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Comparison of femoral stem subsidence between three types of press-fit cementless total hip replacement in dogs

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Abstract

Objective: To compare femoral stem subsidence and determine contributing factors in dogs undergoing total hip replacement (THR) with the traditional BFX, collared BFX, and BFX lateral bolt stems.

Study design: Retrospective radiographic study.

Sample population: Ninety-three dogs with 101 THR including dogs undergoing THR with a BFX lateral bolt femoral stem (n = 40), BFX collared stem (n = 21), and traditional BFX stem (n = 40).

Methods: Radiographs of traditional BFX (n = 40), collared BFX (n = 21), and BFX lateral bolt (n = 40) THR performed from 2015 to 2018 were reviewed. Subsidence, canal flare index (CFI), stem canal fill (CF), stem orientation, and complications confirmed on radiographs were recorded at postoperative and recheck radiographs. Analysis of variance tests were used to compare subsidence, CFI, stem orientation, and CF. A χ^2 analysis was performed to compare complication rates between groups.

Results: Subsidence was lower after placement of BFX lateral bolt stems (median, 0.24 mm; interquartile range [IQR; 1.49) compared with collared (1.27 mm [2.29]) and BFX (1.35 mm [2.26]) stems. No difference in subsidence was detected between collared and BFX implants. Coronal CF was greater after placement of BFX (mean ± SD, 0.72 ± 0.06) compared with lateral bolt (0.69 ± 0.05) or collared (0.66 ± 0.07) stems. Sagittal CF differed between all groups (BFX 0.7 ± 0.05, lateral bolt 0.67 ± 0.06, and collared 0.61 ± 0.06). No differences were identified in CFI or stem orientation in the coronal and sagittal planes or in complication rates between implants.

Conclusion: The BFX lateral bolt femoral stem was associated with less postoperative subsidence compared with the BFX collared and traditional BFX stems. No consistent changes in CF, CFI, or stem orientation or

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complication rates were identified in association with increased subsidence in this study.
Clinical significance: Implantation of a lateral bolt femoral stem should be considered during THR to prevent subsidence.

1 | INTRODUCTION

Total hip replacement (THR) is a common surgical treatment for canine hip dysplasia, coxofemoral degenerative joint disease, and traumatic coxofemoral injuries. The BFX THR system (BioMedtrix LLC, Whippany, New Jersey), one of the most commonly used cementless THR systems, relies on an initial press fit within the femoral canal to provide early femoral stem stability and subsequent osseointegration to provide long-term stem stability.[1] Femoral stem subsidence is commonly observed after cementless THR in dogs. Subsidence is defined as the distal migration of the stem within the femoral medullary canal. Subsidence of 1 to 3 mm is expected in the early postoperative period[2] and is rarely associated with complications. Subsidence greater than 3 mm may predispose to complications, including femoral fracture and coxofemoral luxation.[3-5] Studies have been performed in an attempt to identify risk factors associated with subsidence, and the factors identified include low femoral canal flare index (CFI) and low percentage of femoral canal fill (CF; by the stem).[6]

Several modifications to the traditional BFX EBM titanium femoral stem (traditional BFX) have been developed to help limit stem subsidence in the postoperative period. The BFX EBM collared stem (BFX Collared) incorporates a collar that is positioned on the proximomedial aspect of the femoral stem and is designed to rest near the calcar cortical bone at the femoral neck resection site when a press fit is achieved.[3] The BFX EBM lateral bolt stem (BFX Lateral Bolt) is a recently developed femoral stem modification that incorporates a lateral bolt into the traditional BFX cementless stem. This lateral bolt stem accepts a stabilizing bolt that is threaded into the femoral stem from the lateral side and achieves angular stability via a conical coupling design.[7] The lateral bolt stem was designed to make the stem more resistant to subsidence and rotation after THR.[7] An ex vivo cyclic loading study was performed to evaluate femoral stem subsidence with the BFX Lateral Bolt compared with the traditional BFX, and, in that study, the BFX Lateral Bolt was more resistant to subsidence associated with axial loading in an ex vivo setting compared with the traditional BFX.[7]

To the best of the authors' knowledge, there are no published studies in which stem subsidence has been evaluated in clinically affected dogs undergoing THR with the BFX Lateral Bolt compared with dogs undergoing THR with the traditional BFX and BFX Collared. The objective of this study was to evaluate and compare stem subsidence and factors that may contribute to stem subsidence in dogs undergoing THR with the traditional BFX, BFX Collared, and BFX Lateral Bolt. We hypothesized that dogs undergoing THR with the BFX Lateral Bolt would experience less stem subsidence as assessed radiographically compared with dogs receiving a traditional BFX or BFX Collared.

