



The Accuracy of Single Photon Emission Computed Tomography/Computed Tomography Arthrography in Evaluating Aseptic Loosening of Hip and Knee Prostheses



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ABSTRACT

Aseptic loosening represents the most common complication associated with hip and knee arthroplasty and is a common indication for surgical revision in the post-arthroplasty population. The optimal imaging methodology in evaluating clinical suspected loosening is not well-defined. Our study retrospectively evaluated nuclear medicine arthrography with hybrid single photon emission computed tomography/computed tomography (SPECT/CT) in 38 patients (21 hip, 17 knee) compared with reference standards of surgical evaluation, spontaneous resolution of symptoms without revision, or a minimum of 1 year clinical and radiographic follow-up. Our study demonstrated a sensitivity of 100%, specificity of 96.0%, PPV of 92.9%, NPV of 100%, and accuracy of 97.4% with this imaging technique suggesting utility of nuclear medicine arthrography with SPECT/CT in the clinical evaluation of suspected aseptic loosening.

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Hip arthroplasty and knee arthroplasty procedures are commonly performed surgeries which continue to increase in occurrence. Recent estimates suggest that in the USA in 2009, there were approximately 620,000 knee arthroplasties and 285,000 hip arthroplasties performed [1]. It is projected that by the year 2030, up to 3.48 million knee arthroplasties and 572,000 hip arthroplasties may be performed annually with 6%–12% of these surgeries reflecting revision arthroplasties [2–5]. Aseptic loosening is the most common indication for revision accounting for approximately 40% of revision knee and hip surgeries [2,4].

Up to 44% of patients with a total hip arthroplasty and 27% of patients with a total knee arthroplasty will experience persistent post-surgical pain which can be severe in up to 15% of patients [5]. It is imperative to determine if loosening is present for these patients as revision surgery is indicated in this scenario. Despite the clinical importance of this diagnosis, the available literature evaluating the accuracy of imaging tests in diagnosing aseptic loosening is relatively sparse.

Imaging modalities which have been evaluated include radiography, subtraction arthrography, planar bone scintigraphy, and planar radionuclide arthrography with varying levels of reported success. For hip arthroplasty components, the sensitivities for these modalities have been reported in the range of 47%–89% and specificities 50%–80% [6,7]. Literature regarding the evaluation of aseptic loosening of the knee is even more sparse although a 2006 study of knees as well as a very recent study including both hips and knees suggest a sensitivity of 88%–93% and a specificity of 83%–88% for planar radionuclide arthrography in this scenario [8,9]. Overall, a clear algorithm of when and how to image patients with clinically suspected aseptic loosening has not yet been established [10,11].

Single photon emission tomography combined with computed tomography (SPECT/CT) is a recent advancement that has the potential to improve the accuracy of radionuclide arthrography in assessing arthroplasty loosening. The three-dimensional volume acquisition and precise localization should improve the assessment of activity along the bone–prosthetic interface compared with planar techniques. Despite this potential improvement, to our knowledge only a single retrospective series has been published assessing SPECT/CT for this clinical indication [12]. Chew et al [12] assessed 29 hip arthroplasties and 44 knee arthroplasties compared with a gold standard of operative assessment and reported sensitivities/specificities of 73/71% for the acetabulum hip component, 78/90% for the femoral hip component, 75/63% for the femoral knee component, and 86/86% for the tibial knee component. These authors concluded that SPECT/CT had improved accuracy compared

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with planar techniques for all components except the femoral hip component where the accuracies were similar. It should be noted that only those who had surgery were evaluated. As such, there is a potential for referral bias and uncertainty regarding true negative and false negative image evaluation in this report.

The goal of our study was to determine the accuracy of radionuclide arthrography with SPECT/CT in the evaluation of clinically suspected aseptic loosening of hip and knee arthroplasties. In order to optimally assess both the negative and positive imaging studies, the reference standard included both operative findings and a minimum of 1 year clinical and radiographic follow-up in patients who did not have surgery.

