Clinical Performance of the Zurich Canine Total Hip Replacement: complications, outcomes and risk factors

A retrospective study

ABSTRACT

Objective: This study aims to assess the outcomes and complications in dogs treated with the Zurich Cementless Total Hip Replacement (ZCTHR) at Utrecht University between 2012 and 2024, and to statistically identify parameters influencing postoperative complications, with a focus on surgical parameters, implant positioning, and patient characteristics.
Materials and Methods: Medical records and radiographs of 38 dogs (54 hips) treated with ZCTHR were retrospectively evaluated. Signalment, weight, implant size and positioning, indication for treatment, surgical duration, intraoperative and postoperative complications, and overall outcome were recorded. Manual and automated (backward) logistic regression analysis was performed to determine predictors of postoperative complications.
Results: A 6th generation ZCTHR was placed in 50 hips. Intraoperative and postoperative complication rates were 32% and 34%, respectively. Fissures were the main intraoperative complications, while luxations and aseptic cup loosening were the main post-operative complications. Surgical duration increased the risk of postoperative complications by 2% per additional minute ($p < 0.05$). Medium-sized dogs had a significantly lower risk of complications compared to giant-sized dogs. At the last follow-up, 86% of dogs had near-normal function, 6% showed lameness, and ZCTHR failed in 8% of cases.
Conclusion: Complication rates may have been a result of case selection, surgical technique and materials used, with surgical duration and size of the dog significantly affecting the postoperative complication rate. Despite the complication rate, the outcomes were favorable in most cases.
Clinical Significance: ZCTHR restores mobility and quality of life in most canine patients. Careful case selection and surgical technique are important to reduce complications.

Key words: Canine hip dysplasia, Zurich Cementless Total Hip Replacement (ZCTHR), postoperative complications, surgical outcomes

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INTRODUCTION

Total hip replacement (THR) is a widely accepted surgical option for canine patients suffering from disabling coxofemoral conditions, aiming to improve their mobility and quality of life. Common indications for canine THR include hip dysplasia, coxarthrosis, coxofemoral luxation, intra-articular fractures and failed femoral head osteotomy (FHO) (1-5).

The first veterinary THR system has been available since 1976. This was a cemented THR, using polymethylmethacrylate (PMMA) for short- and long-term stabilization (6). The success rate of cemented THR is good, with reported (short-term) complication rates between 7-20% (1,6,7). While cemented THR showed promising short-term results, aseptic loosening occurred as a significant long-term complication. Skurla et al (2005) reported a 63.2% aseptic loosening rate in post-mortem investigation performed on dogs treated with a cemented THR (8). In response to this significant complication, a cementless THR system was introduced in 1988 to reduce aseptic loosening of the implant (9). These cementless THR systems achieve short-term stability through press-fit, primary stabilization or a combination of these. Long-term stability is provided through bone in-growth into the implants (5,10).

The Zurich Cementless THR (ZCTHR; Kyon Inc., Zurich, Switzerland) combines press-fit for the cup and primary stabilization through a mechanical interlock system for the stem. It was developed in the late 1990s at the University of Zurich and consists of four main components: a titanium acetabular cup lined with polyether ether ketone (PEEK), a titanium femoral stem, a titanium alloy neck and a ceramic head (see Fig. 1). All four components are offered in various sizes, thus allowing a customized prosthesis for each patient (2,7,10). Another commonly used THR system is the BioMedtrix Universal THR. The BioMedtrix THR system differs from the ZCTHR in its three-component structure, consisting of various sizes of femoral heads, femoral stems and acetabular cups (see Fig. 1). Additionally, the BioMedtrix system is available in both a cemented (BioMedtrix CFX) and an uncemented version (BioMedtrix BFX), which can be intermixed, enabling the hybridization of fixation techniques. (5,11)

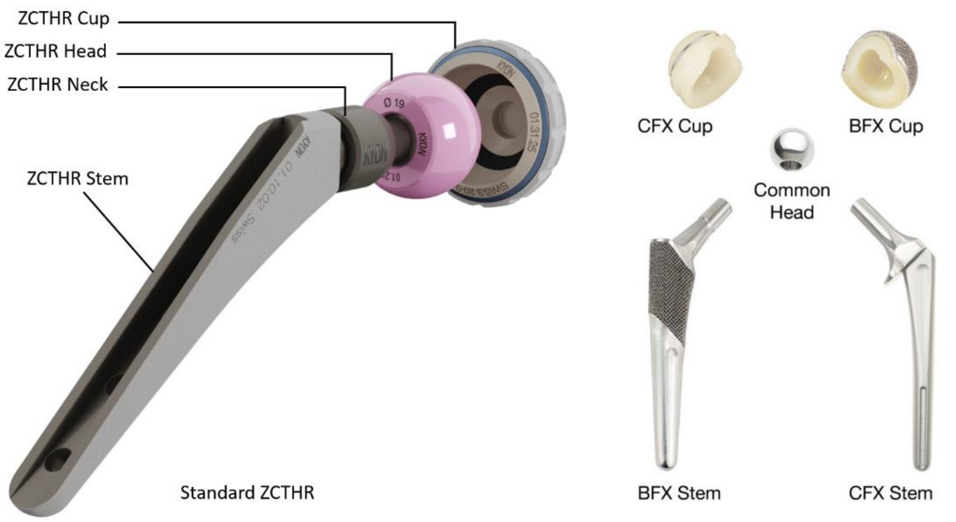

Figure 1*: The Standard ZCTHR (left) consists of a cup, head, neck and stem in various sizes. The BioMedtrix Universal THR (right) consists of a BFX stem, a BFX Cup, a CFX stem, a CFX cup and a common head in various sizes. The different components of the BioMedtrix Universal THR can be intermixed. Reproduced from Kyon Inc. and BioMedtrix (12,13)*

The overall success rates of the different THR systems are well described. The complication rates of the ZCTHR range from 6.75% to 20% (1,2,5,7). Despite good success rates, several complications are associated with this system, including infection, aseptic loosening of implants, coxofemoral luxation, implant failure, femoral fractures, acetabular fractures, sciatic neurapraxia, acetabular cup displacement and acetabular cup wear (2,3,7). The complication rates of the CFX are similar to complication rates of other cemented THR systems, with aseptic loosening being the most commonly reported complication (5,9,11). In the BFX THR, complications occur in 17.8% to 31.1% of the cases and are similar to the complications seen in the ZCTHR (5,11,14).

Various advancements have been made to improve the outcomes and further reduce the complications associated with ZCTHR. One of these improvements is the development of the dual mobility ZCTHR (3). This design was developed to address the dislocation of the implants – the main complication in large and giant breed dogs at that time (1-3,15). The study of Lanz et al. (2021) reported only one complication following 105 cases undergoing THR with this system: a luxation of the implant. The dual mobility cup differs from the standard ZTHR system by incorporating two bearings; a small ball inserted inside a larger polyethylene hemisphere liner, which articulates with the metal surface of the acetabular cup. The primary movement occurs between the ball and the liner, while the secondary movement occurs between the liner and the acetabular cup. This secondary movement is particularly important during activities that push the prosthesis beyond its normal range of motion, when the femoral component impinges on the rim of the liner. (3)

Following the development of the dual mobility cup, the mini THR became available in 2020. This system follows the same fundamental design principles as the standard ZCTHR but is smaller in size and is implanted using specialized instrumentation. This system has made it possible to perform THR in small dogs and cats. In a study of 42 small dogs and cats, the reported postoperative complication rate was 12%. The complications are similar to those seen in the standard ZCTHR system and included femoral fracture, cup dislocation, dislocation of the head, aseptic loosening of the cup, stem breakage and uncoupling of the neck on the peg. (4)

While the ZCTHR system has been studied extensively in various veterinary institutions, no research has been conducted specifically on THR procedures performed at Utrecht University. Given Utrecht University's diverse case variety and potentially unique surgical approach, evaluating the outcomes and complications of the ZCTHR could provide insights that are not available from other institutions, possibly leading to refined treatment protocols and improved patient management strategies. Additionally, to our knowledge, no previous studies have investigated the complication rates of the ZCTHR system up to the 6th generation regarding implant positioning, intraoperative complications, surgical duration and implant choice. As these variables showed a significant influence on post-operative outcomes in earlier generations, understanding their role in the newest generation ZCTHR is crucial for optimizing surgical procedures and improving patient prognosis (2,15).

