https://doi.org/10.17221/36/2020-VETMED

Clinical and radiographic evaluation of subsidence in two femoral stem models for a total hip replacement in dogs

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Citation: Minto BW, Diogo LMI, de Andrade CR, Santos Junior WS, de Faria LG, Kawamoto FYK, Prada TC, Dias LGGG (2022): Clinical and radiographic evaluation of subsidence in two femoral stem models for a total hip replacement in dogs. Vet Med-Czech 67, 70–77.

Abstract: Canine cementless total hip arthroplasty (THA) is a successful technique for the management of hip arthrosis; however, serious potential complications, such as femoral fractures and subsidence of the femoral stem, can occur. To evaluate the effect of two femoral stem designs in reducing subsidence in dogs, twenty-four hips from twenty-one dogs undergoing THA were assessed. The twenty-four arthroplasties were divided into two experimental groups: G1 with a first generation, and G2, which is the second generation, system were used. All the dogs were clinically and radiographically evaluated immediately post-operatively and at 30 (M1) and 120 days post-operatively (M2). Three of ten arthroplasties in the G1 system had subsidence and six of fourteen had subsidence in the G2 system. Both systems are effective for management of hip arthrosis. The varus positions with the sub-optimal filling were not related to the subsidence. The two stem designs both showed some resistance to subsidence, but clinical problems were not identified in any case.

Keywords: arthroplasty; complications; dysplasia; press-fit

Total hip arthroplasty (THA) remains the main surgical treatment option for degenerative diseases of the hip joint (Lascelles et al. 2010; Vezzoni et al. 2015).

Since the first reports of prosthetic models for use in dogs, several designs and fixation systems have been described with varying rates of success and complications (Wallace and Olmstead 1995; Guerrero and Montavon 2009; Ganz et al. 2010; McCulloch et al. 2012). The complication rate after THA in dogs is relatively low, with complications occurring in about 8% to 22% of the procedures (Dyce et al. 2000; Kidd et al. 2016); however, the complications, when they do are occur, are potentially catastrophic (Ganz et al. 2010).

The femoral stem is predisposed to movement resulting in the alteration of the primary positioning and consequently in the loss of the initial stability. Instability results in micromovement and reduced osteointegration, leading to fibrous integration

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and possible fixation failure (Korani et al. 2015). In addition, instability may result in stem subsidence or its rotation in the bone bed.

Malpositioning of the prosthesis may occur secondary to the instability with complications incompatible with joint function, such as pain, dislocation, implant loosening and femoral fractures. In an attempt to reduce the femoral subsidence and rotation, a variety of stem designs have been developed, the main modification being the inclusion of a medial restrictive collar (McCulloch et al. 2012; Liska and Doyle 2015).

The aim of this study was to clinically and radiographically evaluate the alignment and subsidence of two different stem designs, one with additional metal in the lateral and proximal portions of the femoral stem and the other one with a medial collar restrictor; and to compare their clinical success rates.

MATERIAL AND METHODS

The study was approved by the Ethics Committee on the Use of the Faculty of Agrarian and Veterinary Sciences, São Paulo State University, Brazil (Protocol No. 019531/2016).

Inclusion criteria

The medical records of dogs undergoing THA (January, 2011 to March, 2016) using a first-generation prosthesis (Belly VetPlan Hip Prosthesis System) or second-generation prosthesis (Collared VetPlan Hip Prosthesis System) were reviewed. Dogs that had clinical and radiographic evaluations for more than 4 months post-operatively were included in this study. The dogs that met the criteria were divided into two groups: G1 composed of patients that had a first-generation prosthesis – collarless stem with a proximal lateral increment; and G2, composed of patients who had a second-generation prosthesis – collared stem (medial collar restrictor).

All the surgeries were performed by the same surgeon (W.S.J) using a previously described surgical technique (DeYoung et al. 1992). Evaluations were performed: immediately after surgery (Mi), 30-days post-operatively (M1), and 120-days post-operatively (M2).

Implants: Design and material

The prostheses (G1 and G2) evaluated in the present study had cementless acetabular and femoral components and were constructed from a chrome and cobalt alloy. The two generations, however, differed in the femoral stem in some particulars (Figure 1).

