Received: 4 October 2019 | Revised: 7 February 2020 | Accepted: 18 March 2020
DOI: 10.1111/vsu.13427

ORIGINAL ARTICLE - RESEARCH

WILEY

Evaluation of cementless femoral stem level on mediolateral projection radiographs

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Abstract

Objective: To evaluate the accuracy of measuring cementless femoral stem level on mediolateral projection radiographs.

Study design: Benchtop cadaveric.

Sample population: Twelve canine cadaver femurs.

Methods: Cementless femoral stems were inserted into 12 canine cadaver femurs at three levels of subsidence. Mediolateral radiographs were obtained for each femur at 0°, 10°, and − 10° frontal plane angulation and at 0°, 15°, 30°, −15°, and − 30° axial plane rotation. Stem level was measured physically on specimens and on radiographs, and a proportion was used to calculate corrected stem level. Stem level was assessed relative to the greater trochanter and relative to the intertrochanteric fossa. Analysis of variance tests were used to compare actual, radiographically measured, and corrected stem level.

Results: No differences were detected between radiographically measured and actual stem level relative to the greater trochanter at 0°, 15°, 30°, and − 30° axial rotation with 0° frontal plane angulation; introduction of 10° or − 10° frontal plane angulation resulted in differences between radiographically measured and actual stem level. Errors >0.5 mm were observed in 82% of radiographic measurements on the basis of the intertrochanteric fossa. The use of a corrective proportion did not improve the accuracy of radiographic measurements.

Conclusion: Femoral stem level was accurately quantitated on mediolateral projection radiographs in this cadaver model. Frontal plane angulation distorted this measurement.

Clinical significance: Femoral stem subsidence may be assessed on well-positioned mediolateral projection radiographs if the landmarks are visible.

1 | INTRODUCTION

Cementless total hip replacement (THR) is an effective and reliable approach to treating diseases of the canine coxofemoral joint.[1-3] Cementless THR systems have been proven to be dependable, but the implants rely on an

The results of this study were reported in part at the 45th Annual Veterinary Orthopedic Society Conference; March 10-17, 2018; Snowmass, Colorado.

initial press fit to maintain implant position until bone ingrowth into the porous surface of the implants occurs.[4] When shifting of the cementless femoral stem occurs, it typically occurs in the early postoperative period.[4] Recognition of femoral stem subsidence, defined as migration of the stem in a distal direction in the medullary canal of the femur, is important because it predisposes dogs to hip luxation and femoral fracture.[5-7] Mild subsidence in the range of 1 to 3 mm is expected after THR, but subsidence >5 mm may indicate implant instability.[8]

Femoral stem level is commonly measured on postoperative and follow-up craniocaudal projection femoral radiographs to allow calculation of femoral stem subsidence. Limb positioning, particularly if it results in femoral foreshortening, can affect the apparent stem level and may result in differences between the radiographically measured and actual stem level.[9] Use of a proportion to correct the measured subsidence has been shown to increase the accuracy of femoral stem subsidence assessment on craniocaudal projection femoral radiographs.[10] Researchers conducting a study performed in man found that small amounts of femoral rotation can cause significant changes in proximal femoral dimension on radiographs, and the magnitude of these changes increases with rotation.[11]

We theorized that femoral stem level could be measured accurately on a mediolateral projection femoral radiograph. The mediolateral position may help to limit inadvertent animal movement of the femur during radiograph acquisition and limit errors in measurement of stem level secondary to femoral foreshortening, which, in the authors' experience, is common because of difficulty in fully extending the coxofemoral joint for craniocaudal radiographs. The objective of this study was to evaluate the accuracy of femoral stem level measurement on mediolateral projection radiographs of canine cadaver femurs that had been serially radiographed at varying degrees of rotation and frontal plane angulation. We hypothesized that femoral stem level could be accurately assessed on mediolateral projection femoral radiographs, that the use of a corrective proportion would increase the accuracy of femoral stem level measurement, and that increasing magnitude of femoral rotation or frontal plane angulation would decrease the accuracy of stem level measurement.

2 | MATERIALS AND METHODS

2.1 | Study design

Cementless femoral stems were implanted in twelve right canine cadaver femurs obtained from dogs that had been previously euthanized and utilized for a veterinary surgery course. The bones were harvested, and soft tissue attachments were removed and stored at −20°C. Bones were thawed overnight prior to stem implantation.

A femoral head and neck ostectomy was performed on each femur, with the neck cut positioned at least a few millimeters above the level of the lesser trochanter, as previously described.[8] The femoral canal was prepared for stem implantation by reaming, followed by broaching to facilitate insertion of a size 6 BFX femoral stem (BioMedrix, Whippany, New Jersey). The stem was initially implanted with the proximolateral aspect located approximately 4 mm distal to the tip of the greater trochanter. Care was taken to ensure that the stem was coaxial to the long axis of the femur. Actual stem level was measured as the distance from the most proximal aspect of the greater trochanter to the proximolateral aspect of the femoral stem by using an electronic caliper capable of measuring millimeters to the nearest hundredth decimal place (Mituotoyo, Kanagawa, Japan); this measurement was recorded for each femur. A custom alignment guide consisting of one straight arm that could be aligned with the long axis of the femur in the frontal plane and a second slightly offset perpendicular arm designed to sit on the most proximal aspect of the greater trochanter and overhang the intertrochanteric fossa was used to ensure that the caliper measurement of actual stem level was made parallel to the long axis of the femur. A second measurement of femoral stem level, the distance from the proximolateral aspect of the femoral stem to the most distal aspect of the intertrochanteric fossa at the junction with the femoral stem, was also made for each femur.

