

The influence of age at total hip replacement on perioperative complications associated with a press-fit cementless stem with lateral bolt in dogs

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Abstract

Objective: To assess the influence of age on perioperative stem-associated complications when total hip replacement (THR) was performed with a BFX lateral bolt stem.

Study design: Retrospective (2017–2022).

Sample population: A total of 197 client-owned dogs.

Methods: Medical records of dogs that underwent THR with a lateral bolt stem were reviewed. Perioperative complications were recorded. Stem and femoral features were measured on postoperative and follow-up radiographs. The population was divided into juveniles (6–10 months), adults (>10 months to <7 years), and older dogs (≥ 7 years old). Association between groups and perioperative complications was assessed.

Results: Two-hundred and fifty five THRs were recorded: 139 unilateral and 58 bilateral. Intraoperative and early postoperative stem complication rates were 8.6% and 2%, respectively. Juveniles were at increased risk of developing intraoperative fissures. Age was not associated with early postoperative stem complications. German shepherd dogs were associated with postoperative fractures. Subsidence was weakly, but positively, associated with weight and canal flare index.

Conclusion: Juveniles were at increased risk of developing fissures. There was no difference in postoperative stem complications among age groups. German shepherds were at increased risk of postoperative fracture despite the use of a lateral bolt stem. More studies are required to assess the effect of giant breeds on the risk of subsidence, as well as the effect of young age on fissure development.

Clinical significance: Age influenced the development of intraoperative, but not postoperative, stem complications with a lateral bolt stem. Prophylactic

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cerclage application could be considered in juvenile and German shepherd dogs.

1 | INTRODUCTION

Total hip replacement (THR) has been used widely in canine orthopedics to improve joint function and comfort in cases of hip dysplasia and degenerative or traumatic coxofemoral disease.^{1–9} Historically, cemented THR systems predominated in veterinary patients.^{2,3,5} Cemented THR is associated with overall high success and early return to normal activity levels⁵ but aseptic loosening of the bone/cement or cement/implant interface, cortical thinning, and femoral fractures have been reported as long-term complications.^{5,7,10,11}

One of the commonly used cementless THR systems (BFX by BioMedtrix Inc., Whippany, New Jersey) relies on an initial press-fit placement of the stem within the femoral canal to provide early femoral stem stability and subsequent osseointegration that leads to long-term stem stability.^{4,12,13} The reported complications with the BFX standard stem include stem subsidence, femoral fissures, femoral fractures, and coxofemoral luxation.^{14–16}

Stem subsidence may be an early consequence of inadequate initial stability in the immediate postoperative period in dogs with cementless THR.¹⁷ Although stem subsidence between 1 and 3 mm may occur in the early postoperative period and is rarely of any clinical importance,^{4,18} subsidence greater than 3 mm may predispose to femoral fracture and coxofemoral luxation.^{4,15,17–22} Its incidence may be reduced by optimization of femoral canal preparation through a precise broaching technique, ensuring appropriate stem insertion depth and achieving appropriate percent canal fill through an appropriately sized stem.¹⁷ Newer generation BFX stems made of titanium (Ti) alloy and electron beam melted (EBM) surface texture, which replaced the older cobalt-chromium design, aim to resist subsidence, as the ingrowth surface of the implant has a higher frictional resistance compared to previously used biomaterials and textures.¹⁸ Two variations of the BFX EBM stem have been developed to help limit stem subsidence.^{18,23,24} The BFX Collared Stem was developed first, in 2011, and aimed to provide increased protection against subsidence when the collar comes in contact with cortical bone. Subsidence, however, can still occur with the BFX collared stem, even when the collar contacts the bone, if press-fit conditions are not met.¹⁸ The BFX lateral bolt stem was made available in 2013 and incorporates an interlocking bolt that is threaded into the femoral stem via a lateral femoral cortical bone tunnel. The lateral bolt was

designed to enhance the stem's resistance to subsidence and rotation under press-fit conditions following THR, outperforming both the BFX standard stem and collared stems.^{23,24}

The femoral stem design is the same for all BFX systems.¹⁵ Femoral fissures typically occur at the level of the medial calcar during broaching of the femoral canal but can also occur during stem impaction. Fissures can progress to fractures intraoperatively or propagate to fractures postoperatively if they are not stabilized.^{15,20–23} Proximal femoral periprosthetic cerclage wire application has been described to treat^{15,20,25} and prevent intraoperative fissures and minimize the incidence of proximal femoral fractures.^{26,27}

The marked stem/femur derangement that commonly accompanies fractures precludes comparison of subsidence between fractured and nonfractured cases.²⁰ Thus, the fact that the vast majority of fractures are seen in the early postoperative period before osseointegration, suggests that excessive subsidence and/or intraoperative fissures may be the main contributors to postoperative femoral fractures.^{15–17,19–22,28} Preventing stem position change will reduce the incidence of early postoperative complications until osseointegration is achieved. Periprosthetic diaphyseal femoral fractures can also occur distal to the stem tip without communicating with medial calcar fissures sustained intraoperatively.^{15,20,22} In a recent study where the BFX lateral bolt stem was used, only diaphyseal fractures distal to the ingrowth area of the stem were reported suggesting an association with a geriatric and/or iatrogenic bone pathology during femoral canal preparation rather than with, or in addition to, subsidence.²⁹

Older dogs and a lower femoral canal flare index (stovepipe morphology) have been associated positively with postoperative fractures in dogs treated with the older design BFX standard stem.²⁰ A recent large case series with dogs receiving a BFX lateral bolt stem showed an association between fractures and increased age.²⁹ Another recent study, that developed a stem selection process after comparing various BioMedtrix stem types, suggested that dogs from 7 years old should receive a cemented stem to reduce the risk of femoral fractures,³⁰ but no BFX lateral bolt stem was used in that study.