Clinical evaluation

A clinical evaluation was retrieved from the follow-up evaluations on the 30th (M1) and 120th (M2) days post-operatively. The variables were evaluated using a previously described scale adaptation (Guerrero and Montavon 2009), and the THA function was classified as excellent, good, reasonable, poor or failing.

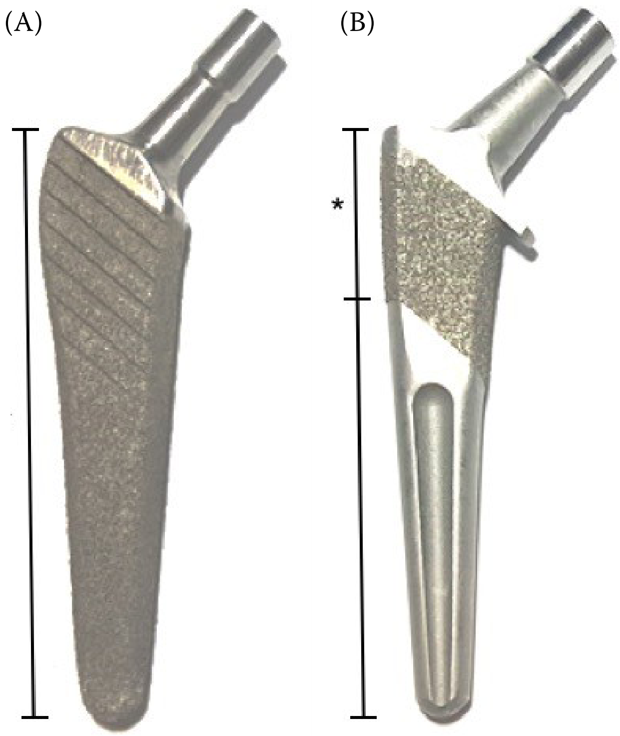

Figure 1. Prosthetic implants of the VetPlan Hip Cementless Total Prosthesis System: Belly-shaped (A) and Collared (B)

The asterisk symbol shows the porous coated surface covering the entire stem length on the first-generation prosthesis, with a lateral belly-shaped increment in its proximal portion (A); and only the proximal third of the second-generation prosthesis stem, with a prominence on the medial surface of the proximal end, called a restrictive collar (B)

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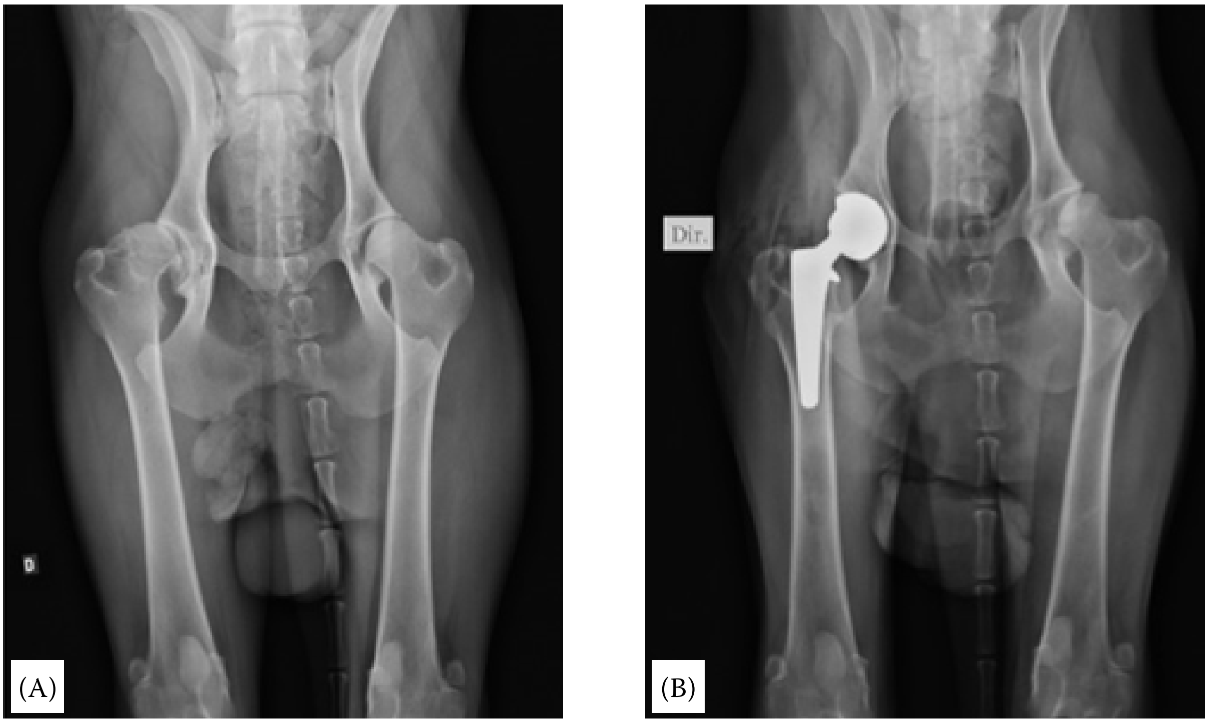