A custom jig was created to allow rotation of the femur in the sagittal, axial, and frontal planes (Figure 1). Protractors were secured to the jig frame to quantitate

FIGURE 1 Triplanar jig used to position cadaver femurs during radiograph acquisition. The jig allows controlled rotation/angulation in frontal, axial, and sagittal planes. Protractors fixed at the axes of rotation allow for precise quantitation of axial rotation and frontal and sagittal plane angulation

axial rotation and frontal plane angulation of the jig. Each femur was then attached to the jig by using 22-gauge orthopedic wire placed around the distal diaphysis of the femur and through holes in the jig. A magnification correction marker measuring 100 mm in length was attached to an articulating arm and was positioned in 0° frontal plane angulation (parallel with the horizon) at the level of the greater trochanter.

Mediolateral projection radiographs were obtained for each femur by using a digital radiography system (Vet-Ray Technology, Sedecal USA, Arlington Heights, Illinois) with the beam centered over the greater trochanter. A true mediolateral projection was obtained by ensuring superimposition of the femoral condyles. Radiographic projections were obtained at frontal plane angulations of 0°, 10°, and − 10° (referring to neutral, abduction and adduction femoral angulation, respectively) and axial plane rotation angles of 0°, 15°, 30°, −15°, and − 30° for each of the 10 femurs. For axial rotation, negative angle values were assigned to internal rotation, and positive angle values were assigned to external rotation.

Each femoral stem was removed from the cadaver femur and reimplanted so that the proximolateral aspect of the stem was positioned approximately 8 mm distal to the greater trochanter. The femoral stem level measurements with the electronic caliper and the initial radiographic series were then repeated. This procedure was repeated, inserting the femoral stem approximately 12 mm distal to the greater trochanter, and caliper measurements and radiographic projections were obtained.

All radiographic measurements were performed in Orthoplan Elite (Sound-Eklin, Carlsbad, California). All images were magnification corrected, and measurements were performed by a nonblinded observer (M.B.). Radiographically measured femoral stem level was defined as the distance measured on radiographs from the most proximal aspect of the greater trochanter to the proximolateral aspect of the femoral stem. The radiographically measured stem length was defined as the distance from the proximolateral aspect of the femoral stem to the distal tip of the stem (Figure 2). A corrective proportion ($X/Y = A/B$) was used to calculate a corrected femoral stem level. The corrected femoral stem level (represented by X) was obtained by cross-multiplying to solve for X, where Y is the actual stem length (58.65 mm), A is the radiographically measured femoral stem level, and B is the radiographically measured stem length. Radiographically measured fossa distance was defined as the distance measured on radiographs from the proximolateral aspect of the femoral stem to the most distal aspect of the intertrochanteric fossa (Figure 2). A corrective proportion was also used to calculate a corrected fossa distance by multiplying the actual femoral stem length by the radiographically measured fossa distance and dividing this product by the radiographically measured stem length.

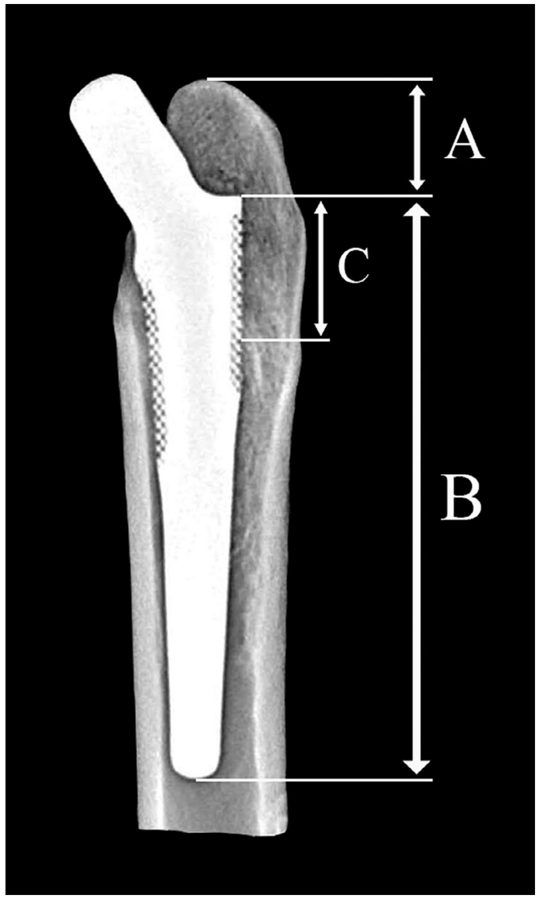

FIGURE 2 Radiographic image illustrating the radiographic measurements. A, The radiographically measured stem level, the distance from the most proximal aspect of the greater trochanter to the proximolateral aspect of the femoral stem. B, The radiographically measured femoral stem length, the distance from the proximolateral aspect of the femoral stem to the most distal point on the stem tip. C, The radiographically measured fossa distance, the distance from the proximolateral aspect of the femoral stem to where the most distal aspect of the intertrochanteric fossa contacts the caudal aspect of the femoral stem

