless Hip System and also known as the HELICA-endoprosthesis in veterinary literature, are the first generation of screw-in implants that resemble other cementless systems (163). The first-generation femoral stem comes in five sizes and includes self-tapping threads, which enable both the femoral stem and acetabular cup shell to be screwed into the prepared acetabulum, femoral neck and proximal metaphysis. The femoral stem is "short", and it is fully implanted within the femoral neck and proximal metaphysis without touching the lateral cortex. This design enables force-controlled implantation and makes the implants firmly anchored in the bone; it also spares bone because the stem is anchored in the metaphysis; therefore, reaming of the femoral diaphysis is not necessary (164). The rough-blasted surfaces increase the bony on growth and osseointegration, providing long-term stability. Additionally, a flange is located on the stem that seats against the femoral neck to improve stability and load transfer and the acetabular insert, which joins with the femoral head (165). The femoral head is coated with titanium nitride for a hard and wear-resistant bearing surface (166). The implantation procedure was initially explained in the literature by Hach and Delfs (167).

The screw-in endoprostheses offer several benefits including a shorter surgery time, due to its ease of implantation and a rapid learning curve compared to other systems, reducing the risk of surgical site infections. One significant difference between the screw-in endoprosthesis preparation of the proximal femur in comparison to the BioMedtrix and Zurich systems is that the osteotomy is conducted at the junction of the femoral head and neck based on the prosthesis size, thereby preserving the femoral neck (167). The preservation of the femoral neck during the procedure maintains the normal joint biomechanics by preserving anteversion. The screw-in system has a lower incidence of luxation, and can better tolerate deviations. The large positive profile threads of the screw-in endoprostheses provide increased stability, reducing the risk of femoral fractures (168) (167). The success of bony ongrowth/ingrowth for cementless implants depends on the initial stability of the implant (169). Stress at the bone-implant interface may also be reduced due to the increased implant surface projected orthogonally to the direction of force (170).

Despite the idea that preserving anatomic structure and minimizing bone removal should maintain joint biomechanics, a biomechanical study has found that the first-generation screw-in femoral prosthesis (formerly known as the HELICA Canine Cementless Hip System) causes alterations in strain distribution in the proximal femur and exhibits initial micromotion (171). This is thought to be due to its short length and location entirely within the proximal femur. This may contribute to the aseptic loosening of the femoral stem seen post-implantation. Additionally, loosening of the acetabular cup may also contribute to femoral stem loosening (172). Similar to other conventional femoral prostheses, the original screw-in femoral prosthesis has limitations (165). The suggestion to shorten the femoral neck through more distal osteotomy has been proposed to better position the femoral prosthesis and engage the lateral femoral cortex for increased stability (173). However, this method may result in a loss of the proposed biomechanical benefits of keeping the original length of the femoral neck, such as preserving version angles and inclination. A recent biomechanical study showed that this modified technique led to smaller prosthetic femoral head and neck angles, as well as increased compressive medial bone strain, indicating that stress shielding may not be the main cause of implant loosening (174). Additionally, the study revealed the presence of implant macromotion, which could also potentially lead to future implant loosening (174). As a solution, the investigators proposed using a larger implant with a longer neck length, combined with a more lateral osteotomy, to engage the lateral cortex while preserving a greater neck angle. The second generation of femoral neck implants now features an advanced short stem design, known as the Helica TPS stem by Innoplant Veterinary, aimed at reducing the risk of aseptic loosening. Both generations of femoral stems have identical inclusion criteria. The longer femoral neck implant provides improved lateral cortical purchase while still preserving a significant portion of the femoral neck (174). It is also a modular design, allowing for customization to meet the specific needs of each patient. The TPS stem consists of three components, as illustrated in Fig. 21. The original femoral stem design has also been improved with the addition of different flange sizes that are interchangeable with the stem, providing greater surgical planning flexibility and increased resistance against shear forces at the implant-femoral osteotomy site interface (175). The standard heads are 18 mm in diameter. They attach to the femoral stem using a Morse taper and are compatible with hybrid THR configurations as they can be used with femoral stems from other manufacturers such as Kyon Zurich and BioMedtrix. A 15 mm diameter head is also available for use with the smallest Helica acetabular cup. The acetabular cups are made of rough-blasted titanium and feature self-tapping threads. The acetabular liner is available as self-retentive or unconstrained, with the exception of the smallest diameter liner, which is only available as unconstrained (176).

What sets the Innoplant system apart is its screw-in cementless femoral stem (TPS stem) and acetabular component (Screw Cup) as shown in Fig. 21. The Innoplant THR system, offers both cemented and cementless components as illustrated in figure 21. These components are designed to enhance stability at the bone-implant interface, reduce micromotion, and decrease stress shielding on the bone (175). Aseptic loosening is the most frequently reported complication, but it appears that the incidence has decreased with the introduction of the second-generation stem (176). Despite this, it is important to note that some cases of loosening have occurred several years after surgery, therefore ongoing monitoring is necessary to confirm the success rate associated with the second-generation stem. There is not enough data available on clinical testing to determine the efficacy of the modifications to the femoral stem or on the long-term outcomes or complications associated with the HELICA TPS stem system or a comparison between the two generations of the femoral stem (176).

4.5 Postoperative Care for THR

As many articles mention, the management of patients after undergoing a Total Hip Replacement is similar regardless of the hip implant or system used, but may vary depending on the surgeon's experience and preference (131) (130) (128).

Postoperative radiographs are taken in the same views and bones position as preoperatively for proper implant evaluation and the fill of PMMA assessment for a cemented THR. Orthogonal pelvic radiographs are conducted for patients who have undergone micro THR (177). Dogs are allowed to return home when they are able to move around on their own. This typically happens within one or two days, but larger or overweight dogs may require a longer hospital stay. Some complications, such as stem loosening and polyethylene wear, have been reported to occur several years after a THR surgery, making regular follow-up evaluations necessary for most THR patients (178) (179) (16). A recommended post-THR evaluation schedule includes appointments at 30 days, 60 days, 90 days after surgery and then every 12 months. Clinical evaluations include assessing muscle mass, hip range of motion, lameness, gait, and the presence of pain when the hip is manipulated. Radiographic evaluations should also be performed at each scheduled appointment and if there are any concerns with the recovery process (130). When reviewing follow-up radiographs, it is essential to compare them with the radiographs taken immediately after the surgery. It is important to inform owners that any lameness related to the hip, occurring after a complete recovery from THR surgery, is not a typical or expected outcome.

The postoperative management after a Total Hip Replacement (THR) procedure involves limiting physical activity to controlled leash walks for 6 to 8 weeks, with a gradual return to normal activity levels typically by 12 weeks. On successful recovery, most THR patients are able to resume their normal active lifestyle without any significant limitations (21).

Patients usually start partially weightbearing on their operated limb within 24 to 48 hours after surgery and show a steady improvement in their function over time. To provide stability during the initial stages of recovery, body harnesses and belly slings are recommended. Any sudden changes in gait and weightbearing in the first 2 to 3 weeks after a cementless THR procedure can indicate a potential complication, and a reassessment with radiographs should be performed (131). For patients with limited hip joint motion due to muscle/tissue tightness after surgery, a controlled stretching and exercise program may be recommended (128). Rehabilitation is also necessary for THR patients with special cases like amputee on their opposite hind limb or have other concomitant orthopedic injuries. The aftercare of small dogs after Micro THR is often simpler compared to that of larger dogs, as small animals can be easily carried during rehabilitation (21).

5. THR failures, complications and their management

Since the early pioneers of hip replacement in dogs published their experiments in 1991, a wealth of knowledge has been accumulated (180). The importance of durable materials, especially polyethylene, was quickly recognized, leading to generations of implants with improved composition and design (181) (182) (183). Despite many generations of implants, the search for perfection continues, driven by high expectations for postoperative function.

Although patients are selected with care and surgery is executed with skillful planning, complications can still occur. THR remains a technically challenging procedure that can result in complications, although almost all of them can be successfully resolved. The level of technical difficulty involved in the procedure requires the surgeons to go through a learning curve to develop the necessary skills for consistent success, case after case (184). It is therefore quite important for the surgeon to be aware of the probable risks of complications and how to address them, just as much as his ability to perform the surgery itself. These complications are generally categorized as either mechanical or biological failures (21). For a successful revision, identifying the factors that led to the failure in the first place is necessary to correct or avoid repeating the original error. In this thesis, those failures, their risk factors and their management are described as well as the major complications seen in different THR systems (Biomedtrix, Zurich, Helica) according to literature. The Helica system is unfortunately not as developed in the literature perspective as the other systems.

5.1 Biological failure and their management

Biological failure can encompass different issues such as a lack of bone ingrowth or ongrowth for cementless implants, or a decrease in bone support (e.g. bone resorption, osteolysis, and osteonecrosis) for both cemented and cementless implants (21). Factors contributing to biological failure may include aseptic loosening, septic loosening, and stress protection. In this context, we will focus on managing the consequences of aseptic loosening mainly as it is a common complication for many of the THR systems.

5.1.1 Aseptic loosening

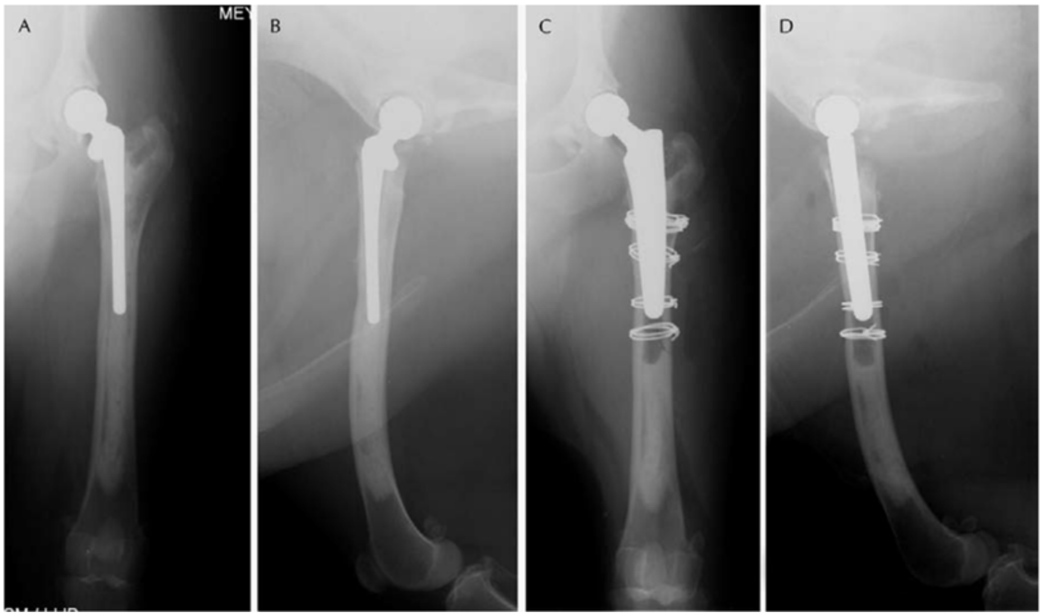

Figure 22- Cranial-caudal (A) and lateral (B) radiographs of the femur of a 3-year-old Labrador retriever who received a cemented total hip prosthesis at 9 months of age. A radiolucent line is visible on the caudal aspect of the stem–cement interface and the stem is retroverted, indicating that debonding has occurred. An extended trochanteric osteotomy was performed (C and D) and stabilized with four double-loop cerclage wires, the stem and proximal portion of the cement mantle were extracted, and a cementless stem was implanted. Bone ingrowth and long-term stem stability were confirmed in subsequent radiographs. (21)

Aseptic loosening refers to the loosening of a hip prosthesis without any clinical or microbiologic signs of infection. This condition can be caused by a biological process resulting from wear of the contact surfaces, or by mechanical failure. In both cases, the motion at the bone-implant or bone-cement interface becomes unacceptable.

The biological process causing aseptic loosening occurs when submicron particles of UHMWPE migrate, leading to osteoclastic activity mediated by macrophages. This process results in bone resorption and the formation of a membrane between the host and implant, leading to unacceptable motion at the bone-cement interface. The parameters affecting this process include prosthesis design, size, and component, surgical technique, loading forces, thermal and chemical factors, and host response. Whereas the mechanical failure causes aseptic loosening, often located between the implant and cement. It includes cement-implant debonding, cementless stem subsidence, implant mispositioning, poor cementing or cementless technique, implant displacement, use of implants with an expired shelf life, third body wear, early excessive repetitive interface micromotion, and traumatic events. Mechanical failure can result in excessive production of particles of UHMWPE and debris, contributing to biological aseptic loosening (185).

Early detection is critical for successful revision, which requires a careful attention of the dog's owner to any reduced clinical function, as well as a thorough review of follow-up radiographs. Follow-up radiographs should be compared to those taken immediately after the surgery (21). In the need of revision, performing a single-stage revision of the cup or stem is more successful if done before extensive remodeling in the presence of osteoclastic activity. Fibrovascular membrane and bone specimens should be cultured to rule out hidden infections. If the acetabular cup becomes loose, the surgeon may choose to reimplant a cementless cup if the DAR (dorsal acetabular rim) is intact and there is enough cranial and caudal bone stock. However, if the bone stock is inadequate, only a cemented cup can be used. If the DAR is insufficient, the dorsal rim can be augmented, allowing for the possibility of reimplanting either a cemented or cementless cup. In the case of aseptic loosening of the stem, the surgeon will remove the stem and reimplant a new cementless stem if the bone stock is adequate. However, if osteolysis has occurred and the bone stock is insufficient, the femur will be protected with a double loop cerclage and possibly a neutralization bone plate. Later, the surgeon may consider reimplanting a cemented or cementless stem (21). Loose implants are usually easy to remove. However, cemented implants can become loose again due to the absence of cancellous bone and stable fixation. Hence, replacement implants should preferably be cementless, with bone stock voids and defects. To prevent femoral fissures or fractures during or after surgery due to thin or weak femoral cortical bone, cerclage wires may be placed preventively. Optionally, the stem can be cemented, and stability can be augmented by a lateral neutralization plate with screws extending from the greater trochanter to the distal femur. In cases with advanced osteolysis and extensive bone changes, explantation of the prosthesis may be the best option. This results in function similar to a femoral head ostectomy (185). Revising an aseptic loose hip replacement prosthesis can recreate a pain-free joint with a return to objectively normal function. The minimum expectation should be to achieve subjectively normal function during normal daily activities.

5.1.2 Septic loosening

According to Tsukayama et al., postoperative infections after arthroplasty can be classified as early, late, hematogenous, or incidentally positive (190). Early signs of infection may include delayed wound healing and purulent discharge, while late infections may have a delayed presentation of over six months in some cases. Late infection is the most common presentation in dogs (191). Risk factors for infection include preexisting infection in a patient, bacterial dermatitis within the draped field, a suppressed immune system, occult septic arthritis (192), preexisting *brucella canis* infection (193), prolonged surgery, and previous surgical exposure.

Although bacterial cultures are often obtained during THR surgery, the presence of positive cultures does not necessarily indicate a postsurgical infection (194) (195). In cases of a septic loosening where there is an active infection, attempting to save the implanted prosthesis using systemic or locally implanted antibiotics is unlikely to be effective. However, there have been successful reports of revising an infected cemented prosthesis using a press-fit cementless stem (196) (197). If the acetabular cup becomes loose due to a septic origin, the cup must be explanted and a bacterial culture must be done before it can be reimplanted later. Similarly, if a cemented or cementless stem becomes loose due to septic loosening, explantation with a bacterial culture is likely the next step. If the infection is treated successfully and a negative culture is obtained after antibiotic treatment, the possibility of reimplanting a stem can be considered later on (21). Treatment for infection typically involves explantation of the prosthesis and any surrounding cement mantle, as well as debridement of infected and necrotic soft tissue. Antibiotics are administered for a prolonged period of time, selected based on the sensitivity of the causative organism (185).

5.1.3 Stress shielding

Moreover, stress shielding can contribute to bone resorption and implant loosening (21). Addressing extensive bone loss resulting from stress shielding can pose a significant challenge for revision. To achieve success in revision, early detection and close monitoring of progression are critical.

5.2 Mechanical failure and their management

There are various complications associated with mechanical failure, such as luxation, femoral or acetabular fracture, stem subsidence, implant failure, and stem or cup avulsion. When there is excessive micromotion, it can lead to a biological failure that causes the osseointegration of cementless implants to fail. Additionally, excessive micromotion can generate wear debris and become closely linked with aseptic loosening. Failure of osseointegration is usually due to inadequate initial press-fit or other types of initial fixation and is therefore categorized as a mechanical failure (21).

5.2.1 Luxation

Figure 23- Luxation secondary to subsidence of a cementless femoral stem. Subsidence of this undersized cementless femoral stem is present 2 weeks aft er surgery in this 11-month-old female German shepherd. As a result of this subsidence, bone along the femoral neck osteotomy contacts the acetabular rim, causing subluxation of the femoral head. Revision involved implantation of a larger femoral stem. (185)

Luxation of the replaced hip is most commonly observed during the first few weeks following hip replacement surgery (198) (199) (200). Post-operative hip luxation has been associated with multiple risk factors (200). Early luxations are typically linked with mistakes in implant positioning (cup anteversion, stem retroversion or anteversion) resulting in secondary impingement or periarticular osteophytes, with subsidence, as well with too much laxity, joint capsule strength or integrity, tension in periarticular soft tissues, and the presence of fibrous tissue (201). However, late luxation is often associated with trauma or implant positioning that lasted for a short period (185). Dorsal luxations can occur due to excessively large angles of lateral opening (ALOs), while ventral luxations can arise from excessively small ALOs (200) eliminating passive capture of the head (202). Ventral luxation is much less common than dorsal luxations and has been reported to occur in only 1.8% of cases (203). Risk factors for ventral luxation include total hip replacement in Saint Bernard breeds with lower femoral displacement ratio, short femoral neck extensions, and a reduced ALO (203), ventroversion of the acetabular cup or excessive ventroversion may result from the surgeon's concerns to avoid dorsal luxation. Luxation that results from laxity may occur in dogs with chronic dorsal displacement of the femur before surgery (199). In some cases, at the time of surgery, tight tissues may lead to the selection of a relatively short femoral neck, but a few weeks later, with tissue relaxation, the prosthetic hip may luxate. An additional risk factor for luxation is contralateral hind limb amputation (204), also dogs with the habitude to lie in abdominal recumbency with abduction of hindlimbs; however, these factors are considered less significant than ALO (200). Whereas for Small breed dogs and cats, there is similarity of occurrence to that of large dogs (205) (35) (206).