2 | MATERIALS AND METHODS

2.1 | Sample population

The medical records from a single veterinary referral hospital were searched for dogs undergoing THR with a BFX Lateral Bolt between March 2016 and July 2018. Separate cohorts of dogs undergoing THR with a traditional BFX (n = 40) or a BFX Collared (n = 21) were selected in reverse chronological order until similar sample sizes were met or until all dogs fitting the cohort and inclusion criteria were identified. Dogs were included in the study when complete medical records and appropriately positioned postoperative and follow-up radiographs were available for review. Dogs with no radiographic follow-up or with inappropriate positioning on radiographs precluding measurement of femoral stem position were excluded from the study. Radiographs were evaluated immediately postoperatively and at all recheck examinations. Breed, age, weight, altered status, days to follow-up radiographic recheck, and implant sizes were recorded from the medical record. In dogs that underwent bilateral THR, each THR was evaluated separately.

2.2 | Radiographic evaluation

Radiographic images were reviewed in DICOM (Digital Imaging and Communications in Medicine) viewing software (eFilm Workstation; Merge Healthcare, Chicago, Illinois) and imported into orthopedic templating software (Orthoplan Elite; Sound-Eklin, Carlsbad, California) to obtain measurements. Radiographic images were calibrated by using a 25.4-mm sphere or 100-mm bar. Radiographic projections evaluated included mediolateral and ventrodorsal pelvis as well as mediolateral and craniocaudal femur. Measurements were performed on the radiographic images in which the femur of interest was the most appropriately positioned to provide true craniocaudal and mediolateral projections. All measurements from radiographs were performed by one individual. Measurements from radiographs included femoral stem position, CFI, stem CF, and stem orientation in the coronal and sagittal planes. Any complications detectable on radiographs were documented. A proportion based on actual stem length, stem length measured on radiographs, and stem position measured on radiographs was used to correct measured stem position on the craniocaudal projection, as previously described by Brand and colleagues[8] (Figure 1). Femoral stem subsidence was calculated as the difference between corrected stem position at the most recent radiographic recheck and corrected stem position on the immediate postoperative craniocaudal femur radiographs. Canal flare index was evaluated on the craniocaudal projection and calculated as a ratio of endosteal width at the lesser trochanter over endosteal width at the narrowest point of the femoral shaft.[6] Canal fill was calculated as a ratio of implant width to endosteal width at the level of the lateral smooth/porous junction of the femoral stem, 5 mm proximal to the tip of the femoral stem, and midway between these two points.[9,10] Stem orientation was determined by comparing the long axes of the femur and the femoral stem in the coronal and sagittal planes.[9] Complications were classified as intraoperative when they were identified on immediate postoperative radiographs and as postoperative when they identified on follow-up radiographs.