2.2 | Statistical analysis

Descriptive statistics are reported for stem level (actual, radiographically measured, and corrected) and fossa distance (actual, radiographically measured, and corrected) as mean ± SD. Normality was assessed by using the Shapiro–Wilk test. A three-way analysis of variance (ANOVA) was used to evaluate the effects of the variables stem insertion level, frontal plane angulation, and axial rotation on both corrected and radiographic femoral stem level measurements. One-way repeated-measures ANOVA was used to evaluate the effect of femoral frontal plane angulation at each axial rotation angle on corrected femoral stem level and radiographically measured femoral stem level, radiographically measured fossa distance, and corrected fossa distance. Separate analyses were performed for each stem insertion level (4, 8, 12 mm). $P < .05$ was considered statistically significant for all analyses. Bland–Altman plots with 95% limits of agreement were constructed to evaluate agreement between actual and radiographically measured stem levels as well as between actual and radiographically measured fossa distances. All statistical analyses were performed in SigmaPlot (Systat Software, San Jose, California). For the purposes of this study, the authors defined a measure of stem level as accurate if a statistical difference was not detected between actual and radiographically measured stem level and if Bland–Altman plots did not reveal evidence of systematic differences or proportional bias between actual and radiographic stem level measurements and 95% limits of agreement were within 0.5 mm of mean value. In addition to the statistical analysis, the clinical reliability of the corrected and radiographic stem level measurements and the corrected and radiographic fossa measurements were assessed. The authors defined corrected or radiographic stem level or fossa measurements varying by less than 0.5 mm from the actual stem level or fossa measurement as clinically reliable, while measurements varying by more than 0.5 mm were defined as clinically unreliable.

3 | RESULTS

The most dorsal aspect of the greater trochanter could not be consistently identified (obscured by the neck of the femoral stem) at 15° of internal rotation, so all measurements collected at −15° axial rotation angle were excluded from analysis. The variables insertion level, frontal plane angulation, and axial rotation each exerted an effect on the stem level measurements. Differences (p-value <0.05) between actual, radiographic, and corrected stem level measurements with changes in frontal plane angulation grouped by subsidence level and axial rotation are presented in Tables S1-S3. No differences were detected between radiographic femoral stem level measurement and actual femoral stem level at 0° frontal plane angulation, but differences were detected at 10° or − 10° frontal plane angulation at all stem subsidence levels (4, 8, 12 mm) and all axial rotation angles (0°, 15°, 30°, −30°) evaluated. The radiographic femoral stem level measurement was clinically reliable for 97% of measurements at 0° frontal plane angulation but was clinically reliable in only 11% of the measurements made at 10° or − 10° frontal plane angulation at all stem subsidence levels and all axial rotation angles evaluated. Use of a corrective proportion did not improve (or decrease) the accuracy or clinical reliability of the radiographic femoral stem level measurement for any subsidence level, axial rotation angle, or frontal plane angulation groups evaluated. Bland–Altman plot analysis at 0° frontal plane angulation did not reveal evidence of systematic differences or proportional bias between actual and radiographic stem level measurements, and 95% limits of agreement were within 0.5 mm of mean value (Figure 3) at all stem subsidence levels (4, 8, 12 mm) and all axial rotation angles (0°, 15°, 30°, −30°) evaluated. Bland–Altman plot analysis revealed a bias of 0.9 mm at 10° frontal plane angulation (Figure 4) and a bias of

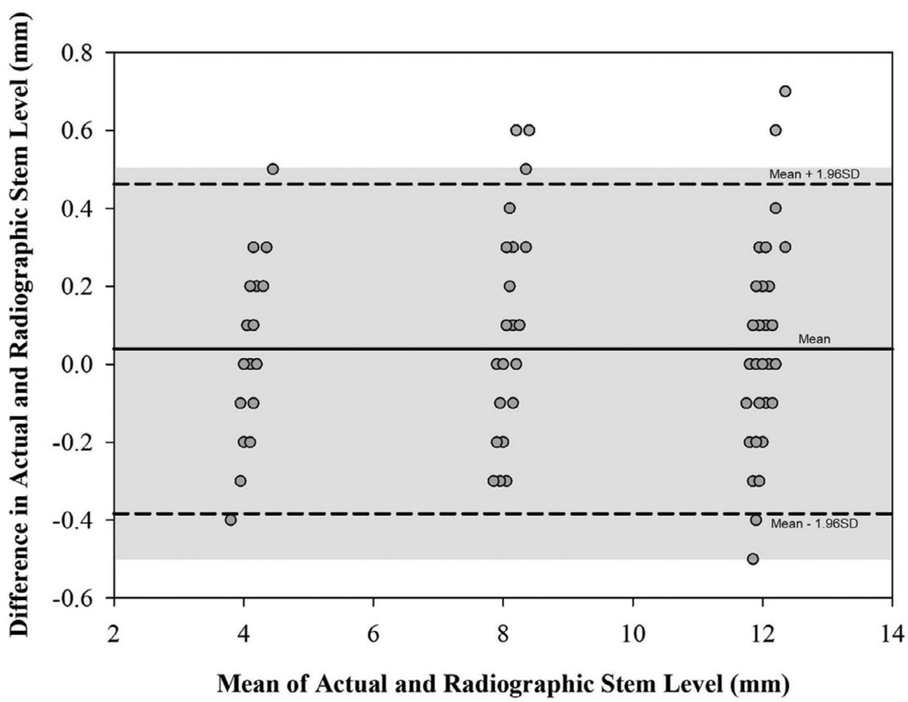

FIGURE 3 Bland–Altman plot of the differences between actual and radiographically measured stem level at 0° of frontal plane angulation with stem levels of 4, 8, and 12 mm. Measurement data from axial rotation angles of 0°, 15°, 30°, and − 30° were pooled for the analysis. Dashed lines represent 95% limits of agreement. The shaded region contains measurement values within 0.5 mm of actual stem level, which were considered clinically reliable

−1.3 mm at −10° frontal plane angulation (Figure 5) as well as an increase in 95% limits of agreement to >0.5 mm for all stem subsidence levels and axial rotation angles.