To date, there are limited published clinical data pertaining to the effect of the lateral bolt on postoperative complications and subsequently the success of this

stem type.^{23,29} The aims of this study are to retrospectively review the perioperative (intraoperative and early postoperative) stem-associated complications and to assess the effect of age on postoperative stem-associated complications when the BFX lateral bolt stem is used for THR in a large cohort of dogs. The null hypotheses are that age is not associated with (1) intraoperative or (2) postoperative stem-associated complications.

2 | MATERIALS AND METHODS

2.1 | Sample population

The medical records from a single veterinary referral hospital were retrieved for dogs undergoing THR with a BFX EBM lateral bolt stem (BioMedtrix Inc.) between November 2017 and December 2022. Owners' written consent for the use of anonymous clinical data for research purposes was obtained for each case. Data retrieved from medical records included age, breed, sex, weight, reason for surgery, hospitalization time, days to follow up, and implant size. Dogs with no radiographic follow up or inadequate follow up were excluded from the study. In dogs that underwent staged bilateral THR surgery, each side was evaluated separately. All the THR surgeries were performed by board-certified specialist surgeons (KP, AB, NB).

The canine population was stratified into three age groups: group 1 (juveniles) included dogs between 6 and 10 months of age; group 2 (adults) included dogs over 10 months and under 84 months (i.e., 7 years) of age, and group 3 (older dogs) included all dogs of 84 months of age and older. The selection of age cutoffs was based on previous reports^{10,29,30} to facilitate comparison of our results with the current literature and discussion. Details pertaining to complications, revision surgery, and radiographic follow up when indicated, were also recorded. Complications were classified as intraoperative (when they were identified during surgery or on immediate postoperative radiographs), and as postoperative when identified on follow-up radiographs within 3 months from surgery.³¹ When surgical revision was indicated based on immediate postoperative radiographs, this was considered as part of the primary surgery provided it took place under the same anesthetic. Complications were also categorized as stem-associated or non-stem-associated. Stem-associated postoperative complications included femoral fractures, stem subsidence over 3 mm with clinical impact (e.g., resulting in coxofemoral luxation), and stem fatigue fracture. When intraoperative fissure occurred, protective double-loop cerclage wire was

applied;²⁵ between one and seven wires were used based on the surgeon's assessment of the fissure. Description of the time of observation and classification of complications, as well as the outcome, followed previously described definitions.³¹ Postoperative fractures in the current study mean that the fractures were observed in the perioperative period (i.e., within 3 months from the surgery) and which was described as the early postoperative period. Periprosthetic femoral fractures were classified according to the Vancouver system as previously described.³²

2.2 | Radiographic evaluation

Radiographs were obtained under general anesthesia immediately postoperatively and under sedation on all other occasions (preoperative planning and recheck examinations). Radiographs were evaluated immediately postoperatively and at all recheck examinations. Four radiographic projections, including ventro-dorsal pelvis, lateral pelvis, craniocaudal (horizontal beams) and open leg mediolateral femur were obtained at the time of preoperative planning, immediately postoperatively, and at follow-up examinations. Standard follow-up radiographic evaluation was typically performed between 6 to 8 weeks after surgery unless clinical concerns justified additional earlier or later examination.

Radiographic measurements included the Canal Flare Index (CFI) in the preoperative craniocaudal view, the femoral canal fill and stem orientation in the immediate postoperative craniocaudal and mediolateral views, and the femoral stem length and level in the immediate postoperative and follow-up craniocaudal views, using previously described methodology.²¹

Stem subsidence was calculated in millimeters (mm) by comparing the femoral stem position on the immediate postoperative and follow-up radiographs. Corrected stem subsidence was calculated as previously described.³³ Stem subsidence of >3 mm was considered a complication only if it was clinically relevant.^{17,21}

Radiographic images were reviewed using the Horos medical image viewer (horosproject.org) (Horos Project, Purview, Nimble Co LLC, Annapolis, Maryland) to obtain measurements. All radiographic images were calibrated by using a 100 mm bar positioned level with the femur. All measurements on radiographs were performed by one individual (PK). Images were exported to an orthopedic templating software for surgical planning; this was OrthoViewVET (Veterinary Orthopedic Surgical Planning, Southampton, UK) between 2017 and 2020 and vPOP (Vetsos Education Limited, Shrewsbury, UK) for the rest of the study period.

2.3 | Statistics

The statistical software Minitab 19 and R 4.2.2 were used for the analyses. Categorical data were compared to one another using Fisher exact tests. Nonparametric continuous data were compared to categorical data using Kruskal–Wallis tests adjusted for ties. Continuous data were compared to one another using Spearman rank correlation. Statistical significance was defined as $p < .05$.

3 | RESULTS

3.1 | Demographics

Two-hundred and seventy four consecutive cementless THRs were performed with a BFX lateral bolt stem in the study period; 255 THRs in 197 dogs met the inclusion criteria. There were 109 males (55.3%; 26.4% neutered) and 88 females (44.7%; 23.3% neutered). Mean age at surgery was 39.9 months (median: 24 months; range: 6–168 months) and the mean body weight was 37.5 kg (median: 27 kg; range: 14–74 kg). There were 31 cases (12.1%) in the “juveniles” group, 183 cases (71.8%) in the “adults” group, and 41 cases (16.1%) in the “older dogs” group. The mean age of each age group was 8.9 months (median: 9; range: 6–10 months), 32.9 months (median: 24; range: 10.5–78 months) and 94.4 months (median: 96; range: 84–168 months), respectively.