Methods

Patient Population

Our institutional imaging database was retrospectively evaluated to identify all patients who had a SPECT/CT arthrogram study to assess for clinically suspected prosthetic loosening (hip or knee) between December 2007 and January 2013. From this cohort, patients were included in the study if they had subsequent surgical evaluation of the prosthesis, spontaneous resolution of symptoms without revision, and/or a minimum of 1 year of clinical and radiographic follow-up. Given the retrospective nature of this study, the parameters for clinically suspected prosthetic loosening were not strictly defined prior to imaging. All patients were referred for imaging by an orthopedic surgeon involved in the patient's routine clinical care. Typically, these patients would have been experiencing unexplained regional post-arthroplasty pain without clear radiographic evidence of loosening.

Image Evaluation

For included patients, all imaging reports from the clinical SPECT/CT arthrogram studies were obtained and reviewed. These were reported by specialists licensed in nuclear medicine and diagnostic radiology with varying levels of experience (range 6–30 years). The images themselves were also evaluated in a non-blinded fashion to ensure the reports matched standard departmental reporting criteria for arthroplasty loosening—the presence of visible activity along the bone/prosthetic interface of the acetabular or femoral stem components (hips) or along the bone/prosthetic interface of the femoral or tibial components (knee). Reports and images from the fluoroscopic tracer injection as well as radiographs obtained during the follow-up period were also reviewed.

SPECT/CT Arthrogram Imaging Procedure

The typical procedure for the evaluation of aseptic loosening with SPECT/CT arthrography at our institution is as follows.

Initially, the patient undergoes fluoroscopic-guided injection of radiotracer into the prosthetic knee or hip joint. This is performed by a diagnostic radiologist with experience in this technique. Typically a 22-gauge needle is directed to the inferolateral margin of the femoral neck component of a hip arthroplasty or subpatellar joint space of a knee arthroplasty under imaging guidance. Once satisfactorily positioned, intracapsular localization is confirmed with the injection of a small amount (2 mL) of water soluble contrast (Omnipaque 300, GE Healthcare, Buckinghamshire, UK). Subsequently, 37 MBq of ^{99m}Tc sulfur colloid in 2 mL sterile saline is injected into the joint space.

The patient is then transferred to the nuclear medicine department. The patient is instructed to ambulate for 30 minutes and then is positioned in a gamma camera for imaging. Initially planar images of the entire arthroplasty region are obtained in anterior, posterior, and lateral projections (low energy high resolution collimator; 128×128 matrix; minimum 1,000,000 counts per image or 10 minute acquisition). SPECT/CT of the arthroplasty is then acquired using a 16-slice dual-head

gamma camera SPECT/CT system (Philips Precedence, Best, the Netherlands). The SPECT parameters for this are: low-energy, high resolution collimator; 128×128 matrix; 1.0 zoom; 20 seconds per frame; and 120 frames at 3° intervals. The CT parameters for this are: 60 mAs, 140 kV, 2 mm slice thickness at 1 mm increments, and 500 mm acquisition length.

All images are processed using the Astonish iterative reconstruction algorithm (Philips Healthcare, Best, the Netherlands) with 4 iterations, 16 subsets, and a uniform start. Decay correction and attenuation correction are both applied. No post-reconstruction filter is applied. The SPECT/CT images are reviewed using Oasis workstations (Segami Corporation, Columbia, MD). The SPECT/CT studies are considered positive for loosening if any activity is visible within the bone–prosthetic interface of any component (Figs. 1 and 2). The SPECT/CT studies are considered negative for loosening if activity is confirmed within the joint space and no activity is demonstrated within the bone–prosthetic interface of either component (Fig. 3). The SPECT/CT study is considered a failed examination if the images demonstrate no activity within the joint space (Fig. 4).