Differences between actual, radiographic, and corrected fossa distance measurements with changes in frontal plane angulation grouped by subsidence level and axial rotation are presented in Tables S4-S6. Radiographic fossa distance measurement was inconsistently different from actual fossa distance, with no effect associated with stem insertion level, axial rotation angle, or frontal plane angulation. Bland–Altman plot analysis did not reveal evidence of systematic differences or proportional bias between actual and radiographic fossa distance measurements. 95% limits of agreement were > 5 mm from the mean value for 0° (Figure 6), 10°, and − 10° frontal plane angulation at all stem

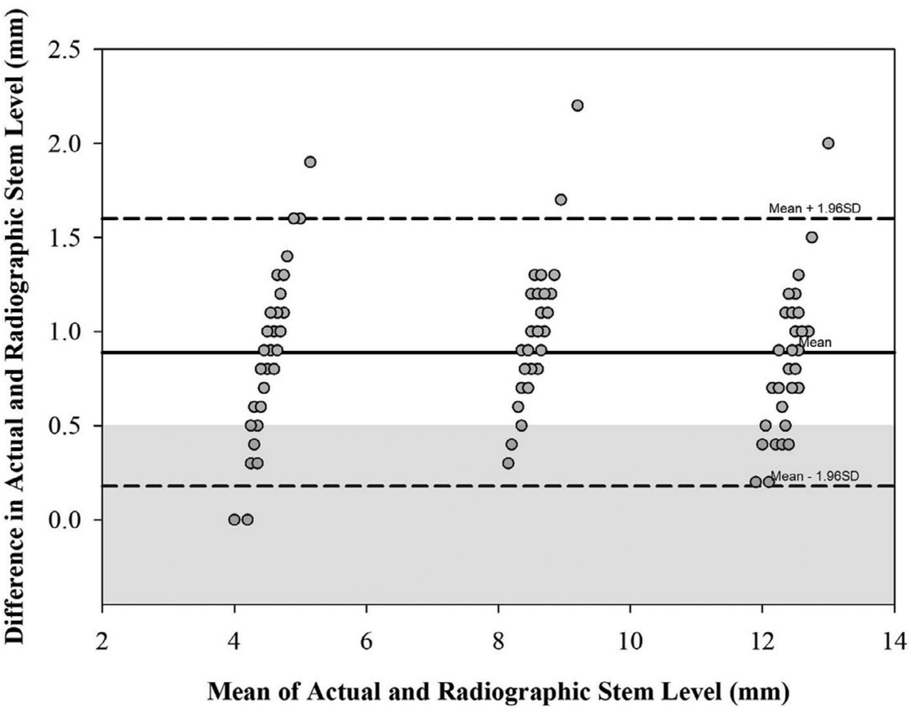

FIGURE 4 Bland–Altman plot of the differences between actual and radiographically measured stem level at 10° of frontal plane angulation with stem levels of 4, 8, and 12 mm. Measurement data from axial rotation angles of 0°, 15°, 30°, and − 30° were pooled for the analysis. Dashed lines represent 95% limits of agreement. The shaded region contains measurement values within 0.5 mm of actual stem level, which were considered clinically reliable

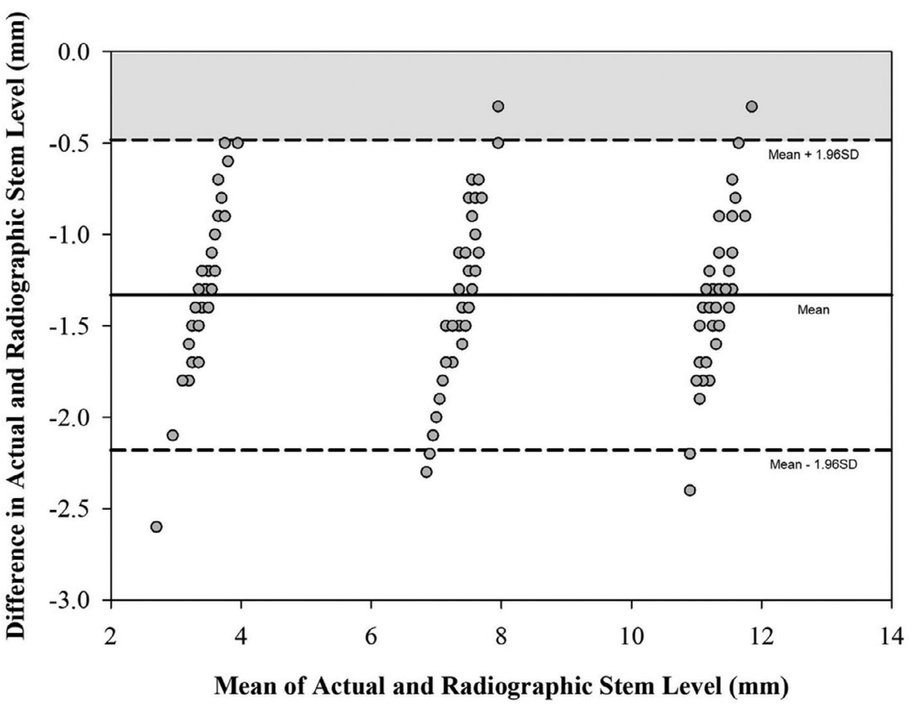

FIGURE 5 Bland–Altman plot of the differences between actual and radiographically measured stem level at −10° of frontal plane angulation with stem levels of 4, 8, and 12 mm. Measurement data from axial rotation angles of 0°, 15°, 30°, and − 30° were pooled for the analysis. Dashed lines represent 95% limits of agreement. The shaded region contains measurement values within 0.5 mm of actual stem level, which were considered clinically reliable