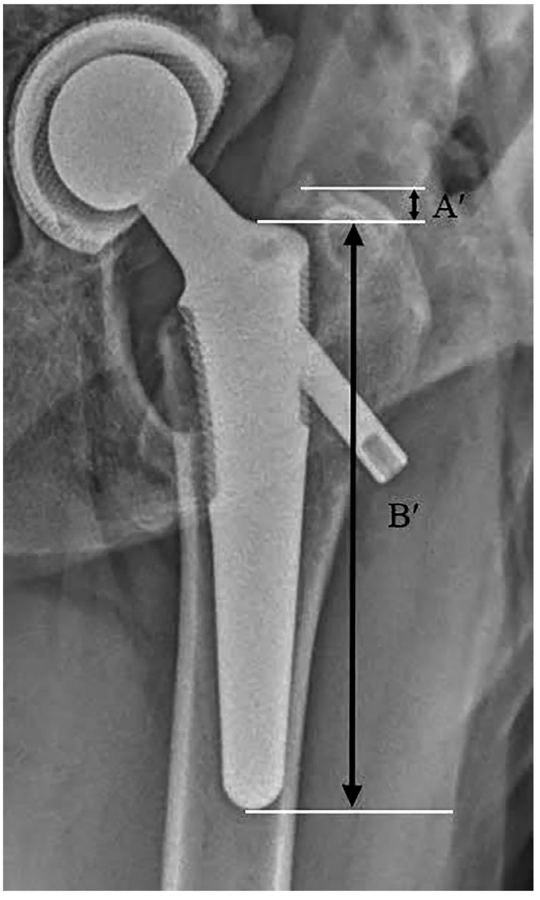

FIGURE 1 Measurements from radiographs to calculate the corrected femoral stem position. Corrected femoral stem position represents the corrected distance from the most proximal aspect of the greater trochanter to the proximolateral shoulder of the femoral stem and is the variable A in the proportion. The variable B is the actual femoral stem length measured from the shoulder to the distal stem tip—this value was obtained from BioMedtrix LLC. Variable A is the actual femoral stem length measured from the shoulder to the distal stem tip—this value was obtained from BioMedtrix LLC. Variable A′ is the radiographically measured distance from the most proximal aspect of the greater trochanter to the proximolateral shoulder of the femoral stem. Variable B′ represents the radiographically measured femoral stem length from the shoulder to the distal stem tip

2.3 | Statistical analysis

The collected data were imported into and statistical analyses were performed in SigmaPlot (Systat Software, San Jose, California). Descriptive statistics were calculated for continuous variables and, for normally distributed data, were reported as mean and SD. Normality was evaluated by using the Shapiro-Wilk test, and, for data failing the normality test, median and range were reported in place of mean and SD. A Kruskal-Wallis analysis of variance (ANOVA) on ranks was used to compare stem subsidence, CFI, age, and stem orientation in the coronal and sagittal planes between groups. A one-way ANOVA was used to compare body weight and CF in the coronal and sagittal planes between groups. Chi-square tests were performed to compare intraoperative, postoperative, and total complications between groups. A Student's t test (normally distributed data) or a Mann-Whitney rank-sum test (data failing normality test) was used to compare magnitude of stem subsidence between dogs without complications and those that experienced a complication within each stem type group. $P < .05$ was considered significant for all analyses.

3 | RESULTS

In total, 93 dogs with 101 THR met our inclusion criteria, and this cohort included dogs undergoing THR with a BFX Lateral Bolt (n = 40), BFX Collared (n = 21), and traditional BFX (n = 40). The mean ± SD body weight of dogs undergoing THR with BFX Lateral Bolt (32.5 ± 8.7 kg), BFX Collared (34.8 ± 7.9 kg), and traditional BFX (31.9 ± 9 kg) was not different between groups. No differences were identified in mean ± SD age of dogs undergoing THR with BFX Lateral Bolt (30 ± 12 months), BFX Collared (24 ± 12 months), or traditional BFX (48 ± 24 months). Radiographic median follow-up times were similar between stem groups: BFX Lateral Bolt (89 days), BFX Collared (94 days), and traditional BFX (112.5 days).

The BFX Lateral Bolt subsided a smaller amount compared with the BFX Collared ($P = .004$) and the traditional BFXs ($P < .001$), while there was no difference in subsidence between BFX Collared and traditional BFX. There were no differences between stem design groups when CFI or stem orientation in the coronal and sagittal planes was evaluated (Table 1). Coronal CF with the traditional BFX was higher than that with the BFX Lateral Bolt ($P = .018$) or the BFX Collared ($P = .001$; Table 2). Sagittal CF was different between all three stem types (Table 2). Complications identified included intraoperative femur fissure, intraoperative or postoperative femur fracture, and coxofemoral luxation. No differences were identified in complication rates (intraoperative, postoperative, or total) between stem types (Table 3). No differences in stem subsidence were identified within stem type groups between the dogs that had a complication and those that did not have a complication.

TABLE 1 Subsidence, CFI, and stem orientation in the coronal and sagittal planes

Variable	BFX lateral bolt stem	BFX collared stem	Traditional BFX stem
Subsidence, mm	0.24 (1.49)[a]	1.27 (2.29)[b]	1.35 (2.26)[b]
CFI	1.67 (0.37)[a]	1.58 (0.56)[a]	1.68 (0.35)[a]
Coronal stem orientation, °	2.20 (2.45)[a]	3.15 (2.38)[a]	2.10 (2.83)[a]
Sagittal stem orientation, °	3.15 (2.40)[a]	2.95 (5.28)[a]	2.75 (1.98)[a]

Note: Values are median (IQR). Stem orientation is described with positive values to represent valgus angulation in the coronal plane and cranial angulation in the sagittal plane.
Abbreviations: CFI, canal flare index; IQR, interquartile range;
[a]$P < .05$ differences between stem groups along a row.
[b]$P < .05$ differences between stem groups along a row.

