Accuracy of noninvasive, single-plane fluoroscopic analysis for measurement of three-dimensional femorotibial joint poses in dogs

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Objective—To compare accuracy of a noninvasive single-plane fluoroscopic technique with radiostereometric analysis (RSA) for determining 3-D femorotibial poses in a canine cadaver with normal stifle joints.

Sample—Right pelvic limb from a 25-kg adult mixed-breed dog.

Procedures—A CT scan of the limb was obtained before and after metal beads were implanted into the right femur and tibia. Orthogonal fluoroscopic images of the right stifle joint were acquired to simulate a biplanar fluoroscopic acquisition setup. Images were obtained at 5 flexion angles from 110° to 150° to simulate a gait cycle; 5 cycles were completed. Joint poses were calculated from the biplanar images by use of RSA with CT-derived beaded bone models and compared with measurements obtained by use of CT-derived nonbeaded bone models matched to single-plane, lateral-view fluoroscopic images. Single-plane measurements were performed by 2 observers and repeated 3 times by the primary observer.

Results—Mean absolute differences between the single-plane fluoroscopic analysis and RSA measurements were 0.60, 1.28, and 0.64 mm for craniocaudal, proximodistal, and mediolateral translations, respectively, and 0.63°, 1.49°, and 1.58° for flexion-extension, abduction-adduction, and internal-external rotations, respectively. Intra- and interobserver repeatability was strong with maximum mean translational and rotational SDs of 0.52 mm and 1.36°, respectively.

Conclusions and Clinical Relevance—Results suggested that single-plane fluoroscopic analysis performed by use of CT-derived bone models is a valid, noninvasive technique for accurately measuring 3-D femorotibial poses in dogs. (Am J Vet Res 2014;75:477–485)
in dogs. Although these techniques provide highly accurate and reproducible results, the invasiveness and inherent risks associated with surgically implanting the markers limit their application in a clinical setting.

Single-plane fluoroscopy has been used to accurately measure 3-D kinematics of the human knee in a noninvasive manner. This technique involves the creation of 3-D femoral and tibial bone models from CT scans of the subject; these models are superimposed over lateral view knee fluoroscopic images acquired during various activities; the 3-D bone models are manipulated until the silhouette of the model and the corresponding 2-D fluoroscopic image precisely overlap. This technique offers the main advantage of being noninvasive. Single-plane fluoroscopic analysis error in humans has been reported to be < 1.2 mm for sagittal plane translations and 1.3° for all rotations. Kinematic analysis with biplanar fluoroscopy with the shape-matching technique has been described in humans and is reported to have superior accuracy over single-plane fluoroscopic analysis. Despite increased accuracy attained with biplanar analyses, the high costs, lack of availability, and limited field of view provided by 2 fluoroscopes operating concurrently limit its applicability in the veterinary clinical setting.

The accuracy of measuring femorotibial joint motion by use of single-plane fluoroscopy in dogs cannot be extrapolated from human studies because of differences in osseous morphology, size, and cadence. Reporting the feasibility and accuracy of single-plane fluoroscopy for the stifle joint of dogs is required to conduct valid in vivo dynamic studies that use this methodology. The purpose of the study reported here was to determine the accuracy of a digital bone-model-based, single-plane fluoroscopic technique for measuring 3-D kinematics of normal canine stifle joints, with a biplanar marker–based digitally modified RSA technique used as a reference for measuring femorotibial poses during simulated pelvic limb ambulation in a cadaver specimen. We hypothesized that single-plane fluoroscopic analysis of canine stifle joints would offer a high degree of accuracy for rotations and translations in the sagittal plane (flexion-extension, craniocaudal translation, and proximodistal translation), with poorer accuracy for rotations and translations out of the sagittal plane (mediolateral translation, abduction-adduction, and internal-external rotation). We further hypothesized that this technique would have a high level of inter- and intraobserver repeatability.