Therefore, this retrospective study aims to evaluate the surgical outcome, complication rate and follow-up of THR in canine patients treated at Utrecht University between 2012 and 2024. By analyzing these findings, we aim to identify the parameters[1] that significantly influence treatment outcomes, particularly when comparing cases with complications to those without. We hypothesized that certain parameters[1] significantly affect the treatment outcome in patients

[1] signalment, post-operative X-ray findings, clinical and surgical parameters

treated with THR at Utrecht university between 2012 and 2024 in terms of complications. The objectives of the study are to

1) describe the cohort of dogs treated with ZCTHR at Utrecht University
2) assess surgical outcome of THR in canine patients by evaluating the surgical outcome in terms of the overall recovery, absence or presence of post-operative complications and the ability to return to normal functionality.
3) statistically compare cases with complications to cases without complications, focusing on differences in signalment[2], post-operative X-ray findings[3], clinical[4] and surgical parameters[5]
4) investigate which parameters significantly affect the risk of postoperative complications.

[2] age, weight/BCS, breed, gender
[3] angle of lateral opening and the retroversion angle of the cup, anteversion angle of the stem
[4] severity of hip dysplasia prior to treatment and other indications for treatment
[5] presence or absence of intraoperative complications, surgical duration, implant choice

MATERIALS AND METHODS

Inclusion criteria

Medical records of all dogs treated with ZCTHR between 2012 and 2024 at Utrecht University were reviewed. Only patients with complete clinical and radiographic evaluation with at least 6 weeks of follow-up were included in this study. In cases where THR was performed on both sides, each side was considered separately. The follow-up time in these cases was defined as the period between the surgery date of a hip and the last follow-up appointment for that specific joint. Cases with implants of the 4th and 5th generation ZCTHR were included in the descriptive statistics because the surgical technique, indications for placement and positioning criteria do not differ between the 4th, 5th and 6th generation. However, these were excluded from the statistical analysis and in the assessment of the complications and the overall surgical outcome because the composition of these implants differs, and this possibly influences the complications and outcomes.

Data collection

Information collected from medical records included:

- signalment: age, size of the dog, gender, weight and body condition score (BCS);
- severity of hip dysplasia prior to surgery based on radiographic findings, as well as other indications for THR;
- postoperative radiographic findings: angle of lateral opening (ALO) of the cup and anteversion angle of the femoral stem;
- surgical data: surgical duration, implant choice, side of surgery and intraoperative complications, the latter being defined as any event deviating from the standard surgical procedure outlined below;
- postoperative complications, defined as any outcome other than a near normal functioning prosthesis.

Radiographic evaluation of hip dysplasia

Pre-surgical radiographic imaging was used to evaluate the severity of hip dysplasia (HD). HD was defined as radiographic evidence of hip joint subluxation (laxity), osteoarthritis or both (16,17). Signs of osteoarthritis collected from the radiographic studies included formation of osteophytes on the femoral periarticular surface or the acetabular margin, subchondral sclerosis of the craniodorsal acetabulum and joint remodeling (flattening of the acetabulum of femoral head) (16). To objectively quantify the degree of femoral subluxation, the acetabular coverage of the femoral head was measured. Normal femoral head coverage was considered to be at least 50%, with lower values indicating hip dysplasia (16). The femoral head coverage was determined on hip-extended ventrodorsal radiographs of the pelvis. First a circle was projected over the femoral head that matched its curvature. Then, the area covered by the acetabulum was projected over this circle (see Fig. 2). Next, the femoral head coverage was calculated by dividing the area of the coverage by the area of the circle and multiplying it by 100%. Based on these parameters, a scoring system (see Table 1) was created to quantify the severity of HD.

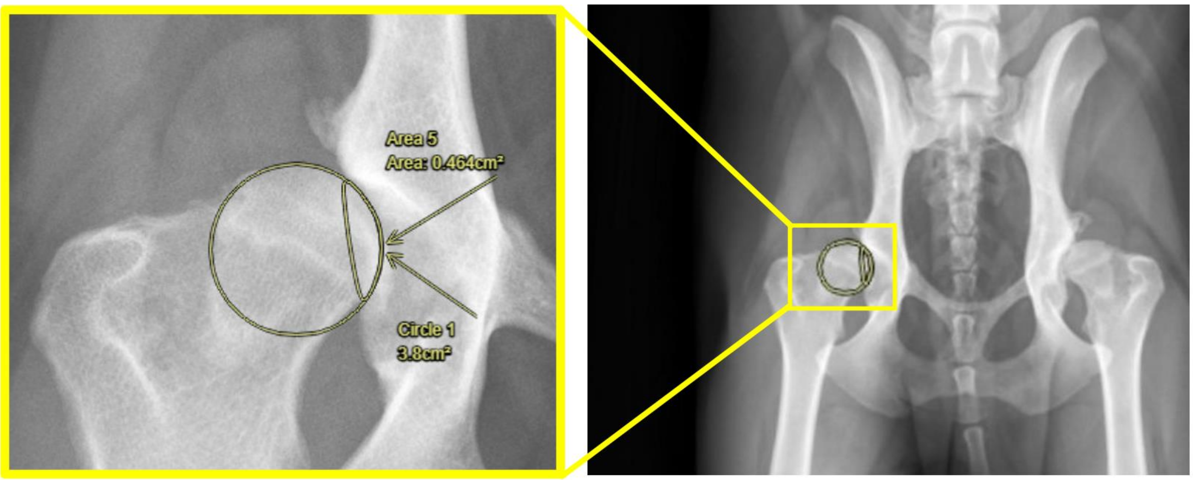

Figure 2*: Measurement of the femoral head coverage on the hip-extended ventrodorsal radiographs of the pelvis (right). A circle, matching its curvature, was projected over the femoral head and the area covered by the acetabulum was measured (left). Femoral head coverage = area of coverage / area of circle x 100%.*

Table 1: *Scoring system to quantify the severity of canine hip dysplasia shown on radiographic studies of the pelvis. Femoral head coverage, osteophyte formation on the periarticular surface, subchondral sclerosis and joint remodeling were scored based on the radiographic report and images. A score was given for each parameter ranging from 0 to 5 and the scores of all parameters were added up to determine the severity of HD, with a high score indicating more severe hip dysplasia.*

	5	4	3	2	1	0
Femoral head coverage	0-9%	10-19%	20-29%	30-39%	40-49%	$\geq$ 50%
Osteophytes on periarticular surface	Severe	Marked	Moderate	Mild	Some	No
Subchondral sclerosis	Severe	Marked	Moderate	Mild	Some	No
Joint remodeling	Severe	Marked	Moderate	Mild	Some	No
TOTAL						

<u>Implant planning</u>

Prior to the surgery, planning radiographs were taken. On the ventrodorsal view with flexed legs, the correct size of the cup was determined. A circle was projected over the radiograph between the cranial and caudal pillars of the acetabulum whilst contacting the medial cortex (see Fig. 3). The diameter of this circle was then used to choose the best matching acetabular cup. The caudocranial projection of the femur (yoga view) was used to select the best size for the femoral stem. The correct size was determined using the Kyon templates and by measuring the femoral diameter at the narrowest portion of the femur and secondly drawing a line from the proximal medial cortex to the proximal trochanter (see Fig. 3). The planning of the cup was repeated in this view and compared to the previously described measurements of the cup.