The case population consisted of crossbreed dogs ($n = 64$), Labrador retrievers ($n = 50$), Border collies ($n = 30$), golden retrievers ($n = 23$), English Springer spaniels ($n = 19$), and German shepherd dogs (GSDs) ($n = 16$). Twenty-two other breeds represented four or fewer cases each.

Staged bilateral THR was performed in 58 dogs (22.7%) and unilateral THR was performed in 139 dogs (77.3%). Left hips were operated in 129 cases (50.6%) and right hips were operated in 126 cases (49.4%).

The median size of the implanted stem was 8 (range: 5 to 13). The most common indication to perform surgery was hip dysplasia ($n = 242$; 94.9%), followed by fracture of the head and/or neck of the femur ($n = 8$; 3.1%), traumatic coxofemoral luxation ($n = 3$; 1.2%), and revision of previous femoral head and neck excision ($n = 2$; 0.8%).

3.2 | Radiographic findings

The median CFI was 1.9 (range 1.1 to 2.9). Overall, the mean femoral canal fill was 67.1% ($SD \pm 6.5$) and 67.6% ($SD \pm 7.1$) on postoperative and follow-up radiographs, respectively. The mean stem orientation on the craniocaudal view was 3.1° varus ($SD \pm 2.4$). Mean stem subsidence between postoperative and follow-up radiographs was 0.8 mm ($SD \pm 1.5$). The average values and ranges of the radiographic measurements are summarized in Table 1.

3.3 | Complications

3.3.1 | Intraoperative stem-associated complications

Twenty-two (8.6%) cases experienced intraoperative stem-associated complications. These consisted of 18 femoral fissures (7%) and four femoral fractures (1.6%). Femoral fissures were observed proximally, either medially involving the calcar or craniomedially. Cerclage wires were applied prior to implant impaction to restore hoop strength in all the cases with femoral fissures. Fractures were classified as one type A and three type B1. Juveniles were found to be at higher risk of developing intraoperative fissures when compared to adults ($p = .024$). No association between any age group and other intraoperative complications was identified. No association was found between stem varus orientation and intraoperative fissures.

TABLE 1 Radiographic measurements.

Variable	Preoperative		Postoperative		Follow up	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
CFI	1.93 $\pm$ 0.34	1.14 to 2.88	-	-	-	-
CF _{av}	-	-	67.1% $\pm$ 6.5	48.9% to 82.2%	67.6% $\pm$ 7.1	35.5% to 85.2%
StemOr _{CrCd}	-	-	3.1° varus $\pm$ 2.4	8° varus to 12° valgus	3.5° varus $\pm$ 2.4	13.2° varus to 4.2° valgus
StemOr _{ML}	-	-	0.7° caudal $\pm$ 3.5	8.8° cranial to 8° caudal	1.5° cranial $\pm$ 3.0	7.1° cranial to 13.9° caudal
Stemsub	-	-	-	-	0.8 mm $\pm$ 1.5	-5 to 13.3 mm

Abbreviations: CF_{av}, average canal fill; CFI, canal flare index; CrCd, craniocaudal; ML, mediolateral; SD, standard deviation; StemOr, stem orientation; Stemsub, stem subsidence.

A case (older Border collie) of intraoperative femoral fracture (type B1) propagated from an intraoperative fissure during hip reduction (*Case 135*). The fissure was initially treated with four double-loop cerclage wires. A laterally positioned 12-hole 3.5 mm locking plate was applied to repair the fracture. Two cases with intraoperative fractures developed subsequent major postoperative complications in the early postoperative period: one case (adult golden retriever; *Case 105*) sustained an avulsion of the greater trochanter (type A) during retraction of the greater trochanter to facilitate broaching in the initial surgery. The avulsion was stabilized with two Kirschner wires and tension band wire and developed a coxofemoral luxation at 21 days. The second case (juvenile GSD; *Case 213*) developed a mid-diaphyseal femoral fracture (type B1) during broaching, and it was treated with six double-loop cerclage wires and a laterally positioned 10-hole 3.5 mm locking plate. It developed a postoperative plate fatigue fracture and was found with a 4.4 mm subsidence at 42 days. All had a successful revision surgery and recovery. The fourth case (adult English springer spaniel; *Case 106*) had a mid-diaphyseal femoral fracture (type B1) and was treated with two double-loop cerclage wires and a laterally positioned 10-hole 3.5 mm locking plate; a cause for the fracture was not documented in the patient's record, and no further perioperative complications were seen.

3.3.2 | Postoperative stem-associated complications

Postoperative stem-associated complications were seen in 5/255 (2%) cases, all classified as major (Table 2). These included three (1.2%) cases of femoral fracture and two (0.8%) cases of coxofemoral luxation.

The fractures were seen in one juvenile Labrador retriever (*Case 3*; type B3), an adult GSD (*Case 163*; type B1) and an older GSD (*Case 127*; type B1). In *Case 3*, the fracture, along with coxofemoral luxation, was only noticed on radiographs at the six-week follow-up examination (Figure 1). Substantial bone derangement and callus formation precluded any revision surgery and therefore explantation was performed. The fractures in *Cases 163* and *127* (Figure 2) were repaired upon diagnosis at 7 and 2 days from the initial surgery, respectively. The latter experienced an intraoperative fissure and had fracture revision surgery twice, one for a plate fatigue fracture at 60 days and one for a fracture nonunion at 385 days postoperatively.

Of the cases with coxofemoral luxation, one was found with a 3.2 mm stem subsidence (*Case 7*; Figure 3). This case underwent cup revision due to a suboptimal

cup orientation. The other case with coxofemoral luxation (*Case 112*), also experienced an intraoperative fissure. This case underwent stem revision due to a suboptimal stem version angle. Following revision, *Case 7* made excellent progress and *Case 112* made fair progress in the early postoperative period.