Materials and Methods

Specimen preparation—The pelvis and intact normal pelvic limbs were collected by disarticulation of the vertebral column at the lumbosacral joint from a 25-kg skeletally mature dog that was euthanized for reasons unrelated to the study. A CT scan of both pelvic limbs from the hips to the tarsocrural joint was obtained. Metal marker beads 2 mm in diameter were then implanted into the cortices of the distal portion of the femur and proximal tibia of both limbs. The metal beads served as radiopaque markers for determining the precise position and orientation of the femur and tibia relative to each other by use of a digital modification to the originally described RSA. A minimum of 4 beads/bone was used to satisfy the requirement of at least 3 markers; beads were positioned in each bone such that the beads would not overlap on mediolateral- and craniocaudal-view fluoroscopic images. No problems with identifying the beads were encountered in any of the fluoroscopic views. A tibial-plateau-leveling osteotomy was performed in the left limb for analyzing hybrid implant-bone model-based shape-matching techniques; the results of that study are presented in a companion article. Following marker bead implantation, a second CT scan was obtained in similar fashion.

Fluoroscopic image acquisition—The specimen was mounted in a custom-designed jig that allowed unconstrained passive movement of the hip, stifle, and hock joints (Figure 1); the specimen was positioned centrally within the field of view of the fluoroscope with a source-to-detector distance of 1,100 mm. Optical geometric features of a ceiling-mounted fluoroscopic system were determined by use of a calibration object with known spatial positions of metal beads. This
object measured 160 × 160 × 160 mm and contained 35 radiopaque metal beads; a CT scan of the calibration object allowed accurate determination of these metal bead locations. A simple validation was conducted to assess for potential calibration errors introduced with C-arm rotation between orthogonal image acquisitions. Fluoroscopic images of the calibration device in the craniocaudal orientation and then in the mediolateral orientation were obtained. These sequential images were completed 6 times with all craniocaudal and mediolateral images and were assessed for variation in marker-bead positioning in the images, with none detected. The x-ray source was configured to supply a 76-kV beam with a 20-mA beam current by use of a 1-shot fluoroscopy acquisition program. The flat panel detector had a field of view of 41 × 30 cm; image resolution was 1,024 × 1,024 pixels. By use of a goniometer, the right stifle joint was sequentially positioned at 5 flexion angles, ranging from 150° to 110°, to simulate a normal gait cycle range of motion. With the left limb manually moved out of the field of view, sequential mediolateral and craniocaudal view fluoroscopic images of the right stifle joint were obtained for each pose, while it was ensured that the specimen did not move between orthogonal image acquisitions. Images were acquired through 5 gait cycles.

3-D model creation and coordinate assignment—Three-dimensional bone models were created from CT-scan Digital Imaging and Communication in Medicine (DICOM) images by use of an open source 3-D segmentation software program. This semiautomatic application uses bone contour edges to create surface models of the bones. For the single-plane fluoroscopic analysis, bone models of the femur and tibia were created from the first CT scan, which was free from any metal artifact (Figure 2). For RSA, marker-based models were created from the second CT scan. Femoral and tibial 3-D models used for RSA did not include the bone around the implanted metallic beads and only contained the implanted beads in these regions. The 3-D bone models were imported into a reverse engineering software program. Radiostereometric analysis marker models were aligned with the corresponding beadless bone models, and coordinate systems were assigned simultaneously to both models. This eliminated variability in the comparative measurements that may have occurred from the use of different coordinate systems for each corresponding 3-D model. Coordinate systems were assigned to the femurs and tibiae on the basis of local anatomic landmarks as described. By use of a best-fit function in the software program, spheres were contoured around both femoral condyles and the femoral head, with the center point of each structure interactively identified. Femoral coordinates were applied so that the mediolateral axis (z-axis) passed through the center of the lateral and medial femoral condyles with the femoral origin located at the midpoint between the centers of the condyles on the mediolateral axis. The proximodistal axis (y-axis) passed proximally, perpendicular to the mediolateral axis, in a plane common to the center of both femoral condyles and the femoral head (Figure 3). Tibial coordinates were applied so that the mediolateral axis passed from the outermost edge of the medial and lateral tibial condyles; the tibial point of origin was set midway between these 2 points on the mediolateral axis. The proximodistal axis passed from distal to proximal, perpendicular to this mediolateral axis in a plane common to this axis and the midpoint of the distal tibia. The craniocaudal axes (x-axes) for the femur and tibia were created from the cross-product of the mediolateral and proximodistal axes, creating a Cartesian coordinate system.