Some luxations after total hip replacement (THR) can be managed successfully with closed reduction and supervised activity for a few weeks. However, most cases require surgical intervention to address the underlying factors that predispose to luxation. During surgery, the joint is reduced, and the luxation is recreated to identify the chain of events leading to it (200). The simplest surgical approach for managing luxation is to increase neck length, which may laterally reposition the femur and prevent impingement. However, this technique carries a higher risk of femur fracture, postoperative discomfort, and gait abnormalities (199). Repositioning of the acetabular and/or femoral components is often the best approach for preventing reluxation. Acetabular repositioning is the most common technique used. Invariably, revising the cup position is necessary in cases of dorsal luxation, and revision is usually successful in most cases of ventral luxation (203). However, one study suggested that the angle of lateral opening and the degree of cup retroversion were not reliable indicators of luxation risk (207). Other options for revision include a triple pelvic osteotomy (TPO) to increase femoral head capture and increasing joint capsule tension with an iliofemoral suture or placement of a prosthetic joint capsule (201). The surgeon must critically evaluate implant positioning and consider individual patient conformation when determining the best course of action.

If a luxation occurs in BFX cups within the first few days of placement, the cup can be removed by tapping its dorsal aspect and rotating it out of its bone bed. If there is no damage to the cup, it can be reimplanted with proper orientation. However, if bone ingrowth has occurred, removal of the cup requires tapping a thin osteotome on its medial aspect. The acetabular area can be expanded with sequentially larger reamers, followed by placing a larger acetabular cup (208). Otherwise, the last option would be to replace the cementless with a cemented cup (185). For cemented cups, both the cup and PMMA can be removed, and a new cemented cup can be placed. In the case of Zurich cups, if the cup has been in place for several weeks and is well-seated, repositioning may require removal. However, the surgeon should first attempt to manipulate the position of the cup. If the same size cup cannot be press-fit, a larger cup can be used, with appropriate reaming. Another option is to use a Zurich Cementless Revision Cup, although long-term follow-up data is not yet available according to the author (185) (21).

While technically challenging, revisions can usually restore joint stability permanently, and a satisfactory result can be anticipated. If revision surgery is unsuccessful or luxation is confirmed to be uncontrollable, explantation may be the only option (209).

5.2.2 Femoral and Acetabular Fractures

Figure 24- (A) following BFX THR in a 5-year-old golden retriever with a #9 stem, acute onset lameness occurred 2 weeks postoperatively and radiographs reveal that stem subsidence, retroversion, and femoral fracture have occurred.
(B) The fracture was stabilized with single-loop cerclage wire; the stem was revised to a CFX #8 and a neutralization plate was placed.

Following the classification of femoral fractures associated with canine THR, the cause of femoral fracture depends on several factors, including the type of implant used, the location of the fracture, the stability of the implant, and the quality of the bone stock in a total hip replacement (210) (211). Intraoperative fissures and fractures can occur, but the majority happen within the initial week after surgery. The risk of periprosthetic femoral fracture is due to variations in the modulus of elasticity of bone, bone cement, and the metal femoral component. This creates a concentration of forces around the stem's tip.

During the learning curve for cementless total hip replacement, femoral fractures are more frequent compared to the placement of a cemented stem. This is due to the impaction needed to achieve a press-fit fixation. If the impaction is excessive, particularly when misaligned with the femoral axis, it can result in iatrogenic fissures or fractures (185). Fractures of the femur with the BFX stem are commonly linked to the subsidence of the femoral stem, which becomes unstable with often a good bone quality. However, it may be difficult to determine whether the stem subsidence causes the fractures or the fractures cause the subsidence. Moreover, when preparing the femoral canal for cementless implants, excessive broaching can remove all cancellous bone, resulting in contact between the stem's endosteal surface and the bone. This leads to an excessive load on the cortical bone.

On another hand, osteopathy and iatrogenic fissures that arise during reaming are risk factors that may lead to femur fractures following cemented THR. Owners of high-risk patients such as senior dogs with osteoarthritis or who have had prior hip surgery, should be made aware of the risk factors (212). Trauma, severe load concentration, and increasing torque can all induce mid-diaphyseal fractures towards the extremity of the femoral stem (213). Fractures of the femur caused by the CFX system typically occur at the stem tip level and are connected to stress concentration at that position. These fractures are most prevalent distal to the prosthesis and entail a stable stem and high bone quality (214). They are generally oblique and frequently result in cement mantle loss at the stem tip. Another possible cause of fractures after cemented THR is the lack of a cement mantle at the stem tip due to incorrect stem placement or direct stem contact with the endosteum (21). Fractures associated with the use of the Zurich system (Kyon, Zurich) are typically caused by torsional failure through either the lateral guide holes or the medial screw holes (185). These fractures generally occur in the prosthesis and are stable with good bone quality. They are usually long-oblique or spiral fractures that commonly originate at the level of one or two of the most distal holes. In some cases, the fracture may extend along the entire length of the implant and affect both the medial and lateral drill holes (21).

Intraoperative fissures that arise during terminal broaching or cementless stem implantation can be stabilized using multiple single- (215) or double-loop cerclage wires placed at least 1 cm beyond the fissure and stem tip, with a spacing of 1 cm between each wire so that the sides of the fissure contact each other with no gap (216). Recently, multiple double-loop cerclage wires have been used prophylactically in patients with predispositions to fissures, including giant-breed dogs with thin cortices, older dogs, and dogs with "stovepipe" femora (217). The cementless stem may be removed, and the fissures secured before replacing it with a cemented stem if a long fissure appears early in the broaching process. For postoperative fissures, strict cage confinement for 4 to 5 weeks, or until radiographic evidence of bone union, is recommended. Alternatively, proactive internal fixation with a plate, screw, and cerclage wires can be applied. In cases of displaced fractures with long oblique or spiral configuration or in cases of femur fractures that occur after cemented THR, immediate open anatomic reduction and internal fixation with plate and screw fixation augmented by full cerclage wires are recommended (218) (219) (212). As well as for the Zurich system where monocortical stem screws can be replaced with bicortical screws but if more than two stem screws are affected or if anatomical reconstruction is not feasible, explantation may be necessary. Repositioning of the implant is a possible solution, along with the consideration of revision with either a BFX or CFX stem. In some cases, explantation with fracture repair and future reimplantation may be an option, but it is worth noting that proximal femoral migration may complicate later reduction due to femoral head and neck ostectomy (FHNO) (212).

Femoral fractures are more common than acetabular fractures after total hip replacement, but managing acetabular fractures is much more challenging without returning to a previous surgical technique called FHNO. The cranial or caudal acetabulum fractures may happen due to excessive force applied while removing osteophytes or over-impaction of a cementless cup. Prompt reconstruction is necessary to restore a stable and functional acetabular prosthesis in cases of periprosthetic acetabular fractures. Attempting to reposition a press-fit acetabular component after repairing a fracture in a single-stage procedure is unlikely to result in a stable prosthesis and may lead to fixation failure. The most commonly used method for repairing a press-fit component with acetabular fracture in a single-stage revision is by cementing the acetabular component. There was one occasion where a fracture with minor displacement was effectively treated through conservative management (220). Corticocancellous grafting may be recommended to enhance the reconstruction, as suggested by Torres et al. (221).

When anatomically reduced and stabilized, fractures have a favorable outlook for healing and preservation of prosthesis integrity and function, typically within a span of 60 days, as noted by Liska (212).

5.2.2 Subsidence

After implantation of cementless press-fit Biomedtrix stems, minor subsidence may occur in the first few weeks before bone ingrowth takes place. However, cementless stems that have undergone osteointegration are not prone to subsidence (185). This minor subsidence typically does not lead to any clinical consequences. On some occasions, major subsidence may occur, which may be linked to stem retroversion, femoral fissure or fracture, dislocation, as well as the use of cementless collarless femoral stems or excessive postoperative activity (185). Major subsidence is more likely when the femur was not prepared with significant resistance to the broach's progress leading to an incomplete impaction or due to under sizing of the cup (142). The anterior-posterior view of the proximal femur shows radiographic evidence of subsidence when compared to immediate postoperative radiographs. In the case of subsidence, the stem retroversion and the presence of a proximal medial femoral fracture should be carefully examined in the radiographs (185). In such instances, the stem is removed, the femur is examined for any fissures or fractures, and any existing fissure or fracture is repaired before a new stem is implanted. The new stem may be cementless if the original stem was undersized and the bone bed is normal. If there are concerns about more mechanical complications, a cemented stem may be utilized.

Subsidence of cemented stems can happen when there is a failure of the implant-cement or cement-bone interface (21). However, cemented stems that are securely fixed are not prone to subsidence. Fragmentation of the cement mantle, calcar bone resorption, or calcar fracture is necessary for cemented stem subsidence to occur. Thus, cemented stem subsidence is typically observed in patients with chronic stem loosening. These chronic failures are often managed through stem and cup extraction, and revision with another cemented hip may be an option, depending on the degree of bone change. It's worth noting that the incidence of aseptic loosening increases following the revision of a failed cemented stem, in comparison to primary cemented THR (222).

5.2.3 Cup, Stem and Cement failure

Polyethylene liner wear-through is a possible issue with any cup, but it's unlikely in dogs due to low cup wear rates (223). However, it's more likely to occur in cups with thin liners (2mm or less) and may be accelerated by oxidation due to long exposure to oxygen before implantation (224). No wear-through or failure has been reported for BFX cups, but if it happens, the liner can be replaced without extracting the cup. Failure of a cemented polyethylene cup is usually due to cement mantle failure. Moreover, wear-through of the UHMWPE liner in the Zurich prosthesis is rare, and revision strategies are similar to those for cup avulsion.

Stem failure due to accumulated fatigue stresses is uncommon, and replacement of the femoral component and removal of the prosthesis are the only options. Failure of the BFX stem has not been reported. Failure of cemented stems is rare and may be due to fatigue in stems with loose proximal portions. Failure of a Zurich Cementless stem is also rare, but it's most often associated with the use of an extra-small stem when a larger stem is more appropriate (185).

In a previous section, we discussed the comparison between Biomedtrix cemented and cementless systems where we explained the cement failure with the bone and the implant interface. In this section, we examine the mechanical causes of cement failure, which include fracture of the cement mantle and separation at the cement-implant interface. If debonding occurs, it necessitates stem revision, specifically cement-in-cement revision, which involves removing the loose stem, cleaning the cement mantle with a high-speed bur without damaging it, drying it, and implanting a new stem with a clean and dry surface. This procedure has been described in studies by Edwards et al. (13) and Duncan et al. (225).

5.2.4 Other mentioned complications

Stem and cup avulsion can occur with the Zurich prosthesis. Giant-breed dogs are most commonly affected by stem avulsion, and using a proximal bicortical screw instead of monocortical was implemented to prevent this. Stem avulsion can occur due to surgeon error, such as improper valgus stem placement, which can lead to a valgus shift or subsidence. If avulsion occurs, the lateral guide holes typically remain open, allowing for screw removal through these holes or replacement with a BFX or CFX implant (21). As well, inadequate initial press-fit, incomplete seating of the implant, inadequate reaming, or inadequate bony support for the implant are common causes of acetabular component avulsion. Treatment options depend on the cause. If the initial press-fit was inadequate due to a reaming error, implanting the next larger cup size may be necessary if adequate bone stock exists. Deeper reaming may also be considered to achieve a press-fit, but it should be noted that stability is primarily provided by the cranial and caudal poles of the acetabulum rather than the dorsal rim or medial wall. In cases where the acetabulum is very shallow, controlled penetration of the medial wall may be an option to medialize the cup and obtain adequate cranial and caudal support, but this should be done carefully (226). Switching from a cementless to a cemented cup or using the revision cup mentioned in the Zurich section are also possible treatment options (227).

Neurapraxia is another common complication seen after a THR, a condition characterized by a temporary cut in peripheral nerve conduction, which arises from damage to the myelin sheath due to ischemia or compression. Although sensory dysfunction is also present, loss of motor function is the most prominent clinical sign. Neurapraxia is the mildest type of peripheral nerve injury, and it doesn't involve Wallerian degeneration. Typically, complete recovery is expected within 6 to 8 weeks (185). However, sciatic neurapraxia may occur as a complication of THR, and certain risk factors such as older age at surgery or manipulation of the gluteal muscles can increase the chances of it happening. Other factors like body weight or revision surgery may slightly heighten the risk. The sciatic nerve should be meticulously examined if there's any indication of nerve entrapment, and persistent stretching or impingement should be resolved. Rehabilitation therapy can be helpful, but spontaneous nerve recovery is necessary for full functional restoration (228).

Pulmonary embolism (PE), also mentioned in many reports, refers to the blockage of a pulmonary artery by a thrombus resulting from the migration of an embolus from a distant site via the systemic venous circulation. This fragment can be of debris from sawing or reaming processes or the risk factor could point on animals predisposed to PE (229) (230) (231). Although uncommon, massive embolism can result in fatal pulmonary vascular occlusion. While most dogs spontaneously recover from PE, this complication should not be overlooked. If dogs exhibit symptoms, appropriate care, such as ventilation-perfusion support and oxygen supplementation, should be provided.

5.3 Literature outcomes and complications of different THR systems

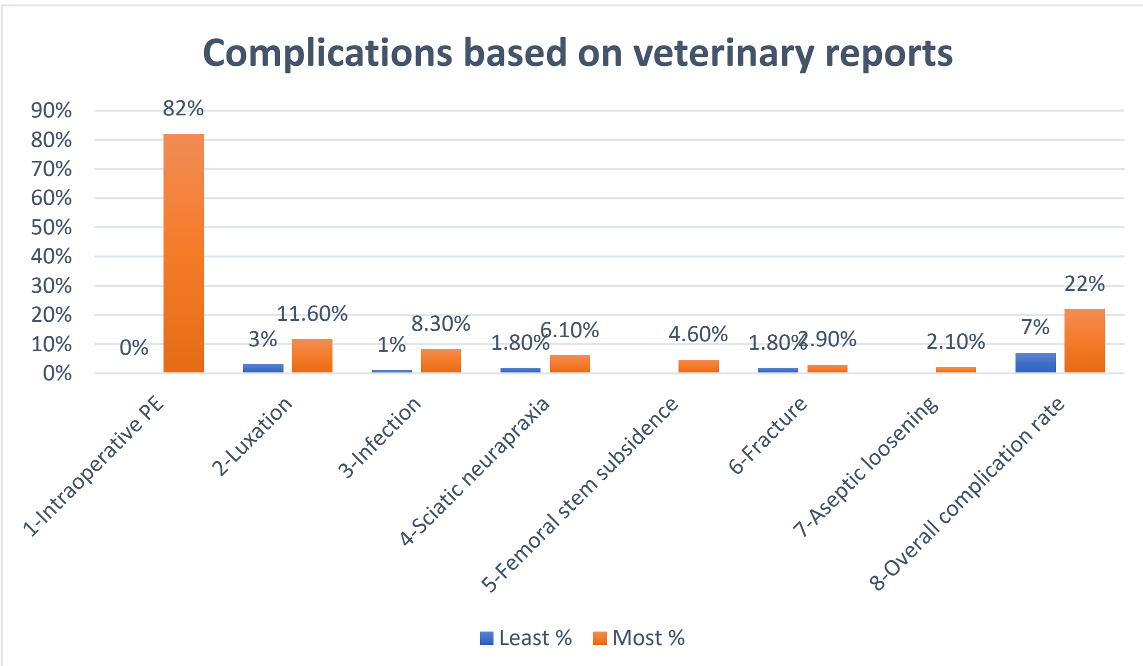

Figure 25- Complications based on veterinary reports.

1- (245) (273)   2- (115) (199) (196)   3- (265) (275)   4- (224)   5- (264)   6- (115) (208)   7- (13) (139)

8- (131) (115)

Complications commonly associated with all THR systems include luxation, aseptic and septic loosening, femur fracture, implant failure, stem subsidence, neurapraxia and pulmonary embolism. However, certain complications have been reported to occur more often in a system than in another (226) (22) (232) (212) (200) (228) (233). In this section, we summarize some of the key findings from the literature regarding the outcomes and complications associated with different THR systems.

Several studies have reported on the clinical outcomes of cemented CFX THR procedures (141) (234) (232). In a case series study of 51 cases, Olmstead found a complication rate of 7% (235). Bergh's retrospective study on 97 hips reported a revision rate of 12.1% for the first side THR procedure (232). Liska's study of 730 consecutive CFX THR procedures reported a successful outcome in 96% of cases (236). Complications commonly associated with cemented THRs are aseptic loosening and luxation, with less common occurrences of infection and femoral fracture complications. Skurla and colleagues conducted a study on 29 dogs that had 38 THRs performed (14). Postmortem evaluation revealed that 14 dogs had experienced loosening of both components. Loosening of the femoral stem was found to be most frequent at the cement-implant interface. Studies have shown that factors such as the metal used for stem fabrication, stem handling during surgery, and stem orientation within the femoral canal can increase the risk of implant-cement interface. Whereas concerning postoperative hip luxation, several factors have been associated with it as mentioned earlier in the mechanical failures; moreover, pre-existing hip subluxation or tissue laxity were found to be significant contributing factors according to Hayes and colleagues (199). There is a suspicion that cemented cups may have a higher occurrence of luxation compared to cementless cups that have a metal shell. The reason for this difference is not entirely clear, but it is believed that the lower luxation rate with cementless cups may be due to the reduced risk of UHMWPE deformation along the dorsal acetabular rim, where it is strengthened by the metal backing. Surgeons who aim for complete bone coverage at the acetabular rim may tend to position cemented cups in high ALOs, which can induce dorsiversion of the cup (185). Dyce and colleagues confirm this when they reported that cup orientation with an increased angle of lateral opening predisposes to dorsal luxation (200). However, another study found that the angle of lateral opening and degree of cup retroversion were not good indicators of luxation risk (198). Body type, size, breed, short femoral neck, and cup orientation were identified as well as risk factors for luxation by Nelson and colleagues (203). Another complication well mentioned in Liska's study of 684 consecutive CFX THR cases, a femoral fracture rate of 2.9% (212).

On the other hand, the most common complications for the BFX cementless THR system are reported to be technique-related fissures and luxation. However, with improved broaching technique, the fissure evaluation in the series of cases decreased significantly. In a study by Roe and Marcellin-Little, which evaluated 204 cases over six years, 48% of patients had no complications (220). Among the remaining cases, 25% had minor complications such as subsidence and stem rotation with or without associated fissures. Major complications were observed in 11% of patients, with luxation being the most common (8.4%) and femoral fractures occurring in 4.4% of cases. All fractures except one were successfully managed with surgical reduction and internal fixation, using either a BFX stem or a cemented stem. Sciatic neuropraxia was recorded in one case, and two cups failed to achieve stable bone ingrowth. One of these cups was cultured positive for a Staphylococcus organism, which had also been found on the dog's skin after an episode of pyoderma that preceded the lameness. However, there were no femoral stems that showed a lack of bone ingrowth (220). In cementless THR procedures, Ganz and colleagues reported that older dogs and those with a lower canal flare index had a higher risk of femoral fracture, which could explain the motive of the Biomedtrix system of creating newer customized stems (237). Kidd and colleagues reported a total complication rate of 31.1% in 219 BFX THR procedures performed in 183 dogs, with major complications occurring in 17.8% of cases (238). Specifically, femoral fissures (46), femoral fractures (15), and coxofemoral luxation (9) were noted. However, with a median follow-up of 42 months, 88.1% of cases achieved full return to function.