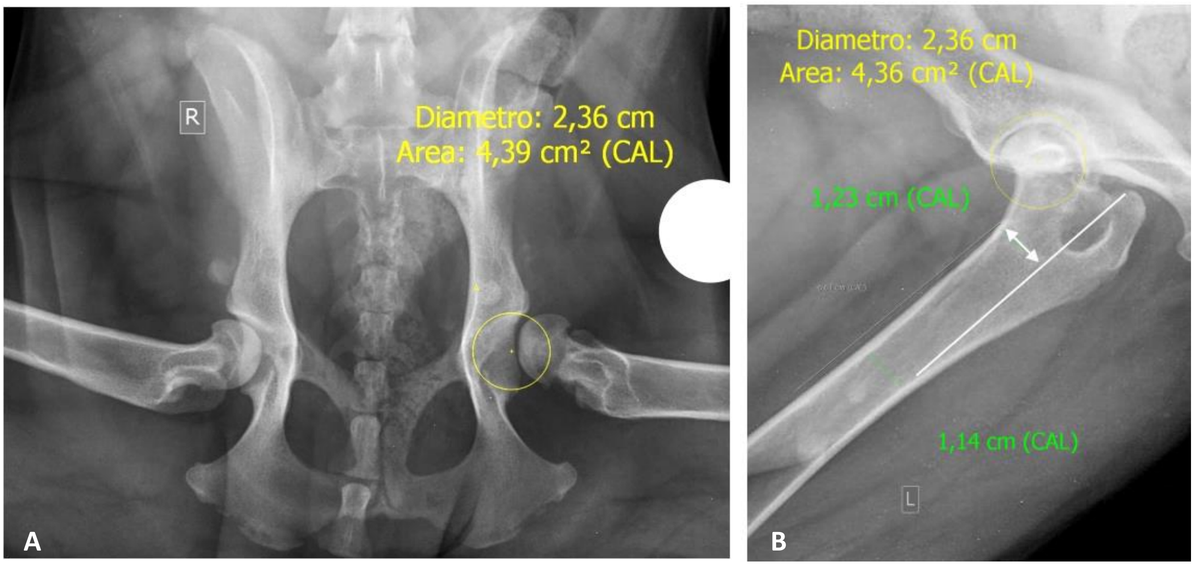

Figure 3: *Implant planning of the ZCTHR reproduced from Vezzoni et al. (18)* ***(A)*** *The correct size of the cup was determined on the ventrodorsal view with flexed legs by using the diameter of a circle projected between the cranial and caudal pillars of the acetabulum whilst contacting the medial cortex.* ***(B)*** *The correct femoral stem was chosen using the caudocranial view of the femur (yoga view) by using the Kyon templates and by measuring the femoral diameter at the narrowest portion of the femur and secondly drawing a line from the proximal medial cortex to the proximal trochanter. Planning of the cup was repeated in this view and compared to the measurements in the ventrodorsal view.*

In addition to the skeletal size of the dog, the weight of the dog and the matching of the different THR components were considered in choosing the right implants. The recommendations for the implants available per body weight category and their recommended combinations are summarized in Table 2 (10,18). Definitive implant selection was based on a combination of these preoperative measurements and intraoperative findings.

Table 2: *Recommendations for the implants available per body weight category and their recommended combinations.*

Body weight (kg)	Cup	Head (mm)	Neck	Stem
<4	10-14	6-8	S3	Extra small Mini
<6	10-14	6-8	S4	S narrow
<8	10-16	8-10	S4	S Mini
<14	11-20	10-12	S5	M Mini
<16	18-23	12-16	S6	L Mini
<18	18-23	12-16	S6	XL Mini
<20	21.5	16	Extra short / short	Extra small / small
<30	23.5	16	Short	Small or medium
<40	26.5	19	Short / medium	Medium / Large
>40	29.5	19	Medium	Large
>50	29.5-32.5 DM	19	Medium	Extra large / Custom Giant

Surgical technique

All surgeries were performed by two board certified surgeons, since 2023 both accredited as Kyon THR surgeons. Patients were positioned in lateral recumbency with fluoroscopic guidance. The skin was incised at the level of the greater trochanter, extending to the femoral midshaft. After incising the fascia over the biceps muscle, the muscle was retracted caudally. The fascia lata was incised, with caution to preserve the integrity of the tensor fascia lata muscle, and the incision was extended dorsally between this muscle the superficial gluteal muscle. The deep gluteal tendon was separated from the joint capsule and a partial tenotomy was performed. After opening the joint capsule, the femoral head was dislocated, and the ligamentum teres was severed. The femur was externally rotated by 90º and the proximal femur was elevated into a horizontal position. Then, a straight femoral head ostectomy was performed to just under the head and proximal to the lesser trochanter. After the removal of the femoral head, axial access to the medullary canal was ensured by inserting a reamer into the endosteal cavity. (10,19)

The femoral canal was gradually enlarged, avoiding excessive force and preserving critical vascular structures. The size and the correct anteversion (+/- 25º) were assessed using a trial stem. (10,19)

The acetabular fossa was exposed by retracting the gluteal muscles and removing the soft tissues and the round ligament. The ventral transverse ligament was preserved as the ventral landmark for cup positioning. The acetabular fossa was initially deepened with a reamer 1 to 2 sizes smaller than the final one, preserving the cranial and caudal bone margins, and final reaming was performed manually with the appropriately sized reamer. Osteostixis was performed and osteophytes protruding over the reamer were removed. (10,19)

After preparation of the acetabulum and the femur, the implants were placed. Before implantation, the stem and the cup were soaked in the patient's blood. The acetabular cup was impacted into place and a cancellous bone graft was used to improve the prosthesis' fit. The correct cup position was assessed by estimating the ALO of the cup and cup retroversion at fluoroscopy before final impaction. Alignment of the stem was provided through a jig before the stem was fixed into place using titanium screws (bicortical and monocortical). (10,19)

Once the cup and stem were implanted, the correct neck length was estimated using the position of the peg of the stem relative to the cup. A short neck was chosen if the peg was touching the dorsal border of the cup. If the peg was located in the middle of the cup, a medium neck was used. A long neck was placed when the peg was touching the ventral border of the cup. In cases where the peg was proximal to the dorsal rim of the cup and reduction with a short neck was not possible, an extra-short neck was chosen. After selecting the correct neck, the suitable ceramic head was assembled on the neck by impacting it. Then, the head-neck component was impacted onto the peg of the stem. Next, the prosthetic joint was reduced while pulling the leg distally. If a large head diameter resulted in a hard reduction, the head-neck component was placed in the cup and the femur was then retracted laterally and distally to guide the peg towards the recess of the neck. (10,19)

After reduction, the joint was tested for impingement, stability and luxation. The stability of the prosthetic joint was assessed using the pull-down and pull-up test. The joint was checked for caudoventral and craniodorsal luxation by rotating the femur externally and internally, respectively. Once it was found to be stable, free of impingement and no luxations occurred, the surgical site was closed with absorbable sutures, followed by skin closure and sterile dressing application. (10,19)

Post-surgical radiographic assessment

In order to assess the implant positioning, radiographic images were taken postoperatively. These included a lateral view of the pelvis, ventrodorsal view with flexed legs, yoga view of the femur and the mediolateral view of the femur. The implant position was assessed on implant size, the seating of the cup and the stem, the angle of lateral opening (ALO) of the cup, retroversion angle of the cup and anteversion angle of the stem.

Angle of lateral opening

The ALO of the cup was assessed on laterolateral radiographs of the pelvis. It was measured by drawing an ellipse following the inside borders of the cup (see Fig 4A). The short axis (dorsoventral distance) of the cup was divided by the long axis (craniocaudal distance) of the cup. The ALO of the cup was calculated with the following formula: ALO = $\sin^{-1}$(quotient). The optimum ALO was defined as 45° ± 3° (20).

Anteversion angle of the stem

The assessment of the anteversion angle of the stem was performed on the mediolateral radiographs of the femur with a 90º flexed stifle. The centers of the head, neck and proximal and distal stem were determined by projecting circles over the radiographs. Then, one line was drawn through the center of the head and the center of the neck and a second line through the centers of the proximal and distal stem (see Fig 4B). The angle between these lines was measured and translated to the true anteversion angle by using the following formula: anteversion angle of the stem = $\sin^{-1}$ [(tan 55°) x (tan of measured angle)]. The optimum anteversion angle of the stem was defined as 20º ± 5º (20).