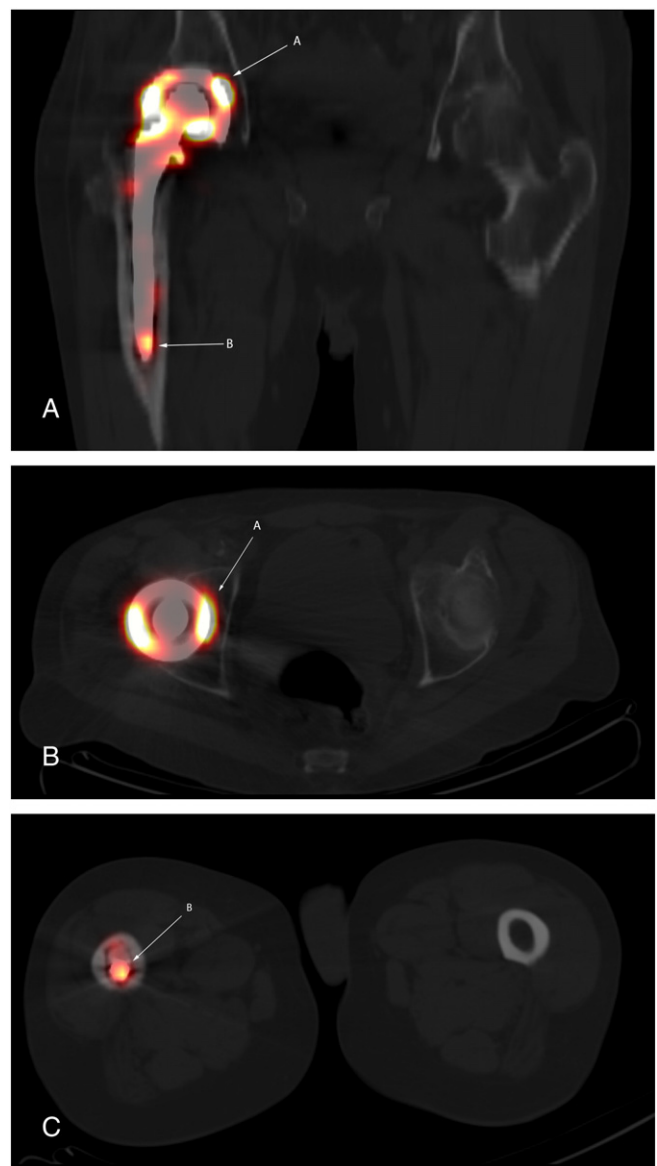


Fig. 1. Loosening of both the acetabular and femoral stem components of a hip arthroplasty. Coronal (A), transverse superior (B), and transverse inferior (C) fused SPECT/CT images demonstrate activity between the bone–prosthetic interface of both the acetabular (arrow A) and femoral stem (arrow B) components.

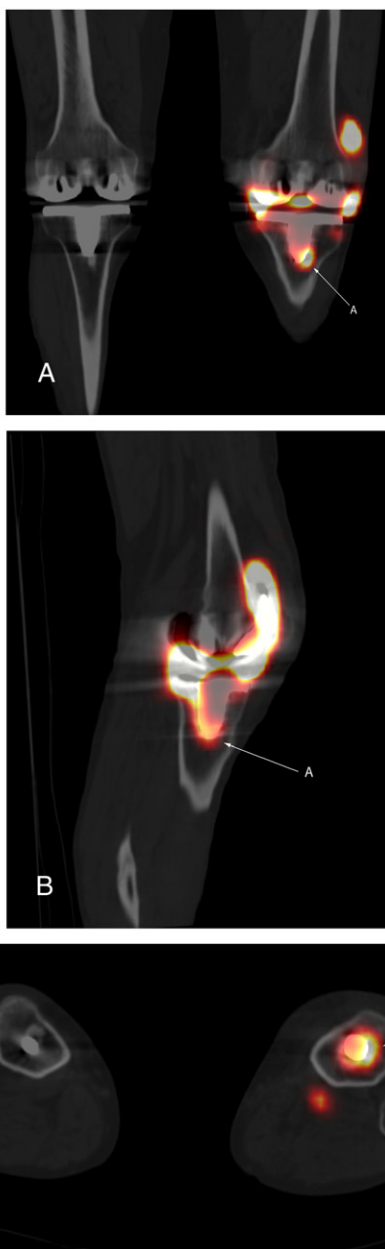


Fig. 2. Loosening of the tibial component of a left knee arthroplasty. Coronal (A), sagittal (B), and transverse (C) fused SPECT/CT images demonstrate activity within the bone–prosthetic interface of the tibial stem (arrow A). The patient also has a right knee arthroplasty which was not injected.

