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REVIEW ARTICLE

SPECT/CT arthrography

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ABSTRACT

Single photon emission CT (SPECT)/CT arthrography, the combination of CT arthrography and late phase bone SPECT/CT, has been developed in 2011 and so far used in knee, ankle and wrist joints. SPECT/CT offers functional information about increased bone turnover in combination with morphological details. Compared with SPECT/CT alone, additional intra-articular contrast enables the assessment of cartilage, menisci, ligaments and loose bodies. SPECT/CT arthrography is a promising alternative technique for the evaluation of internal derangement of joints in patients with MR contraindications and/or metallic implants. In this article, we review and report our 5-year experience with this technique illustrated with patient examples and give a perspective for future applications.

INTRODUCTION

Joint single photon emission CT (SPECT)/CT is increasingly used to image degenerative, inflammatory or traumatic joint disorders.^{1–4} The combination of morphological details shown by the diagnostic CT part of the SPECT/CT study fused with metabolic information given by the SPECT part provides unique information of joint disorders. In conventional SPECT/CT without intra-articular contrast application, the visualization of cartilage defects, intra-articular loose bodies or ligament tears is not possible or only indirectly possible.⁵ CT arthrography is well established for the evaluation of cartilage defects and ligament tears in different joints.^{6–10} MR with or without intra-articular contrast serves as the imaging modality of choice for the evaluation of joint disorders but MR may not be performable in patients with claustrophobia, pacemakers or metallic foreign bodies. Thus, we developed the combination of joint SPECT/CT and CT arthrography at the department of Nuclear Medicine and Radiology, Cantonal Hospital Lucerne, called SPECT/CT arthrography and evaluated this new technique in the knee, ankle and wrist joints.^{11–13} In this review article, we describe the technique, workflow and the imaging protocol of SPECT/CT arthrography and show illustrative examples in several pathologies.

Workflow and imaging protocol for SPECT/CT arthrography

The first step in SPECT/CT arthrography is the intravenous injection of approximately 500–600 MBq

(13–16 mCi) of ^{99m}Tc phosphonates. The molecules most commonly used for performing bone scintigraphy are methylene diphosphonate, hydroxymethylene diphosphonate, hydroxyethylene diphosphonate and 2,3-dicarboxypropane-1,1-diphosphonate.¹⁴ Unless contraindicated, patients should be well hydrated and drink 1 l water after injection and late phase imaging to obtain optimal image quality. Pregnancy should be excluded. Regularly, we obtain early phase planar images of the respective joint in one or two planes depending on the clinical problem 3 to 8 min after radionuclide injection. For planar imaging and SPECT/CT, we use a hybrid SPECT/CT system with a built-in flat panel CT component (BrightView XCT; Philips Healthcare, Best, Netherlands). Matrix size of early phase images is 256 × 256 with 40 cm field of view. Approximately 3 h after radionuclide injection, arthrography is performed. Before arthrography, the patient has to be informed about the procedure and possible complications like infection, bleeding, pain and allergic reactions. Written informed consent should be obtained. We perform intra-articular injection always under fluoroscopic guidance. After careful skin disinfection and application of local anesthetics, we prefer an oblique lateral access for the knee joint, an anterior access for the upper ankle joint and a midcarpal and/or radiocarpal and/or distal radioulnar joint access for the wrist joint. We inject usually 10 ml of a 1:1 mixture of iodine (Iopamiro 300; Bracco, Milano, Italy) and sodium chloride (0.9%) in the knee, 3–5 ml in the upper ankle and 1–3 ml in the wrist joints. Correct intra-articular application

Figure 1. SPECT/CT arthrography images of an 18-year-old female patient with persisting load-dependent pain 3 years after conservative therapy of a distal radius fracture. (a) puncture (arrow: needle tip) of the distal radioulnar joint under fluoroscopic guidance and injection of contrast. Contrast passover through the TFCC into the distal radiocarpal joint. (b) Early phase planar images of both wrists without pathologic uptake. (c) Late phase planar images of both wrists with increased uptake (arrow) at the ulnar edge of distal radius. (d) Coronal CT arthrography image showing an additional small bony fragment (arrow) and degenerative changes at the neighbouring radius edge. (e) Coronal SPECT/CT arthrography image with markedly increased uptake at the distal ulnar edge of the radius and the adjacent ossicle (arrow). CT arthrography (f) and SPECT/CT arthrography (g) image with defect of the TFCC (arrow). The ossicle was afterwards removed arthroscopically with good clinical success. SPECT, single photon emission CT; TFCC, triangular fibro cartilage complex.