Lascelles and colleagues evaluated 35 BFX THR cases using a pressure-sensing walkway and noted a return to normal weightbearing on the operated leg by 3 months postoperatively (239). While cementless BFX THR procedures have proven to be successful, there is a learning curve involved. To minimize fissure and fracture complications, it is important to carefully select cases and to achieve an exact surgical technique. Experience can help decrease the occurrence of such complications. In fact, Roe and Marcellin-Little observed a decrease in their fissure rate from 30% in their first 50 patients to 4% in their last 50. Some surgeons have opted for hybrid procedures, which involve a cementless cup and a cemented stem, to reduce the risk of femoral fissure complications (201). Gemmill and colleagues reported on 78 hybrid THR procedures in 71 dogs and found that major postoperative complications occurred in only 5% (4) of cases (240). Only one intraoperative femoral fissure was reported, while postoperative complications included one luxation, one femoral fracture, one implant fracture, and one case of aseptic femoral loosening (240).

Concerning the micro and nano cemented THRs, several cases series have reported on their outcome (194) (81) (205). The largest series had an overall success rate of 91%, and the reported complications, such as luxation and cup loosening, were comparable to those seen in medium or large dogs treated with cemented THR (81). Although potential complications following Micro

THR include sciatic neurapraxia (228), infection, femoral fractures, femoral fissures, pulmonary embolism, and aseptic loosening; the series of 66 consecutive Micro THR reported by Liska had a very low frequency or absence of these complications (35). Moreover, a study on FHO, an alternative procedure to THR in dogs, showed only 63% good to excellent final outcomes (241). It has been reported that measured peak vertical force and impulse do not return to normal after FHO (242) unlike after THR (243). Body weight distribution returns to normal after THR as demonstrated by advanced gait analysis, however, there is a lack of information on similar studies after FHO. Despite reports of improved function and longer rehabilitation after FHO, limb length discrepancy and "ball-and-socket joint" biomechanics remain compromised. Long-term follow-up with objective outcome data comparing both Micro THR and FHO would be necessary for a fair comparison, but the general outcome in these literatures of the Micro THR is satisfactory.

Several large case series and case reports have documented and managed complications after the Zurich THR (226) (16) (20) (162) (209), but the reported follow-up and complication rates vary between studies. Hummel et al. reported luxation and fissure fracture being the highest complications rates each occurring in 7.4% of cases, and a 3.7% rate of infection (120). Guerrero et al. reported 11.7% of luxation and 3.3% of aseptic loosening of the acetabular cup (226), while Vezzoni et al. found a 5.2% rate of implant failure and 4% of luxation and aseptic stem loosening (19). It is notable that the mechanical complication of prosthesis luxation was observed in all three studies despite the significant variations in reported complications. The overall complication rate (perioperative and postoperative) for Zurich THR ranged from 16.4% to 26.3% across the different studies (226) (244) (16). However, caution should be exercised when comparing these case series as several variables, such as the surgeon or surgeons performing the series of cases, their level of experience, and the inclusion or exclusion of perioperative fissure fractures and greater trochanter fractures in the complications, were not consistent across all studies. There are various risk factors associated with complications after Zurich THR. These include increased preoperative body weight and higher body condition scores (16) (20), as well as being a giant breed dog which is linked to implant loosening and luxation (16). Older dogs with suspected bone fragility may require adjunctive femoral plating to prevent fractures (245). Although patient age does not affect the rate of complications, the types of complications encountered propose that juvenile dogs are more prone to acetabular cup wear or stem loosening, while older dogs may experience femoral fracture, cup loosening, and cup fracture (16). Moreover, specific technical errors during the surgery can increase the likelihood of certain intraoperative and postoperative complications, such as prosthesis luxation (226) (20).

Luxation, femoral fracture, infection, aseptic loosening, and implant failure are the most common indications for revision surgery for the Zurich system (118) (20) (16) (162). Aseptic loosening, luxation, and implant failure can often be resolved by adjusting or replacing the implants with a different size (226) (16). On the other hand, fractures of the femoral diaphysis usually require plate and screw fixation as described earlier, while infections may require explantation, either temporarily or permanently (226). The rate of explantation after a major complication with the Zurich THR ranges from 1% to 7% (119). According to Guerrero's report, one case required explantation due to infection, and new implants were implanted 2.5 months after the initial explantation (226).

Unfortunately, there have been few documented complications related to the 1st generation of the INNOPLANT Total Hip Replacement system's screw-in components (HELICA-endoprosthesis) in veterinary literature, unlike the more commonly used THR systems mentioned earlier (201) (172) (167). One of those limited reports by Hach and Delfs concerns 40 dogs that received the HELICA-endoprosthesis and noted several complications including 2 cases of resorption of bone under the collar of the femoral implant, 1 case of sciatic neuropraxia, another of femur fissure, and one case of femoral neck fracture, 4 cases of acetabular cup loosening, and one case of femoral prosthesis loosening (167). These complications were mostly attributed to technical errors during the learning phase (167), revisions were performed successfully in most cases and the researchers observed that the revisions for acetabular cup loosening were relatively straightforward to carry out.

Other reports of complications include septic and aseptic loosening, which were successfully revised using different systems (246) (30) (220). Those reports included a case of septic acetabular cup loosening, which was successfully revised using a hybrid BioMedtrix BFX cementless acetabular cup and CFX cemented femoral stem (246), an aseptic loosening of both components, which was successfully revised using the Zurich Cementless system (30), and a loose femoral prosthesis that was revised using a standard BioMedtrix BFX long stem cementless femoral prosthesis (174). In contrast, aseptic loosening was seen in 33.3% of dogs within 1year post-implantation in one study and the implants were removed in these cases (172). As described, complications with the Helica endoprothesis are quite various and the lack of literature complicates the outcome of this system, and subsequently requires higher effort for improvement. The revision with other systems highlights the significance and effectiveness of alternative systems.

Other complications were reported like the femoral medullary infarction (247) described on the radiographs as cigarette smoke opacities most probably due to excessive reaming depth in the Zurich system according to a follow-up study by Haney et al., as well as pulmonary embolism associated with THR which was first documented in cases involving cemented THR (248), leading to sudden intraoperative death in one patient, as reported by Liska and Poteet in 2003 (249).

Even though THR procedure is by now proven to be effective and safe, surgeons can use morbidity and mortality rates to compare the outcomes of total hip replacement surgeries and to inform pet owners of the anesthesia and procedural risks involved. A review of the total hip replacement registry, which included 1,864 dogs, found that 642 dogs had known dates and causes of death. The average lifespan of the dogs in the study was 11.3 years, with the longest lifespan being 17.1 years. The mean survival time after THR was 4.66 years, with the longest survival time being 16.1 years. The study showed that multiorgan system failure was more common than any single organ system failure, and neoplasia was the most common cause of death, although none were found near the THR site. Overall, the study indicated that THR had low perioperative mortality and a low incidence of implant failure leading to euthanasia (250).

6. Case studies

6.1 Cases presentation

During my internship with the Ortovet team in Italy, I received guidance and support from Dr. Chadi Eid, who facilitated my learning experience. The team employed the Biomedtrix systems at that time, which will be the focus of the cases we will examine. Within this chapter, there will be a collection of 11 cases that pertain to Biomedtrix BFX THRs in dogs with different conditions and indications for this surgical procedure.

All cases were referred due to suspicion of hip joint disease or trauma. Those cases underwent a thorough clinical, orthopedic and neurological examination before final diagnosis in Ortovet clinic.

All front and hind limb joints were clinically manipulated, and calibrated radiographs were taken to rule out any abnormalities other than those arising from the hip joint, particularly in young dogs, to exclude any developmental diseases or abnormalities.

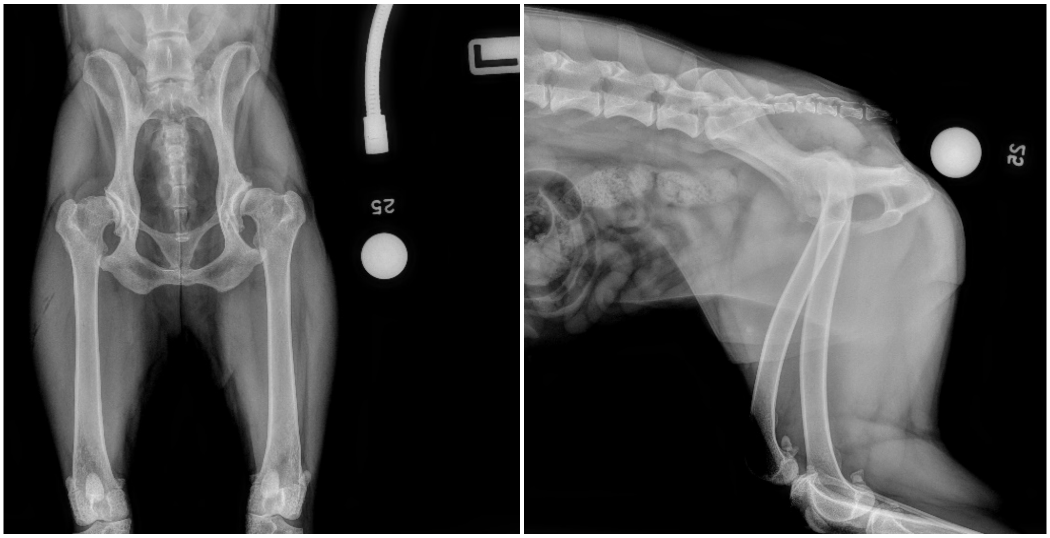

Figure 27- Calibrated ventrodorsal and lateral radiographs of the pelvis of ***Dog 1.***

Dog 1, a 4-year-old female Brittany spaniel dog, weighting 18 kgs was brought to the attention of Ortovet for hindlimb lameness. The specialist has noted pain during the hyperextension and hyperflexion manipulations of the hips. The radiographs performed on the pelvis has allowed to highlight bilateral hip dysplasia. The dog was recommended to go through surgical intervention for both hip joints, first a total hip prothesis unilateral (left) and subsequently, after the healing of the treated joint, a treatment of the contralateral hip by the same surgical approach (THR).

Figure 26- Calibrated ventrodorsal and lateral radiographs of ***Dog 2.***

Dog 2, an 11 months old male Corso (an Italian breed of mastiff), weighting 40 kg was taken to the facility for an orthopedic visit as there was lameness in the left rear hindlimb. At the orthopedic examination, he presents reduced muscle development of the hindquarters and third-degree lameness affecting the left rear limb. The orthopedic examination and radiographic study show severe bilateral hip dysplasia, with severe incongruity and subluxation of the femoral head on the right and dislocation of the femoral head on the left. It was advised to perform total left hip replacement as soon as possible as it is certainly the best therapeutic choice in large-sized patients with severe hip dysplasia.

Figure 28- Ventrodorsal, frogleg ventrodorsal and lateral radiographs of the pelvis of ***Dog 3.***

Dog 3, an 18 months male mixed breed had a lameness in his left rear hindlimb for about a month. At the time of the visit, there was a second-degree lameness affecting the left hindlimb, muscle atrophy on the left side was also noted as well as pain during hip extension. The radiographic examination performed highlighted a serious picture of bilateral hip dysplasia. Total hip replacement surgery was recommended to be performed in the first instance on the left hip.

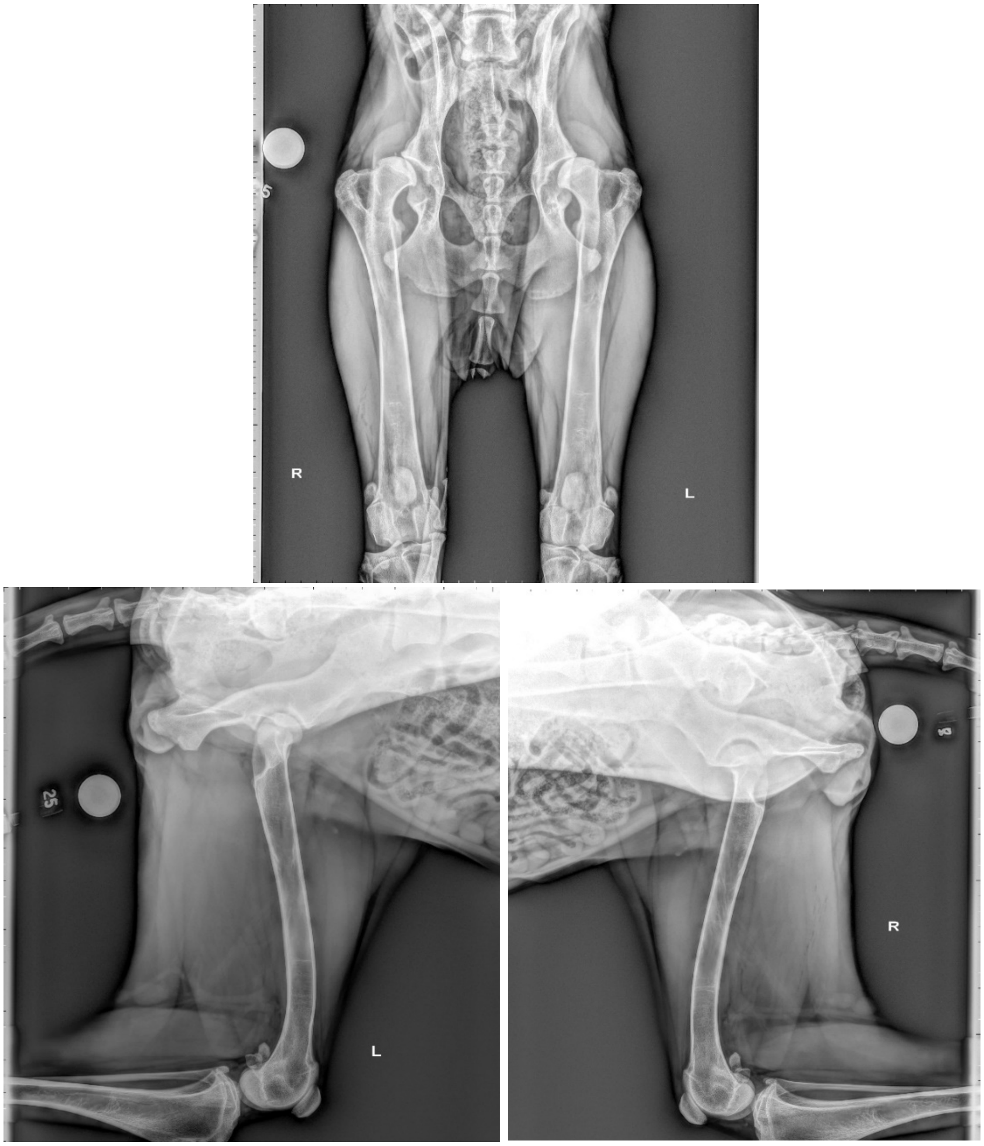

Figure 29- Extended ventrodorsal and lateral left and right radiographic views of the pelvis of ***Dog 4.***

Dog 4, a 10 months old female weimaraner weighting 31kg, was submitted to the attention of Ortovet for weakness to load of joints during extension from about 30 days. The owner reported that in the last week, the subject developed difficulty jumping and climbing stairs. During the orthopedic examination, the subject presented itself in a good health state in the presence of muscle mass reduction of the entire rear and slight cranial shift of the body gravity center. Pain was noted during the manipulation in hyperextension and hyperflexion of the hips. The radiographic study performed allowed to highlight severe bilateral arthrosis of the coxofemoral joint resulting in hip dysplasia characterized by a marked subluxation of the femoral heads with erosion of the dorsal edge of the acetabulum. Erosion and deformation of the femoral heads in presence of muscular hypotrophy of the entire rear. Overall, the clinical and radiographic findings of the hips indicate that the degree of dysplasia already present is such that the joints of the subject are no more recoverable with simple interventions; the treatment indicated to avoid the progression of arthritic degeneration and to allow the dog a normal function free of pain, is the bilateral total hip protheses to perform in two times at a distance of 1-2 months from each other.

*Figure 30- Ventrodorsal and lateral right and left radiographic views of the pelvis of **Dog 5.***

Dog 5, a 6 years old female mixed breed weighting 28kgs was brought to the attention of Ortovet for hindlimb lameness. The radiographs performed on the pelvis has allowed to highlight bilateral hip dysplasia, more severe on the right side. The dog was recommended to go through surgical intervention for both hip joints, first a total hip prothesis unilateral (right) and subsequently, after the healing of the treated joint, a treatment of the contralateral hip by the same surgical approach.

Figure 31- Ventrodorsal, frogleg ventrodorsal and lateral right and left radiographic views of the pelvis of ***Dog 6.***

Dog 6, a 9 months old male mixed breed weighting 24 kg was presented for an orthopedic consultation due to the presence of reduced development of his left hindlimb muscles and lameness affecting the left hind limb from the time of adoption. The past history, concerning the period before the adoption, is unknown. At the orthopedic visit, the patient had a normal nutrition state and muscle hypotrophy of the left hindlimb. At the walk and trot he showed second to third-degree lameness and the left hip joint was painful. Mild hypotrophy of the limb compared to the healthy contralateral limb was present. It should also be noted that bilateral metatarsal rotation does not have serious consequences on the functionality of the joint. Dog 6 presents severe results of an alleged trauma he had a few months earlier, involving the acetabulum and the left proximal femur.

The radiographs show a mild hypotrophy of the left femur, with a completely altered conformation of the femoral head, which is almost absent, as well as the femoral neck and greater trochanter; in addition, there is an associated impaired development of the acetabular cavity. The clinical signs were as serious as the radiographic results, and the dog has developed clinical compensation, therefore the following surgical therapy was recommended: total hip replacement. The altered anatomical conditions of the left hind limb (contraction of the gluteal muscles and altered morphology of the proximal femur and acetabular cavity) make the application of a cementless hip prosthesis, a procedure with high percentage of complications compared to a “standard” hip prosthesis. To promote better functionality of the affected limb, rest and activity were recommended controlled on a leash and anti-inflammatory therapy as needed to be able to proceed with the surgical procedure later on.