Figure 2. Ventrodorsal radiographic of the pelvis and coxofemoral joints of a dog that underwent a total hip arthroplasty, using the second-generation prosthesis (G2) before the procedure [M0 (A)]; and (B) immediately after (Mi)

Radiographic assessment

The last follow-up radiographs (M2) were evaluated and compared with the immediate post-operative radiographs (Mi) (Figure 2). The radiographs were assessed for signs of implant failure, migration or change in position, dislocation of the prosthesis, signs of bone remodelling secondary to non-detected bone fractures or to infection, and for presence of radiolucent zones between the implants and bone. The osteointegration of the implants were evaluated indirectly, characterised by the absence of radiolucent zones around the acetabular component and by no gap increase between the femoral stem and bone with time, as well as no detectable implant migration.

The mediolateral and craniocaudal alignments of the stem were evaluated at times Mi and M2 and compared with one another. The determination was made according to Korani et al. (2015). The stem angle was measured on the craniocaudal image by drawing a horizontal line at the narrowest point between the endosteal surfaces of the femoral shaft. Two horizontal lines were drawn 20 mm above and below the first line. The midpoints of the three lines were determined and a line connecting these midpoints, which represents the proximal femoral anatomic axis, was drawn (red line). A line bisecting the femoral prosthesis was then drawn (yellow). The stem angle was the angle between the red and yellow lines (Figure 3). Stems positioned between 0° and 1° were classified as neutral; positive deviation stems > 1° were

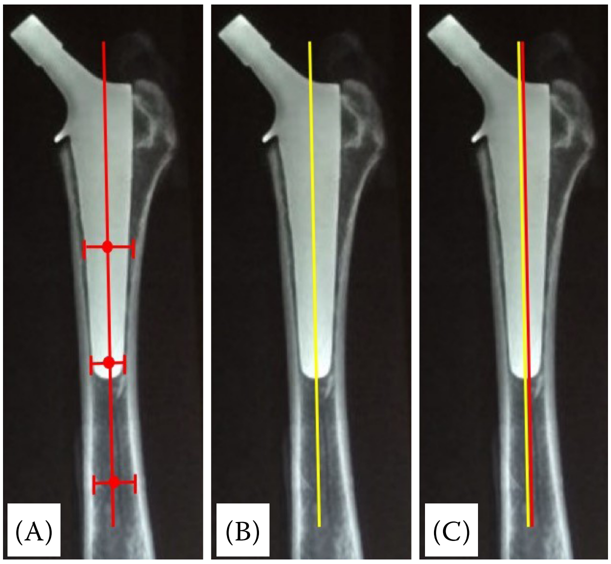

Figure 3. Mediolateral alignment methodology used (A) The proximal femoral anatomic axis was drawn (red line). (B) A line bisecting the femoral prosthesis was then drawn (yellow line). (C) The stem angle was the angle between the red and yellow lines