and distribution of contrast media is documented. Directly after the arthrography—too much time delay between intra-articular injection and CT imaging would lead to wash out of contrast by the synovium and decreased image quality—late phase SPECT/CT images are obtained in a step-and-shoot mode with 64 projections and a frame time of 20 s (SPECT frame format 128×128). CT images are acquired with 30 mA (219.3 mAs) and 120 kV, in high-resolution mode with an isotropic CT voxel size of $0.33 \times 0.33 \times 0.33 \text{ mm}^3$ (CT slice thickness 0.33 mm, matrix 512×512) and reconstructed with iterative filters. SPECT images are reconstructed with an iterative 3D ordered subsets expectation maximization algorithm (Astonish, Philips Healthcare, Best, Netherlands). SPECT and CT images are automatically fused with dedicated software (Extended Brilliance Workspace, Philips Healthcare, Best, Netherlands), reformatted in axial, coronal and sagittal planes. Radiation exposure from SPECT/CT arthrography consists of the exposure from the injected

radiotracer (approx. effective dose 3.5–4 mSv, the exposure from fluoroscopy for intra-articular contrast injection (approx. 0.0003 mSv) and exposure from diagnostic CT (approx. 0.2 mSv for knee, 0.07 for ankle and 0.03 for wrist) resulting in an overall radiation exposure of approximately 3.5–4.2 mSv.¹⁵ Thus, the radiation exposure caused by the fluoroscopy to guide intra-articular contrast application is negligible low.

Clinical applications for SPECT/CT arthrography of the wrist

Exact anatomic assignment of abnormal uptake in the wrist might be difficult on conventional planar images. SPECT/CT of the wrist provides combined information of increased bone turnover and structural abnormalities. We recommend to obtain thin slice high-resolution CT images in combination with SPECT to visualize also small lesions in this complex anatomic area. Schleich et al¹⁶ showed that SPECT/CT without

Figure 2. SPECT/CT arthrography images of a 24-year-old male after femur osteotomy and refixation of an osteochondral defect with recurrent blockages. (a) Arthrography with needle (arrowhead) in the retropatellar joint space and correct distribution of contrast (arrow) intra articularly. Planar early phase (b) and late phase (c) images of the knee joints with increased uptake in the femur condyles (arrows). Coronal CT arthrography (d) and SPECT/CT arthrography (e) images with preserved cartilage (d, arrow) over the refixed osteochondral defect in the medial femur condyle and increased uptake (e, arrow) around the screw. Axial (f) SPECT/CT image with loose body (arrow) in the medial recess. The loose body (synovial fragment) was removed arthroscopically. SPECT, single photon emission CT.

intra-articular contrast already has a significant impact on therapy in 37% of patients with clinically unspecific wrist pain. Typical applications for wrist SPECT/CT are trauma/occult fractures with negative conventional imaging,¹⁷ unclear pain,¹⁸ equivocal MR imaging and “staging” of osteoarthritis. Further applications include therapy control, fracture healing and post-operative controls, *e.g.* after arthrodesis. Specific applications like ulnocarpal impaction (Figure 1),¹² carpal boss¹⁹ and bone tumours like osteoid osteoma^{20,21} have been described in the literature. In general, increased uptake in SPECT/CT corresponds quite well with bone marrow oedema in MR as could be shown in a comparative study in 28 wrists with a concordance rate of 75%.¹² Very often, increased uptake grade indicates the pain generator in symptomatic patients but careful correlation between uptake and clinical investigation is crucial to avoid overdiagnosis with SPECT/CT: in a current study, increased bone tracer SPECT/CT uptake was observed in one-third of asymptomatic wrists/hands and all of them remained asymptomatic during short time follow-up.²² CT

arthrography of the wrist is an established imaging modality used to evaluate triangular fibrocartilage complex (TFCC), lunotriquetral, scapholunate and capsular ligaments, to assess hamolunate impingement, ulnocarpal impaction, cartilage lesions and other abnormalities.^{23,24} In our experience, SPECT/CT arthrography of the wrist delivers information comparable with MR arthrography.¹² In 28 wrists of patients with suspicion for ulnocarpal impaction, MR and SPECT/CT images showed concordant findings regarding TFCC lesions in 81%, scapholunate ligament lesions in 81% and lunotriquetral ligament lesions in 85%. Regarding diagnosis of ulnar impaction, a high concordance between SPECT/CT arthrography and MR arthrography was found. We see advantages for SPECT/CT arthrography in patients with metallic implants. Despite the impressive technical progress in MR metal artefact suppression techniques using fast spin echo and short tau inversion recovery sequences with high bandwidth parameters, as well as view angle tilting and more, CT remains superior in the evaluation of bony structures adjacent to metallic material.^{25,26}