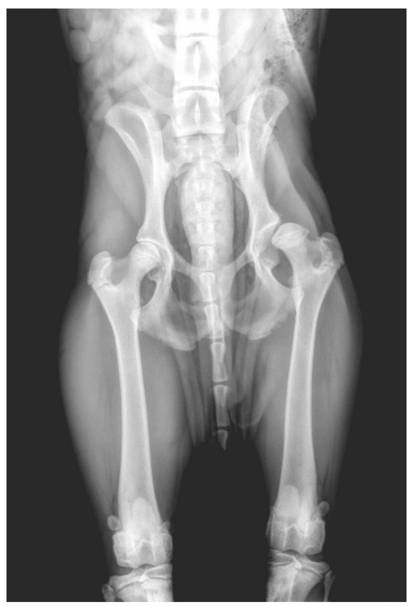

Figure 32- Extended ventrodorsal radiographic view of the pelvis of ***Dog 7.***

Dog 7, a 7 years old male mixed breed weighting 22kgs was taken to the facility for an orthopedic visit as there was lameness in the left rear hindlimb. At the orthopedic examination, he presents reduced muscle development of the hindquarters and third-degree lameness affecting the left rear limb. The orthopedic examination and radiographic study show severe hip dysplasia, with severe incongruity and subluxation of the femoral head on the left side. THR was advised for this case.

Dog 8, a 3.5 years old female Bernese Mountain Dog weighting 39.8 kg, was as well diagnosed for severe hip dysplasia of the left coxofemoral joint, was recommended for a left THR.

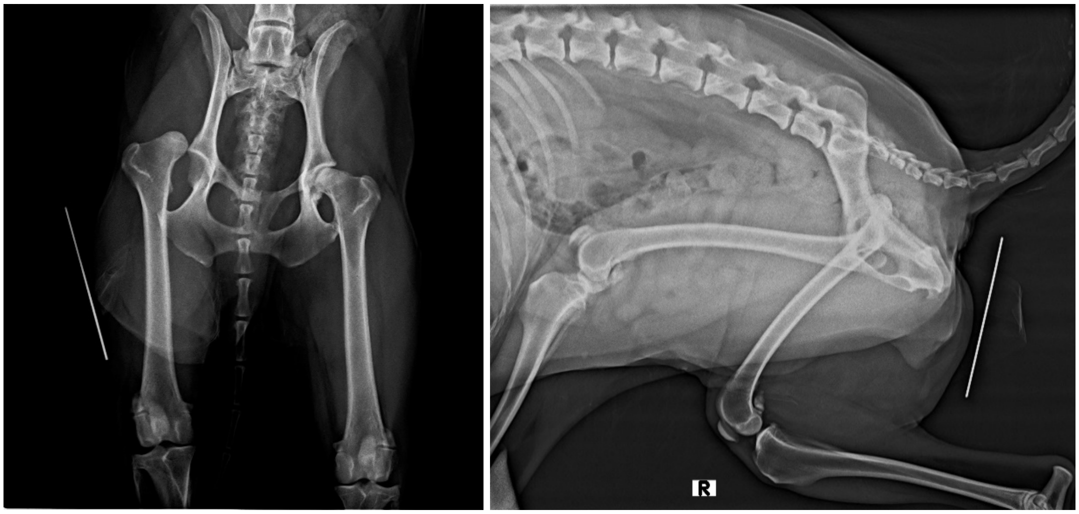

Figure 33- Calibrated ventrodorsal and lateral radiographic views of the pelvis of ***Dog 9.***

Dog 9, a 6 years old female border collie weighting 18.5kgs, previously seen by the referring physician for right traumatic hip dysplastic dislocation. Total hip replacement for the right side was recommended as a treatment for this traumatic luxation.

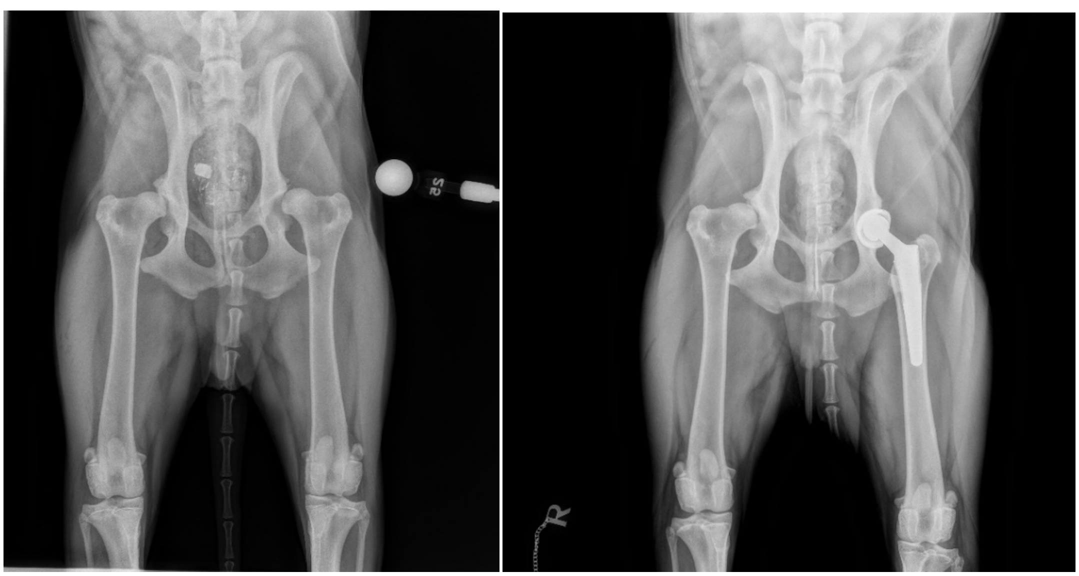

Figure 34- Extended ventrodorsal radiographic views of the pelvis of ***Dog 10*** *before and after undergoing left cementless Biomedtrix BFX THR.*

Dog 10, a 6 years old male mixed breed weighting 32 kgs was diagnosed for severe bilateral hip dysplasia with severe incongruity and subluxation of the femoral head on the left. He underwent a cementless THR for the left coxofemoral joint in 2017. Later in 2022, the patient was recommended the same surgical intervention on the coxofemoral joint affected by arthrosis on a dysplastic basis with cementless prosthetic implant for osteointegration.

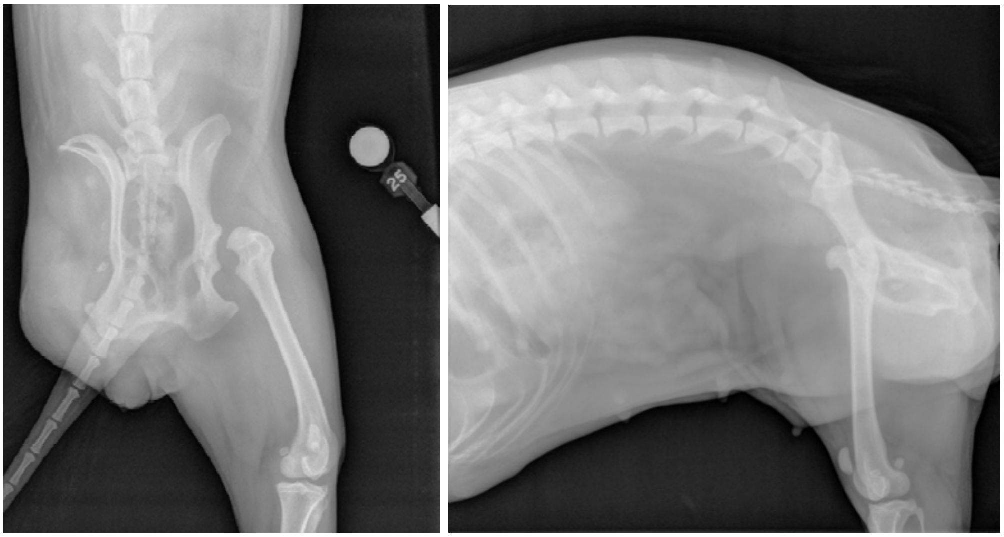

*Figure 35- Ventrodorsal and lateral radiographic views of the pelvis of **Dog 11.***

Dog 11, a 3 years old female mixed breed weighting 20kgs, with an amputated right leg was presented with a firmly established ventral luxation of the left coxofemoral joint. Dog 11 was recommended a total hip replacement surgery on the left coxo-femoral joint affected by inveterate ventral luxation through cementless prosthetic implant with osteo-integration.

6.2 Surgical procedure and postoperative management

Few weeks after diagnosis, all patients underwent a total hip replacement using BFX Biomedtrix cementless protheses as previously described in chapter 4. The only exception was dog 6, who required additional time for inflammation to subside before proceeding with the THR intervention. This surgical procedure involves the complete replacement of the diseased joint and its replacement with a prosthetic implant, with the goal of restoring complete coxofemoral function and alleviating pain in order to improve the patient's quality of life.

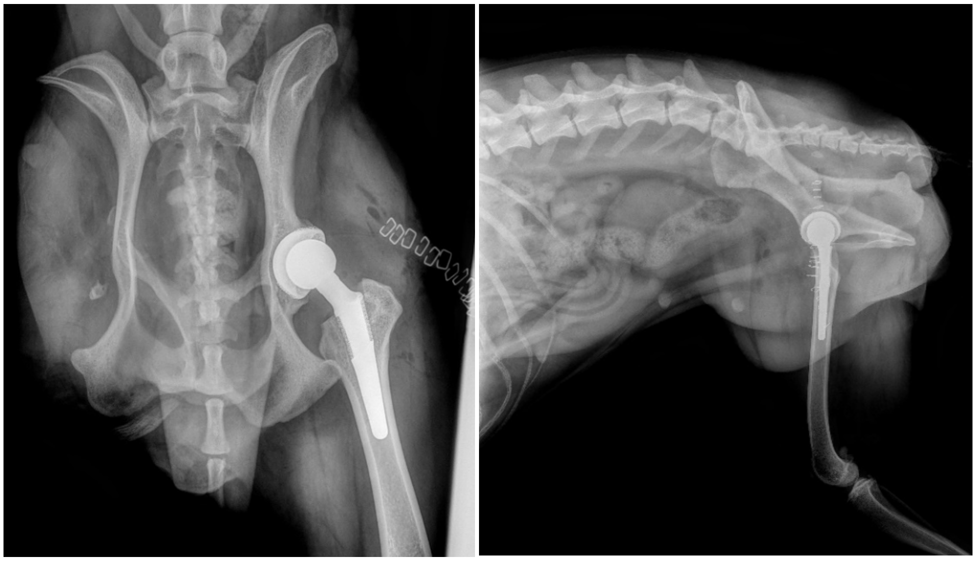

*Figure 36- Extended ventrodorsal and lateral radiographic views of the pelvis of **Dog 11** after Cementless Biomedtrix BFX THR.*

Dog 11's procedure was completed under exceptional circumstances. Due to the previous amputation of his right hindlimb, the surgical intervention on his left coxofemoral joint was more challenging. The surgeon had to adjust his technique to address the position of the acetabular cup. He had to tilt the cup to provide ventral support due to the dog's indication of ventral luxation, while also ensuring dorsal coverage to prevent dorsal luxation as a complication following the total hip replacement, which could be induced by the dog's gait. Additionally, the foot had to be kept in the middle to compensate for the amputated leg.

Dog	1	2	3	4	5	6	7	8	9	10	11
Side	Left	Left	Left	Right	Right	Left	Left	Left	Right	Right	Left
Stem	7	10	6	10	10	7	7	9	6	9	6
Cup	24	26	22	28	28	24	24	26	22	28	24
Head	17+3	17+0	14+3	17+0	17+0	17+3	17+3	17+3	14+3	17+0	17+3

Figure 37- Biomedtrix BFX implants sizes of Dog 1 till 11.

Figure 36 highlights the importance of selecting the right size of implants for each patient for the success of the Biomedtrix BFX THR procedure. By choosing appropriately sized implants, the surgeon can ensure that the prosthesis fits securely within the patient's femur and acetabulum, after a thorough preparation of the bone to determine the exact positioning and stability of the implants press-fitted, providing optimal stability, range of motion, and load-bearing capacity. Improper sizing can lead to a range of complications such as joint instability, dislocation, implant loosening, and premature wear, which can result in pain, decreased mobility, and the need for revision surgery. Therefore, the radiographs presented above are crucial to determine the ideal size and shape of the implants needed to match the patients' anatomy when templated. Proper implant sizing also takes into account factors such as bone quality and density, as well as any underlying medical conditions that may affect healing and recovery. Therefore, careful attention to implant sizing is a critical component of the overall success of a THR procedure using BFX Biomedtrix cementless implants and plays an important role in the outcome of this procedure.

After the surgery, radiographs are necessary to evaluate the procedure and make any necessary adjustments before the dog wakes up. Concerning postoperative management, to obtain a good recovery, it is necessary to give the dog continuous care. In order to optimize the outcome of the surgical treatment, it is advisable to scrupulously follow the medical prescription indicated at the time of discharge (like anti-inflammatories and antibiotics) and indications regarding management postoperative. The postoperative management is the same regardless the surgeon in charge as mentioned previously, but some tips are added by some surgeons to better monitor the healing. All cases were required to a confinement in a clean and well-defined environment (box, carrier, cage) for 40 days and the limitation of physical activity to simple and short walks strictly on a leash (5-10 minutes per walk) in the first weeks, to obtain a correct osteointegration of the prosthetic implant and functional recovery of the affected limb. The dogs had to Avoid running, jumping and playing with other animals as well as the application of the Elizabethan collar until the stitches are removed and the wound is completely healed. Some surgeons recommended additional follow-up visits 3, 7 and 15 days after surgery to check the healing of the surgical wound and the patient's ambulation in addition to the standard check-ups and radiographic examination which are recommended at 30 days, 60 days, 90 days after surgery and then every 12 months. Respecting these simple precautions limited the risk of the onset of any complication mentioned in the chapter of complications and favored proper recovery of all patients presented.

6.3 Surgical outcome and discussion

Following the cementless Biomedtrix BFX total hip replacement surgeries, postoperative radiographs were promptly taken as required. The images indicated that no further interventions were needed. After adhering to all the recommended protocols for a successful outcome, all dogs were observed to be in good health during their clinical and radiographic evaluations 30 days post-surgery. The limbs that underwent the prosthetic surgery were observed to be deflated without any signs of inflammation. The dogs were able to walk normally with full support from the operated limb. The radiographic assessments confirmed the initial osseointegration of the implants. While controlled leash activity was still advised for the next month, walking time was gradually increased.

During the next check-up, which was a month later, the dogs showed no signs of lameness and the affected limbs had recovered well in terms of muscle strength and function. Radiographic examinations confirmed the integrity of the prosthetic implant, adequate osseointegration, and no adverse reactions. Gradual resumption of normal motor activity was recommended over a period of two weeks. However, it was still advised to avoid excessive jumping, playing with other dogs, and long or demanding walks, such as mountain hikes, for the next two months. A follow-up clinical and radiographic check-up was scheduled for one month later, followed by annual visits. Further follow-ups were done and no complications were presented. The implant survival rate in those cases was flawless, and no further surgeries were required for revisions.

Radiographs from postoperative and follow-up check-ups are provided below to evaluate the outcomes of the surgery, assess improvements, and evaluate implant integration in later months.

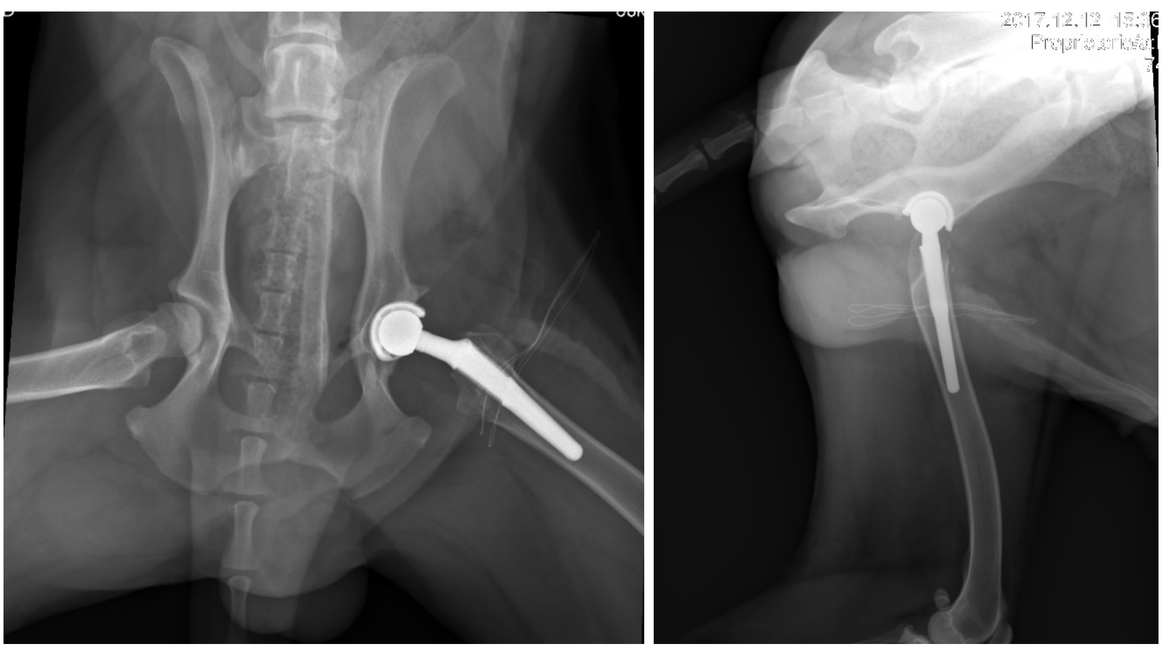

Figure 38- Frogleg ventrodorsal and left lateral radiographic views of the pelvis of ***Dog 3,*** *1 month after cementless Biomedtrix BFX THR.*

*Figure 39- 1st row: Ventrodorsal radiographic views of the pelvis of **Dog 1** postoperatively, 1month and 2months postoperatively.*

*2nd row: Lateral radiographic views of the pelvis of **Dog 1** postoperatively, 1month and 2months postoperatively.*