3-D to 2-D shape matching—Two-dimensional fluoroscopic images and 3-D bone models were import-
ed into a custom-written open-source shape-matching software program. For RSA, 3-D models of implanted beads were superimposed over the mediolateral and craniocaudal fluoroscopic images simultaneously and manually manipulated to overlie the beads in the orthogonal fluoroscopic images (Figure 4). This process was repeated 3 times for all images to assess repeatability of the modified RSA technique. For the single-plane fluoroscopic analysis, 3-D bone models of the femur and tibia were superimposed over the lateral fluoroscopic images only and manually manipulated to precisely match the silhouette of their respective bones (Figure 5). Frames were analyzed in a random fashion so that the shape matching from one frame could not bias the next corresponding frame in that gait cycle. All frames were analyzed 3 times by the primary observer (SCJ) to assess for intraobserver repeatability. A second observer (GT) completed the process once for all 5 cycles, to assess for interobserver variability. Interobserver variability was assessed by comparison of the first 5 cycle values measured the first time by the primary observer to the 5 cycle values measured by the second observer. Both observers underwent training in the shape-matching procedure before study commencement; this involved tutoring from an engineer experienced with the fluoroscopic analysis technique (SAB). Three-dimensional position and orientation of each bone model were determined from the shape-matching software; these data were then imported into a custom-written transformation matrix decomposition program, which transformed the data into clinically relevant femorotibial poses in 6 DOF.

Statistical analysis—A statistical software package was used for all analyses. Rotations (flexion-extension, abduction-adduction, and internal-external) and translations (craniocaudal, mediolateral, and proximodistal) calculated by use of RSA and single-plane fluoroscopic analysis were compared. The accuracy of each DOF was defined by the mean absolute difference and RMS errors between RSA and single-plane fluoroscopic analysis. Intraobserver repeatability was assessed by comparison of the 3 trials completed by the primary observer. Standard deviations were determined for each DOF from each fluoroscopic frame from the 3 times they were analyzed. A single repeatability measure was determined by calculation of the mean SD for each DOF (75 frames). Intraobserver variation was further assessed by use of a 1-way repeated-measures ANOVA for the absolute difference between the single-plane fluoroscopic analysis and RSA for all 5 cycles that were completed 3 times by the primary observer. Interobserver repeatability was similarly assessed by determination of the SD for each DOF in each fluoroscopic frame measured by both observers, with overall repeatability described as the mean SD for each DOF. Interobserver agreement was also assessed by means of a paired t test on the abso-

Figure 5—Representative digital images of a canine femur and tibia obtained by use of shape-matching software used for single-plane fluoroscopic analysis by use of CT-derived femoral and tibial models matched to bone silhouettes. A—Mediolateral fluoroscopic image. B—Femoral and tibial bone models manipulated into a different perspective, compared with image A, by use of a free-view function. Manipulation of the viewing angle with the free-view function does not affect the position of the bone models in the fluoroscopic image.

Figure 6—Bland-Altman plots of the agreement between measurements made in 3 trials by use of a modified RSA and the mean of these 3 measurements for determining craniocaudal (A), proximodistal (B), and mediolateral (C) translations of a canine femorotibial joint. The solid line represents the mean difference between the measurements; the dashed lines represent limits of agreement, between which 95% of differences between the measurements are expected.
lute differences between the single-plane fluoroscopic analysis and RSA for each DOF. The agreement between the single-plane fluoroscopic analysis and RSA for both intra- and interobserver analysis was further described by the limits-of-agreement approach, as described by Bland and Altman. Agreement between the measurements, repeated 3 times on all biplanar images by use of the modified RSA, was evaluated with Bland-Altman plots. For all statistical analyses, values of $P < 0.05$ were considered significant.