Reference Standard

The patients were considered to have loosened prosthesis if this was verified at the time of revision/evaluation surgery on the surgical report or if the patient had continued pain at 1 year follow-up which was thought to be typical for loosening and had follow-up imaging demonstrating progressive radiographic features of loosening [11]. The patients were considered to be negative for aseptic loosening if there was no evidence of loosening at the time of surgery (based on the surgical report), if the patient's pain resolved during 1 year clinical follow-up without revision, or if minimum 1 year clinical and/or radiographic follow-up demonstrated an alternate non-loosening explanation for the patient's symptoms (as determined by the patient's orthopedic surgeon). Note that the surgeon was aware of and not blinded to the SPECT/CT arthrogram results during the follow-up period.

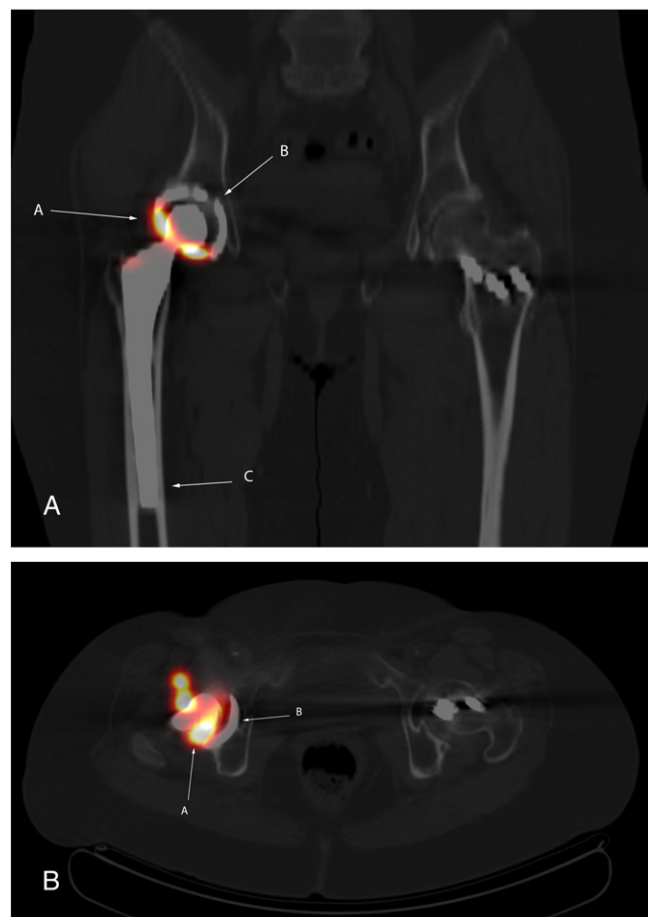


Fig. 3. No evidence of loosening. Coronal (A) and superior transverse (B) fused SPECT/CT images demonstrate activity within the intracapsular joint space (arrow A) without any demonstrable activity within the bone–prosthetic interface of the acetabular (arrow B) or femoral stem (arrow C) components. Incidental note is made of 3 cannulated hip screws on the left.

Results

Sixty-nine SPECT/CT arthrogram studies were performed during the evaluation period. Of these, 5 patients were excluded from analysis due to failed examinations (ie. SPECT/CT demonstrated injected activity outside of the joint capsule). Twenty-six patients were excluded as no reference standard was available (they did not have subsequent surgical evaluation or minimum 1 year clinical and radiographic follow-up data could not be obtained). The remaining 38 patients were included in the analysis. The mean time from initial surgery to SPECT/CT imaging was 3.8 years (SD 6.9; range 0.4–37.8 years) for this group. These included 21 hip prostheses and 17 knee prostheses. There were no documented adverse reactions to the SPECT/CT arthrogram procedure. There were no discrepancies noted between the reviewed images and the clinical reports.