TABLE 2 Coronal canal fill and sagittal canal fill

Variable	BFX lateral bolt stem	BFX collared stem	Traditional BFX stem
Coronal canal fill	0.69 ± 0.05[a]	0.66 ± 0.07[a]	0.72 ± 0.06[b]
Sagittal canal fill	0.67 ± 0.06[a]	0.61 ± 0.06[b]	0.70 ± 0.05[c]

Note: Values are mean ± SD.
[a]$P < .05$ differences between stem groups along a row.
[b]$P < .05$ differences between stem groups along a row.
[c]$P < .05$ differences between stem groups along a row.

TABLE 3 Complications recorded with each type of implant

Types of Complications	BFX lateral bolt stem	BFX collared stem	Traditional BFX stem
Intraoperative femur fissure	4	3	1
Intraoperative femoral fracture	2	3	3
Postoperative femoral fracture	0	0	2
Luxation	2	2	3
Intraoperative complications	6[a]	6[a]	4[a]
Postoperative complications	2[a]	2[a]	5[a]
Total complications	8[a]	8[a]	9[a]

Note: Intraoperative complications include intraoperative femur fissure and intraoperative femoral fracture. Postoperative complications consist of postoperative femoral fractures and luxations.
[a]$P < .05$ differences between stem groups along a row.
[b]$P < .05$ differences between stem groups along a row.

4 | DISCUSSION

In this study, subsidence was lower after implantation of BFX Lateral Bolt than after implantation of BFX Collared and traditional BFX in dogs treated with THR. The reduced subsidence was likely due to immediately increased construct stability provided by the bolt early in the postoperative period, prior to bone ingrowth.[7] The authors expected that the BFX Collared would also be more resistant to subsidence compared with the traditional BFX, but this supposition was not supported by the results of this study because similar subsidence was identified between BFX Collared and traditional BFX. The similar magnitude of subsidence identified in the BFX Collared and traditional BFX groups in this study is probably related to the BFX Collared insertion technique used in the dogs included in this study. The authors typically insert the BFX Collared to achieve a snug “press fit” prior to the collar contacting the femoral neck at the ostectomy. Leaving a small gap of 1 to 2 mm between the collar and the femoral neck bone helps ensure that the collar coming into contact with the bone does not stop insertion of the stem before a press fit is achieved. This insertion technique could allow the BFX Collared to subside 1 to 2 mm before the collar comes into contact with the femoral neck bone in the early postoperative period, which is similar to the magnitude of subsidence that was observed in the BFX Collared in this study.

Undersizing the femoral stem has previously been identified as a factor contributing to postoperative stem subsidence.[6,11] The average CF for all of the stem groups in this study was undersized compared with the recommendation of 85% CF; however, the traditional BFX group had the highest coronal and sagittal CF yet still experienced the greatest magnitude of subsidence.[12] Canal fill in the sagittal plane was evaluated to identify differences between groups. The clinical relevance of differences in sagittal CF between the three stem types remains unclear. Townsend and colleagues[10] suggested that the percentage CF value measured radiographically has minimal clinical significance and that evaluation of stem size by postoperative templating may be more predictive of postoperative subsidence and development of future complications. Our results provide evidence to support the supposition that, at least for the BFX Lateral Bolt, achieving an 85% CF may not be required to obtain a stable stem that experiences minimal subsidence in the postoperative period.

The results of previous studies have provided evidence to support the idea that dogs with a CFI of less than 1.8 undergoing THR were more likely to experience subsidence.[6] No significant difference in CFI was identified between groups in our study, but median CFI in all three groups was less than 1.8. The authors' clinical experience has been that the use of BFX Collared or BFX Lateral Bolt allows the case selection for cementless to expand to include some clinically affected dogs that may not have classic “champagne flute” femoral morphology with a similar success rate to that achieved with the older generations of cementless stems in dogs with a CFI greater than 1.8.

The complications identified in this study included coxofemoral luxation, intraoperative fissure fracture, intraoperative femoral fracture, and postoperative femoral fracture. No differences were identified in complication rates between groups in this study. Magnitude of stem subsidence in the dogs that experienced complications intraoperatively or postoperatively was evaluated separately to determine whether these cases experienced unusually high subsidence compared with the average overall subsidence for each group. This analysis failed to identify any differences in stem subsidence between dogs that experienced a complication and dogs that did not experience a complication within each stem group. Two dogs in this study were found to have both an intraoperative and a postoperative complication. One dog with a BFX Collared had an intraoperative femur fracture and subsequently luxated in the postoperative period, while one dog with a traditional BFX had an intraoperative fissure fracture and then was found to have a subsequent femoral diaphyseal fracture postoperatively. While the case numbers were too low for statistical evaluation, the authors suspect that dogs experiencing an intraoperative complication may be at a higher risk for experiencing a subsequent postoperative complication compared with dogs that do not experience an intraoperative complication. Additional studies in which intraoperative and postoperative complications are evaluated are warranted to determine whether dogs experiencing an intraoperative complication are at higher risk for experiencing a postoperative complication.