**Results**

Agreement between the repeated biplanar images by use of the modified RSA was high, as indicated by narrow 95% limits of agreement in all 6 DOF on Bland-Altman plots (Figures 6 and 7). The absolute values of the differences of the means for single-plane fluoroscopic analysis and RSA were determined (Table 1). Mean absolute differences between the techniques were small, at $\leq 1.28$ mm for all translations and $\leq 1.58^\circ$ for all rotations. The RMS errors between the single-plane fluoroscopic analysis and RSA were $\leq 1.42$ mm for all translations and $\leq 2.01^\circ$ for all rotations. For intraobserver variability, mean SDs were $\leq 0.52$ mm for all translations and $\leq 1.36^\circ$ for all rotations (Table 2). Significant differences were found in the absolute mean difference for proximodistal ($P = 0.001$), mediolateral ($P = 0.001$), abduction-adduction ($P = 0.03$), and internal-external ($P = 0.04$) measurements over the 3 times all kinematics were measured (Table 3). For interobserver repeatability, mean SDs were $\leq 0.52$ mm for all translations and $\leq 0.91^\circ$ for all rotations. The absolute differences between the single-plane fluoroscopic analysis and RSA techniques were significantly different between the 2 observers for abduction-adduction ($P = 0.02$) and internal-external rotation ($P = 0.03$; Table 4). Bland-Altman plots revealed narrow 95% limits of agreement for all 6 DOF within (Figures 8 and 9) and between (Figures 10 and 11) observers.

**Discussion**

Results suggested that single-plane fluoroscopic analysis is a highly accurate method for measuring stifle joint kinematics in dogs in all 6 DOF. The largest absolute mean difference between RSA and single-plane fluoroscopic analysis is 1.19 mm for proximodistal rotation.

### Table 1—Comparison of the mean ± SD absolute differences, 95% confidence interval (CIs), and RMS errors obtained by use of single-plane fluoroscopic analysis versus a modified RSA technique evaluating 6 DOF for all fluoroscopic images, each assessed 3 times, in the right pelvic limb of a canine cadaver.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Craniocaudal (mm)</th>
<th>Proximodistal (mm)</th>
<th>Mediolateral (mm)</th>
<th>Flexion-extension (°)</th>
<th>Abduction-adduction (°)</th>
<th>Internal-external (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraobserver variability</td>
<td>0.25</td>
<td>0.32</td>
<td>0.52</td>
<td>0.52</td>
<td>1.19</td>
<td>1.36</td>
</tr>
<tr>
<td>Interobserver variability</td>
<td>0.27</td>
<td>0.46</td>
<td>0.52</td>
<td>0.78</td>
<td>0.91</td>
<td>0.82</td>
</tr>
</tbody>
</table>

*Intraobserver data represent analysis completed 3 times on all fluoroscopic images by the primary observer. Interobserver data represent analysis completed on all fluoroscopic images by both observers.*

![Figure 7-Bland-Altman plots of the agreement between measurements made in 3 trials by use of a modified RSA and the mean of these 3 measurements for determining flexion-extension (A), abduction-adduction (B), and internal-external (C) rotations of a canine femorotibial joint. The solid line represents the mean difference between the measurements; the dashed lines represent limits of agreement, between which 95% of differences between the measurements are expected.](image-url)
plane fluoroscopy was not > 1.28 mm for translations and 1.38° for rotations. The results were in accordance with similar studies of the human knee, in which single-plane fluoroscopic analysis resulted in mean errors of 1.2 mm for sagittal plane translations and 1.3° for all rotations. Intuitively, motion of objects parallel to the flat panel detector will be seen as changes in position of that object in the image, whereas motion perpendicular to the detector will be seen primarily as changes in silhouette shape or size, which are more subtle and difficult to identify. For instance, with lateral images, changes in mediolateral translation are seen as changes in bone silhouette size, whereas changes in abduction-adduction and internal-external rotations are seen as changes in bone silhouette shape. Consistent with the hypothesis of greatest accuracy being found in the sagittal plane, the largest errors for rotations were found with abduction-adduction and internal-external rotations.

The proximodistal translation results did not support the hypothesis that accuracy would be greatest in the sagittal plane. A systematic bias in the proximodistal translations measured by use of bone models was found, compared with the biplanar bead-based measurements. The source of this bias, which makes the bones appear slightly farther from the x-ray source, is the graphic method used to superimpose the bones on the fluoroscopic image. The bones are projected as solid objects, not as radiolucent objects, and thus they always will appear slightly larger than a true radiographic view in which the edges are slightly attenuated to make the object appear slightly smaller. Correction for this size discrepancy during the shape-matching process results in femoral and tibial origins being distracted by approximately 1 mm, giving the bias. This bias was consistently present and was clearly evident in the Bland-Altman plots, where differences between the fluoroscopic analysis technique and RSA were not centered about 0, unlike the 5 other DOF (Figures 8 and 10).