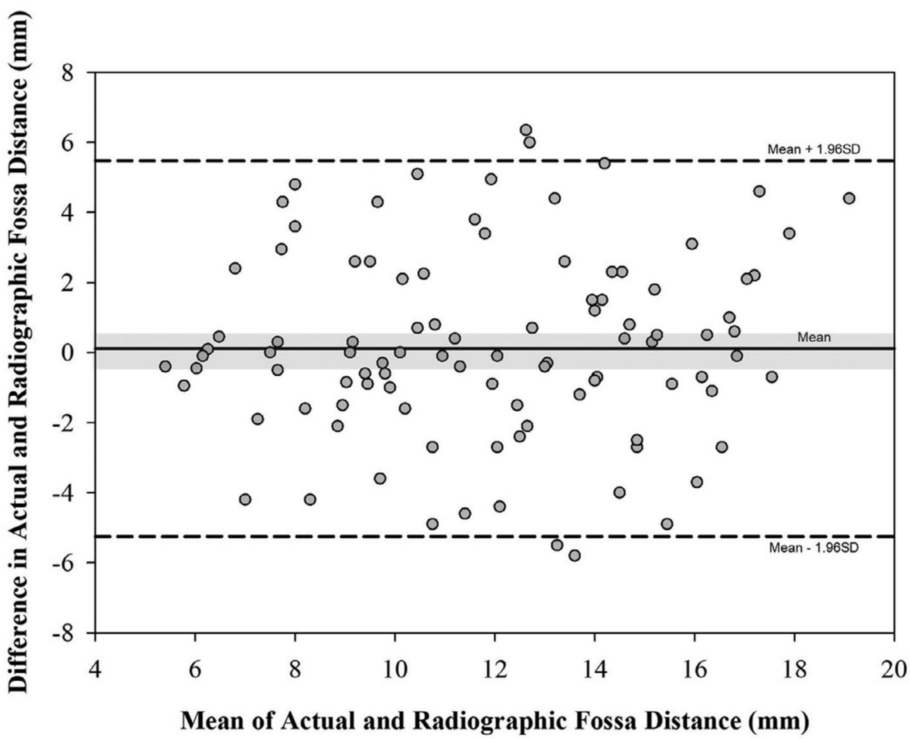

FIGURE 6 Bland–Altman plot of the differences between actual and radiographic fossa distance measurement at 0° of frontal plane angulation with stem levels of 4, 8, and 12 mm. Measurement data from axial rotation angles of 0°, 15°, 30°, and − 30° were pooled for the analysis. Dashed lines represent 95% limits of agreement. The shaded region contains measurement values within 0.5 mm of actual fossa distance, which were considered clinically reliable

subsidence levels (4, 8, 12 mm) and all axial rotation angles (0°, 15°, 30°, −30°) evaluated. Most (82%) radiographic fossa distance measurements were considered clinically unreliable. The use of a corrective proportion did not affect the accuracy or clinical reliability of the radiographic fossa distance measurement.

4 | DISCUSSION

Reliable detection of femoral stem subsidence in the early postoperative period is important because stem subsidence may indicate an unstable implant and could lead to the development of major implant associated complications.[7,8] The results of the present study provide evidence to support the use of a well-positioned mediolateral radiograph of the femur to measure femoral stem level to calculate femoral stem subsidence. The mediolateral projection radiograph was chosen for this study for several reasons. It is difficult to extend the hip fully to get a perfectly positioned craniocaudal view of the femur, but, in the authors' opinion, a well-positioned mediolateral projection femoral radiograph is relatively easy to obtain. It can also be difficult to assess femoral foreshortening on the craniocaudal radiographic projection. On the mediolateral projection, mild limb abduction, adduction, or rotation can be easily assessed by evaluating the degree of femoral condyle superimposition, assuming that a femoral deformity is not present (Figure 7).

Accurate measurements of femoral stem level were obtained in this study with the femur positioned at multiple axial rotation angles. Femoral positioning at 15° of internal rotation resulted in the femoral stem neck obscuring the most proximal point on the greater trochanter, making accurate assessment of femoral stem level impossible. At 0° axial rotation and at 15° and 30° external rotation, the most dorsal aspect of the greater trochanter was consistently located caudal to the femoral stem neck on the radiographic projection, while at 30° internal rotation the most dorsal aspect of the trochanter was located cranial to the femoral neck. In the study reported here, the authors endeavored to position all femoral stems in the same orientation in the femoral canal with approximately 15° of neck anteversion. Because of the similarity of stem positioning between cadaver femurs, it is not surprising that the neck of the stems would obscure the greater trochanter at a similar angle of internal rotation (a femoral stem placed at 15° anteversion will be at neutral version when the femur is internally rotated 15°). In clinical cases, the axial rotation angle of the femur, which might interfere with identification of the most dorsal aspect of the greater trochanter, would likely be different than 15° of internal rotation and would depend on the location of the trochanter relative to the femoral canal, the neck version angle at which the femoral stem was inserted, the angle of femoral stem insertion in the sagittal plane, and the depth of stem insertion in the femoral canal.