Surgical Cohort

Twenty patients went on to have surgical evaluation/revision performed subsequent to the SPECT/CT study. This cohort included 10 true positive (TP), 9 true negative (TN), and 1 false positive (FP) study. Twelve of these were hip arthroplasties (9 TP, 3TN) and eight of these were knee arthroplasties (1 TP, 6 TN, and 1 FP). For this cohort, the mean time from SPECT/CT imaging to surgery was 1.1 years (SD 1.0; range 0.1–3.6 years). The single false positive study demonstrated activity along the bone–prosthetic interface of the tibial component. It should be

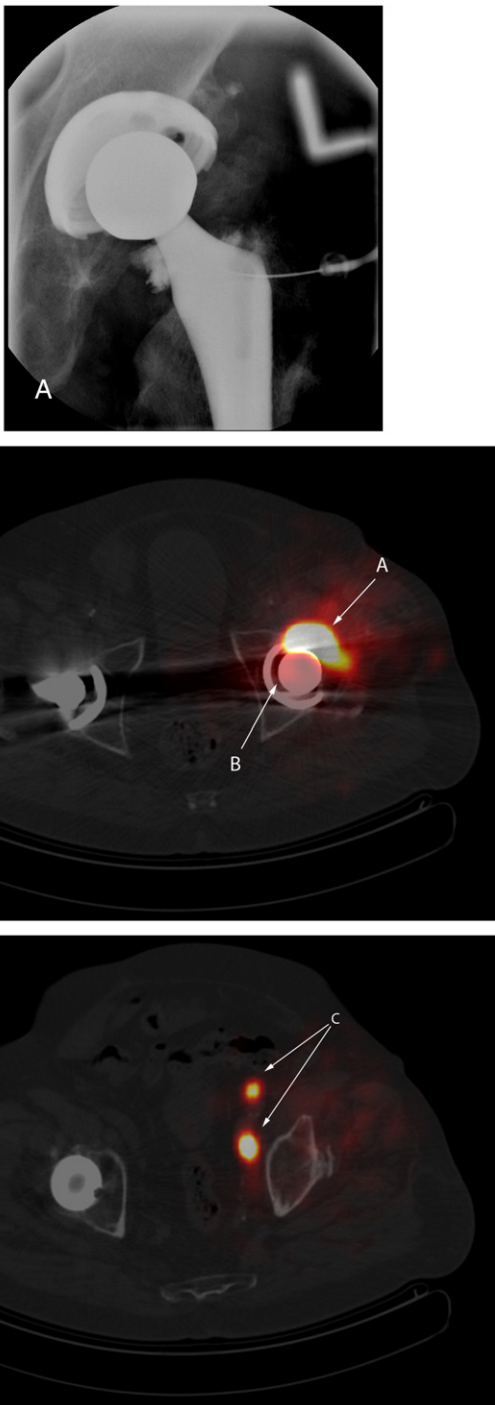


Fig. 4. Failed examination. The fluoroscopic injection image (A) demonstrates contrast injection into what was thought to be within the intracapsular joint space of a left hip arthroplasty. The SPECT/CT images (B and C) demonstrate the injected activity (arrow A) to actually lie outside of the intracapsular joint space (arrow B). The SPECT/CT images also demonstrate activity within left pelvic lymph nodes (arrow C) in keeping with an extracapsular soft tissue injection. This patient was re-booked for a repeat examination and the data were excluded from analysis in this study.

noted that there was a 29 month delay between the SPECT/CT study and the surgical investigation in this specific patient.

Clinical/Radiographic Follow-up Cohort

Eighteen patients had the reference standard defined by resolution of symptoms without revision and/or a minimum of 1 year clinical and

Table 1

Radiographic Features of Prosthetic Loosening (Adapted From Miller [11]).