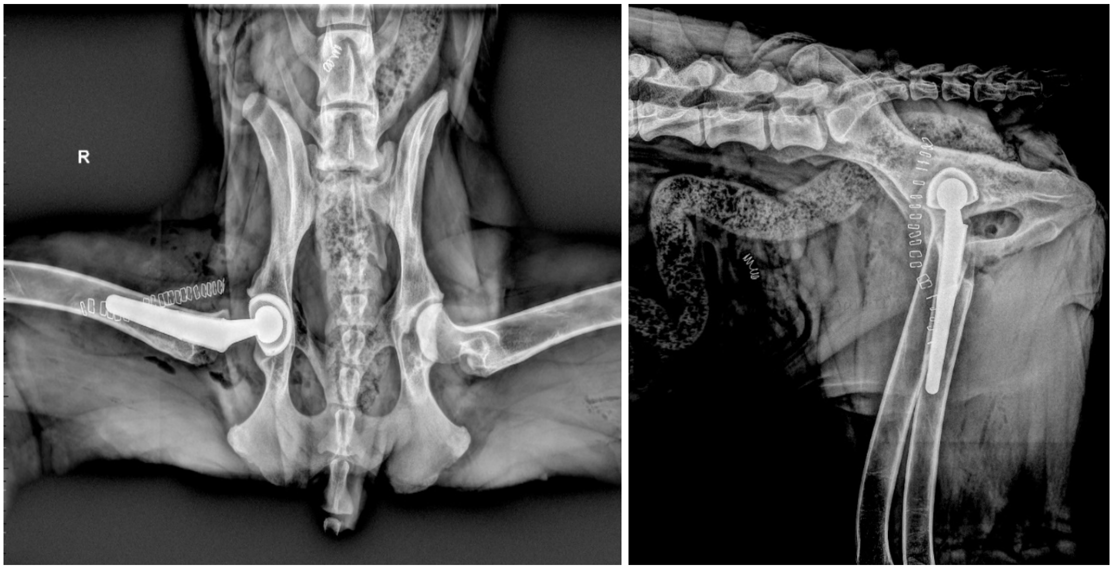

*Figure 40- Frogleg ventrodorsal and right lateral radiographic views of the pelvis of **Dog 4** postoperatively.*

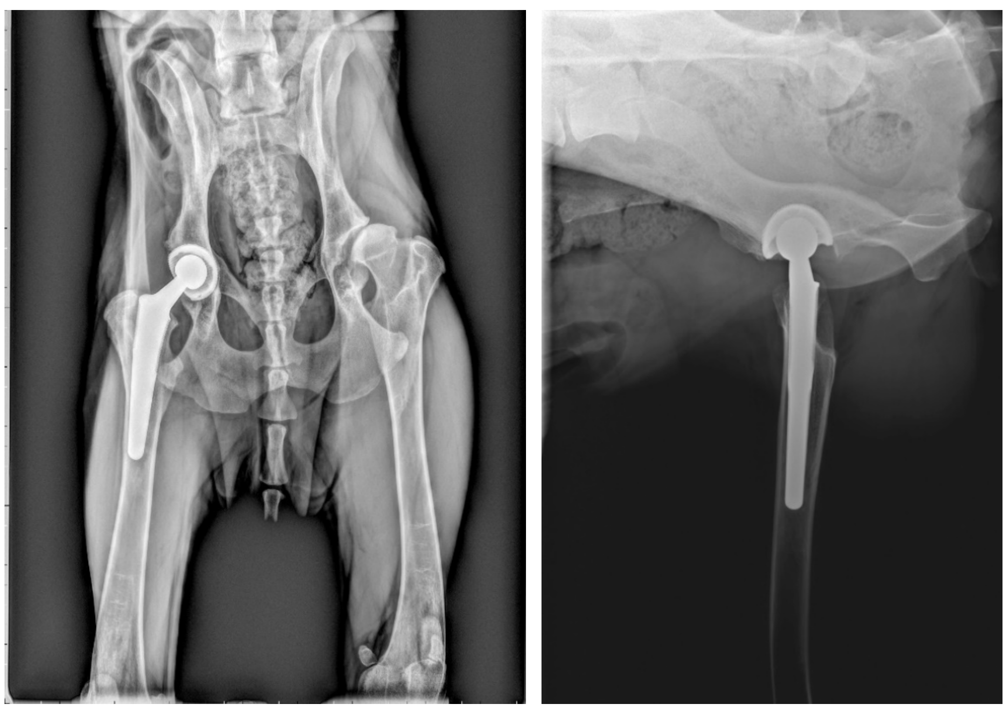

*Figure 41- Ventrodorsal and right lateral radiographic views of the pelvis of **Dog 4,** 1 month after cementless Biomedtrix BFX THR.*

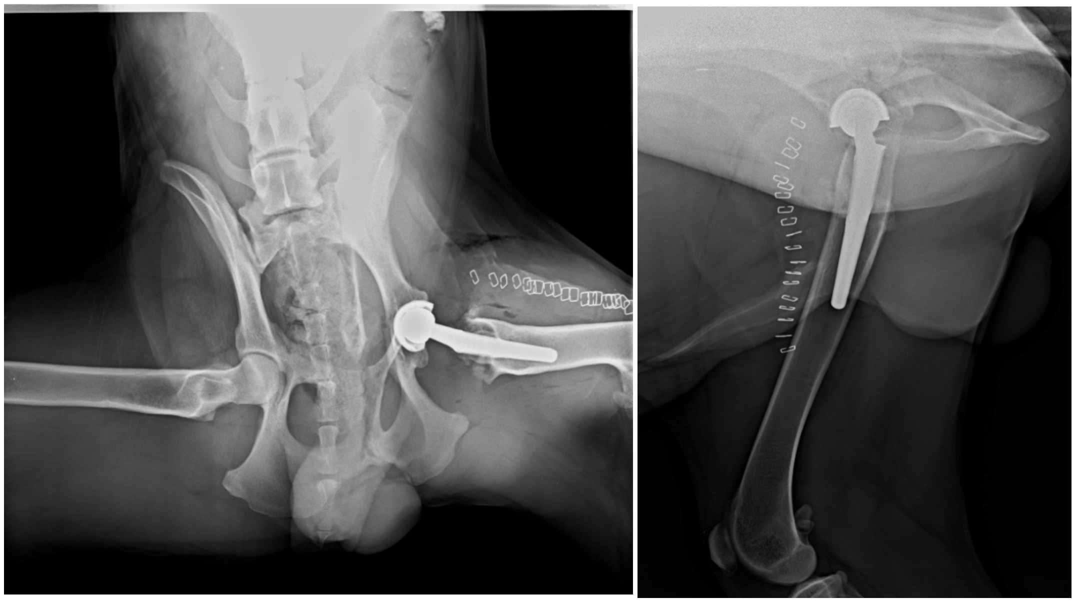

*Figure 42- Frogleg ventrodorsal and lateral radiographic views of the pelvis of **Dog 6** postoperatively.*

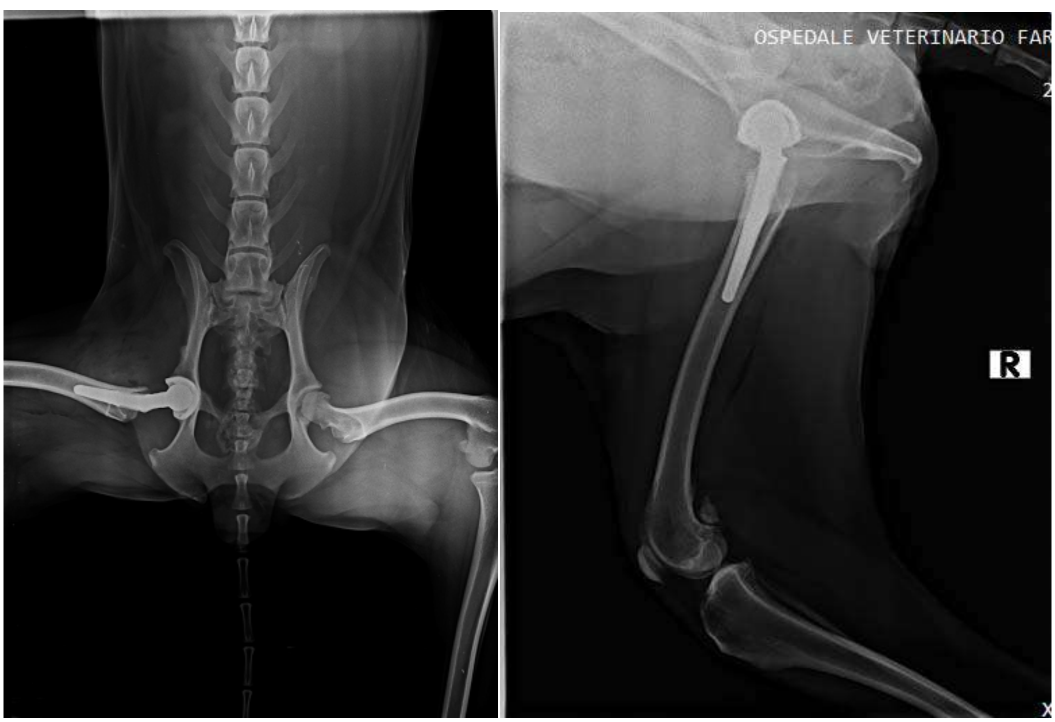

*Figure 43- Frogleg ventrodorsal and lateral radiographic views of the pelvis of **Dog 9**, 2months after cementless Biomedtrix BFX THR.*

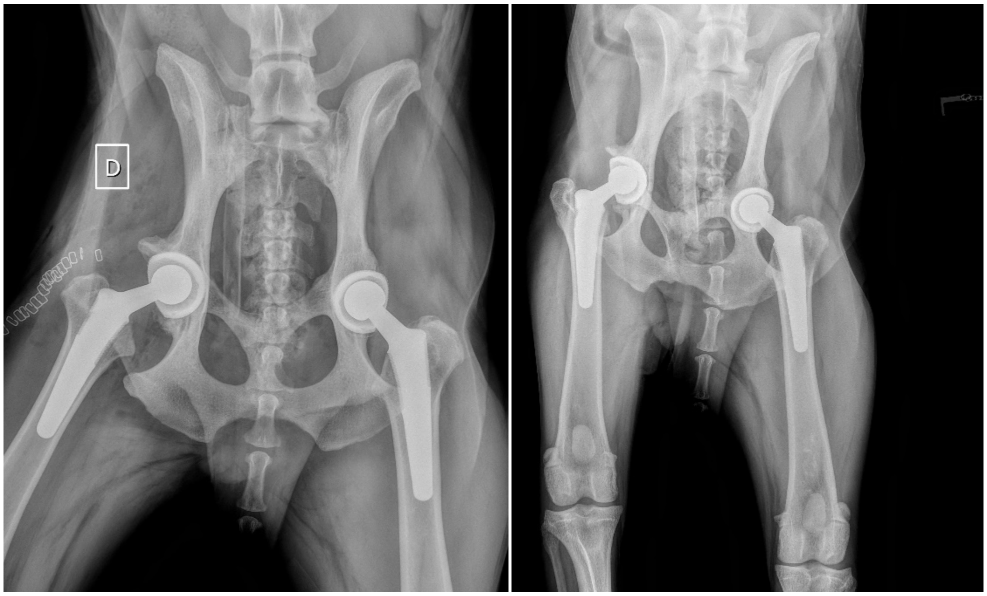

Figure 44- Ventrodorsal radiographic views of the pelvis of ***Dog 10*** *postoperatively and 1 month later.*

The several successful cases presented in this thesis, have demonstrated the effectiveness of Biomedtrix BFX cementless total hip replacement as a treatment for various indications. The prevalence of hip dysplasia among large dogs is also confirmed by the numerous cases described. Despite the prevalence of hip dysplasia, the surgery has been successful in treating a variety of indications, such as those seen in dogs 6, 9, and 11. Additionally, bilateral BFX total hip replacements have been successful when the surgeries are separated by a sufficient interval to allow for implant integration and bone stabilization. As demonstrated by dog 11 who was treated for ventral luxation while presented with an amputated contralateral hindlimb, each case should be evaluated individually, taking into account the dog's specific conditions. While complications can occur with the BFX system, the literature and the cases support its effectiveness. Thorough pre-operative planning is crucial for optimal outcomes. Patient positioning as well as proper implant selection and positioning are essential to avoid issues such as aseptic loosening, subsidence, and luxation or femoral fracture. The surgeon’s skills contribute enormously in the decrease of complications risks such as intraoperative fractures. While the surgeon's expertise is important in the success of a Biomedtrix BFX cementless THR surgery in dogs, other factors such as the dog's age, overall health, weight, and activity level, as well as postoperative care, also play a significant role in the surgery's success. This all highlights the fact that complications are quite case dependent unlike the cemented THR where implant loosening tends to occur because bone-cement and implant-cement interfaces are influenced by several factors.

The successful outcome of this series of cases was a result of various factors previously mentioned. Notably, pain relief, functional improvement, and implant survival were observed. Despite the potential impact of age on the outcome of Biomedtrix BFX cementless total hip replacement surgery, the results were not significantly affected by age since surgery was achieved after the acetabular growth plates are closed. One case, Dog 9, highlights the importance of the owner's knowledge of their dog's medical history, as it can lead to early diagnosis, avoiding incorrect compensation and better treatment outcomes. Additionally, it is the owner's responsibility to observe their dog's behavior and clinical signs, as it can aid in early detection of abnormalities. Biomedtrix BFX cementless THR is a successful option for improving the quality of life for dogs affected with coxofemoral joint abnormalities. Although FHO is still widely used for smaller breeds even with micro and nano THRs being available in the market; cementless THR is the preferred option for larger breeds with load-bearing capacity.

7. Conclusion

In conclusion, this thesis provides a comprehensive overview of the current state of canine total hip replacement (THR) and compares three different systems while focusing on the Biomedtrix system with the cases studied. The comparison of the three different systems shows that they all have their unique features and benefits.

The literature review reveals that THR is a well-established surgical procedure in canine, with a high success rate and significant improvement in quality of life. The choice of implant system is crucial for the success of the surgery, and selecting the right implants based on the patient's individual characteristics is key to achieving optimal outcomes. The analysis of the Biomedtrix system reveals that it has several advantages, such as many implant combinations that can be used to address a variety of patient presentations, providing good stability and range of motion, as well as a quick recovery time. However, it also has potential drawbacks, such as implant migration and the need for special instrumentation. The cases studied in this thesis of dogs that underwent THR with the Biomedtrix BFX cementless system confirms these findings and demonstrates the importance of careful patient and implant selection and surgical technique in achieving successful outcomes.

Overall, this thesis contributes to advancing the field of canine THR and improving the outcomes of this surgery for dogs. By providing a detailed comparison of different implant systems and highlighting the advantages and disadvantages of the Biomedtrix system, the thesis provides valuable insights in selecting the most appropriate implant system for their patients. This knowledge can lead to improved patient selection and surgical technique, resulting in better outcomes and increased quality of life for dogs undergoing THR. In addition, it's important to critically evaluate the outcomes in order to recognize the need for improvement. This evaluation should include defining what is meant by a "successful" or "unsuccessful" outcome, as validated joint scores play a crucial role in the decision-making process for patients with severe joint disease and the assessment of total joint prostheses' effectiveness.

In general, cemented, cementless, and hybrid THR procedures have the potential to be highly effective. However, the success of these procedures depends on the surgeon's experience and adherence to the surgical principles of each system. No single system is flawless and complications are always a possibility, but they are typically manageable. With surgery, it is reasonable to expect that most THR patients will achieve a satisfactory or better outcome.

In the future, advances in biomaterials, surgical techniques, and revision THR procedures resulting from clinical and basic research will likely lead to even better outcomes for patients. Encouraging dog owners to schedule annual orthopedic check-ups for their pets can also improve outcomes by enabling early diagnosis of problems.

As this procedure becomes more widely used, it will become more accessible from various perspectives such as financial, material and manufacturing, surgeon experience, and outcome knowledge.

Summary

Calvin Tanios (2023): Canine Total Hip Replacement: state of the art.

This tier master's thesis examines the current state of canine total hip replacement (THR) by comparing three different systems, namely the Biomedtrix BFX & CFX systems, the Zurich system, and the Helica System. The main focus of the thesis is on the Biomedtrix systems, its advantages and disadvantages in comparison to the other two systems and on the BFX cementless system in the cases studied.

The study begins with a comprehensive review of the current state of THR in canine, including the history of the different THR systems, the different techniques, materials and implants used, and the outcomes of the surgery. The review highlights the importance of selecting the right implant system for each individual patient based on factors such as the indication, size, weight, bone conformation and activity level.

The research then proceeds to compare the three different systems of THR based on a comprehensive literature. The Zurich system, which is based on the cementless principle, is designed to provide a stable and long-lasting implant. The Helica system is a modular system that preserves the femoral neck maintaining the normal joint biomechanics. Finally, the Biomedtrix BFX system is a cementless system that utilizes a unique geometry to ensure optimal fit and stability whereas the CFX system requires a cemented mantle in cases where bone quality is in question.

The thesis then focuses on the Biomedtrix system and provides an in-depth analysis of its advantages and disadvantages. The analysis includes cases studies of canine that underwent THR with the BFX Biomedtrix system, examining the indications, the surgical technique, postoperative care, and outcomes. The cases studied in this thesis show that the Biomedtrix system provides good stability and range of motion, a quick recovery time, as well as proves the similarity of the outcome with the literature available. However, the system is also associated with some potential drawbacks, such as implant migration, the need for special instrumentation and a high learning curve for the surgeons.

Overall, this thesis provides a comprehensive overview of the current state of THR in canine and compares three different systems focusing mainly on the Biomedtrix system which was used in the cases analyzed in this thesis. This overall provides valuable insights for veterinary surgeons in selecting the most appropriate implant system for their patients.

References

1. *A new prosthetic hip joint; experiences in its use in the dog, and its probable application to man.* **HA., Gorman.** [ed.] Mil Med. 1957, pp. 121(2):91–93.

2. **Paul HA, Bargar WL, Mittlestadt B, et al.** *Development of a surgical robot for cementless total hip arthroplasty.* Clin Orthop Relat Res . 1992. pp. 286:57–66.