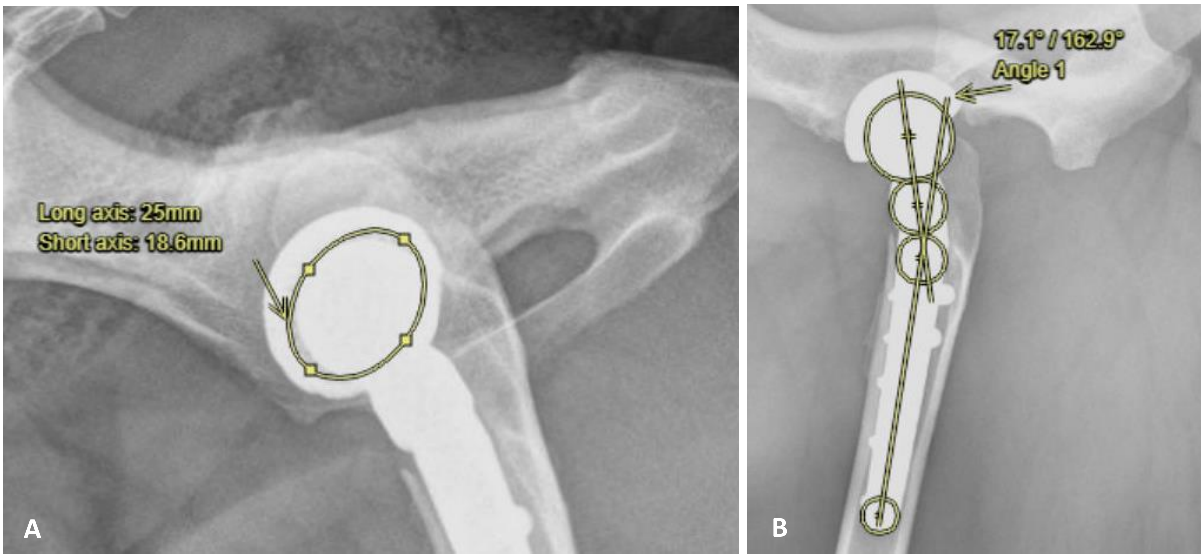

***Figure 4:** Postoperative measurements after ZCTHR. **(A)** ALO of the cup determined on laterolateral radiographs by measuring the short and long axes of the ellipse within the cup and applying the formula: ALO = $\sin^{-1}$(short axis/long axis). **(B)** Anteversion angle of the stem determined on mediolateral femur radiographs with a 90° flexed stifle. Circles were drawn over the head, neck, and proximal and distal stem, with lines connecting the centers of these structures. The true anteversion angle was calculated using the formula: anteversion angle = $\sin^{-1}$[(tan 55°) × (tan of measured angle)].*

Clinical evaluations

Follow-up examinations were performed after a minimum period of six weeks after surgery. All available follow-up exams were evaluated, and all complications and revisions were reported. Clinical parameters collected from the most recent follow-up exam were signs of lameness, and pain on manipulation and range of motion (ROM) of the joint. These variables were used to determine the overall outcome using a scale adapted from the one reported by Guerrero et al. (2009) (see Table 3). Muscle mass was excluded from the original scale as some atrophy is expected at six weeks post-surgery and the changes in muscle mass are influenced by multiple factors (e.g. baseline muscle mass and postsurgical rehabilitation) (21-23).

Table 3: *Determination of the overall surgical outcome using the scale adapted from Guerrero et al. (2009). Lameness, signs of pain on manipulation of the hip and range of motion were collected from the last follow-up examination.*

	Pain on manipulation	ROM	Lameness
Excellent	No	Normal	No
Good	No	Reduced, mainly in extension	No
Fair	Moderate	Reduced	Intermittent to persistent
Poor	Marked / severe	Severely reduced	Constant to no weight bearing
Failed	Implants removed / animal euthanized because of ZCTHR		

Statistical Analysis

The outcome of the THR was recorded as successful (no postsurgical complications) or unsuccessful (postsurgical complications). Because of sparsity of the data, the dogs were divided into categories according to their bodyweight: small (< 15 kg), medium (15-30 kg), large (30-40 kg) and giant (> 40 kg). Before hypothesis testing, descriptive statistics were used. The continuous variables included age (days), angle of lateral opening, anteversion angle of the stem, severity of hip dysplasia prior to treatment, surgical duration (minutes). The categorical variables included size of the dog (small, medium, large, giant), BCS (< 5, 5, > 5), gender (male, female, male spayed, female spayed), intraoperative complications (yes/no), neck (MINI, XS, S, M, L), cup (16-20, 21.5-26.5, 29.5-32.5, DM 29.5-32.5) and stem (MINI, XS, S, M, L).

Binary logistic regression was used to identify the relationship between the prognostic parameters and the outcome (no complications/complications). Due to the low number of complications, the number of parameters could not be fitted in a full model of the data (24,25). Therefore, variable selection was performed. First, all variables were screened in univariable logistic regression analyses and variables with $p < 0.25$ were used in the multivariate model (25). The model was further built using manual and automated (backward) selection of the variables. Manual variable selection was performed by first putting all variables, selected in univariate analysis, in the model and then removing one variable at a time. The models were assessed on their fit by using the Akaike Information Criterion (AIC). The variable with the highest p-value in the old model and of which removal resulted in the lowest AIC was tested for multicollinearity and removed. This process was repeated until the AIC did not further decrease by removing a variable. The removed variables were then added back to the model and evaluated for potential confounding ($\Delta\beta > 20\%$). If confounding was present, the confounders were added back to the model and the old and new model were compared using the AIC, Bayesian Information Criterion (BIC) and log-likelihoodtest. The confounder was kept in the model if it significantly improved the model's fit. The final model produced with manual backward selection was then compared to the model created by automated backward variable selection. All analyses were performed using R studio (version 4.4.1) (26)

RESULTS

Signalment

A total of 54 ZCTHRs were performed between November 2012 and November 2024 in 38 dogs, with bilateral arthroplasty in 16 dogs. There were 23 males (13 castrated) and 15 females (12 spayed). The dogs had a mean age at surgery of 3.4 ± 2.2 years, ranging from 8.19 months to 8.72 years. Crossbreeds were represented most frequently (*n* = 13), followed by Labrador Retrievers (n = 3), Border Collies (*n* = 2) and Rottweilers (*n* = 2). The body condition score ranged from 4 to 8 with a mean of 5.1 ± 1.1. The bodyweight ranged from 10.5 kg to 54.5 kg with a mean of 30.0 ± 10.07 kg. A summary of the represented breeds and their distribution across bodyweight groups is provided in Table 4.

Table 4: *Distribution of dogs treated with Zurich Cementless Total Hip Replacement (ZCTHR) based on breed type (purebred vs. crossbreed) and body size categories (small, medium, large, and giant). Body size categories are defined by weight ranges: small (< 15 kg), medium (15-30 kg), large (30-40 kg), and giant (> 40 kg).*

	Small (*n*)	**Medium (*n*)**	**Large (*n*)**	**Giant (*n*)**
	<15 kg	**15-30 kg**	**30-40 kg**	**>40 kg**
Purebred (n = 25)	Labradoodle (1) Welsh Terrier (1)	American Staffordshire Terrier (1) Appenzeller Sennenhund (1) Border Collie (2) Husky (1) Labrador retriever (1) Lagotto Romagnolo (1) Podenco Iberico (1) Staffordshire Bullterrier (1)	Bouvier (1) Boxer (1) German Shepherd (1) Golden Retriever (1) Labrador retriever (2) Maremma Sheepdog (1) Rottweiler (1) Scottish Collie (1)	Bernese Mountain Dog (1) Cane Corso (1) Mastiff (1) Newfoundlander (1) Rottweiler (1)
Crossbreed (n= 13)	Crossbreed (1)	Crossbreed (6)	Crossbreed (4)	Crossbreed (2)
Total:	3	15	13	7

Surgical results

The main indication for surgery was hip dysplasia (and secondary coxarthrosis) (*n* = 31). Other indications included acetabular fracture (*n* = 1), fracture of the femoral head (*n* = 3), fracture of acetabulum and trochanter (*n* = 1), Leg Calve Perthes (*n* = 1) and chronic luxation of the coxofemoral joint (*n* = 1). The severity of hip dysplasia ranged from 7 to 20 with a mean score of 13.74 ± 3.34. The surgical implants used were implants from the mini, standard and dual mobility systems (see Table 5). The surgical duration ranged from 156 to 408 minutes with a mean of 229 ± 49.52 minutes. ZCTHR was performed 26 times on the right coxofemoral joint and 28 times on the left coxofemoral joint. A 6th generation ZCTHR was placed in 50 of the dogs, while three dogs were treated with a 5th generation ZCTHR and one was treated with a 4th generation ZCTHR.