Early research on press-fit femoral stems has supported the idea that a small amount of femoral stem subsidence in the early postoperative period may actually improve stem stability by allowing the stem to wedge more tightly into the femur, creating a tighter press fit.[2,3] A stem modification such as a collar or bolt that is added to help the stem resist subsidence might prevent an undersized femoral stem or incompletely impacted femoral stem from shifting into a more stable position in the proximal femur. Excessive subsidence of the femoral stem may unfortunately result in significant complications post–total hip replacement, such as femoral fissure, fracture, or coxofemoral luxation.[3-5] Both the collar and the lateral bolt are attempts to balance the possible requirement for small amounts of femoral stem subsidence postoperatively if the stem has not been inserted to achieve a stable press fit, with the risk of the stem subsiding excessively in the postoperative period leading to the development of complications. The authors' experience has been that neither the collar nor the lateral bolt will prevent a significantly undersized or underimpacted stem from subsiding in the postoperative period; in fact, the authors have documented as much as 8 mm of subsidence in a dog that was implanted with an undersized BFX Lateral Bolt (without identifiable complications in this instance). The authors suggest that, when a cementless femoral stem is properly impacted intraoperatively such that a stable press fit is achieved and this stem is then augmented by the addition of a lateral bolt, the stem is stable enough that minimal subsidence would be expected to occur before the implant achieves bone ingrowth. This supposition is just a hypothesis at this point because no study has been published in which the quality of bone ingrowth achieved in canine femurs implanted with a BFX lateral bolt cementless femoral stem has been evaluated; however, the authors' clinical experience with the BFX Lateral Bolt would support the theory.

The main limitations of our study were the small sample and the retrospective design. The retrospective design of this study largely affected standardization of positioning on radiographs and timing of radiographic follow-up. The postoperative and follow-up radiographic views obtained and timing of follow-up radiographs were somewhat standardized for each surgeon but were not the same between surgeons. Length of time to final radiographic follow-up obtained for dogs in all groups ranged from 42 to 1008 days. It is possible that some stems may have continued to subside after the most recent follow-up visit documented in this study; however, median follow-up times between groups were similar in the study. Measurements from radiographs were performed on postoperative projections and the most current follow-up projections. The variability in radiographic views made obtaining consistent measurements from radiographs, particularly on follow-up radiographs, somewhat difficult. In addition, radiographic follow-up timing was variable, and some dogs were excluded from the study because of lack of appropriate follow-up. The results of this study are based entirely on radiograph observations and measurements, which is a limitation because clinical outcomes were not evaluated. In addition, there are limitations to measurement of stem subsidence from radiographs. Korani and colleagues[13] reported a large variability in subsidence related to limb positioning observed on radiographs and demonstrated positive subsidence values for what appeared to be proximal migration of the femoral stem. Proximal migration of the femoral stem is highly unlikely, and positive subsidence results are likely secondary to positioning errors on radiographs. In this study, the authors corrected subsidence measurements using a previously described proportion.[8] Use of the proportion has been shown to improve the accuracy of femoral stem position measurement; however, the proportion accurately corrects subsidence measurements only when small amounts of malpositioning on radiographs are present.[8] Severe femoral malpositioning will result in inaccurate measurement of femoral stem position regardless of whether the proportion is used. The authors recorded positive values for stem subsidence in several instances in this study. In all cases of apparent positive subsidence, some degree of femoral foreshortening was subjectively present on the craniocaudal femur projection.

In conclusion, the BFX Lateral Bolt was associated with less postoperative subsidence compared with the BFX Collared and traditional BFX in this study. Increased subsidence was not associated with consistent changes in CF, CFI, or stem orientation between stem design groups, and complication rates were comparable between stem designs in this retrospective study. Despite the statistically significant difference in subsidence between groups, all stem groups in this study subsided on average what would be considered a clinically acceptable magnitude of subsidence in the postoperative period.

CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this report.

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