As would be expected at 0° frontal plane angulation and 0° axial rotation, radiographic femoral stem level measurement accurately represented true femoral stem level. The authors expected that increasing the axial

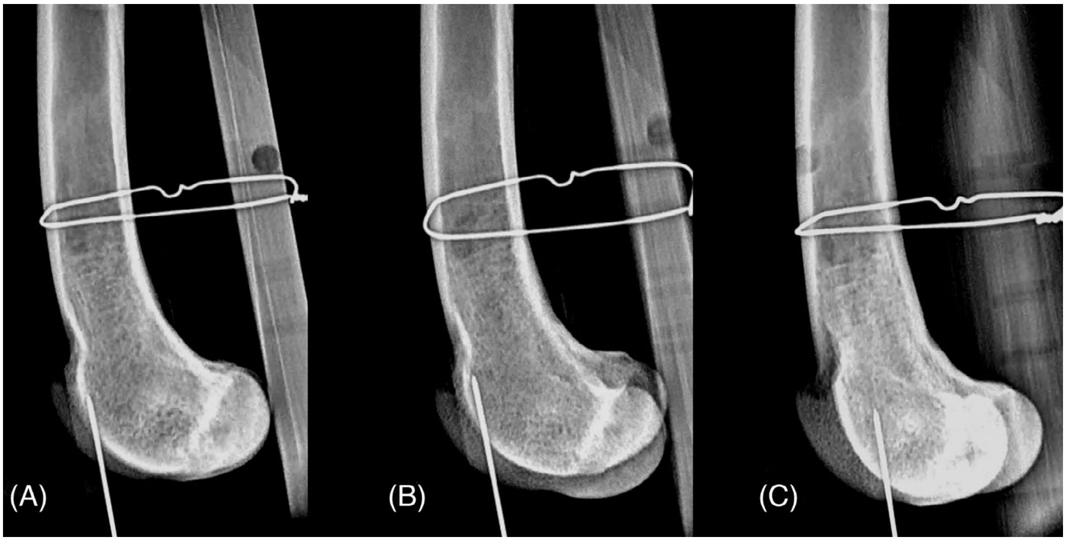

FIGURE 7 Femoral condyle superimposition as assessed on a mediolateral projection radiograph during serial positional changes of a single femur. A, Excellent femoral condyle superimposition obtained when the femur is positioned at 0° axial rotation and 0° frontal plane angulation. B, Loss of femoral condyle superimposition when the femur is positioned at 10° frontal plane angulation and 0° axial rotation. C, Loss of femoral condyle superimposition when the femur is positioned at 0° frontal plane angulation and 15° axial rotation

rotation would reduce the accuracy of radiographic measurement of femoral stem level, but this hypothesis was not supported by the results of this study except at 15° of internal rotation. The results of this study provide evidence that radiographic measurement of femoral stem level can be accurate in the presence of axial rotation (up to 30°) as long as frontal plane angulation is not present. These findings are similar to those of a previous study in which Brand et al.[10] evaluated the effects of axial rotation and sagittal plane angulation of radiographically measured femoral stem level on craniocaudal projection femoral radiographs. In the Brand et al.[10] study, axial rotation up to 30° had minimal effect on radiographically measured femoral stem level as long as minimal femoral angulation in the sagittal plane was present. Presumably, the most dorsal aspect of the greater trochanter in the cadaver femurs included in the current study was a relatively focal position, and the apparent location of this most dorsal aspect did not change with the introduction of moderate amounts of axial rotation. In contrast, the introduction of 10° of frontal plane angulation had a significant effect on femoral stem level measurement. Adduction angulation (−10°) consistently decreased the radiographic femoral stem level measurement, while abduction angulation (10°) consistently increased radiographically measured femoral stem level. The authors expected that both adduction and abduction angulation would decrease radiographically measured femoral stem level due to apparent foreshortening of the trochanter. Presumably, the relatively irregular profile of the greater trochanter in the mediolateral plane resulted in a more lateral region of the greater trochanter shifting into a more dorsal position with abduction angulation, increasing the apparent height of the trochanter relative to the femoral stem on the radiographic projection when abduction angulation was present.