No association was found between age groups and overall postoperative stem-associated complications. There was no association between age group and postoperative femoral fractures ($p = 0.193$). An association was found between the risk of developing postoperative femoral fracture and the GSD breed ($p = .012$). No association was found between femoral fractures and CFI, canal fill, and stem orientation.

Stem subsidence greater than 3 mm (range between 3.2 and 13.3 mm) was observed in 13 cases (5.1%). Stem-associated postoperative complications were recorded in two (0.8%) cases with stem subsidence greater than 3 mm; the previously mentioned *Case 7*, which developed coxofemoral luxation (3.2 mm), and *Case 213*, which experienced an intraoperative mid-diaphyseal femoral fracture and developed a postoperative plate fatigue fracture at 6 weeks (4.4 mm). The cases with the highest recorded subsidence were two young adult Saint Bernard dogs: a 12-month-old dog weighing 72 kg (13.3 mm; *Case 185*; Figure 4) and an 18-month-old dog weighing 60 kg (6 mm; *Case 205*). Both dogs received a size 13 stem. Apart from incisional seroma formation, no other complication was recorded in the early postoperative period of these two cases. Stem subsidence was associated weakly with increased body weight ($p = .026$; R_s : 0.140, CI: 0.016–0.259) and CFI values ($p = .024$; R_s : 0.142, CI: 0.018–0.261) when the Spearman rank correlation was performed. When CFI was grouped,¹⁷ further assessment with the Kruskal–Wallis test did not identify any association between stem subsidence and CFI ($p = .071$). No association was found between stem subsidence and age, canal fill, stem varus orientation, or GSD breed.

3.4 | Outcome

The overall early postoperative outcome was excellent progress in 250/255 cases (98%). Twenty-three dogs (9%) required 24 revision surgeries in the early postoperative period. Of those, revision surgery involved the stem in 5/24 cases and included femoral fracture repair (2/24 cases), femoral complete implant removal (1/24), plate fatigue fracture revision (1/24) and replacement of a retroverted stem (1/24). Eventually, 20/23 dogs recovered to full function following revision surgeries. Of the five cases that did not return to full function in the early postoperative period, three (1.2%) underwent removal of the

TABLE 2 Demographic data of cases with stem-associated early postoperative complications.

Variables/case		Case 3	Case 7	Case 112	Case 127	Case 163
Breed		LR	GR	LR	GSD	GSD
Age (months)		8	12	30	84	60
Sex		M	MN	M	MN	FN
Weight (kg)		18	31	29	47	40
Reason for THR		HD	HD	HD	HD	HD
Canal flare index		2.78	1.74	2.0	2.14	1.98
Corrected stem _{sub}		n/a ^a	3.2 mm	1.6 mm	2.3 mm	n/a ^a
Average CF	CrCd	78.1%	72.6%	76.4%	61.7%	70.5%
	ML	75.4%	73.8%	58.8%	52%	62.2%
Orientation	CrCd	1.6° varus	5.5° varus	4.3° varus	8.8° varus	7.3° varus
	ML	1.4° caudal	2.5° caudal	5.5° cranial	3.7° caudal	3.8° cranial
Implant size	Stem	7	8	8	9	9
	Cup	24	22	24	30	26
	Head	17 + 3	14 + 5	17 + 6	22 + 3	17 + 6
	Bolt	14	16	14	16	18
Side		Right	Right	Left	left	Right
Postoperative complications		Femoral fracture	Coxofemoral luxation	Coxofemoral luxation	Femoral fracture	Femoral fracture
Other perioperative complications		Coxofemoral luxation	Stem subsidence	Intraoperative fissure	Intraoperative fissure and plate fatigue fracture 8.5 weeks post revision	Plate fatigue fracture 8 weeks post revision
Severity		Major	Major	Major	Major	Major
Time to diagnosis		6 weeks	8 weeks	3 weeks	1 day	4 days
Revision surgery		Explantation	Upsize cup/head	Upsize stem (without the bolt)	Osteosynthesis	Osteosynthesis

Abbreviations: CF, canal fill; CrCd, craniocaudal; FN, female neutered; GR, Golden retriever; GSD, German Shepherd dog; HD, hip dysplasia; LR, Labrador retriever; M, male; ML, mediolateral; MN, male neutered; THR, total hip replacement.

^aSubsidence was not documented due to the marked bone derangement and stem displacement in Case 3 and due to severe superimposition of the osteosynthesis implants with the stem and femoral landmarks precluding reliable measurements in Case 163.

BFX lateral bolt stem. Two had the prosthesis removed; one case with a type B3 fracture (Case 3; Figure 1) and a case with cup loosening with limited acetabular bone stock to allow revision (Case 91). The third case had a suboptimal version angle of the stem and was revised with a bigger BFX lateral bolt stem without the bolt (Case 112). The other two (0.8%) had ongoing lameness but did not undergo revision surgery.

4 | DISCUSSION

Juvenile dogs were at increased risk of developing intraoperative femoral fissures in comparison with adults; the

first null hypothesis is therefore not accepted. There was no difference between age groups and the development of postoperative stem-associated complications; the second null hypothesis is therefore accepted. Older dogs were not associated with stem-associated postoperative complications in the early postoperative period in the current study. The BFX lateral bolt stem should therefore be considered as a safe and effective option for canine THR, regardless of age. The intraoperative and early postoperative stem-associated complications rates were 8.6% and 2%, respectively. The postoperative femoral fracture rate in our study (1.2%) was lower than previous rates (5% to 13.1%)^{15,20–23} reported with the BFX standard stem—both the older cobalt-chromium and the newer



FIGURE 1 Mediolateral radiographic projection of the right femur (A) postoperatively and (B) at 6-week follow-up examination, showing a proximo-caudal femoral fracture in Case 3. The fracture was suspected to have occurred 2 weeks postoperatively; however, the owner did not seek veterinary attention. Complete implant removal was performed.