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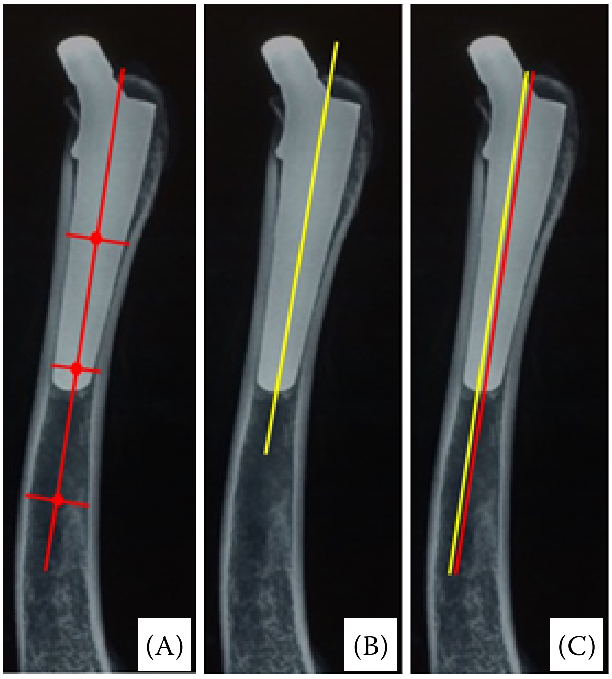

Figure 4. The craniocaudal alignment stem angle was measured on the lateral image as the angle between the femoral anatomic axis and the stem using the measurement technique described for the mediolateral alignment

(A) The proximal femoral anatomic axis was drawn (red line). (B) A line bisecting the femoral prosthesis was then drawn (yellow line). (C) The stem angle was the angle between the red and yellow lines

classified as varus; and stems with negative a deviation were classified as valgus. For the craniocaudal alignment, the determination was based on a previously described methodology (Jehn and Manley 2002). Using a laterolateral radiographic projection, the longitudinal axes of the stem and femoral shaft were first determined and traced. Immediately thereafter, the angle between them was determined, setting the alignment (Figure 4). In cases where there was an overlap of the longitudinal axis of the stem and of the femoral diaphyseal, the stem was classified as neutral, and in cases where the overlap did not occur, they were classified as cranial or caudal deviations, according to the respective positioning changes.

The femoral canal fill was calculated based on a previously described methodology (Marcellin-Little et al. 1999) using the radiographs obtained from the Mi. The canal fill was calculated by the ratio between the width of the implant and the width of the femoral canal. Three measurements were made in a ventrodorsal projection, the first being 5 mm proximally to the distal tip, the second at the limit of the proximal third and the third at the midpoint between them (Figure 5).

The femurs were radiographically classified (M0) by the canal flare index (CFI) as stovepipe, champagne-fluted or normal according to Rashmir-Raven et al. (1992). The CFI was obtained by the ratio between the endosteal width at the midpoint of the lesser trochanter and the endosteal width of the isthmus on the craniocaudal images.

The femoral stem subsidence was determined based on the methodology of Marcellin-Little et al. (1999) comparing the radiographs obtained at Mi and M2. The initial stem level (ISL) was defined