1. Lucency at the cement–bone or metal–bone interface >2 mm
2. Progressive widening of lucency at the cement–bone or metal–bone interface
3. Fracture of the cement mantle
4. Subsidence of >1 cm or progressive subsidence >1 year after surgery
5. Migration of prosthetic components
6. Fracture of prosthetic components
7. Component motion with stress views

radiographic follow-up. This cohort included 4 TP and 14 TN studies. The 4 TP studies all demonstrated radiographic evidence of progressive loosening as per standard defined criteria (Table 1) [11]. The 14 TN studies included 4 patients in whom the pain spontaneously resolved and 10 patients in whom alternative diagnoses were made by the orthopedic surgeon based on a minimum of 1 year clinical and radiographic follow-up. Alternative diagnoses made included lumbar facet osteoarthritis, lumbar stenosis, trochanteric bursitis, claudication, iliotibial band syndrome, myofascial pain, peroneal nerve injury, and patellofemoral pain syndrome. None of these patients demonstrated radiographic criteria for loosening. This cohort included 9 hip (3 TP, 6 TN) and 9 knee prostheses (1 TP, 8 TN). In one patient the pain completely resolved without revision at 0.2 years after the scan. Excluding this patient, the time from SPECT/CT imaging to clinical and radiographic follow-up averaged 1.7 years (SD 0.7; range 1.0–3.2).

Cemented Versus Non-cemented

The study cohort included 10 cemented prostheses (4 TP, 6 TN), 23 non-cemented prostheses (7 TP, 16 TN), and 5 hybrid prosthesis with one component cemented and the other non-cemented (2 TP, 2 TN, 1 FP).

Overall Accuracy

Overall, the study group demonstrated 13 TP, 24 TN, 1 FP, and 0 FN studies. This results in a sensitivity of 100.0%, specificity of 96.0%, positive predictive value (PPV) of 92.9%, negative predictive value (NPV) of 100.0%, and overall accuracy of 97.4% (Fig. 5).

Discussion

Aseptic prosthetic loosening is the most common cause for hip and knee prosthesis revision surgery [8,11]. Given that treatment of aseptic loosening requires revision arthroplasty, the accurate diagnosis of this complication is critical [13]. Multiple imaging modalities have been previously utilized in the evaluation of this condition, none of which are ideal [6–8,12].

SPECT/CT imaging represents a major advance in nuclear medicine technology which has been rapidly evolving over the past 10 years. There are numerous advantages compared with planar scintigraphy including volumetric data acquisition, attenuation correction, and accurate anatomical localization [14]. Considering this, there is a potential for marked improvement in the evaluation of prosthetic loosening at the hip and knee. Our study demonstrated a very high diagnostic accuracy of SPECT/CT arthrography in evaluating suspected aseptic loosening in patients with hip and knee arthroplasties (sensitivity 100.0%, specificity 96.0%, PPV 92.9%, NPV 100.0%, and accuracy 97.4%). The accuracies were similar for hip and knee prostheses and similar for both cemented and non-cemented components.

There was only 1 false positive SPECT/CT scan (knee prosthesis). In this case, there was activity demonstrated along the bone–prosthetic interface of the tibial component but no evidence of loosening on surgery which was performed 29 months after the imaging study. Given the long period of time between the scan and surgery for this patient, the significance of this is uncertain.