The mediolateral alignment of the normal stifle joint is highly constrained in dogs. The shape-matching software has a free-view function that allows the operator to view and manipulate the femoral and tibial bone models together in 3-D from any perspective (Figure 5). Seeing the bone models together, par-

Table 3—Mean absolute differences between results of single-plane fluoroscopic analysis and a modified RSA for DOF measurements of a canine femorotibial joint over 3 trials.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Craniocaudal (mm)</th>
<th>Proximodistal (mm)</th>
<th>Mediolateral (mm)</th>
<th>Flexion-extension (°)</th>
<th>Abduction-adduction (°)</th>
<th>Internal-external (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.74*</td>
<td>1.01*</td>
<td>0.95*</td>
<td>0.81*</td>
<td>1.94*</td>
<td>1.93*</td>
</tr>
<tr>
<td>2</td>
<td>0.50*</td>
<td>1.25*</td>
<td>0.59*</td>
<td>0.52*</td>
<td>1.55*</td>
<td>1.65*</td>
</tr>
<tr>
<td>3</td>
<td>0.55*</td>
<td>1.58*</td>
<td>0.38*</td>
<td>0.55*</td>
<td>0.58*</td>
<td>1.15*</td>
</tr>
</tbody>
</table>

*Within a column, values with different superscript letters are significantly (P < 0.05) different. Each analysis was repeated 3 times.

Table 4—Mean absolute differences between results of single-plane fluoroscopic analysis and RSA for DOF measurements of a canine femorotibial joint obtained by 2 observers.

<table>
<thead>
<tr>
<th>Observer</th>
<th>Craniocaudal (mm)</th>
<th>Proximodistal (mm)</th>
<th>Mediolateral (mm)</th>
<th>Flexion-extension (°)</th>
<th>Abduction-adduction (°)</th>
<th>Internal-external (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.74*</td>
<td>1.01*</td>
<td>0.95*</td>
<td>0.81*</td>
<td>1.94*</td>
<td>1.93*</td>
</tr>
<tr>
<td>2</td>
<td>0.46*</td>
<td>1.06*</td>
<td>0.75*</td>
<td>1.03*</td>
<td>1.04*</td>
<td>1.18*</td>
</tr>
</tbody>
</table>

See Table 3 for key.

Figure 8—Bland-Altman plots of the agreement between single-plane fluoroscopic analysis and a modified RSA for determining craniocaudal (A), proximodistal (B), and mediolateral (C) translations of a canine femorotibial joint by a single observer. The solid line represents the mean difference between the 2 techniques. The dashed lines represent limits of agreement, between which 95% of differences between the 2 techniques are expected. Notice how differences between the techniques are not centered around 0 for proximodistal translations because of systematic bias in this DOF.
particularly from a digital craniocaudal view, allows the operator to estimate the relative positions of the femur and the tibia for mediolateral alignment. Thus, the high degree of accuracy in the mediolateral translations was a reflection of the observer's best guess in this DOF. It was suspected that a mediolateral translation of < 1 mm would result in subtle changes in bone silhouette size that are not easily detectable on mediolateral views. Hence, caution is advised in the interpretation of the apparently high accuracy for quantifying mediolateral alignment with single-plane fluoroscopy.

To assess intraobserver repeatability, the primary observer performed shape-matching analysis on all 5 cycles 3 times. Significant differences in the mean absolute error were found for 4 variables (proximodistal, mediolateral, abduction-adduction, and internal-external), but the magnitude of difference that was detected was < 0.70 mm for translations and 0.96° for rotations and was not considered a clinically relevant source of error. Three of the 4 variables with significant differences in the magnitude of error were out-of-sagittal-plane rotations (abduction-adduction and internal-external) and translations (mediolateral), consistent with previous findings that measurements made out of the sagittal plane are less repeatable than those made in plane.16 Interobserver repeatability for single-plane fluoroscopic analysis was high, with no significant differences observed in the magnitude of error between observers for 4 of the 6 DOF. Significant differences between observers were found for abduction-adduction and internal-external rotations. These variables may have been associated with poorer repeatability because these rotations do not occur in the sagittal plane.16 Despite the detection of significant differences in the mean absolute er-

Figure 9—Bland-Altman plots of the agreement between single-plane fluoroscopic analysis and a modified RSA for determining flexion-extension (A), abduction-adduction (B), and internal-external (C) rotations of a canine femorotibial joint by a single observer. The solid line represents the mean difference between the 2 techniques. The dashed lines represent limits of agreement, between which 95% of differences between the 2 techniques are expected.