EBM designs—and was comparable with recent studies where the BFX collared stem (1.1%)²⁷ and the lateral bolt (3.6%)²⁹ stems were used. Our low complication rate makes statistical analysis more difficult but it may reflect the protective effect of the lateral bolt against postoperative stem-associated complications in all age groups.

Juvenile dogs were found to be at higher risk of developing intraoperative fissures than adult dogs. This complication has not been reported in a previous study on juvenile dogs when the older generation (cobalt-chromium) BFX standard stem was used.⁹ In that study, however, 4/20 cases received prophylactic cerclage wire on the proximal metaphysis before final tamping of the broach.⁹ Furthermore, a recent study with BFX collared stems reported no proximal intraoperative fissures (at any age) when a proximal femoral periprosthetic cerclage wire was placed.²⁷ A stem varus orientation of 5° or greater was previously associated with increased risk of intraoperative fissures.²¹ Five (27.8%) out of 18 cases with fissures were seen in juvenile dogs in our population and all had a stem varus orientation less than 5°. Most intraoperative complications in our study were associated with

the surgical procedure prior to insertion of the lateral bolt, which is the last step of the procedure. As the approach is otherwise similar with THR when other types of BFX stems are used, the intraoperative complications are not considered to be associated with the application of the lateral bolt itself. It is unknown whether the intraoperative fissures in juveniles could be related to the increased frictional resistance of the EBM Ti surface texture, which may have led to use of higher impaction forces, or only the femoral canal preparation technique. With a technique-dependent complication, the authors would expect to see an even distribution of fissures among age groups. On the other hand, the higher fissure rate in the juvenile population was seen with an overall fissure rate of 7%, which was slightly lower than the 10% reported previously with BFX lateral bolt stem,^{23,29} and with no association with age.²⁹ The juvenile group was the smallest subpopulation among age groups and, therefore, a statistical Type I error cannot be excluded. Further studies focusing on risks factors for development of intraoperative fissures in juvenile dogs with BFX EBM stems are required. However, in light of the findings of our study, prophylactic cerclage wire application²⁷ might be warranted in juvenile dogs.

In our study, only three cases experienced a postoperative femoral fracture, one in each age group. Furthermore, the dog in the older group was 84 months (7 years) old at surgery, which is the lower age limit of the older dogs group. Ganz et al., reported an association between older age and postoperative fractures, when an older generation (cobalt chromium) BFX standard stem was used with less resistance to subsidence.²⁰ A recent study with BFX lateral bolt stem reported an association of older age (median 7.3 years) with fractures.²⁹ The older dog(s) in that study were 11 years old and the potential effect of older age on the development of fractures was not discussed.²⁹ In our study, with an age range from 0.5 to 14 years, and 41 (16.1%) dogs in the “older dogs” group, no postoperative fractures were documented in dogs over 7 years old. In a recent study where the BFX collared stem was used along with proximal periprosthetic cerclage, postoperative fractures were documented only in 2/184 (1.1%) cases.²⁷ In that population, age ranged between 0.58 and 12.8 years old, however, no details about the age of the fracture cases were provided.²⁷ Macroscopic¹⁷ and microscopic^{34,35} changes to the canine bone have been documented previously, but their relative contributions to the risk of femoral fracture in aged dogs remain to be elucidated. Our study suggests that age does not influence the development of postoperative femoral fractures when a BFX lateral bolt stem is used. However, the authors believe that careful assessment of the trabecular bone during femoral canal preparation is pivotal for

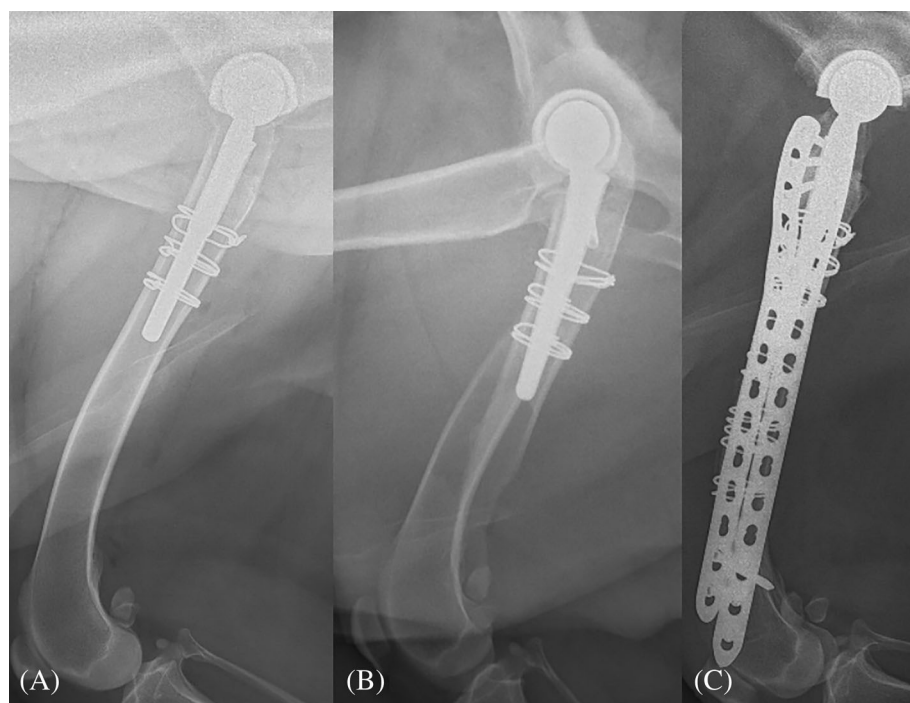


FIGURE 2 Mediolateral view of the left femur in *Case 127*:

(A) postoperative, showing double cerclage wiring applied after an intraoperative fissure was identified; (B) 1 day postoperatively, following a long oblique diaphyseal femoral fracture during hospitalization; and (C) immediately after revision surgery, performed 1 day after the initial procedure, with double plating and additional double cerclage wiring to repair the fracture.