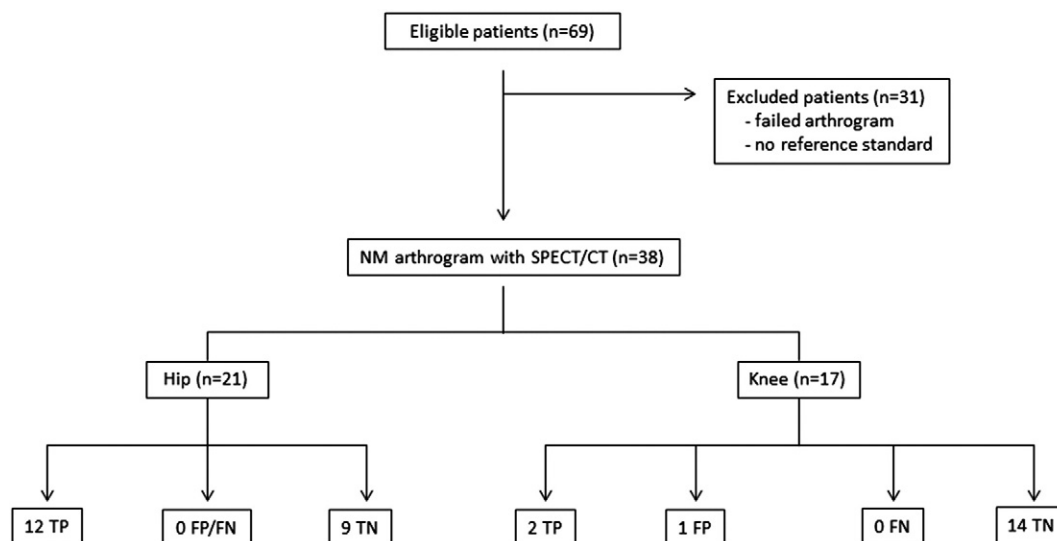


Fig. 5. Summary of study cohort. Abbreviations: TN = true negative, TP = true positive, FP = false positive, NM = nuclear medicine, SPECT/CT = single photon emission computed tomography/computed tomography.

A previous report from Chew et al [12] demonstrated improved accuracy for SPECT/CT compared with planar nuclear medicine arthrography in the evaluation of hip and knee prosthesis loosening. The accuracy demonstrated in our study is even greater. This may relate to a variety of factors including the inclusion of clinical and radiography follow-up in the reference standard (reduced referral bias), the exclusion of failed examinations (studies where the tracer was demonstrated to not be located within the joint on SPECT/CT), and differences in technique (our scans used ^{99m}Tc sulfur colloid as the radiotracer; our scans utilized a 16-slice SPECT/CT system with faster scan times and higher mA output; our scans all utilized iterative reconstruction algorithms). In any case, the combination of the findings of Chew et al with the data presented in our study demonstrates nuclear medicine arthrography with SPECT/CT to have a higher accuracy than other imaging techniques in the evaluation of aseptic loosening of hip and knee prostheses.

The major limitations of our study include the retrospective data collection with potential associated bias as well as the absence of a reference standard on 26/69 patients resulting in exclusion of this data. Five patients were also excluded from analysis because of failed examinations (injected activity not within joint space/capsule on SPECT/CT). While the latter resulted in some data exclusion, it exemplifies one of the strengths of SPECT/CT utilization compared with planar radionuclide and iodinated contrast techniques. Finally, the overall numbers evaluated are relatively low (hips $n = 21$; knees $n = 17$). While this limits statistical evaluation of the data, the overall high accuracy numbers (only 1 false study) suggest that this represents a very effective technique.

Future evaluation of a larger number of patients and multiple centers, possibly in a prospective fashion would help to more confidently address the accuracy of this technique. There may even be further improvements in scanner technology in the future resulting in even greater accuracy including the introduction of metallic beam hardening artifact suppression techniques, resulting improved attenuation correction and localization, as well as improved SPECT spatial resolution with solid state detector technology.

Conclusion

In summary, our study demonstrates a very high accuracy for nuclear medicine arthrography with SPECT/CT in the evaluation of aseptic loosening in hip and knee arthroplasties (sensitivity 100%, specificity 96.0%, PPV 92.9%, NPV 100%, and accuracy 97.4%). This

technique demonstrates a marked improvement over published planar nuclear medicine arthrography and conventional arthrography/radiography techniques. Given the anticipated incidence of aseptic loosening as a complication in the next 15 years, this technique may prove to be an important component of optimizing the effectiveness of revision arthroplasty.

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