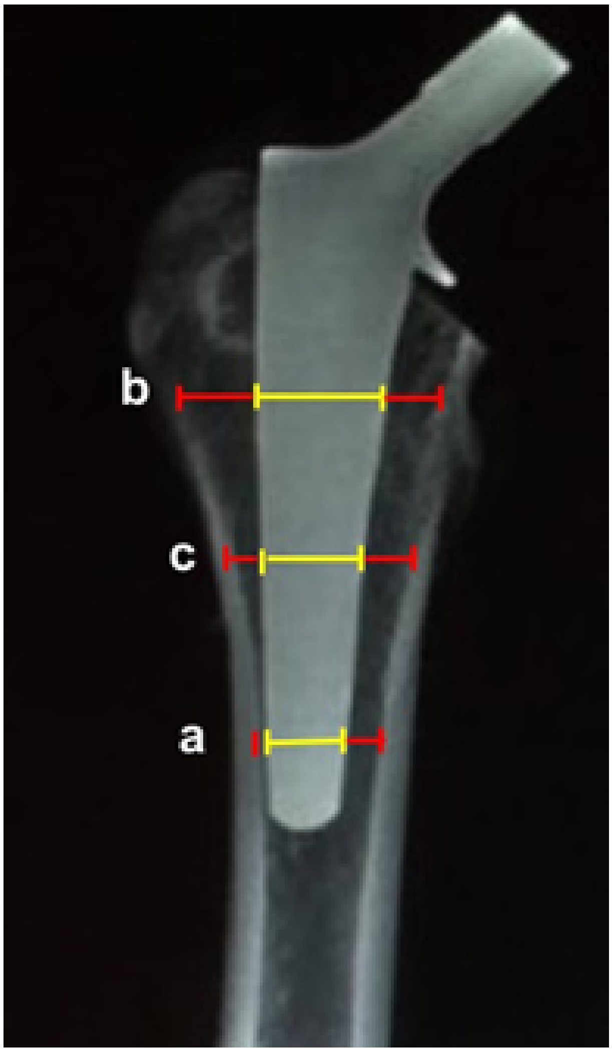

Figure 5. Femoral canal fill measurement

Three measurements are averaged mediolaterally, at the lateral smooth/beaded junction, 5 mm above the stem tip, and in the middle of these two points. The canal fill is the ratio of the implant width (yellow) to the endosteal width (red)

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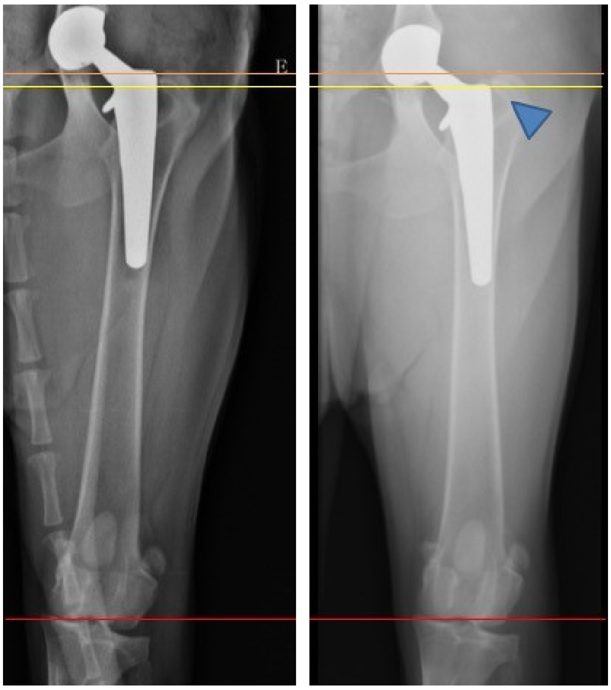

Figure 6. The stem level was measured as the vertical distance from the shoulder of the stem to the point of intersection of the lateral aspect of the stem with the line depicting the intertrochanteric crest (arrow)
Note the discrepancy between the immediate postoperative level (Mi) and after 120 days (M2) (arrowhead)

as the distance between the level of the proximolateral shoulder of the stem and the most proximal top of the greater trochanter at Mi. The final stem level (FSL) was defined as the distance between the level of the proximolateral shoulder of the stem and the most proximal top of the greater trochanter at M2. Finally, the stem subsidence was determined as the difference between the ISL and FSL (Figure 6). In other words, the stem subsidence was defined as any vertical displacement of the prosthetic stem within the femoral canal.

Statistical analysis

The variables were subjected to an analysis of variance (ANOVA), including the effects of the group (2 levels), sex and breed (7 levels), as well as the interactions between these effects, considering a total of 24 joints (21 animals), and a significance level of 5%. In multiple comparisons of means, Tukey's test ($\alpha = 0.05$) was used. For these analyses, the general linear models (GLM) procedure of the SAS computer program was used.

RESULTS

The clinical and radiographic follow-up information was available in 21 dogs, totalling 24 joints in which a THA had been performed. Of these dogs, three underwent bilateral arthroplasty in different procedures. Ten joints received the first-generation implant (G1) and fourteen received the second-generation implants (G2) (Table 1).

Clinical evaluation

In G1, only one patient was classified as good in the clinical hip function evaluation. In G2, one patient was classified as good and another one as reasonable. All the remaining patients had an excellent clinical hip function evaluation at 30 (M1) and 120 (M2) days post-operatively.

Radiographic assessment

There were no signs of osteolysis or presence of a periprosthetic radiolucent line ≥ 1 mm in any patient at the two reassessment times (M1 and M2). The mean femoral canal fill was 65.71% in the mediolateral plane. The femoral classifications were stovepipe in 16 femurs and normal in 8.

In the mediolateral alignment evaluation, only 5 stems had neutral positioning. Two of these were from G1 and three were from G2 (Table 1). The other stems had a varus orientation, with the lateral deviation ranging from 2° to 11° (Table 1).