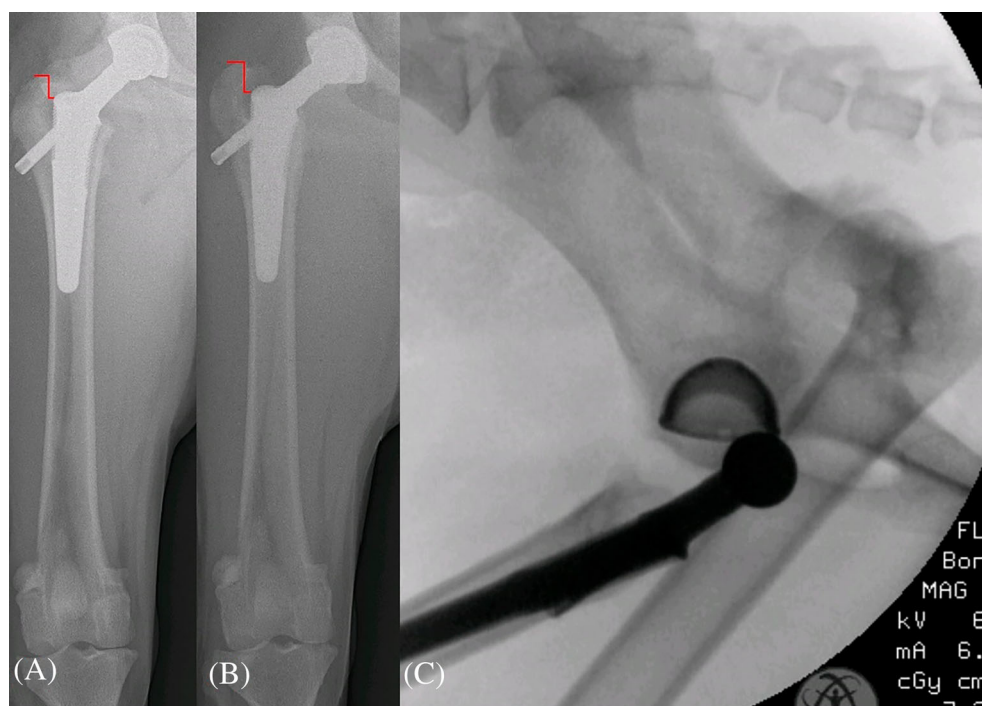


FIGURE 3 Craniocaudal view of the right femur

(A) postoperatively and (B) at 5 week follow-up examination showing the gross difference (red elbow connector) at the stem level in *Case 7*. Stem subsidence was calculated 3.2 mm. This case was diagnosed with intermittent coxofemoral luxation confirmed by a fluoroscopic study (C).

the final decision to select an appropriate THR system, as a cemented prosthesis might be preferred when the trabecular bone is of poor quality irrespective of age. With a poor-quality trabecular bone, the press-fit effect and stem stability may be compromised following stem impaction risking potential stem subsidence and development of postoperative femoral fractures.

The published literature describing fracture incidence with the BFX standard stem commonly describes fracture propagation from the medial calcar, with or without a preceding intraoperative fissure.^{20,21} In the study by Monotti et al., where the BFX standard stem was used, postoperative fractures were only documented adjacent or distal to the tip of the stem, and 65% of them



FIGURE 4 Craniocaudal view of the left femur in Case 185 (A) postoperatively and (B) at 7-week follow up. The stem subsidence in (B) is apparent; the proximo-lateral aspect of the stem has moved distal to the greater trochanter into its fossa and the lateral bolt protrudes more laterally on the follow-up view in comparison with (A).

propagated from intraoperative fissures.²² All postoperative fractures in Kwok and Wendelburg were located distal to the ingrowth area of the stem (type B1) or distal to the stem (type C), and none exhibited progressive subsidence,²⁹ similar to two (type B1) out of three postoperative fractures in our cohort. The postoperative fractures in that study did not exhibit progressive subsidence and the authors presumed that in some cases fractures may propagate from the weakened femoral diaphysis at the tip of the stem, but without advanced imaging, it remains uncertain whether the fracture can propagate from impingement or a fissure that goes unnoticed.²⁹ Similar findings were also reported with biomechanical studies utilizing the BFX lateral bolt stem²⁴ and clinical studies with the BFX collared stem.²⁷ It is unclear why the localization of postoperative fractures in the study by Monotti et al.²² was different from previous studies which used the older design BFX standard stem.^{20,21} Nevertheless, their overall postoperative fracture rate (5.6%)²² was also higher than our study (1.2%). We speculate that the reported locking position of the lateral bolt and the EBM

texture surface augment stem stability and impede distalization and rotation of the stem²⁴ hence protecting the medial calcar and/or propagation of intraoperative fissures to fractures in the early postoperative period.