3. ***Hoefle WD. A surgical procedure prosthetic total hip replacement in the dog.*** **J Am Anim Hosp Assoc. 1974. pp. 10:269–276.**

4. Olmstead ML, Hohn RB, Turner TM. ***A five-year study of 221 total hip replacements in the dog.*** **J Am Vet Med Assoc . 1983. pp. 183:191–194.**

5. Gitelis S, Chen PQ, Andersson GBJ, et al. ***The influence of early weight-bearing on experimental total hip arthroplasties in dogs.*** **Clin Orthop Relat Res . 1982. pp. 169:291–302.**

6. Dowd JE, Schwendeman LJ, Macaulay W, et al. ***Aseptic loosening in uncemented total hip arthroplasty in a canine model.*** **Clin Orthop Relat Res . 1995. pp. 319: 106–121.**

7. ML., Olmstead. ***The canine cemented modular total hip prosthesis.*** **J Am Anim Hosp Assoc . 1995. pp. 31:109–124. .**

8. ***Cemented total hip replacement: Experience in USA with the BioMedtrix prosthesis.*** **WD., Liska. [ed.] In: Proceedings of the Pre congress of the European Society of Veterinary Orthopaedics and Traumatology. Munich, Germany : s.n., 2004.**

9. ***Agins HJ, Alcock NW, Bansal M, et al. Metallic wear in failed titanium-alloy total hip replacements.*** **J Bone Joint Surg Am . 1988. pp. 70:347–356.**

10. Goldring SR, Schiller AL, Roelke M, et al. ***The synovial like membrane at the bone-cement interface in loose total hip replacements and its proposed role in bone lysis.*** **J Bone Joint Surg Am. 1983. pp. 65:575–584.**

11. Marcellin-Little DJ, DeYoung DJ, Thrall DE, Merrill CL. ***Osteosarcoma at the site of bone infarction associated with total hip arthroplasty in a dog.*** **Vet Surg . 1999. pp. 28:54–60.**

12. DeYoung DJ, DeYoung BA, Aberman HA, et al. ***Implantation of an uncemented total hip prosthesis: Technique and initial results of 100 arthroplasties.*** **Vet Surg . 1992. pp. 21:168–177.**

13. Edwards MR, Egger EL, Schwarz PD. ***Aseptic loosening of the femoral implant after cemented total hip arthroplasty in dogs: 11 cases in 10 dogs (1991–1995).*** **J Am Vet Med Assoc . 1997. pp. 211:580–586.**

14. Skurla CP, Pluhar GE, Frankel DJ, et al. ***Assessment of the dog as a model for human total hip replacement.*** **J Bone Joint Surg Br. 2005. pp. 87:120–127.**

15. Schiller TD, DeYoung DJ, Schiller RA, et al. ***Quantitative ingrowth analysis of a porous-coated acetabular component in a canine model.*** **Vet Surg . 1993. pp. 22: 276–80.**

16. Vezzoni L, Vezzoni A, Boudrieau RJ. *Long-term outcome of zurich cementless total hip arthroplasty in 439 cases.* Vet Surg . 2015. pp. 44(8):921–9.

17. Bourne RB, Rorabeck CH, Burkart BC, et al. *Ingrowth surfaces. Plasma spray coating to titaniumalloy hip replacements.* Clin Orthop Relat Res. 1994. pp. (298):37–46.

18. Guerrero TG, Montavon PM. *Zurich cementless total hip replacement: retrospective evaluation of 2nd generation implants in 60 dogs.* Vet Surg. 2009. pp. 38(1):70–80.

19. Vezzoni L, Vezzoni A, Boudrieau RJ. *Long-term outcome of zurich cementless total hip arthroplasty in 439 cases.* Vet Surg . 2005. pp. 44(8):921–9.

20. Hummel DW, Lanz OI, Werre SR. *Complications of cementless total hip replacement. A retrospective study of 163 cases.* Vet Comp Orthop Traumatol . 2010. pp. 23(6):424–32.

21. Peck, J. N., Marcellin-Little, D. J. *Advances in Small Animal Total Joint Replacement.* 2013. https://doi.org/10.1002/9781118704776.

22. Olmstead ML, Hohn RB, Turner TM. *A five-year study of 221 total hip replacements in the dog.* J Am Vet Med Assoc. 1983. pp. 183:191–194.

23. Marcellin-Little DJ, DeYoung BA, Doyens DH, et al. *Canine uncemented porous-coated anatomic total hip arthroplasty: Results of a long-term prospective evaluation of 50 consecutive cases.* Vet Surg . 1999. pp. 28: 10–20.

24. Guerrero TG, Montavon PM. *Zurich cementless total hip replacement: Retrospective evaluation of 2nd generation implants in 60 dogs.* Vet Surg. 2009. pp. 38:70–80.

25. Mawby DI, Bartges JW, d'Avignon A, et al. *Comparison of various methods for estimating body fat in dogs.* J Am Anim Hosp Assoc . 2004. pp. 40:109–114.

26. DJ., Marcellin-Little. Medical treatment of coxofemoral joint disease. [book auth.] Twedt DC (eds.). Bonagura JD. *Kirk's Current Veterinary Therapy XIV.* 2008, pp. pp. 1120–1125.

27. Schulz KS, Dejardin LM. Surgical treatment of canine hip dysplasia. [book auth.] editor. Slatter D. *Textbook of small animal surgery. 3rd edition.* 2002., pp. p. 2029–59.

28. Peck JN, Liska WD, DeYoung DJ, et al. Clinical application of total hip replacement. . [book auth.] Marcellin-Little DJ, editors. Peck JN. *Advances in small animal total joint replacement.* s.l. : Wiley-Blackwell, 2013., pp. p. 69–107.

29. Fitzpatrick N, Pratola L, Yeadon R et al. *Total hip replacement after failed femoral head and neck excision in two dogs and two cats.* Vet Surg. 2012. pp. 41:136–142.

30. Andreoni AA, Guerrero TG, Hurter K, et al. *Revision of an unstable HELICA endoprosthesis with a Zurich cementless total hip replacement.* Vet Comp Orthop Traumatol . 2010. pp. 23(3):177–81.

31. Peck JN, Liska WD, DeYoung DJ, et al. Clinical application of total hip replacement. . [book auth.] Marcellin-Little DJ, editors. Peck JN. *Advances in small animal total joint replacement.* s.l. : Wiley-Blackwell, 2013, pp. p. 69–107.

32. Off W, Matis U. *Excision arthroplasty of the hip joint in dogs and cats.* Clinical, radiographic, and gait analysis findings from the Department of Surgery, Veterinary Faculty of the Ludwig Maximilians-University of Munich, Germany., Vet Comp Orthop Traumatol. 2010. pp. 23:297–305.

33. Liska WD, Doyle N, Marcellin-Little DJ, et al. *Total hip replacement in three cats: Surgical technique, shortterm outcome and comparison to femoral head ostectomy.* Vet Comp Orthop Traumatol . 2009. pp. 22:505–510.

34. Fitzpatrick N, Pratola L, Yeadon R et al. *Total hip replacement after failed femoral head and neck excision in two dogs and two cats.* Vet Surg. 2012. pp. 41:136–142.

35. Liska, W.D. *Micro total hip replacement for dogs and cats: surgical technique and outcomes.* Veterinary Surgery . 2010. pp. 39, 797-810.

36. Smith GK, Leighton EA, Karbe GT, McDonald-Lynch MB. Pathogenesis, Diagnosis, and Control of Canine Hip Dysplasia. . [book auth.] Tobias K, eds. In: Johnston SA. *Veterinary Surgery: Small Animal. 2nd ed.* 2018, pp. 964-992.

37. Johnson J, Austin C, Breur G. *Incidence of Canine Appendicular Musculoskeletal Disorders in 16 Veterinary Teaching Hospitals from 1980 through 1989.* Vet Comp Orthop Traumatol. 1994. p. 07(02):56 69. .

38. Ginja MMD, Silvestre AM, Gonzalo-Orden JM, Ferreira AJA. *Diagnosis, genetic control and preventive management of canine hip dysplasia: A review.* Vet J. 2010. pp. 184(3):269-276.

39. —. *Diagnosis, genetic control and preventive management of canine hip dysplasia: A review.* Vet J. 2010. pp. 184(3):269-276. .

40. Vezzoni A, Peck JN. Surgical Management of Hip Dysplasia. . [book auth.] Tobias K, eds. Johnson SA. *Veterinary Surgery: Small Animal. 2nd ed.* Elsevier Inc. : s.n., 2018, pp. 992-1018.

41. Piermattei DL, Flo GL, DeCamp CE. The hip joint. . [book auth.] Flo GL, DeCamp CE, editors. Piermattei DL. *Brinker, Piermattei, and Flo's handbook of small animal orthopedics and fracture repair. 4th edition.* s.l. : Saunders Elsevier, 2006, pp. p. 416–511.

42. Wallace LJ, Olmstead ML. Disabling conditions of the coxofemoral joint. . [book auth.] editor. Olmstead ML. *Small animal orthopedics.* s.l. : Mosby, 1995, pp. p. 361–93.

43. Riser WH, Rhodes WH, Newton CD. Hip dysplasia. [book auth.] Nunamaker DM, editors. Newton CD. *Textbook of small animal orthopedics.* s.l. : JB Lippincott, 1985, pp. p. 953–80.

44. Smith GK, Leighton EA, Karbe GT, McDonald-Lynch MB. Pathogenesis, Diagnosis, and Control of Canine Hip Dysplasia. . [book auth.] Tobias K, eds. Johnston SA. *Veterinary Surgery: Small Animal. 2nd ed.* s.l. : Elsevier Inc., 2018, pp. 964-992.

45. Fry, T.R., Clark, D.M. *Canine hip dysplasia: clinical signs and physical diagnosis.* Veterinary Clinics of North America: Small Animal Practice. 1992. pp. 22, 551– 558.

46. TG., Barlow. *Early diagnosis and treatment of congenital dislocation of the hip.* Proc R Soc Med. 1963. pp. 56:804–6.

47. M., Ortolani. *Congenital hip dysplasia in the light of early and very early diagnosis.* Clin Orthop Relat Res . 1976. pp. 119:6–10.

48. Bardens JW, Hardwick H. *New observations on the diagnosis and cause of hip dysplasia.* Vet Med Small Anim Clin . 1968. pp. 63:238–45.

49. Ginja, M.M.D., Ferreira, A.J., Jesus, S.S., Melo-Pinto, P., Bulas-Cruz, J., Orden, M.A., San Roman, F., Llorens-Pena, M.P., Gonzalo-Orden, J.M. *Comparison of clinical, radiographic, computed tomographic and magnetic resonance imaging methods for early prediction of canine hip dysplasia.* Veterinary Radiology and Ultrasound . 2009. pp. 50, 135–143.

50. Adams, W.M., Dueland, R.T., Daniels, R., Fialkowski, J.P., Nordheim, E.V. *Comparison of two palpation, four radiographic and three ultrasound methods for early detection of mild to moderate canine hip dysplasia.* Veterinary Radiology and Ultrasound. 2000. pp. 41, 484–490.

51. Bardens, J.W., Hardwick, H. *New observations on the diagnosis and cause of hip dysplasia.* Veterinary Medicine: Small Animal Clinician . 1968. pp. 63, 238-245.

52. Puerto DA, Smith GK, Gregor TP, et al. *Relationships between results of the Ortolani method of hip joint palpation and distraction index, Norberg angle, and hip score in dogs.* J Am Vet Med Assoc. 1999. pp. 214:497–501.

53. Fry, T.R., Clark, D.M. *Canine hip dysplasia: clinical signs and physical diagnosis.* Veterinary Clinics of North America: Small Animal Practice. 1992. . pp. 22, 551– 558.

54. Powers MY, Karbe GT, Gregor TP, et al. *Evaluation of the relationship between Orthopedic Foundation for Animals' hip joint scores and PennHIP distraction index values in dogs.* Assoc, J Am Vet Med. 2010. pp. 237(5):532–41.

55. GB., Schelle. *Some new diseases in the dog. Am Kennel Gazette.* 1935. p. 52:25.

56. WH., Riser. *Producing diagnostic pelvic radiographs for canine hip dysplasia.* J Am Vet Med Assoc . 1962. p. 141:600.

57. Owens JM, Biery NA. *Radiographic interpretation for the small animal clinician.* s.l. : Baltimore (MD): Williams & Wilkins, 1999.

58. WH., Riser. *The dysplastic hip joint: its radiographic and histologic development.* Vet Radiol Ultrasound . 1973. pp. 14:35–40.

59. Henricson B, Norberg I, Olsson SE. *On the etiology and pathogenesis of hip dysplasia: a comparative review.* J Small Anim Pract . 1966. p. 7:673.

60. Smith GK, Biery DN, Gregor TP. *New concepts of coxofemoral joint stability and the development of a clinical stress-radiographic method for quantitating hip joint laxity in the dog.* J Am Vet Med Assoc . 1990. pp. 196(1):59–70.

61. Heyman SJ, Smith GK, Cofone MA. *Biomechanical study of the effect of coxofemoral positioning on passive hip joint laxity in dogs.* Am J Vet Res. 1993. pp. 54(2): 210–5.

62. MB., Willis. ***A review of the progress in canine hip dysplasia control in Britain.*** **J Am Vet Med Assoc. 1997. p. 210:1480.**

63. Skurkova´ L, Hluchy´ M, Lackova´ M, et al. ***Relation of the Norberg angle and position of the femoral head centre to the dorsal acetabular edge in evaluation of canine hip dysplasia.*** **Vet Comp Orthop Traumatol . 2010. pp. 23(6):433–8.**

64. Tomlinson JL, Johnson JC. ***Quantification of measurement of femoral head coverage and Norberg angle within and among four breeds of dogs.*** **Am J Vet Res . 2000. pp. 61(12):1492–500.**

65. . Smith GK, Karge GT, Angello KA, et al. Pathogenesis, diagnosis, and control of canine hip dysplasia. . [book auth.] Johnson SA, editors. Tobais KM. ***Veterinary surgery: small animal, vol. 1, 1st edition.*** **s.l. : St Louis (MO): Saunders/Elsevier, 2012., pp. p. 824–48.**

66. Smith GK, Biery DN, Gregor TP. ***New concepts of coxofemoral joint stability and the development of a clinical stress-radiographic method for quantitating hip joint laxity in the dog.*** **J Am Vet Med Assoc . 1990. pp. 196(1):59–70.**

67. Smith GK, Karge GT, Angello KA, et al. Pathogenesis, diagnosis, and control of canine hip dysplasia. . [book auth.] Johnson SA, editors. Tobais KM. ***Veterinary surgery: small animal, vol. 1, 1st edition.*** **s.l. : St Louis (MO): Saunders/Elsevier, 2012., pp. p. 824–48.**

68. Gold RM, Gregor TP, Huck JL, et al. ***Effects of osteoarthritis on radiographic measures of laxity and congruence in hip joints of Labrador Retrievers.*** **J Am Vet Med Assoc. 2009. p. 234:1549.**

69. Smith GK, Hill CM, Gregor TP, et al. ***Reliability of the hip distraction index in twomonth- old German Shepherd dogs.*** **J Am Vet Med Assoc . 1998. p. 212:1560.**

70. Adams WM, Dueland RT, Meinen J, et al. ***Early detection of canine hip dysplasia: comparison of two palpation and five radiographic methods.*** **J Am Anim Hosp Assoc . 1998. p. 34:339.**

71. Smith GK, Gregor TP, Rhodes WH, et al. ***Coxofemoral joint laxity from distraction radiography and its contemporaneous and prospective correlation with laxity, subjective score, and evidence of degenerative joint disease from conventional hip-extended radiography in dogs.*** **Am J Vet Res . 1993. p. 54:1021.**

72. Ginja, M.M.D., Llorens-Pena, M.P., Gonzalo-Orden, J.M., Ferreira, A.J.A.,. ***Mechanical devices to help in PennHIP examination.*** **Acta Veterinaria Hungarica . 2007. pp. 55, 199–205.**

73. Slocum B, Devine T. ***Dorsal acetabular rim radiographic view for evaluation of the canine hip.*** **J Am Anim Hosp Assoc. 1990. pp. 26:289–96.**

74. WH., Riser. ***The dysplastic hip joint: its radiographic and histologic development.*** **Vet Radiol Ultrasound . 1973. pp. 14:35–40.**

75. DeJardin LM, Perry RL, Arnoczky SP. ***The effect of triple pelvic osteotomy on the articular contact area of the hip joint in dysplastic dogs: as in vitro experimental study.*** **Vet Surg . 1998. pp. 27:194–202.**

76. Weigel JP, Wasserman JF. ***Biomechanics of the normal and abnormal hip joint.*** **Vet Clin North Am Small Anim Pract . 1992. pp. 22:513–28.**

77. WD., Prieru. *Coxarthrosis in the dog: part 1 normal and abnormal biomechanics of the hip joint.* Vet Surg . 1980. pp. 9:145–9.

78. Slocum B, Devine T. *Dorsal acetabular rim radiographic view for evaluation of the canine hip.* J Am Anim Hosp Assoc . 1990. pp. 26:289–96.

79. Devin-Slocum T, Slocum B. Radiographic characteristics of hip dysplasia. [book auth.] editor. Bojrab MJ. *Current techniques in small animal surgery. 4th edition.* s.l. : Baltimore (MD): Williams and Wilkins, 1998, pp. p. 1145–51.

80. Gatineau M, Dupuis J, Beauregard G, et al. *Palpation and dorsal acetabular rim radiographic projection for early detection of canine hip dysplasia: a prospective study.* Vet Surg. 2012. pp. 41(1):42–53.

81. Liska WD, Doyle ND, Schwartz Z. *Successful revision of a femoral head ostectomy (complicated by postoperative sciatic neurapraxia) to a total hip replacement in a cat.* Vet Comp Orthop Traumatol . 2010. pp. 23:119–123.

82. Mickelson MR, McCurnin DM, Awbrey BJ, et al:. *Legg-Calv´e-Perthes disease in dogs: a comparison to human Legg- Calv´e-Perthes disease.* Clin Orthop Relat Res. 1981. pp. 157:287–300.

83. Lee R, Fry PD:. *Some observations on the occurrence of Legg-Calv´e-Perthes' disease (Coxaplana) in the dog, and an evaluation of excision arthroplasty as a method of treatment.* J Small Anim Pract . 1969. pp. 10:309–317.

84. G:, Ljunggren. *Legg-Perthes disease in the dog.* Acta Orthop Scand . 1967. pp. 95:1–79.

85. GL:, Junggren. *A comparative study of conservative and surgical treatment of Legg Perthes disease in the dog.* J Am Anim Hosp Assoc . 1966. pp. 1:6–10.

86. DM, Nunamaker. Legg-Calv´e-Perthes disease. . [book auth.] Nunamaker DM (eds) Newton CD. *Textbook of small animal orthopaedics.* Philadelphia, PA, Lippincott, : s.n., 1985, pp. pp 949–952.

87. Warren DV, Dingwall JS. *Legg-Perthes disease in the dog – a review.* Can Vet J . 1972. pp. 13:135–137.

88. Bassett FH, Wilson JW, Allen BL, et al. *Normal vascular anatomy of the head of the femur in puppies with emphasis on the inferior retinacular vessels.* J Bone Joint Surg Am. 1969. pp. 51:1139–1153.

89. Pidduck H, Webbon PM:. *The genetic control of Perthes' disease in toy poodles—a working hypothesis.* J Small Anim Pract . 1978. pp. 19:729–733.

90. Vasseur PB, Foley PF, Stevenson S, et al. *Mode of inheritance of Perthes' disease in Manchester Terriers.* Clin Pathol . 1989. pp. 233:281–292.

91. Paatsama S, Rissanen P, Rokkanen R, et al. *Legg-Perthes' disease in the dog.* J Small Anim Pract . 1967. p. 8:215.

92. G:, Ljunggren. *Legg-Perthes disease in the dog.* Acta Orthop Scand . 1967. pp. 95:1–79.

93. Liu SL, Ho TC. *The role of venous hypertension in the pathogenesis of Legg-Perthes disease.* J Bone Joint Surg Am . 1991. pp. 73A:194–200.