In this study, we also evaluated the level of the femoral stem relative to the most distal aspect of the intertrochanteric fossa. Lascelles and colleagues[12] used the distance from the dorsolateral aspect of the femoral stem to the bottom of the intertrochanteric fossa on craniocaudal projection femoral radiographs to assess femoral stem level and calculate femoral stem subsidence. Korani et al.[9] assessed femoral stem level by measuring the distance from the dorsolateral aspect of the femoral stem to the intersection of the intertrochanteric crest with the caudal aspect of the femoral stem on mediolateral projection radiographs and concluded that the measurement technique compared favorably to other methods of assessing femoral stem level. In the present study, relatively few statistically significant differences were identified between the results of the radiographic fossa measurement technique and the actual fossa measurement. However, on the basis of assessment of the clinical reliability outcome measure, the radiographic fossa measurement was inconsistent and unreliable most (82%) of the time. The explanation for the relatively few significant differences identified between actual and radiographic or corrected fossa measurement results is likely due to the high intermeasurement variability between the fossa measurements (resulting in a low power for this portion of the analysis) compared with the relatively low variability in the femoral stem level measurements groups. The high variability in the fossa measurement values is reflected in the excessively high SD values for the fossa measurements (SD range, 1.4-4.1 mm) compared with the much lower SD values for the radiographic stem level measurement technique (SD range, 0.1-0.5 mm) as well as the large differences in measurement values contained within the 95% confidence limits on the Bland–Altman plot by which actual and radiographically measured fossa measurements were assessed. The authors' impression was that identification of the most distal portion of the intertrochanteric fossa on mediolateral projection radiographs was very subjective. Wide variability was noted in ability to detect the most distal part of the fossa between femur specimens. Even in the same femur specimen, high variability was noted in the apparent location of the most distal portion of the intertrochanteric fossa depending on the degrees of axial rotation and frontal plane angulation. The fossa could not be identified at all at certain positions in most of the femoral specimens (Figure 8).

The use of a corrective proportion increased the accuracy of stem level measurement on craniocaudal projection radiographs of the femur with varying degrees of axial rotation and sagittal plane angulation in a previous study.[10] In the present study, use of a corrective proportion did not significantly improve the accuracy of radiographic stem level measurements or radiographic fossa measurements. The use of the corrective proportion is based on the idea that, as an object with relatively focal endpoints is rotated in the plane of the radiographic beam, it appears to become shorter (foreshortening). If two objects in the same plane are rotated an equivalent amount and undergo foreshortening in an equivalent and linear fashion, the corrective proportion would be expected to improve the accuracy of length measurements performed on the foreshortened objects. In this study, the femoral stem and greater trochanter were both somewhat irregular and did not have a focal endpoint, with the exception of the rounded distal tip of the femoral stem. The most dorsal aspect of the greater trochanter is also located lateral to the dorsolateral aspect of the femoral stem (out of plane). That the greater trochanter did not foreshorten in a consistent fashion with angulation is evident because the apparent distance between the dorsolateral femoral stem and the most proximal aspect of the trochanter appeared to increase after abduction angulation, while the radiographically measured length of the femoral stem decreased as expected. The lateral location of the greater trochanter relative to the femoral stem means that the most dorsal aspect of the greater trochanter will first appear to move proximally with abduction of the femur. With continued abduction, the trochanter would start to foreshorten as expected (Figure 9). Conversely,

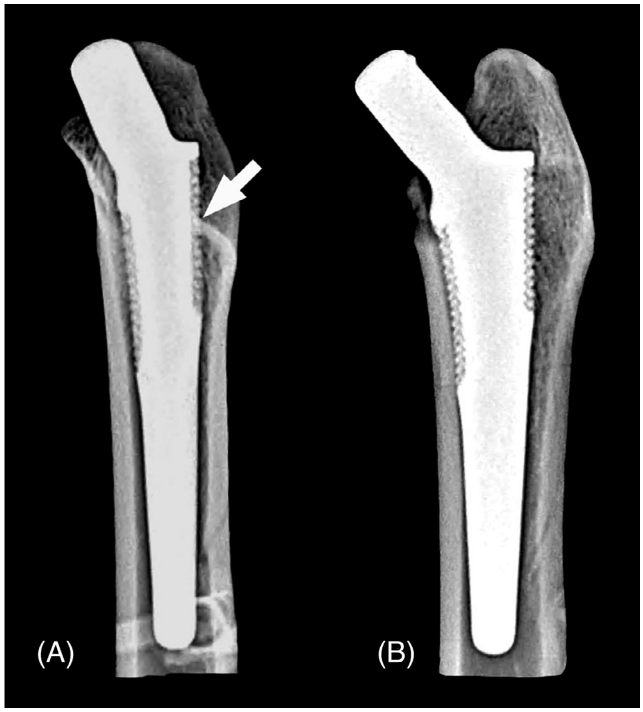

FIGURE 8 Intertrochanteric fossa identification associated with changes in femoral position. A, The distal aspect of the intertrochanteric fossa is identified as a radiopaque line intersecting the caudal aspect of the femoral stem at the white arrow when the femur is positioned at 0° frontal angulation and 0° axial rotation. B. The distal aspect of the intertrochanteric fossa is not identifiable when the same femur is positioned at 0° frontal plane angulation and 30° axial rotation

with adduction, the lateral location of the greater trochanter means that the trochanter will appear to shorten at a rate greater than expected (nonlinear foreshortening relative to the femoral stem). The out of plane (lateral) location of the greater trochanter likely explains the inability of the corrective proportion to improve the accuracy of the radiographic femoral stem level and fossa distance measurements.