Table 5: *Used ZCTHR implants in 38 dogs in 54 coxofemoral joints.*

Cup	(n)	Stem	(n)	Neck	(n)
16	(2)	MINI 5 narrow	(1)	MINI Short S5H10	(2)
18	(3)	MINI 5	(1)	MINI Short S6H16	(3)
20	(1)	MNI 6 Large	(3)	MINI Medium	(5)
21.5	(4)	MINI 6 Extra-Large	(5)	Extra Short	(7)
23.5	(13)	Extra Small	(7)	Short	(18)
26.5	(17)	Small	(13)	Medium	(17)
29.5	(5)	Medium	(22)	Long	(2)
29.5 DM	(2)	Large	(2)		
32.5	(4)				
32.5 DM	(2)				
32.5 DM rev	(1)				

Post-operative radiographs

The ALO of the cup ranged from 23º to 58º with a mean value of 41.94º ± 18.0º. The ALO was within the reference values (40º-50º) in 38 cases (71.6%). It deviated five degrees or less from the reference values in six cases (11.3%). In one case, the ALO could not be determined because the laterolateral radiograph was missing. In two cases, the cup was initially positioned too open, which resulted in intra-operative luxation. In both cases, immediate revision was performed and the ALO was found to be within reference values after the revisions. In these cases, the revised ALO was used in the analysis. In two cases, the cup was found to be in too much retroversion and in one case the cup was placed too dorsal. The cup was impacted completely in all cases, with sufficient contact between the cup and the caudal and cranial acetabular margins.

The anteversion angle of the stem varied between 7.1º and 55.5º with a mean angle of 29.68º ± 6.6º. The anteversion angle could not be determined in three cases because the mediolateral radiographs were missing. Twenty (39.2%) of the cases had anteversion angles within reference values (16.1º-25.9º). The anteversion angle of the stem deviated five degrees or less from the reference values in three cases (5.9%). The stems were placed completely in the femoral canal in all cases except one small dog. In this dog, the stems in both hips were too large, resulting in over-reaming of the caudal cortex, causing the stems to penetrate out of the femoral canal. The screws were all placed in the stem except for one case where no screws were placed initially.

Complications

Four cases were operated between 2012 and 2016, using implants of the 4th and 5th generation. These dogs were excluded from the assessment of the complications and the overall outcome and the statistical analysis.

Two of these four dogs had intraoperative complications. In one of these cases, the femur fractured during the surgery, which was immediately revised, and the dog had no postoperative complications. During the last follow-up exam, the dog showed signs of pain on manipulation of the joint, resulting in a fair outcome. In the second dog, the prosthesis luxated intraoperative and the trochanter major fractured. The luxation was a result of a too large ALO of the cup, which was successfully revised during the initial procedure. The fracture was revised with cerclage.

Post operative complications occurred in three of the four excluded dogs. In the first dog, failure of the stem and aseptic loosening were seen after 1784 days. Revision surgery was advised but the owner opted for conservative treatment (with NSAIDs), resulting in a poor outcome.

The second dog already sustained complications during the initial procedure; intraoperative luxation and a fractured trochanter major. Nineteen days later, implant failure of the cup occurred simultaneously with failure of the fixation of the fracture, necessitating additional stabilization of the fracture with a plate and revision surgery to treat the implant failure of the cup. Implant failure of the plate, in combination with abnormalities on the radiographs consistent with mild osteomyelitis or inactivity-osteoporosis, were seen at nineteen days after revision surgery. In addition to these THR-related complications, the dog was suffering from bilateral ruptures of the craniate cruciate ligaments and behavioral problems, causing the owner to choose euthanasia 83 days after the initial procedure.

In the third excluded dog, the stem was seated too deep in the femur, causing disconnection of the head-neck component after sixteen days. This was revised by removing additional bone from the proximal femur to ensure a better fit of the neck recess onto the peg of the stem. However, the neck and stem disconnected again two weeks later. This was revised by placing a larger neck. Two days after this surgery, the cup loosened and the implants were subsequently removed, resulting in a failed outcome.

Surgical complications

Surgical complications occurred in 16 out of 50 cases (32%) treated with the 6th generation ZCTHR. In one case, the prosthesis luxated intraoperatively due to a too large ALO of the cup. This was revised by altering the cup position. In ten cases, a fissure of the femur occurred during the placement of the (trial)stem or reduction of the hip joint. Cerclage wires were placed in five of these cases to prevent the fissures from developing into a fracture. In the other five cases, the fissures were minor and did not require additional intervention. One of the fissure lines ran over the drill holes. Therefore, the stem was initially not stabilized with screws. After 268 days, the screws were implanted successfully. The femur fractured completely in four cases. Three of these fractures caused the stem to break out of the femoral canal. The remaining case involved a fracture of the trochanter major and did not include displacement of the stem. All fractures were revised with cerclage wires. Additional to the cerclage, a plate and an iliofemoral sling were used in two cases. Other surgical complications included an arterial bleeding and an unstable cup. The arterial bleeding occurred during the acetabulum preparation and originated from the femoral artery. The bleeding was stopped with electrocoagulation and the dog was hospitalized for one day. Insufficient stability of the press-fit cup resulted in implantation of a revision cup with screws, providing adequate stability.

Post-operative complications

In the 50 dogs treated with the 6th generation of the ZCTHR, postsurgical complications were observed in 17 cases (34%) after a mean duration of 158 ± 280.0 days (range 8-918) *(*see Fig. 5).

The most frequent complications included (a)septic loosening of the cup (*n* = 7) and (sub)luxation of the prosthesis (*n* =11). In seven cases, (sub)luxation of the prosthesis occurred simultaneously with (a)septic loosening of the cup. Metallosis was identified in three of the joints with cup loosening and led to initial removal of the implants in all cases. Metallosis was seen in two dogs. The first dog was affected by unilateral metallosis, which resulted in permanent removal of the implant. In the second dog, metallosis in the left leg occurred after 50 days and resulted in initial implant removal, followed by reimplantation 97 days later without complications. In right hip of this dog, the cup loosened septically (*S. pseudintermedius)* in combination with metallosis, necessitating implant removal after 55 days. A new dual mobility implant was placed 227 days later and was removed 40 days post-implantation because of inner shell luxation. A third revision surgery was performed. During this surgery, signs of metallosis resulted again in removal of the prosthesis. After 324 days, a new dual mobility prosthesis was placed, but this prosthesis luxated 43 days later. A surgical repositioning of the implant combined with a triple pelvic osteotomy followed, but the joint luxated again 63 days later. Therefore, the implant was permanently removed on the right side.

Prosthesis (sub)luxation was managed with revision surgery in six cases, while two cases were treated with non-surgical repositioning. One dog with bilateral dislocations underwent non-surgical repositioning for one hip and revision surgery for the other hip. The revised hip remained stable after treatment. However, the non-surgical repositioned hip reluxated after 41 days. This led to the owner’s decision for euthanasia 2.63 years after initial surgery.

Implant failure of fixation used to stabilize fractures sustained during the initial surgery or postoperative was seen four times. The stabilization was placed for two fractures sustained during the initial THR procedure and two fractures sustained after the initial THR procedure. All fractures were managed with surgical fixation using plate osteosynthesis (*n* = 2), cerclage wires (*n* = 2) or k-wires (*n* = 1). In all four cases, implant failure of the used fixation method required revision surgery. The plate was completely removed in one case and shortened in another. The cerclage wires broke in one dog, causing lameness, and were subsequently removed. The k-wires broke in another dog and were replaced with a plate.