94. Sanchis M, Zahir A, Freeman MAR, et al. *The experimental simulation of Perthes disease by consecutive interruption of the blood supply to the capital femoral epiphysis in the puppy.* J Bone Joint Surg Am . 1979. pp. 55:335–342.

95. Brenig B, Leeb T, Jansen S, et al. *Analysis of blood clotting factor activities in canine Legg-Calve´-Perthes' disease.* J Vet Intern Med. 1999. pp. 13:570–573.

96. Vasseur PB, Foley PF, Stevenson S, et al:. *Mode of inheritance of Perthes' disease in Manchester Terriers.* Clin Pathol . 1989. pp. 233:281–292.

97. Warren DV, Dingwall JS. *Legg-Perthes disease in the dog – a review.* Can Vet J . 1972. pp. 13:135–137.

98. DM:, Nunamaker. Legg-Calv´e-Perthes disease. [book auth.] Nunamaker DM (eds) Newton CD. *Textbook of small animal orthopaedics.* 1985, pp. pp 949–952.

99. R:, Lee. *A study of the radiographic and histological changes occurring in Legg-Calv´e Perthes disease (LCP) in the dog.* J Small Anim Pract . 1970. pp. 11:621–638.

100. R, Lee. *A study of the radiographic and histological changes occurring in Legg-Calv´e-Perthes disease (LCP) in the dog.* J Small Anim Pract . 1970. pp. 11:621–638.

101. Mickelson MR, McCurnin DM, Awbrey BJ, et al:. *Legg-Calv´e-Perthes disease in dogs: a comparison to human Legg- Calv´e-Perthes disease.* Clin Orthop Relat Res. 1981. pp. 157:287–300.

102. Jankovits DA, Liska WD, Kalis RH. *Treatment of avascular necrosis of the femoral head in small dogs with micro total hip replacement.* Vet Surg. 2012. pp. 41:143–147.

103. ML, Olmstead. *The canine cemented modular total hip prosthesis.* J Am AnimHosp Assoc . 1995. p. 31:109 124.

104. Pozzi A, Kowaleski MP, Dyce J, et al. *Treatment of traumatic coxo-femoral luxation by cemented total hip arthroplasty.* Vet Comp Orthop Traumatol . 2004. pp. 17:198–203.

105. Moores AP, Owen MR, Fews D, et al. *Slipped capital femoral epiphysis in dogs.* J Small Anim Pract . 2004. pp. 45:602–608.

106. R, Lee. *Proximal femoral epiphyseal separation in the dog.* J Small Anim Pract. 1976. pp. 11:669–679.

107. Culvenor JA, Black AP, Lorkin KF, et al. *Repair of femoral capital physeal injuries in cats - 14 cases.* Vet Comp Orthop Traumatol . 1996. pp. 1996;9:182–185.

108. DE, O'Reilly. *Acute traumatic separation of the capital femoral epiphysis.* South Med J . 1971. pp. 64:847-851.

109. Perez-Aparicio FJ, Fjeld TO. *Femoral neck fractures and capital epiphyseal separations in cats.* J Small Anim Pract . 1993. pp. 34:445–449.

110. Moores AP, Owen MR, Fews D, et al. *Slipped capital femoral epiphysis in dogs.* J Small Anim Pract. 2004. pp. 45:602–608.

111. Perez-Aparicio FJ, Fjeld TO. *Femoral neck fractures and capital epiphyseal separations in cats.* J Small Anim Pract . 1993. pp. 34:445–449.

112. RM., McLaughlin. *Traumatic joint luxations in small animals.* Vet Clin North Am Small Anim Pract. . 1995. pp. 25:1175-1196.

113. Pozzi A, Kowaleski MP, Dyce J, Johnson KA. *Treatment of traumatic coxo-femoral luxation by cemented total hip arthroplasty.* Vet Comp Orthop Traumatol. . 2004. pp. 17:198-203.

114. Berzon JL, Howard PE, Covell SJ, Trotter EJ, Dueland AR. *A retrospective study of the efficacy of femoral head and neck excisions in 94 dogs and cats.* Vet Surg. . 1980. pp. 9:88-92.

115. Forster KE, Wills A, Torrington AM, et al. *Complications and owner assessment of canine total hip replacement: a multicenter internet based survey.* Vet Surg. . 2012. pp. 41:545-550.

116. Boswell KA, Boone EG, Boudrieau RJ. *Reduction and temporary stabilization of acetabular fractures using ASIF mandibular reduction forceps: Technique and results using plate fixation in 25 dogs.* Veterinary Surgery. . 2001. pp. 30:1-10.

117. Gao YS, Zhu ZH, Chen SB, Cheng XG, Jin DX, Zhang CQ. *Injury-to-surgery interval does not affect the occurrence of osteonecrosis of the femoral head: a prospective study in a canine model of femoral neck fractures.* Med Sci Monit. 2012 Jul. pp. 18(7):BR259-64.

118. Guerrero TG, Montavon PM. *Zurich cementless total hip replacement: retrospective evaluation of 2nd generation implants in 60 dogs.* Vet Surg. 2009. pp. 38(1):70–80.

119. Vezzoni L, Vezzoni A, Boudrieau RJ. *Long-term outcome of zurich cementless total hip arthroplasty in 439 cases.* Vet Surg . 2015. pp. 44(8):921–9.

120. Hummel DW, Lanz OI, Werre SR. *Complications of cementless total hip replacement. A retrospective study of 163 cases.* Vet Comp Orthop Traumatol . 2010. pp. 23(6):424–32.

121. Andreoni AA, Guerrero TG, Hurter K, et al. *Revision of an unstable HELICA endoprosthesis with a Zurich cementless total hip replacement.* Vet Comp Orthop Traumatol . 2010. pp. 23(3):177–81.

122. Smith GK, Langenbach A, Green PA, et al. *Evaluation of the association between medial patellar luxation and hip dysplasia in cats.* J Am Vet Med Assoc. 1999. pp. 215:40–45.

123. Peck JN, Liska WD, DeYoung DJ, et al. Clinical application of total hip replacement. . [book auth.] Marcellin-Little DJ, editors. Peck JN. *Advances in small animal total joint replacement.* s.l. : Wiley-Blackwell, 2013., pp. p.69–107.

124. *Canine total hip replacement using a cementless threaded cup and stem: a review of 55 cases. J Small Anim Pract.* Denny HR, Linnell M, Maddox TW, Comerford EJ. 2018, pp. 59(6):350-356. .

125. Liska, W., & Dyce, J. Total Hip Replacement. *Complications in Small Animal Surgery.* s.l. : John Wiley & Sons, 2016, pp. pp. 778–833.

126. Vezzoni A, Peck JN. Surgical Management of Hip Dysplasia. . [book auth.] Tobias K, eds. Johnson SA. *Veterinary Surgery: Small Animal. 2nd ed.* s.l. : Elsevier Inc., 2018, pp. 992-1018.

127. —. Surgical Management of Hip Dysplasia. [book auth.] Tobias K, eds. Johnson SA. *Veterinary Surgery: Small Animal. 2nd ed.* s.l. : Elsevier Inc., 2018, pp. 992-1018.

128. Mai KT, Verioti CA, Casey K, et al. *Cementless femoral fixation in total hip arthroplasty.* Am J Orthop. 2010. pp. 39:126–130.

129. Khanuja HS, Vakil JJ, Goddard MS, et al. *Cementless femoral fixation in total hip arthroplasty.* J Bone Joint Surg Am . 2011. pp. 93:500–509.

130. TAM., Harper. *INNOPLANT Total Hip Replacement System.* Vet Clin North Am Small Anim Pract. . 2017. pp. 47(4):935-944.

131. Olmstead, M. L. *Canine cemented total hip replacements: State of the art.* Journal of Small Animal Practice. 1995. pp. 36(9), 395–399.

132. D., Hummel. *Zurich Cementless Total Hip Replacement.* Vet Clin North Am Small Anim Pract. . 2017 Jul. pp. 47(4):917-934. .

133. TD., Schiller. *BioMedtrix Total Hip Replacement Systems: An Overview.* 2017. 47(4):899-916..

134. Rashmir-Raven AM, DeYoung DJ, Abrams CF, et al. *Subsidence of an uncemented canine femoral stem.* Vet Surg . 1992. pp. 21:327–31.

135. Sariali E, Boukhelifa N, Catonne Y, Moussellard HP. *Comparison of three-dimensional planning-assisted and conventional acetabular cup positioning in total hip arthroplasty a randomized controlled trial.* J Bone Jt Surg Am Vol. . 2016. 98(2):108-116..

136. Dearmin MG, Schulz KS. *The effect of stem length on femoral component positioning in canine total hip arthroplasty.* Vet Surg . 2004. pp. 33:272–278.

137. Shields SL, Schulz KS, Hagan CE, et al. *The effects of acetabular cup temperature and duration of cement pressurization on cement porosity in a canine total hip replacement model.* Vet Surg . 2002. p. 31:167.

138. Clayton R, Cravens R, Hupfer T, et al. *Intermediate results of a cemented Femoral stem with a PMMA premantle.* Orthopedics . 2007. p. 30:950.

139. Ota J, Cook JL, Lewis DD, et al. *Short-term aseptic loosening of the femoral component in canine total hip replacement: Effects of cementing technique on cement mantle grade.* Vet Surg . 2005. pp. 34:345–352.

140. Davies JP, Connor DO, Burke DW, et al. *The effect of centrifugation on the fatigue life of bone cement in the presence of surface irregularities.* Clin Orthop Rel Res. 1998. pp. 229:156–161.

141. Weisman DL, Olmstead ML, Kowalski JJ. *In vitro evaluation of antibiotic elution from polymethylmethacrylate (PMMA) and mechanical assessment of antibiotic-PMMA composites.* Vet Surg . 2000. pp. 29: 245–251.

142. Mann KA, Miller MA, Cleary RJ, et al. *Experimental micromechanics of the cement–bone interface.* J Orthop Res . 2008. pp. 26:872–879.

143. WD., Liska. Cemented total hip replacement: experience in USA with the Bio-Medtrix prosthesis. . [book auth.] European Society of Veterinary Orthoped Munich. *Proceedings of the pre-congress of the European Society of Veterinary Orthopaedics and Traumatology.* Munich : s.n., 2004.

144. Rashmir-Raven AM, DeYoung DJ, Abrams CF Jr., et al. *Subsidence of an uncemented canine femoral stem.* Vet Surg. 1992. pp. 21:327–331.

145. *https://biomedtrix.com/bfx-ebm-titanium-stem/.* [Online]

146. Ordway NR, Ash KJ, Miller MA, Mann KA, Hayashi K. A. *Biomechanical Comparison of Four Hip Arthroplasty Designs in a Canine Model. .* Vet Comp Orthop Traumatol. . 2019. pp. 32(5):369-375.

147. https://www.freelance-veterinary.co.uk/bfxcollaredfemoralstemtitanium . [Online]

148. *https://biomedtrix.com/bfx-centerline-stem/.* [Online]

149. Robert A. Poggie, PhD President, BioVera, Inc. *Highly Crosslinked and Vitamin E Stabilized UHMWPE .*

150. Ireifej S, Marino D, Loughin C. *Nano total hip replacement in 12 dogs. .* Vet Surg. 2012. pp. 41(1):130-135.

151. https://biomedtrix.com/total-hip-replacement/. [Online]

152. Marino DJ, Ireifej SJ, Loughin CA. *Micro total hip replacement in dogs and cats.* Vet Surg. . 2012. pp. 41(1):121-129. .

153. Piermattei DJ, Johnson KA. Approach to the craniodorsal aspect of the hip joint through a craniolateral incision. [book auth.] Johnson K, editors. Piermattei D. *An atlas of surgical approaches to the bones and joints of the dog and cat. 4th edition.* Philadephia: W : s.n., 2004, pp. p. 290–5.

154. *Initial stability and femoral strain pattern during axial loading of canine cementless femoral prostheses: effect of resection level and implant size.* Townsend KL, Kowaleski MP, Johnson KA. s.l. : Scientific Abstracts Proceedings of the Veterinary Symposium, Chicago 2006, 2007. American College of Veterinary Surgeons. Vet Surg . p. 36:E26.

155. Montgomery ML, Kim SE, Dyce J, et al. *The effect of dorsal rim loss on the initial stability of the BioMedtrix cementless acetabular cup.* BMC Vet Res. 2015. p. 11:68.

156. Margalit KA, Hyashi K, Jackson J, et al. *Biomechanical evaluation of acetabular cup implantation in cementless total hip arthroplasty.* Vet Surg . 2010. pp. 39:818–23.

157. MacDonald W, Swarts E, Beaver R. *Penetration and shear strength of cementbone interfaces in vivo.* Clin Orthop Relat Res . 1993. pp. 286:283–8.

158. Stone MH, Wilkinson R, Stother IG. *Some factors affecting the strength of the cement-metal interface.* J Bone Joint Surg Br . 1989. pp. 71:217–221.

159. ***Concepts of cementless Zurich prosthesis. .*** **S, Tepic. Munich : s.n., 2004. Proceedings of the ESVOT 2004 Pre-congress Total Hip Replacement Seminar. pp. pp 18–20.**

160. Bourne RB, Rorabeck CH, Cecil H, et al. ***In-growth surfaces: plasma spray coating to titanium alloy hip replacements.*** **Clin Orthop Rel Res. 1994. pp. 298:37–46.**

161. Hanson SP, Peck JN, Berry CR et al. ***Radiographic evaluation of the Z€urich cementless total hip acetabular component.*** **Vet Surg. 2006. pp. 35:550–558.**

162. ***Clinical application of Z€urich Cementless canine total hip prosthesis.*** **Montavon P, Tepic S. Munich, Germany : s.n., 2002,. Proceedings of 1stWorld Orthopaedic Veterinary Congress. p. p 150.**

163. kyon. [Online] https://www.kyon.ch/products-solutions/thr-total-hip-replacement/?_gl=1*8nn8dl*_ga*NTk1MzQxNDkyLjE2NzUyNTc3ODI.*_ga_SF4WJZLVT0*MTY3NTI1Nzc4Mi4xLjEuMTY3NTI1Nzc4Mi42MC4wLjA. .

164. Vezzoni L, Montinaro V, Vezzoni A. ***Use of a revision cup for treatment of Zurich cementless acetabular cup loosening. Surgical technique and clinical application in 31 cases.*** **Vet Comp Orthop Traumatol. 2013. pp. 26(5):408–15.**

165. SC., Roe. Implant materials: structural. [book auth.] Marcellin-Little DJ, editor In: Peck JN. ***Advances in small animal total joint replacement.*** **s.l. : Wiley-Blackwell, 2913, pp. p. 11–8.**

166. Kim, J. Y., Hayashi, K., Garcia, T. C., et al. ***Biomechanical evaluation of screw-in femoral implant in cementless total hip system.*** **Veterinary Surgery. 2012. pp. 41, 94 102.**

167. Kim JY, Hayashi K, Garcia TC, et al. ***Biomechanical evaluation of screw-in femoral implant in cementless total hip system.*** **Vet Surg. 2012. pp. 41(1):94–102.**

168. SC., Roe. Implant materials: structural. [book auth.] Marcellin-Little DJ, editors. Peck JN. ***Advances in small animal total joint replacement.*** **s.l. : Wiley-Blackwell, 2013, pp. p. 11–8.**

169. Hach V, Delfs G. ***Initial experience with a newly developed cementless hip endoprosthesis.*** **Vet Comp Orthop Traumatol . 2009. pp. 22(2):153–8.**

170. Hayashi K, Schulz K. Methods of immediate fixation. . [book auth.] Marcellin- Little DJ, editors. In: Peck JN. ***Advances in small animal total joint replacement.*** **s.l. : Wiley-Blackwell, 2013, pp. p. 39–51.**

171. Kold S, Rahbek O, Vestermark M, et al. ***Bone compaction enhances fixation of weightbearing titanium implants.*** **Clin Orthop Relat Res. 2005. pp. (431):138–44.**

172. Windolf M, Braunstein V, Dutoit C, et al. ***Is a helical shaped implant a superior alternative to the dynamic hip screw for unstable femoral neck fractures? A biomechanical investigation.*** **Clin Biomech . (Bristol, Avon) : s.n., 2009. pp. 24(1):59–64.**

173. Kim JY, Hayashi K, Garcia TC, et al. ***Biomechanical evaluation of screw-in femoral implant in cementless total hip system.*** **Vet Surg. 2012. pp. 41(1):94–102.**

174. Agnello KA, Cimino Brown D, Aoki K, et al. ***Risk factors for loosening of cementless threaded femoral implants in canine total hip arthroplasty.*** **Vet Comp Orthop Traumatol. 2015. pp. 28(1):48–53.**

175. Hayashi K, Schulz K. Methods of immediate fixation. [book auth.] Marcellin- Little DJ, editors. Peck JN. *Advances in small animal total joint replacement.* s.l. : Wiley-Blackwell, 2013, pp. p. 39–51. .

176. Dosch M, Hayashi K, Garcia TC, et al. *Biomechanical evaluation of the helica femoral implant system using traditional and modified techniques.* Vet Surg. 2013. pp. 42(7):867–76.

177. Hayashi K, Schulz K. Methods of immediate fixation. [book auth.] Marcellin- Little DJ, editors. Peck JN. *Advances in small animal total joint replacement.* s.l. : Wiley-Blackwell, 2013, pp. p. 39–51.

178. *Micro total hip replacement in dogs and cats. .* Marino DJ, Ireifej SJ, Loughin CA. s.l. : Vet Surg., 2012, pp. 41(1):121-129.

179. Schulz KS, Dejardin LM. Surgical treatment of canine hip dysplasia. [book auth.] editor. Slatter D. *Textbook of small animal surgery. 3rd edition.* Philadelphia: Elsevier : s.n., 2002, pp. p. 2029–59.

180. JK., Roush. Surgical therapy of canine hip dysplasia. . [book auth.] Johnston SA, editors. Tobias KM. *Veterinary surgery small animal.* St Louis (MO): Elsevier Saunders : s.n., 2012, pp. p. 849–64.

181. McElfresh, E. History of arthroplasty. [book auth.] W. (ed.) In Petty. *Total Joint Replacement.* Philadelphia : Saunders, (1991) , pp. pp. 3-18.

182. *The use of an artificial head for arthroplasty of the hip joint.* Judet, J., Judet, R. (1950), The Journal of Bone & Joint Surgery, pp. 32B, 166-173.

183. *Unsuitability of polyethylene for moveable weight bearing prosthesis.* Newman, P.E., Scales, J.T. (1951), The Journal of Bone & Joint Surgery, pp. 33B, 392-398.