Figure 10—Bland-Altman plots of the agreement between single-plane fluoroscopic analysis and a modified RSA for determining craniocaudal (A), proximodistal (B), and mediolateral (C) translations of a canine femorotibial joint for 2 observers. The solid line represents the mean difference between the techniques for the 2 observers. The dashed lines represent limits of agreement, between which 95% of differences between the 2 techniques are expected. Notice how differences between the techniques are not centered around 0 for proximodistal translations because of systematic bias in this direction.
rors, the actual magnitude of the discrepancies between the 2 observers was extremely small (0.90° and 0.75° for abduction-adduction and internal-external, respectively) and would not be considered to be a clinically relevant source of error in future clinical studies.

The main limitation of this study was that images were acquired under static conditions, which may not directly replicate the image quality acquired in a dynamic setting with live dogs. The static setup in this study did not reproduce potential motion artifact that occurs with dynamic image acquisition, which can affect the accuracy of this fluoroscopic analysis technique. Fluoroscopic systems used in dynamic musculoskeletal studies must be able to generate a sufficiently fast frame rate and a short enough exposure time to avoid motion artifact while capturing enough data to analyze the gait in its entirety. The system is capable of generating 30 exposures/s with an exposure time of 1 millisecond; pilot dynamic trials with live dogs performed in the authors’ laboratory suggested that image quality obtained in dogs while walking and trotting was excellent and comparable to the images acquired in this validation study. In the present study, the order in which the fluoroscopic images were shape matched to the bone models was random so that the preceding image did not influence the shape matching of the following fluoroscopic image. A previous study found that dynamic trials had mean accuracy the same as or better than that of static trials, likely because the operator’s knowledge of bone position in the previous frame aided the shape-matching process. Thus, dynamic data collected in live subjects by use of single-plane fluoroscopy may indeed have accuracy similar to or better than the accuracy reported here. Limb overlap was avoided by manual removal of the contralateral limb from the radiographic field of view. Limb overlap on the fluoroscopic images would be unavoidable in a dynamic setting and could negatively affect the shape-matching process. Finally, the results may not be applicable to all dogs, given the anatomic variations among dogs. The cadaveric specimen used in this study was a 25-kg nonchondrodystrophic mixed-breed dog. Potential variations in the accuracy of this technique may be introduced with dogs of different sizes, with anatomic anomalies, or with radiographically evident disease such as osteoarthritis.

There was a distinct learning curve associated with the shape-matching process. Both observers underwent appropriate training before commencing the study. No statistical improvement in accuracy was detected among the 3 trials completed by the primary observer; however, both observers found that shape matching became easier and less time-consuming as more experience was gained. The accuracy of results for future studies will be dependent on the training of those performing the analysis and their attention to detail with the shape matching of the models to the corresponding bones on the fluoroscopic images.

Results of the present study indicated that 3-D femorotibial poses of dogs can be measured with a high level of accuracy by use of noninvasive single-plane fluoroscopic analysis. High interobserver and intraobserver repeatability was evident. This method of quantifying femorotibial kinematics could be a useful tool to investigate kinematics in normal and abnormal stifles joints during a variety of dynamic motions encountered during daily activities in clinical subjects. In addition, single-plane fluoroscopic analysis could be used to assess the efficacy of surgical procedures performed to improve kinematics of diseased stifle joints.

Figure 11—Bland-Altman plots of the agreement between single-plane fluoroscopic analysis and a modified RSA for determining flexion-extension (A), abduction-adduction (B), and internal-external (C) rotations of a canine femorotibial joint for each observer. The solid line represents the mean difference between the techniques for the 2 observers. The dashed lines represent limits of agreement, between which 95% of differences between the 2 techniques are expected.

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b. Toshiba Infinix-i flat panel C-arm fluoroscope, Toshiba American Medical Systems Inc, Tustin, Calif.
d. Geomagic Studio, Geomagic Inc, Research Triangle Park, NC.
g. SigmaPlot, version 12, Systat Software Inc, San Jose, Calif.

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