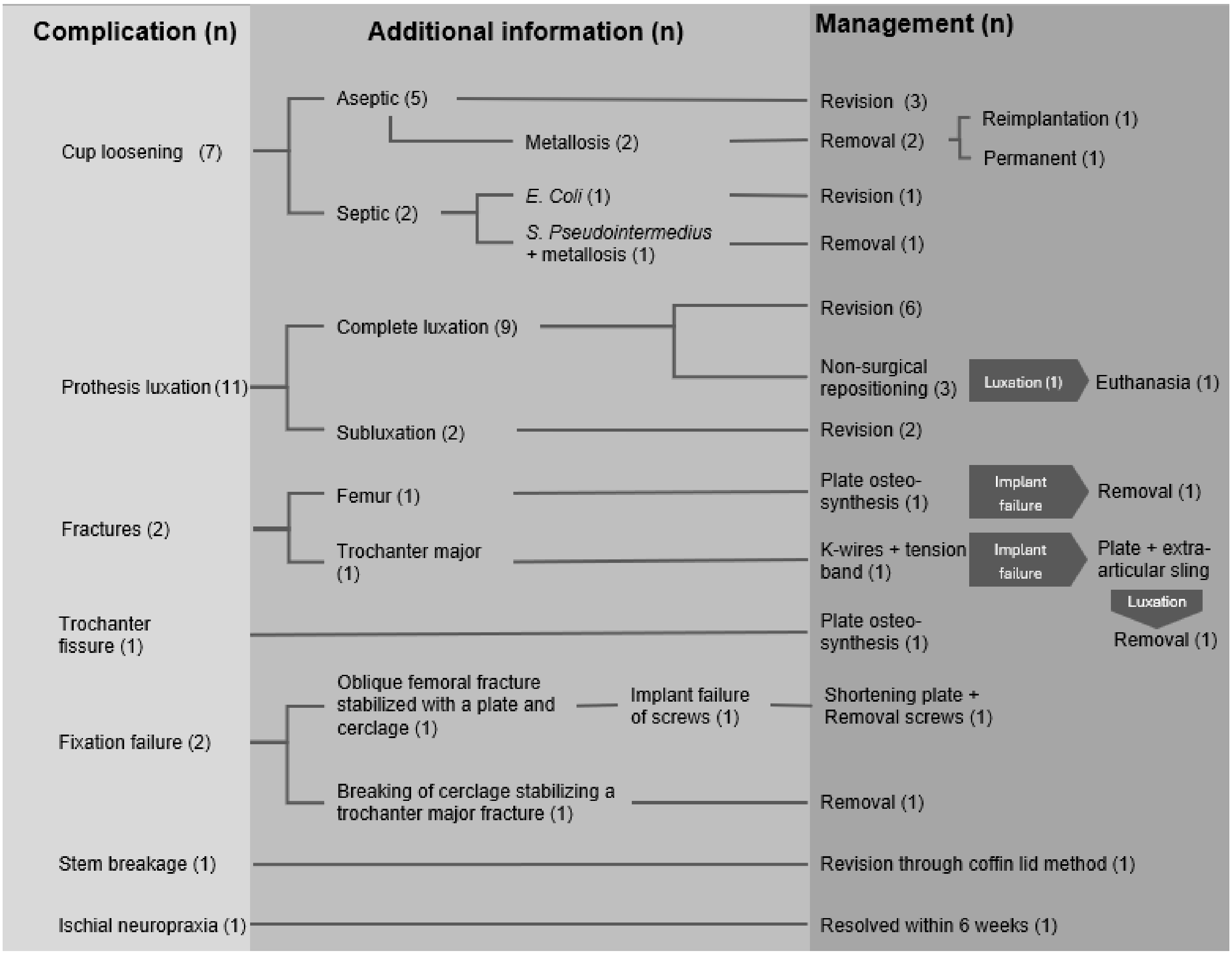

Figure 5: *Complications, additional information and management of postoperative complications seen in the 6th generation ZCTHR at Utrecht University between 2019 and 2024.*

Follow-up and outcome

The mean clinical follow-up was 336 ± 374.81 days (range 42-1617) and the mean follow-up through communication was 379 ± 371.50 (range 42-1636). The most frequent outcome at the last follow-up examination was "Excellent" (*n* = 36), followed by "Good" (*n* = 7), "Failed" (*n* = 4), "Fair" (*n* = 2) and "Poor" (*n* = 1) (see Fig. 6). Six of the dogs in the outcome category "Excellent" had a post-surgical complication; cup loosening and subsequent (sub)luxation (*n* = 2), failure of the fixation of fractures sustained during initial THR (*n* = 2), stem breakage (*n* = 1) and luxation of the prosthesis (*n* = 1). In the category "Good", all complications included luxation of the prosthesis. In two dogs the luxation was accompanied by loosening of the cup and in one case metallosis occurred. The main reason that dogs were categorized as "Good" instead of "Excellent" was a reduced range of motion of the hip joint. Two dogs had a fair outcome. One of these dogs suffered from a trochanter major fracture while the other suffered from aseptic cup loosening. They were both categorized as "Fair" because of mild lameness during the last follow-up exam. One dog had a poor outcome after an unsuccessfully revised femoral fracture using an osteosynthesis plate. Implant failure of the plate led to its removal and caused the dog to present with persistent lameness and severe pain during manipulation at the time of the last follow-up examination. In four dogs the THR failed. One of these dogs was euthanized, and implant removal occurred in the three remaining dogs. All of the dogs in this outcome category suffered from luxation of the prosthesis, two dogs suffered from cup loosening in addition to luxation and one dog had an additional fracture of the femur.

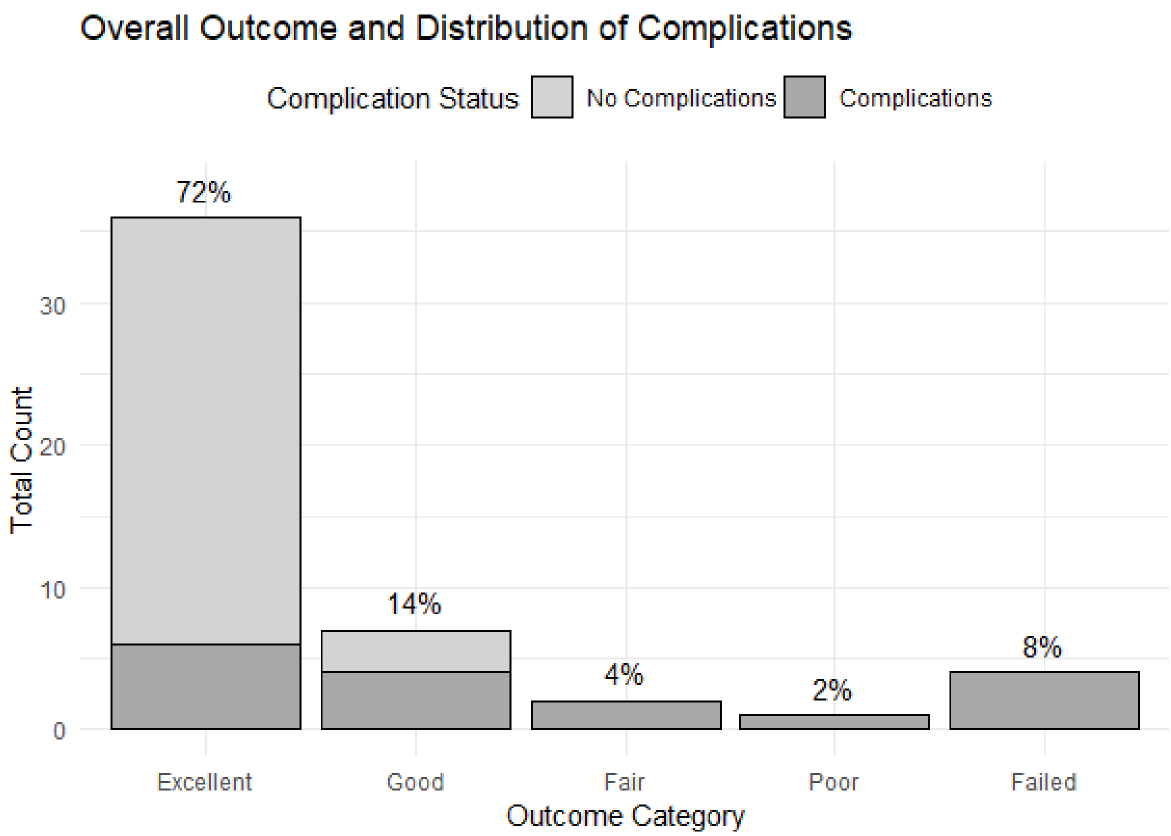

Figure 6: *Bar plot illustrating the overall outcomes of the ZCTHR, categorized as excellent, good, fair, poor or failed, and the corresponding distribution of complications within each outcome category.*

<u>Statistical analysis</u>

Univariate analysis showed some significance (p < 0.25) between the occurrence of complications and the following parameters: size, gender, age, surgical duration and surgical complications (see Table 6).