184. Markowitz, J., Archibald, J., Downie, H.G. Surgery of bone and joints. . [book auth.] J., Archibald, J., Downie H.G. (eds.) Markowitz. *Experimental Surgery, 5th edn.* Baltimore : Williams & Wilkins, (1964), pp. pp. 297-331.

185. Hayes, G.M., Ramirez, J., Langley-Hobbs, M.A. *Use of the cumulative summation technique to quantitatively assess a surgical learning curve: canine total hip replacement.* Veterinary Surgery. (2011) . pp. 40, 1-5.

186. *Infection after total hip arthroplasty. A study of a treatment of one hundred and six infections.* Tsukayama, D.T., Estrada, R., Gustilo, R.B. 1996, Journal of Bone and Joint Surgery Am, pp. 78, 512-523.

187. Dyce, J., Olmstead, M.L. *Removal of infected canine cemented total hip prostheses using a femoral window technique.* Veterinary Surgery. 2002. pp. 31, 552-560.

188. *Bacterial infective arthritis of a coxofemoral joint in dogs with hip dysplasia.* Benzioni, H., Shahar, R., Yudelevitch, S., et al. 2008, Veterinary and Comparative Orthopaedics and Traumatology , pp. 21, 262-266.

189. *Brucella canis osteomyelitis in two dogs with total hip replacements.* Smeak, D.D., Olmstead, M.L. (1987), Journal of the American Veterinary Medical Association , pp. 191, 986- 990.

190. *Risk factors and clinical relevance of positive intraoperative bacterial cultures in dogs with total hip replacement.* Ireifej S, Marino D, Loughin CA et al. 2012, Vet Surg, pp. 41(1):63–68.

191. *Positive intraoperative cultures and canine total hip replacement: Risk factors, periprosthetic infection, and surgical success.* Lee KC, Kapatkin AS. s.l. : J Am Anim Hosp Assoc, 2002, pp. 38:271–278.

192. *Successful cementless cup reimplantation using cortical bone graft augmentation after an acetabular fracture and cup displacement.* Torres BT, Chambers JN, Busdsberg SC. 2009, Vet Surg, pp. 38:87–91.

193. *Revision of cemented total hip arthroplasty with cementless components in three dogs.* Torres BT, Budsberg SC. 2009, Vet Surg, pp. 38:81–86.

194. *Acetabular component orientation as an indicator of implant luxation in cemented total hip arthroplasty.* Cross AR, Newell SM, Chambers JN, Shultz KB, Kubilis PS. s.l. : Vet Surg., 2000, pp. (26):517-523.

195. *Hayes GM, Ramirez J, Langley Hobbs SJ. Does the Degree of Preoperative Subluxation or Soft Tissue Tension Affect the Incidence of Postoperative Luxation in Dogs after Total Hip Replacement?* s.l. : Vet Surg., 2011, pp. 40(1):6-13.

196. *Evaluation of risk factors for luxation after total hip replacement in dogs. 2000;29(6):524-532.* Dyce J, Wisner ER, Wang Q, Olmstead ML. s.l. : Vet Surg, 2000, pp. 29(6)524-532.

197. *Acetabular cup liner and prosthetic head exchange to increase the head diameter for management of recurrent luxation of a prosthetic hip in two dogs. .* Roe SC, Sidebotham C, Marcellin-Little DJ. 2015, Vet Comp Orthop Traumatol., pp. 28(1):60-66.

198. Dyce, J., Wisner, E.R., Schrader, S.C., et al. *Radiographic evaluation of acetabular component position in dogs.* Veterinary Surgery . 2001. pp. 30, 28-39.

199. *Risk factors for ventral luxation in canine total hip replacement.* Nelson LL, Dyce J, Shott S. 2007, Vet Surg., pp. 36(7):644-653.

200. *Total hip replacement in 9 canine hind limb amputees: A retrospective study. Preston CA, Schulz KS, Vasseur PB. Total hip replacement in 9 canine hind limb amputees: A retrospective study.* Preston CA, Schulz KS, Vasseur PB. 1999, Vet Surg , pp. 28:341–347.

201. Warnock, J.J., Dyce, J., Pooya, H., et al. *Retrospective analysis of canine miniature total hip prostheses.* Veterinary Surgery. 2003. pp. 32, 285-291.

202. *Preliminary results of fi ve feline total hip replacements.* Witte, P.G., Scott, H.W., Tonzing, M.A. 2010, Journal of Small Animal Practice , pp. 51, 397-402.

203. *Acetabular component orientation as an indicator of implant luxation in cemented total hip arthroplasty.* Cross AR, Newell SM, Chambers JN, et al. 2000, Vet Surg , pp. 29:517–23.

204. *Implantation of an Uncemented Total Hip Prosthesis Technique and Initial Results of 100 Arthroplasties.* DeYoung DJ, DeYoungBA, Aberman HA, Kenna R V, Hungerford DS. 1992, Vet Surg. , pp. 21(3):168-177.

205. *Severe Polyethylene Wear Requiring Revision Total Hip Arthroplasty in Three Dogs.* Nesser VE, Kowaleski MP, Boudrieau RJ. 2016, Vet Surg., pp. 45(5):664-671.

206. ***Periprosthetic fractures evaluation and treatment. Clin Orthop Rel Res.*** **Masri BA, Meek RMB, Duncan CP. 2004, pp. 420:80–95.**

207. ***The Vancouver classification of periprosthetic fractures of the hip: A rational approach to treatment.*** **Brady OH, Kerry R, Masri BA, et al. 1999, Tech Orthop , pp. 14:107–114.**

208. Liska, W. D. ***Femur Fractures Associated with Canine Total Hip Replacement.*** **Veterinary Surgery. 2004. pp. (2), 164–172.**

209. ***Surgical management of intra- and postoperative fractures of the femur about the tip of the stem in total hip arthroplasty. .*** **Schmotzer H, Tchejeyan GH, Dall DM. 1996, J Arthroplasty, pp. 11:709–717.**

210. Lever JP, Zdero R, Nousiainen MT, Waddell JP, Schemitsch EH. ***The biomechanical analysis of three plating fixation systems for periprosthetic femoral fracture near the tip of a total hip arthroplasty.*** **J Orthop Surg. . 2010. p. 5:45.**

211. uMK, Wu SS, et al. s.l. ***J Formos Med Assoc.*** **1999. pp. pp. 98:190–194.**

212. ***Fractures of the femur after hip replacement.*** **Duncan CP, Masri BA. 1995, . Instr Course Lect, . p. p. 44:293.**

213. DeYoung DJ, Schiller RA. ***Radiographic criteria for evaluation of uncemented total hip replacement in dogs.*** **Vet Surg. 1992. pp. 21:88–98.**

214. Liska, W.D. Wires in long bone fracture repair. [book auth.] D.H. (ed.) Slatter. ***Textbook of Small Animal Surgery, vol. II, 1st edn.*** **s.l. : WB Saunders,, 1985, pp. pp. 2003-2013.**

215. Fitzpatrick, N., Nikolaou, C., Yeadon, R., et al. ***String-of-pearls locking plate and cerclage wire stabilization of periprosthetic femoral fractures after total hip replacement in six dogs.*** **s.l. : Veterinary Surgery, (2012b). pp. 41, 180-188.**

216. ***Short-term outcome of uncemented THR.*** **Roe S, Marcellin-Little D, Lascelles D. s.l. : American College of Veterinary Surgeons Veterinary Symposium., 2010. Proceedings of the 2010.**

217. Torres, B.T., Chambers, J.N., Budsberg, S.C. ***Successful cementless cup reimplantation using cortical bone graft augmentation aft er an acetabular fracture and cup displacement.*** **Veterinary Surgery. (2009). pp. 38, 87-91.**

218. Gramkow J, Jensen TH, Varmarken JE et al. ***Long-term results after cemented revision of the femoral component in total hip arthroplasty.*** **J Arthroplasty . 2001. pp. 16:777–783.**

219. Skurla CT, James SP. ***A comparison of canine and human UHMWPE acetabular component wear.*** **Biomed Sci Instrum . 2001. pp. 37:245–250.**

220. Besong AA, Hailey JL, Ingham E et al. ***A study of the combined effects of shelf ageing following irradiation in air and counterface roughness on the wear of UHMWPE.*** **Biomed Mater Eng. 1997. pp. 7:59–65.**

221. Duncan WW, Hubble MJ, Howell JR et al. ***Revision of the cemented femoral stem using a cement-in-cement technique: A five- to 15-year review.*** **J Bone Joint Surg Br. 2009. pp. 91:577–582.**

222. Guerrero TG, Montavon PM. *Zurich cementless total hip replacement: retrospective evaluation of 2nd generation implants in 60 dogs. .* Vet Surg. . 2009 Jan;38. pp. (1):70-80.

223. Vezzoni L, Montinaro V, Vezzoni A. *Use of a revision cup for treatment of Zurich cementless acetabular cup loosening. Surgical technique and clinical application in 31 cases.* Vet Comp Orthop Traumatol. 2013. pp. 26(5):408-15.

224. Andrews CM, Liska WD, Roberts DJ. *Sciatic neurapraxia as a complication in 1000 consecutive canine total hip replacements.* Vet Surg. . 2008. pp. 37(3):254-262.

225. Lozman, J., Deno, D.C., Feustel, P.J., et al. *Pulmonary and cardiovascular consequences of immediate fi xation or conservative management of long bone fractures.* Archives of Surgery 121. (1986) . pp. 992-999.

226. Hofmann, S., Huemer, G., Salzer, M. *Pathophysiology and management of the fat embolism syndrome.* Anaesthesia 53 (2). (1998) . pp. 35-37.

227. *Transesophageal echocardiography for detection of propagating, massive emboli during prosthetic hip fracture surgery.* Shine, T.J., Feinglass, N.G., Leone, B.J., et al. (2012) , Iowa Orthopaedic Journal 30, pp. 211-214.

228. Bergh MS, Gilley RS, Shofer FS, et al. *Complications and radiographic findings following cemented total hip replacement: a retrospective evaluation of 97 dogs.* Vet Comp Orthop Traumatol . 2006. pp. 19(3):172–9.

229. Liska WD, Poteet BA. *Pulmonary embolism associated with canine total hip replacement.* Vet Surg . 2003. pp. 32(2):178–86.

230. ML., Olmstead. *The canine cemented modular total hip prosthesis.* J Am Anim Hosp Assoc . 1995. pp. 31:109–24.

231. —. *The canine cemented modular total hip prosthesis.* J Am Anim Hosp Assoc. 1995. pp. 31:109–24.

232. WD., Liska. Cemented total hip replacement: experience in USA with the Bio-Medtrix prosthesis. [book auth.] European Society of Veterinary Orthopedics and Traumatology Orthoped. *Proceedings of the pre-congress of the European Society of Veterinary Orthopaedics and Traumatology.* Munich (Germany) : s.n., 2004., p. p. 15.

233. Ganz SM, Jackson J, VanEnkevort B. *Risk factors for femoral fracture after canine press-fit cementless total hip arthroplasty.* Vet Surg . 2010. pp. 39:688–95.

234. Kidd SW, Preston CA, Moore GE. *Complications of porous-coated press-fit cementless total hip replacement in dogs.* Vet Comp Orthop Traumatol. 2016. pp. 29: 402–8.

235. Lascelles BD, Friere M, Roe SC, et al. *Evaluation of functional outcome after BFX total hip replacement using a pressure sensitive walkway.* Vet Surg . 2010. pp. 39:71–7.

236. Gemmill TJ, Pink J, Renwick A, et al. *Hybrid cemented/cementless total hip replacement in dogs: seventy-eight consecutive joint replacements.* Vet Surg . 2011. pp. 40:621–30.

237. Gendreau C, Cawley AJ. *Excision of the femoral head and neck: The long-term results of 35 operations.* J Am Anim Hosp Assoc . 1977. pp. 13:605–608.

238. Plante J, Dupuis J, Beauregard G, et.al. *Long-term results of conservative treatment, excision arthroplasty and triple pelvic osteotomy for the treatment of hip dysplasia in the immature dog. Part 2: analysis of the ground reaction forces.* Vet Comp Orthop Traumatol . 1997. pp. 10:130–135.

239. Budsberg S, Chambers J, Van Lue S, et al. *Prospective evaluation of ground reaction forces in dogs undergoing unilateral total hip replacement.* Am J Vet Res . 1996. pp. 57:1781–1785.

240. *Concepts of cementless Zurich prosthesis.* ST. [ed.] in ESVOT. Munich : s.n., 2004 . Pre-congress Total Hip Replacement Seminar.

241. Pozzi A, Peck JN, Chao P, et al. *Mechanical evaluation of adjunctive fixation for prevention of periprosthetic femur fracture with the Zurich cementless total hip prosthesis.* Vet Surg . 2013. pp. 42(5):529–34.

242. Ficklin MG, Kowaleski MP, Kunkel KA, et al. *One-stage revision of an infected cementless total hip replacement.* Vet Comp Orthop Traumatol . 2016. pp. 29(6):541–6.

243. Sebestyen P, Marcellin-Little DJ, DeYoung BA. *Femoral medullary infarction secondary to canine total hip arthroplasty.* Vet Surg. 2000. pp. 29:227–236.

244. Otto K, Matis U. *Changes in cardiopulmonary variables and platelet count during anesthesia for total hip replacement in dogs.* Vet Surg. 1994. pp. 23:266–273.

245. Liska WD, Poteet BA. *Pulmonary embolism associated with canine total hip replacement.* Vet Surg. 2003. pp. 32: 178–186.

246. Liska WD, Israel SK. *Morbidity and Mortality Following Total Hip Replacement in Dogs. .* Vet Comp Orthop Traumatol. . 2018 May. pp. 31(3):218-221.

247. *Effect of Zoledronate on Bone Quality in the Treatment of Aseptic Loosening of Hip Arthroplasty in the Dog.* Wise, L.M., Waldman, S.D., Kasra, M. et al. 2005, Calcif Tissue Int 77, pp. 367–375.

248. *Effects of bisphosphonates in preventing periprosthetic bone loss following total hip arthroplasty: a systematic review and meta-analysis.* Shi J, Liang G, Huang R, Liao L, Qin D. Sep 4, 2018, J Orthop Surg Res. . 13(1):225.

249. Sabokbar, A., Fujikawa, Y., Murray, D.W. and Athanasou, N.A. Bisphosphonates in bone cement inhibit PMMA particle induced bone resorption. *Annals of the rheumatic diseases, 57(10),.* 1998, pp. pp.614-618.

250. *Effect of risedronate on bone metabolism after total hip arthroplasty: A prospective randomized study.* Kinov P, Tircher P, Doukova P et al. Acta Orthop Belg : s.n., 2006b. 72:44–50.

251. *Fractures of the femur after hip replacement.* Duncan CP, Masri BA:. 1995, Instr Course Lect, p. 44:293.

252. *Risk factors for postoperative femoral fracture in cementless hip arthroplasty.* Wu CC, AuMK,Wu SS, et al. s.l. : J Formos Med Assoc , 1999, pp. 98:190–194.

254. Henderson ER, Wills A, Torrington AM, et al. *Evaluation of variables influencing success and complication rates in canine total hip replacement: results.* from the British Veterinary Orthopaedic Association Canine Hip Registry (collation of data: 2010-2012).

255. Hummel DW, Lanz OI, Werre SR. *Complications of cementless total hip replacement. A retrospective study of 163 cases.* Vet Comp Orthop Traumatol . 2010. pp. 23(6):424–32.

256. WD., Liska. *Cemented total hip replacement: experience in USA with the Bio-.*

257. Bergh MS, Gilley RS, Shofer FS, et al. *Complications and radiographic findings following cemented total hip replacement: a retrospective evaluation of 97 dogs. .* Vet Comp Orthop Traumatol. 2006. pp. 19:172–179.

258. by Forster, K E., et al. *Complications and Owner Assessment of Canine Total Hip Replacement: A Multicenter Internte Based Survery.* Veterinary Surgery ,. July 2012. pp. Vol. 41 Issue: Number 5 p545-550.

259. ML., Olmstead. *The canine cemented modular total hip prosthesis.* J Am AnimHosp Assoc . 1995. pp. 31:109–124.

260. Lascelles, B: Duncan, X, et al. *Evaluation of Functional Outcome After BFX Total Hop Replacement Using a Pressire Sensitive Walkway.* Veterinary Surgery. January 2010,. p. Vol. 39.

261. Gemmill, T J., et al. *Hybrid Cemented/Cementless Total Hip Replacement in Dogs: Seventy-Eight Consecutive Joint Replacements.* Veterinary Surgery. July 2011. pp. Vol. 40 Issue: Number 5 p621-630. .

262. Simon Roe, Denis Marcellin-Little, Duncan Lascelles. *Short Term Outcome of Uncemented THR.* s.l. : NC State University publication, July 01, 2010.

263. GUERRERO, TSG. Zurich Cementless Total Hip Replacement; retrospective Evaluation. *www.kyon.ch.* [Online] 2008.

264. Liska, W D. and Doyle, N D. *Use of an Electron Beam Melting Manufactured Titanium Collared Cementless Femoral Stem to Resist Subsidence After Canine Total Hip Replacement. .* Veterinary Surgery. October 2015. pp. Vol. 44 Issue: Number 7 p883- 894. .

265. Iwata D, Broun HC, Black AP, et al. *Total hip replacement outcomes assessment using functional and radiographic scores to compare canine systems. .* Vet Comp Orthop Traumatol . 2008. pp. 21:221–230.

266. *https://swvetsurgery.com/services/orthopedic-surgery/total-hip-replacement/.* [Online]

267. *https://www.mvshospital.com/hip-dysplasia/.* [Online]

268. *https://www.animalsurgicalcenter.com/early-detection-of-hip-dysplasia-with-pennhip-radi.* [Online]

269. https://www.mdpi.com/2306-5354/8/12/200#. [Online] Published in 2 December 2021.

270. https://biomedtrix.com/total-hip-replacement/. [Online]

271. https://www.freelance-veterinary.co.uk/bfxcollaredfemoralstemtitanium . [Online]

272. https://biomedtrix.com/bfx-ebm-lateral-bolt-stem/. [Online]

273. Tidwell, A: Graham, P: Peck, N: Berry,R. *Incidence of Pulmonary Embolism After Non-Cemented Total Hip Arthroplasty in Eleven Dogs: Computed Tomographic Pulmonary Angiography and Pulmonary Perfusion Scintigraphy.* Veterinary Surgery. January 2007. pp. Vol. 36 Issue: Number 1 p37-42.

274. by Forster, K E., et al. *Complications and Owner Assessment of Canine Total Hip Replacement: A Multicenter Internte Based Survery. .*

275. Am, Olmstead ML. J. *The canine cemented modular total hip prosthesis.* AnimHosp Assoc . 1995. pp. 31:109–124.

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Department: Department and Clinic of Surgery and Ophtalmology

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