All the femoral stems had a craniocaudal deviation. Seven had angles of deviation ≤ 2.5°; eight between 3° and 5° and nine ≥ 5.5°, the largest being 11° (Table 1).

Femoral canal fill in the mediolateral plane ranged from 48.22% to 80.54% with an average of 65.71%. G1 had an average canal fill of 68.57%, ranging from 53.23% to 80.54% and G2 had an average of 63.17% (48.22% to 73.99%). There was a statistical difference in the mediolateral femoral canal fill ($\alpha < 0.05$), with a mean of 0.685 73 in G1 and 0.631 74 in G2.

Subsidence was observed in 9 of the 24 prostheses, three in G1 and six in G2, with a displacement ranging from 2 mm to 20 mm (Table 1). This aspect was the most heterogeneous parameter studied, with coefficients of variation of 206.83% in group 1 and 210.93% in group 2. The means of G1 and G2

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Table 1. Radiographic evaluation of the hip joint after the total cementless hip replacement in dogs with the G1 (Belly-shape) or G2 (Collared) prosthesis. Values obtained from the evaluation of the canal flare index (CFI) in M0, and in the complete radiographic evaluation at 120 days post-operatively (M2)

Animal	Mediolateral angular deviation (°)	Craniocaudal angular deviation (°)	Canal fill – ML (%)	Canal flare index	Initial stem level[1] (mm)	Final stem level[2] (mm)	Subsidence[3] (mm)
			group 1 (G1)				
B1	4	11	72.93	2	3	7	4
B2	5.5	2	74.17	1.6	0	0	0
B3	5	3	66.52	1.61	2	2	0
B4	6	4	67.50	1.3	8	8	0
B5	1	4.8	80.54	2	2	2	0
B6	5.5	3	53.23	1.77	3	6	3
B7	7	2	67.18	1.45	0	13	13
B8	4	5	69.81	1.53	3	3	0
B9	5.5	9.5	68.20	1.8	0	0	0
B10	1	6	65.65	1.12	2	2	0
			group 2 (G2)				
C1	9	9	69.92	1.66	5	5	0
C2	1	5	70.74	1.57	4	4	0
C3	7	2.5	66.62	1.43	0	4	4
C4	9	2.5	64.43	1.56	0	2	2
C5	5	2	48.22	1.62	1	1	0
C6	0	8.5	66.39	1.83	0	2	2
C7	6.5	3.5	61.39	1.26	0	0	0
C8	11	1.5	58.49	1.85	0	4	4
C9	8	4.5	60.43	2.35	2	2	0
C10	8	5.5	68.12	2	0	3	3
C11	6	7.5	67.12	1.76	0	0	0
C12	9	6.5	55.71	2	5	5	0
C13	2	2.5	73.99	1.51	10	10	0
C14	1	5.5	52.86	2.42	3	23	20

[1]Defined as the distance between the level of the proximolateral shoulder of the stem and the most proximal top of the greater trochanter at Mi; [2]Defined as the distance between the level of the proximolateral shoulder of the stem and the most proximal top of the greater trochanter at M2; [3]Defined as the difference between the ISL and FSL
ML = mediolateral

were 2.0 (SD 4.13) and 2.5 (SD 5.27), respectively. However, there was no statistical difference in the variable between the groups.

DISCUSSION

The femoral stem modifications in this study aim to improve the proximal stem fixation reducing the subsidence rate. However, significant rates of femoral stem subsidence were observed in both groups. According to Liska and Doyle (2015), the femoral stem design can be a determining factor in the quality of fixation and stabilisation. One of the most appropriate methods of evaluating this aspect is the proximal femoral canal fill. Canal fill values greater than 80% are defined as ideal, providing a high potential for osteointegration. However, in the present study, filling was less than ideal (65.71%) despite the good clinical results and radiographic signs of osteointegration, as well the absence of any femoral stem movement.

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These findings are similar to those previously described (Marcellin-Little et al. 1999), and may represent a methodological failure in evaluating or interpreting the filling.