In this study, measurement results were evaluated with a clinical reliability assessment in addition to statistical testing. The definition of clinical reliability was based on the authors' clinical impression that femoral stem measurement distance changes of ±0.5 mm are very difficult to accurately assess radiographically in clinical patients. In addition, an error in stem level measurement accuracy of ±0.5 mm or less would not significantly affect the outcome of a clinical patient. While a statistical test may detect a very small difference in absolute magnitude between different groups if minimal variability exists in the measurements obtained within each group, the clinical implications of this statistically significant difference may be minimal. The authors' impression is that the clinical reliability assessment may be a more useful method

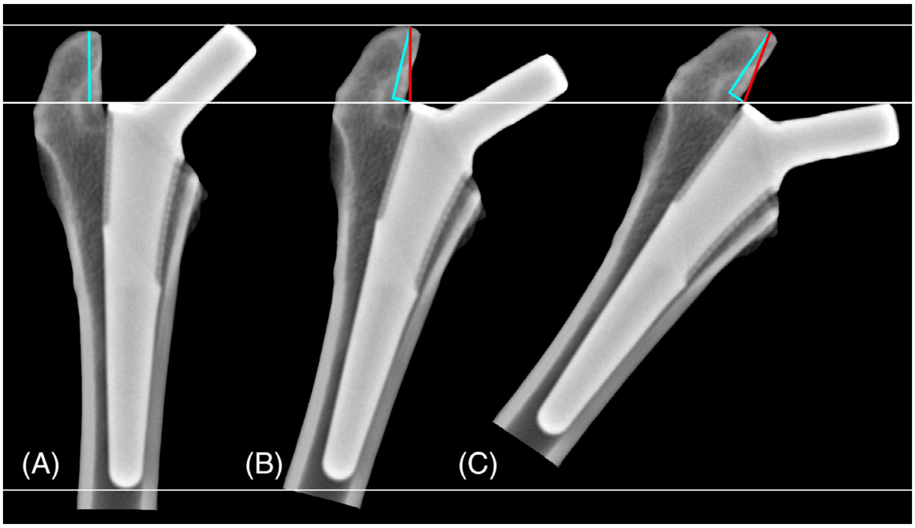

FIGURE 9 A, Relative femoral stem and trochanter position with 0° frontal plane angulation. The blue line represents the actual distance from the dorsal aspect of the greater trochanter to the dorsolateral femoral stem. B, With abduction (positive frontal plane) angulation, the dorsal aspect of the greater trochanter initially appears to move farther away from the dorsolateral aspect of the femoral stem up to a maximal amount equal to the length of the hypotenuse of the triangle formed between the most dorsal aspect of the greater trochanter, the most lateral aspect of the dorsolateral femoral stem and a point lateral to the dorsolateral aspect of the femoral stem, which is directly aligned with the dorsal aspect of the greater trochanter in the sagittal plane. C, With continued abduction angulation past the maximal point indicated by the hypotenuse of the triangle, the most dorsal aspect of the greater trochanter would appear to move closer to the dorsolateral femoral stem (foreshortening on a mediolateral projection radiograph)

of determining the limits of femoral positioning at which accurate femoral stem level measurements and fossa measurements can be obtained on mediolateral projection radiographs in the clinical setting. Clinical reliability results were overall similar to statistical significance results for all radiographic stem level measurements. For fossa measurements, the clinical reliability results provided evidence that radiographic and corrected fossa measurements were overall not consistently reliable.

This study had several limitations. Only one stem size and type was evaluated in this study, and results cannot necessarily be extrapolated to other sizes of stems or stems made by other manufacturers. The authors attempted to place the magnification marker at the exact level of the greater trochanter in all radiographic projections by attaching the marker to a flexible stand that allowed movement in different planes. This system relied on a subjective assessment that the marker was at the exact level of the greater trochanter in every projection, which was likely not the case. Small amounts of variability in magnification marker positioning may have introduced variability into the radiographic measurements of stem level. This study was a cadaveric bench top study in which femoral stem level was very carefully measured and controlled. Our measurement results may not prove to be as accurate in the clinical setting in which femoral position cannot be as finely controlled or assessed. In clinical animals, the position of the prosthetic femoral neck, prosthetic femoral head, or acetabular cup may obscure the most proximal aspect of the greater trochanter on the mediolateral projection femur radiograph, making it impossible to assess subsidence in the clinical animal by using the technique described in this study. The authors reviewed serial radiographs (postoperative and follow-up) from the 50 most recently performed total-hip arthroplasties at a single specialty hospital. The technique of subsidence measurement on the mediolateral projection femur radiograph was able to be performed in 27 of 50 cases. In the remaining 23 cases, the prosthetic femoral neck/head or the acetabular cup obscured the most proximal aspect of the greater trochanter on the postoperative or follow-up radiographs. It has been the authors' clinical experience that positioning the hip in slight flexion rather than at a standing extension angle during acquisition of the mediolateral projection femur radiograph substantially increases the likelihood of clear identification of the most proximal aspect of the greater trochanter.

In conclusion, our hypothesis was partially accepted because the results of this study provide evidence that femoral stem level can be accurately measured on mediolateral projection radiographs at 0° frontal plane angulation for all evaluated subsidence levels and that increasing magnitude of frontal plane angulation (10° or − 10°) results in inaccurate and clinically unreliable stem level measurements. However, we found that axial rotation (15°, 30°, −30°) did not affect the accuracy or clinical reliability of femoral stem level measurement, nor did the use of a corrective proportion increase the accuracy or clinical reliability of the stem level measurement. The use of the intertrochanteric fossa as a landmark for assessing femoral stem level was associated with a high degree of measurement variability between femurs and in the same femur with changes in axial rotation or frontal plane angulation. Measurement of femoral stem level on mediolateral projection radiographs should be considered as an alternative to avoid the limitations of femoral foreshortening that can be associated with assessment of stem level on craniocaudal projection femoral radiographs.

CONFLICT OF INTEREST

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

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Burneko M, Hudson CC, Beale BS. Evaluation of cementless femoral stem level on mediolateral projection radiographs. *Veterinary Surgery*. 2020;49:1203–1212. https://doi.org/10.1111/vsu.13427