The GSD breed was associated with postoperative femoral fractures in the current study, despite the use of the BFX lateral bolt stem. Previously, GSDs were disproportionately represented in cases of femoral fractures, although this finding lacked statistical significance.²⁰ In another recent study, GSDs were associated with the development of intraoperative fissures, but not with fractures.²⁹ In this breed, it has been hypothesized that bone quality and thin cortices may increase the risk of fracture.²⁹ German shepherds also tend to have a lower CFI,¹⁷ a previously reported risk factor for stem complications.^{17,20} The number of postoperative fractures in our study was low, and two out of total three cases were GSDs (Case 127 and 163). Both those cases had a stem varus orientation greater than 5° and one also sustained an intraoperative fissure. The latter is a recognized complication with excessive stem varus orientation²¹ and a separate risk factor for postoperative femoral fractures.^{15,21} No direct association was identified between stem varus orientation and postoperative fractures in our study; however, a Type II error cannot be excluded. Those two cases were out of only 16 GSDs in our cohort. Although the BFX lateral bolt stem did not prevent the risk of fracture in these cases, one case had a femur with compromised integrity due to an intraoperative fissure and both cases had an excessive stem varus orientation. Despite the previous concerns about the breed, given the low number of postoperative fracture cases raising suspicion of a Type II error, and the presence of other (confounding) risks factors in those cases, these results should be evaluated with caution. Nevertheless, additional care and attention to surgical technique, and consideration for prophylactic cerclage wiring²⁵ to preserve the integrity of the femur in this breed might be indicated.

Stem subsidence is considered among the risk factors for postoperative complications and, in turn, it can be influenced by various factors.^{15,17,21,22} A recent comparative clinical study among BFX stem types demonstrated that the BFX lateral bolt stem was only limiting but not preventing subsidence.²³ In our study, the mean stem subsidence was 0.8 mm, which is in agreement with previous clinical studies with BFX lateral bolt stem.^{23,29} Furthermore, only 13/255 cases (5.1%) were recorded with stem subsidence greater than 3 mm, but only 2/255 cases (0.8%) had concomitant stem-associated complications. Those were a 12-month-old golden retriever (3.2 mm; Case 7) with a nonstem complication (revision involved replacement of the cup) and a 7-month-old GSD

(4.4 mm; *Case 213*). There are reports of cases with subsidence over 3 mm but without clinical importance.^{15,21} However, a recent study reported that cases with subsidence greater than 3 mm had a 45.3-fold likelihood to develop postoperative stem-associated complications compared to those with less than 3 mm,²¹ and several studies have used the 3 mm cutoff for subsidence to assess the risk of complications,^{23,29} hence our decision to adopt it too. Nevertheless, stem subsidence may not have been the main cause of the coxofemoral luxation in *Case 7* as the cup orientation was suboptimal and had to be revised. In *Case 213*, the plate fatigue fracture may not have been influenced by subsidence only, as the case was also recorded with a stem varus orientation greater than 5° and sustained an intraoperative fracture.²¹ It is often difficult to prove the causation of the two events, especially when subsidence is marginally over the determined cutoff and confounding factors exist, or other cases have higher subsidence with no clinical impact. Some studies have used 5 mm as cutoff for clinically associated subsidence,^{15,18} and documented a subsidence rate of 2.3% with an old generation BFX standard stem.¹⁵ Applying the 5 mm cutoff, only 0.8% (2/255) of our cases would be recorded with subsidence and none with concurrent stem-associated complications.

Heavier dogs were more likely to experience stem subsidence in this population. Indeed, the two cases (*Cases 185* and *205*) with the highest recorded subsidence (13.3 and 6 mm) were among the heaviest dogs in our cohort. These cases involved one undersized and one oversized implant (both #13) in two Saint Bernard dogs (72 and 60 kg). Undersized stems based on postoperative templating were found to be more likely to develop stem complications and subside more than 3 mm in a study with a BFX standard stem.²¹ Yet, similar to our study, subsidence up to 8 mm without identifiable complications has been previously reported with the BFX lateral bolt stem.²³ Although the cause of the complications in the cases mentioned above is unclear, it is speculated that such a level of subsidence was associated with some degree of lateral cortex failure at the level of bolt/bone interface allowing the subsidence. Radiographic assessment could not confirm that hypothesis. Although the association of weight and stem subsidence was also reported in a recent study with the BFX lateral bolt stem,²⁹ our results should be interpreted cautiously given the low number ($n = 8$) of dogs weighing over 50 kg and the weak correlation. Further studies are warranted to assess if giant breed dogs may have a higher rate of stem-related postoperative complications associated with subsidence.

In the present study, an association was found between higher values of femoral CFI (champagne-fluted

shape) and stem subsidence. This is in contrast with previous studies where a lower CFI (stovepipe shape) was associated with subsidence.^{17,20} The correlation was weak ($R_s = 0.14$) and further statistical analysis with the Kruskal–Wallis test only reached $p = 0.071$. Interestingly, two of the heaviest dogs in our population (*Cases 185* and *205*) with the highest recorded subsidence had a CFI of 2.1 and 1.6, respectively. Considering their CFI, these two cases with the highest subsidence in our population are in discordance with our aforementioned results, and in line with literature.^{17,20} In addition, given the overall low number of cases with high CFI (>2.5), a Type I error cannot be excluded and therefore this result should be interpreted with caution. Larger studies exploring the influence of CFI and body weight on stem subsidence with current implant type and generation, will help provide stronger evidence on this matter.