Additionally, it is widely accepted that use of a smaller femoral stem in a mediolateral alignment protects against subsidence although, in theory, the poor filling would impair the initial fixation and posterior osteointegration (Pernell et al. 1994). Rashmir-Raven et al. (1992) and Gemmill et al. (2011) suggest that a maximum bone bed filling with a three-dimensional neutral stem alignment in the femoral canal would provide the best chance of preventing complications and increasing the osteointegration capacity. However, the high rates of fractures and femoral fissures make these goals precariously close to creating potential complications. Given this, the variability observed in different models and designs may determine distinct fill patterns without negative correlations. In the present study, both stem models provided an adequate initial proximal fixation, which may explain the success rates despite imperfections detected in the radiographic evaluation criteria, such as stem centralisation and canal filling.

Suboptimal filling and undersized stems, especially in the collared shape femora, may hypothetically be important ways to find the balance between excess milling and increased expansion pressure. The need to maximise the femoral bed filling, as well as to apply the stem in a neutral alignment, increases the risk of creating femoral fractures or fissures (Pernell et al. 1994; Liska and Doyle 2015). On the other hand, "controlled undersizing" of the stem, applied in a varus position, may result in an acceptable initial fixation, although lateral displacement is a risk factor for perioperative femoral fractures. Pernell et al. (1994) proved that prosthetic femoral stems applied in a varus alignment have the same resistance to axial loads as stems with a neutral alignment and canal filling above 80%. As yet, there is no definitive answer as to which is the most appropriate application.

Despite the subsidence observed in the two evaluated designs, the first-generation Belly-shape (G1) prosthesis clearly had low subsidence rates with no clinical implications. The increase in the diameter and lateral dimension maximises the mediolateral contact of the proximal portion of the stem with the bone bed, effectively preventing distal displacement without impairing the implant fixation. The proximal fixation of cementless femoral stems is crucial for their proper fixation and integration, and the importance of the lateral and medial contact is highlighted by Pernell et al. (1994).

The distal migration or malposition of the femoral component may cause minor or major (catastrophic) complications, such as pain due to impact with the soft tissue or the bone of the femoral neck region with the acetabular rim, subluxation or prosthetic dislocation and a length discrepancy between the limbs (Liska and Doyle 2015). None of these complications were found in the subsidences observed in the present study. It is believed that the level and intensity of the stem displacement may have been benign in these patients, considering that a number of patients had significant subsidence (13 and 20 mm) with no clinical impact. Pernell et al. (1994) also concluded that some degree of distal dislocation of the cementless prosthetic femoral stem may be beneficial, since it allows a better adjustment between femoral stem and bone bed resulting in a better fit.

No ideal or beneficial distal displacement limit value has been defined. In our study, nine subsidences were observed in 24 implanted stems. A significant number, although none suffered clinical implications. In two cases, displacements greater than 10 mm were observed, which can be considered catastrophic; however, the patients had no alterations in locomotion and the stem was integrated in the radiographic evaluation as proposed by Marcellin-Little et al. (1999).

Other risk factors related to subsidence are the stem alignment in the femoral canal (Pernell et al. 1995; Jehn and Manley 2002) and the CFI (McCulloch et al. 2012; Liska and Doyle 2015). The anatomical characteristics of the femur may be a relevant risk factor for subsidence or other changes in the prosthetic femoral stem positioning. In the present study, although 62.5% of patients had a CFI ≤ 1.8, representing a high risk for catastrophic subsidence, only 37.5% had subsidence and this was not considered malignant in any patient. Some factors may be related to these findings, such as the varus positioning of the stem (19 of 24) and the presence of the collar, which may have acted as a restrictor, as described by Demey et al. (2011) and Liska and Doyle (2015). The varus positioning and purposely undersizing the femoral stems may result in a low risk of subsidence without interfering with the implant integration (Pernell et al. 1994). In these cases,

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canal filling is impaired, as observed in the present study (65.71% average filling).

Conclusions regarding the clinical and radiographic evaluations are limited in the present study by the inclusion of the three dogs that underwent a bilateral arthroplasty. In these dogs, the values may have been affected by the bilateral operation misrepresenting the results.

This study showed that both systems are effective in managing hip osteoarthritis. Although the two femoral stem designs evaluated did not prevent subsidence, clinical problems were not observed. An important finding of the study was that the radiographic osteointegration did not correlate with the subsidence in patients with a suboptimal femoral canal filling associated with a mediolateral stem deviation (varus).

Conflict of interest

The authors declare no conflict of interest.

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Received: February 11, 2020
Accepted: September 6, 2021