Table 6: *Variables selected from univariable binary logistic regression based on their p-value (< 0.25) with odds ratio and 95% confidence intervals of the odds ratio.*

Variable	Included	Odds ratio	95% CI Lower	95% CI Upper	p-value
Size	Large	0.41	0.05	2.61	0.36
	Medium	0.13	0.01	0.87	0.04
	Small	0.13	0.00	1.59	0.14
Gender	Male castrated	0.70	0.12	3.36	0.66
	Female	5.57	0.59	125.11	0.17
	Female spayed	0.84	0.20	3.42	0.81
Age (days)		1.00	1.00	1.00	0.19
Surgical duration (minutes)		1.01	1.00	1.03	0.03
Surgical complications	Yes	2.50	0.74	8.73	0.14

These variables were all included in the multivariate model and after manual and automated (backward) selection, age, gender and surgical complications were removed. Variance inflation factors (*GVIF*) were assessed to examine multicollinearity among predictors; no multicollinearity was present (*GVIF* < 5). The removed variables were added back to the model one at a time to check for confounding. Age, gender and surgical complications showed confounding, but adding them to the model resulted in a larger AIC (ΔAIC = 1.07) and BIC (ΔBIC = 4.94), indicating a worse fitting model. The log-likelihood test was performed to further compare the models. It yielded a non-significant difference in fit between the two models ($\Delta Deviance$ = 2.92; ΔDf = 2; p = 0.232), indicating that the reduced model did not significantly worsen the fit compared to the full model. Based on these tests, the final model produced by manual variable selection included size and surgical duration. Both variables were significantly associated with the likelihood of postoperative complications (see Table 7).

Table 7: *Results of the multivariable logistic regression analysis evaluating the association between predictor variables (size and surgical duration) and the occurrence of post-operative complications in patients treated with ZCTHR. The regression coefficients (B) with standard errors (SE), p-values, 95% confidence intervals (CI) for odds ratios (OR), and the OR itself are shown in the table. Significant predictors (p < 0.05) are indicated. The reference category for size is "Giant".*

Variable included		B (SE)	p-value	95% CI Lower	OR	95% CI Up
	(Intercept)	-4.81 (2.25)	0.03	0.00	0.01	0.49
Size	Large	-0.30 (1.09)	0.78	0.08	0.74	6.51
	Medium	-2.59 (1.23)	0.04	0.01	0.07	0.74
	Small	-2.16(1.54)	0.16	0.11	0.11	1.93
Surgical duration		0.02 (0.01)	0.01	1.01	1.02	1.05

Note: McFadden's R^2 = 0.23. Model χ^2 (1) = 15.62, p < 0.01.

Medium dogs had a significantly lower likelihood of post-operative complications compared to giant dogs (p = 0.04). Small and large dogs did not have a significantly different likelihood of developing postoperative complications compared to giant dogs (p_{small} = 0.16; p_{large} = 0.78). The odds of a post-surgical complication occurring decreased with 93% in medium sized dogs. A longer surgical duration significantly increased the likelihood of a post-surgical complication (p = 0.01) with each additional minute increasing the odds of a postoperative complication by 2%.

DISCUSSION

This study evaluates the outcomes and complications associated with the ZCTHR in a cohort of 38 dogs treated with 54 prostheses. The main indication for performing total hip replacement was pain resulting from marked to severe hip dysplasia. We found a wide range in age at presentation: 8.19 months to 8.72 years. This finding is reflective of the biphasic nature of hip dysplasia, where juvenile dogs are presented with hip laxity and older dogs develop osteoarthritis secondary to laxity (16,17). No breed predisposition was found in this study, even though crossbreeds were most frequently represented. This is likely to be a result of an overrepresentation of crossbreeds in our patient population, rather than a predisposition. The wide weight range of treated dogs (10.5-54.5 kg) demonstrates that HD affects dogs of all sizes, emphasizing the need for treatment options adaptable to a diverse patient population.

Correct positioning of the components during surgery is crucial for the success of ZCTHR. Anteversion angles of the stem ranged from 7.1º to 55.5º with a mean angle of 29.68º and did not significantly affect the risk of postoperative complications ($p > 0.05$). This average value is greater than the anteversion of 20º ± 5º advised by Kyon. However, our findings are in line with the results of several studies on the anatomical femoral neck anteversion angle. These studies reported angles ranging from 7.6º ± 5.5º to 45º ± 4.5º, with most studies reporting a mean femoral anteversion angle between 26.9º and 34.2º, across various breeds and sizes (27-33). This variability suggests a wide range of anatomical orientation between different dogs, which could indicate a dog dependent anteversion angle (34). The higher mean and wide range of the anatomical anteversion angle reported in several studies, combined with our findings that neither a high mean anteversion angle nor a wide variation in this angle significantly contributed to complications, suggests that an anteversion angle of 20º may be too small and that an anteversion angle of 30º mimics the average anatomical situation more accurately.

Intraoperative complications occurred in sixteen cases, resulting in an intraoperative complication rate of 32%. This is higher when compared to previous studies on the ZCTHR (1-4,7,35). Femoral fissures were the most frequently observed intraoperative complication in our study. Other, less frequently seen complications were bleeding of the femoral artery ($n = 1$) and insufficient stability of the press-fit cup resulting in the use of a revision cup ($n = 1$). Technical errors, such as over-reaming of the femoral canal or reaming at an improper angle, are established contributors to the occurrence of femoral fissures (1,36). Similarly, insufficient press-fit stability can be attributed to excessive or inadequate acetabular reaming (37). In addition to these technical factors, patient-specific variables, including age at surgery and femoral morphology, are known to significantly affect the likelihood of intraoperative complications, such as fissures and fractures (36). Thus, we speculate that while technical errors play a role in the relatively high complication rate observed in this study, differences in case selection may also contribute to the complication rate.

Postoperative complications were seen in 34% of our patients. While this exceeds the complication rate reported by other studies on the ZCTHR, it is similar to the reported complication rate of the BFX (31.3%) (14). Surgical duration was significantly associated with the likelihood of sustaining a postoperative complication. This potentially reflects a correlation between postoperative complications and an increased complexity of cases requiring an increased surgical duration. Nine of the seventeen dogs that sustained a postoperative complication had luxoid hips (52,9%) and three dogs were treated for an indication other than hip dysplasia; fractures of the femur ($n = 2$) or acetabulum ($n = 1$) (17.6%). Luxoid hips are a known risk factor for complications such as postoperative luxation, fissures and fractures (38,39). This deformity also impedes reduction of the prosthetic joint as a result of soft tissue remodeling secondary to chronic subluxation of the joint, thus potentially increasing the surgical duration (38,39). The cases where ZCTHR was performed to treat fractures had a surgical duration longer than the mean reported surgical duration in this study. This could be a result of additional steps necessary to stabilize the fracture in addition to the implantation of the ZCTHR. Another explanation for the relationship between surgical duration and the occurrence of postoperative complications could be that a longer surgery heightens the risk of surgical site infections (40,41). However, the infection rate being merely 4% suggests that infections were not a major contributor to the complication rate in our cohort. Additionally, dog size was identified as a significant predictor, with medium-sized dogs having a notably lower risk of postoperative complications compared to giant breeds. To our knowledge, no previous studies reported size as a significant predictor variable for postoperative complications. Nonetheless, Nelson et al. (2007) did report a near-significant association between giant breed dogs and the risk of postoperative luxation, indicating that the size of the dog could potentially predispose for certain complications. To mitigate this potential complication in giant and large breed dogs, the dual mobility implant was developed (3).