No association was found between CFI and femoral fractures in our study. In a recent study with the BFX lateral bolt stem, although CFI was not associated with subsidence, a higher CFI was associated with femoral fractures; however, a type I error was suspected.²⁹ In our study, a subset of cases was found with “negative” subsidence, suggesting proximalization of the stem, which may have affected the results of the analysis. This finding has been already reported in previous studies and is likely due to a position artifact despite the method to correct subsidence.^{4,21,36} The use of computed tomography for surgical planning and follow-up examination may provide a more practical and accurate calculation of the stem level and potential subsidence in the future.

In the current study, femoral canal fill was not associated with early postoperative complications. An average canal fill of 67.1% was documented, yet no association was found with stem subsidence or femoral fractures. Canal fill is determined by the stem/canal ratio at different levels of the femoral canal.²⁸ It has been historically associated with stem subsidence, though a different stem design was used, when canal fill was below 85%.¹⁷ An ex vivo study did not achieve canal fill greater than an average of 64% with BFX standard and lateral bolt stems.²⁴ Furthermore, a recent clinical study demonstrated no association between subsidence and canal fill, when three types of BFX stems were used, with average values from 66% to 79% in the coronal view.²³ Although multiple strategies—such as electron beam melted (EBM) titanium surface texture, press-fit application, and lateral bolt—are employed to reduce stem subsidence, achieving a high canal fill ($>85\%$) to prevent subsidence appears to be unnecessary.^{21,23} Nevertheless, although successful initial implant stability can be achieved with a lower overall canal fill using the BFX lateral bolt stem,

undersizing the stem should be avoided due to the risk for potential implant fatigue fracture.^{21,29,37}

Prosthesis luxation is commonly associated with cup positioning.^{29,38} Although it can be secondary to subsidence, previous studies have shown that this is uncommon. No such case was identified in a recent study with the BFX lateral bolt stem,²⁹ and only 2/58 cases were reported in a study with an older generation BFX standard stem.²¹ In our study, only 2/17 cases with luxation were recorded with stem complications, and only one of them was recorded with stem subsidence (3.2 mm; *Case 7*). In the latter case, although it is unclear to what extent subsidence influenced luxation, revision surgery involved only replacement of the cup and head, but not the stem. In the second case (*Case 112*) the luxation was attributed to a surgical technique error (stem retroversion) and, as revision involved upsizing the stem, the complication was recorded as stem associated.

According to subjective clinical follow-up assessment and owner feedback, the early postoperative outcome was good to excellent progress in 98% because satisfactory function was achieved. The overall early postoperative outcome in our study corroborates the results from a recent study with BFX lateral bolt stem.²⁹

Limitations of the study are those attributed to its retrospective nature, which affected the standardization of perioperative protocols (e.g., radiographic projections obtained under general anesthesia postoperatively and under sedation at follow-up examinations, which definitely could have affected positioning and radiographic measurements). The lack of a comparison (control) group using the BFX standard stem, and the subjective assessment of clinical outcomes are also limitations. Although stem-associated complications are mainly encountered in the early postoperative period or at routine follow-up examinations, the acquisition of longer term follow up was not standardized as we did not perform a systematic owner phone interview, which might have influenced the complication rate beyond the perioperative period. Femoral stem fatigue fracture is a stem complication that has been reported as a long-term complication,^{29,37} which we have also encountered, but investigating long-term outcomes was beyond the objective of our study. Systematic clinical and radiographic follow up is limited due to the additional costs imposed on the owners and to limit the number of periods of sedation undergone by dogs without any obvious clinical signs. Surgeons had different levels of experience with the technique at certain times throughout the study period. A lower level of experience could affect the quality of bone preparation, stem orientation, and subsequent development of subsidence, fissure, or fracture. The small number of cases with complications might have led to a Type II statistical error and

further studies with larger populations would be required to assess this. On the other hand, however, it might be the addition of the BFX lateral bolt stem that helped mitigate the risk of stem-associated postoperative complications and led to the low numbers found in our study population. Furthermore, complications could be influenced by other factors, such as a long neck, by increasing the longer moment arm, which may have contributed to stem instability and early development of fissure/fracture. The cases that underwent staged bilateral surgery may have contributed to a case selection bias as the owners of dogs with bilateral disease, who experienced major complications on the first THR, may have not returned for surgery on the contralateral hip. Finally, direct comparison with previously published studies should be interpreted cautiously given the diversity in the literature in stem types and generations. A major part of the relevant literature did not use BFX EBM stems, which likely influences the risk of subsidence,^{15,16,29} and poses the risk of comparing dissimilar things and drawing inaccurate conclusions.

In summary, use of a BFX lateral bolt stem mitigated any potential age effect on postoperative stem complications in our study. The authors believe that intraoperative assessment of the trabecular bone quality is an essential step when choosing the type of implant, regardless of the patient's age. Indeed, a cemented stem may be preferred in situations where the trabecular bone appears to be of poor quality. Although recommendations cannot be made given the low numbers of juveniles with fissures, prophylactic cerclage wire could be considered in juvenile dogs to prevent development of intraoperative fissures. More studies are required to assess the effect of body weight on the risk of subsidence, as well as the effect of young age and fissures.

AUTHOR CONTRIBUTIONS

Kokkinos P, DVM, MSc: Acquisition of clinical and imaging data, measurements, and data analysis and interpretation. Drafted, revised, and approved the submitted manuscript. Parsons K, BVSc, PhD, AFHEA, DipECVS: Surgical management of the cases. Reviewed and approved the submitted manuscript. Belch A, BVMS, MSc, CertAVP(GSAS), DipECVS: Surgical management of the cases. Reviewed and approved the submitted manuscript. Barthelmy N, DMV, DipECVS: Conception of the study, study design, acquisition of imaging data, overseeing data collection and surgical management of the cases. Reviewed and approved the submitted manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any financial relationship that could be construed as a potential conflict of interest.

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