The most frequently reported postoperative complication was luxation of the prosthesis (n = 11). The ALO of the cup is known to significantly contribute to the chances of postoperative luxation, with al large ALO increasing the risk of luxation (15,42). In our study, 71.6% of ALO values were within the recommended range (45° ± 3°), and deviations of ≤ 5° occurred in 11.3% of cases. Two prostheses luxated intraoperatively as a result of a too large ALO. In these cases, the ALO was within reference values after revision and the prostheses presented stable. Despite the correct ALO, the prosthesis luxated postoperatively in both of these cases. In eight out of the nine other cases where luxation occurred, the ALO measured directly post-operatively, fell within the reference range as well. This indicates that most of the cups where luxation was seen, were initially positioned correctly and points out that other factors possibly contributed to luxation in these cases. A possible factor contributing to the luxation is cup loosening, as it was seen in seven of the cases where luxation was seen. An explanation for this finding is rotation of the loosened cup, resulting in an increased ALO and predisposing the prosthesis to luxate (15,42). In the remaining four cases where luxation was identified, no cup loosening was seen but three of these cases did have luxoid hips. This condition is a known risk factor for postoperative dislocations, as it triggers soft tissue remodeling, which potentially predisposes the femur to spring back to its preoperative location, thereby luxating the prosthesis (38,39). In the remaining case without sign of cup loosening or luxoid hips, other described risk factors such as breed predispositions and short neck extensions may have contributed to the luxation (15,39).

Seven instances of cup loosening were observed, with two cases being septic and five aseptic. The rate of septic loosening found in our study was 4% and is similar to the rate reported by Lanz et al. (2010). Prolonged surgeries and the use of implants are established risk factors for surgical site infections that could lead to septic loosening of the implants (40,41). Although not statistically proven, both cases in which infection occurred had a surgical duration longer than the mean surgical duration, indicating that this may have contributed to the infection. Aseptic loosening was the second most common postoperative complication and is traditionally more associated with cemented rather than cementless THR systems as a long-term complication (8). The reported aseptic loosening rate of the ZCTHR ranges from 0-11% and the reported time intervals range from 24 to 136 weeks (1,2,43). The loosening is believed to be a result of bone resorption in reaction to an inflammatory response to titanium or polyethylene wear debris, making the THR in theory susceptible to aseptic loosening (44,3). A single case with a 5^{th} generation ZCTHR showed aseptic loosening after 1784 days, indicating failure of the long-term stability provided by osteointegration. This time interval is consistent with the findings of previous studies (1,2,43). In contrast, the other five dogs (treated with the 6^{th} generation) showed aseptic loosening after a mean time of 29 days, pointing out a failure of the short-term stability through the press-fit mechanism. Early aseptic loosening is a less frequently reported complication and can be attributed to numerous factors including systemic infection, incomplete or excessive acetabular reaming and premature weight bearing in active dogs (37). An interesting finding regarding early loosening of the cup was that it was only observed in cases treated before 2023. This finding suggests that improvements in surgical technique and increased experience of the surgical team improved the placement of the press-fit cup.

Metallosis was the cause of the cup loosening in two dogs, with unilateral metallosis identified in one case and bilateral metallosis in the other. Metallosis is defined as the accumulation of wear debris in soft tissues and is a recognized complication of joint arthroplasty (45,46). Orthopedic disorders affecting other joints are thought to be a risk factor in developing metallosis because lameness in other limbs increases the load on prosthetic joint, potentially leading to accelerated wear. Both titanium wear and polyethylene wear are associated with the development of metallosis and therefore the ZCTHR is susceptible to metallosis (45,46). In the dog with bilateral metallosis, orthopedic diseases were present in the front limbs and could have contributed to accelerated wear of the hip prosthesis. In the dog where unilateral metallosis occurred, no other orthopedic diseases were found and therefore the pathogenesis of the metallosis in this dog remains unexplained.

Failure of implants used for fracture stabilization, either intraoperative or postoperative, was observed in five cases – four involving the 6^{th} generation ZCTHR and one involving the 5^{th} generation. Failure of single loop cerclage wire was seen twice and is likely attributable to the forces acting on the wire, combined with the choice of technique and wire type. Single-loop cerclage wires are known to be able to withstand lower forces than double-loop wires or cable cerclage systems, which could explain the higher likelihood of failure (47,48).

The follow-up period in this study was 336 days on average, which is comparable to or longer than the follow-up periods reported in some studies (1,3,4,35). We used a scale adapted from Guerero et al. (2009) to assess the overall outcome. The rate of excellent outcomes in our study is 72% after a mean follow-up time of 11.02 months, compared to 92.3% reported by Guerero et al. (2009) after a mean follow-up time of 22.68 months. Good outcomes were identified in 14% of our cases, primarily due to a reduced ROM, which prevented classification as excellent. Two dogs were categorized as having a fair outcome and needed revision surgery – one for fissure stabilization and the other to replace a loosened cup. Follow-up examination occurred 40 and 43 days post-revision, respectively, during which mild lameness was observed in both dogs. Given the limited recovery time before the final follow-up in the cases categorized as "Good" and "Fair", we speculate that these outcomes might improve over time. This could potentially increase the number of dogs with a normal or near normal functioning prosthesis in our cohort. All dogs that had an outcome other than good or excellent suffered from post-surgical complications. Although a direct statistical correlation could not be established due to the small sample size, this raises the possibility that such complications may impact overall clinical outcomes.

In conclusion, this study demonstrates that surgical duration and the size of the dog significantly affect the occurrence of post-surgical complications following ZCTHR. These findings support our hypothesis that certain parameters significantly affect the treatment outcome in patients treated with THR at Utrecht university between 2012 and 2024 in terms of complications. The complication rates found in this study are probably a result of technical errors, case selection and materials used. Despite a relatively high complication rate compared to previous studies, the clinical outcomes were predominantly positive, with 72% of dogs achieving normal functionality and an additional 14% returning to near-normal functionality without signs of lameness. These findings highlight the potential of the ZCTHR in restoring quality of life in dogs with marked to severe hip dysplasia.

Nonetheless, several limitations of this study must be acknowledged. The follow-up period in this study might be too short to evaluate long-term complications such as implant failure (e.g. breaking or wear) and aseptic loosening as a result of failure of long-term osteointegration. Additionally, the small cohort size limited the power of our statistical analyses, making variable selection necessary and thereby potentially introducing bias into the interpretation of the results. Furthermore, the effect of the predictor variables on the overall outcome could not be assessed as a result of this small sample size. In future studies, these limitations could be addressed by including a larger and more diverse patient population and ensuring a longer follow-up period to better understand the progression and resolution of complications over time.

The findings of the present study also open up an interesting direction for further research relating to the anatomical femoral anteversion angle and that of the ZCTHR. Given the spread of the anatomical anteversion angle in different breeds, in combination with our finding that neither a high mean anteversion angle nor a wide variation in anteversion angle significantly contributed to complications, one could pose the question whether a femoral anteversion angle of 20° accurately mimics the anatomical situation. To answer this question, the optimal femoral anteversion angle of the ZCTHR in relation to the anatomical anteversion angle should be studied in different breeds. Additionally, the effect of the femoral anteversion angle on the outcome and occurrence of complications should be studied further.

By addressing these gaps, future research could provide a deeper understanding of the factors influencing both the short- and long-term overall clinical outcome of the 6th generation ZCTHR, ultimately guiding improvements in surgical protocols and patient outcomes.

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