Figure 3. SPECT/CT arthrography images of a 59-year-old patient with persisting pain in the upper ankle joint 4 months after trauma. (a) Injection of contrast under fluoroscopic guidance in the upper ankle joint. (b) Planar late phase bone scintigraphy images with increased uptake (arrow) in the medial subchondral talus. (c, d) Coronal CT arthrography and SPECT/CT arthrography with a subchondral lesion in the medial talus with increased uptake (arrow) and corresponding cartilage defect (Grade IV). SPECT, single photon emission CT.

Clinical applications for SPECT/CT arthrography of the knee

MR serves as imaging reference standard for the majority of patients with knee pain caused by trauma or degenerative disease. CT arthrography of knee is a valuable alternative to MRI. Owing to its high spatial resolution, CT arthrography is the most accurate method for the evaluation of cartilage thickness.²⁷ It has been shown that meniscal abnormalities and unstable meniscal tears are detectable with CT arthrography reliably.²⁸ Furthermore, diagnosis of anterior cruciate ligament tears and intra-articular bodies is possible by CT arthrography.^{29,30} Another interesting application is the assessment of post-operative knees regarding cartilage, Figure 2 ligaments and menisci.³¹ Conventional SPECT/CT of the knee without intra-articular contrast provides important metabolic information in various knee conditions like subchondral lesions, overload and osteoarthritis.^{2,5,32-34} SPECT/

CT without intra-articular contrast lacks of direct visualization of cartilage defects, ligament tears or meniscal abnormalities. Thus, it is obvious that the combination of SPECT/CT and CT arthrography increases the information about knee lesions. We use SPECT/CT arthrography of knee preferably in patients with MR contraindications and metallic implants. The main applications, in our experience, are the assessment of internal derangement before or after operative interventions and loose bodies.^{13,30,35}

Clinical applications for SPECT/CT arthrography of the ankle

It has been shown that CT arthrography of ankle joint is more accurate than MR arthrography in depicting small surface cartilage lesions with a higher interobserver reproducibility.³⁶ CT arthrography was used successfully to image osteochondrosis dissecans

already in 1989. Assessment of osteochondral lesions in osteochondrosis dissecans, osteoarthritis and search for intra-articular loose bodies are interesting applications for SPECT/CT arthrography of the ankle. Further, evaluation of bone metabolism and cartilage integrity [Figure 3](#) after operative procedures like cartilage repair or osteosynthesis of intra-articular fractures like pilon tibial are promising applications. We use SPECT/CT arthrography of the ankle, especially in patients with metallic implants or MR contraindications for the assessment of osteochondral lesions.

DISCUSSION

The combination of metabolic SPECT and morphologic CT arthrography information in one imaging procedure, called SPECT/CT arthrography is feasible in the knee, wrist and ankle joints and provides important information of joint disorders. Compared with “conventional” SPECT/CT without intra-articular contrast, the new technique enables the visualization of cartilage and osteochondral defects, tears of important ligaments, TFCC, menisci and loose intra-articular bodies. SPECT/CT arthrography can serve as an alternative imaging modality in patients with MR contraindications. Further, SPECT/CT arthrography is valuable to evaluate joints after osteosynthesis. SPECT/CT arthrography needs good cooperation between nuclear medicine and radiology to guarantee an effective workflow. Special training in intra-articular contrast application is mandatory and a prerequisite. A time delay of more than 30 min between arthrography and SPECT/CT should be avoided because diffusion of contrast in the cartilage and synovium and resorption of intra-articular contrast might impair the image quality and detection of lesions.³⁷ For the adequate interpretation of SPECT/CT arthrography, knowledge in interpretation of SPECT/CT and CT arthrography should confluence to a comprehensive report. In suspected ulnocarpal impaction, SPECT/CT arthrography proved to perform as well as MR arthrography in 28 wrists.¹² Other studies with direct

comparison of both techniques are missing. Our SPECT/CT arthrography protocol should not be mixed with “radionuclide arthrography with SPECT/CT” described since 1986 from different authors.^{38–40} Chew et al⁴⁰ injected 20 MBq (0.5 mCi) of ^{99m}Tc calcium phytate intra-articularly followed by SPECT/CT to observe radionuclide entrance in the interface of hip and knee joint prosthesis components as a sign for loosening.

FUTURE DIRECTIONS

So far, we performed SPECT/CT arthrography only in knee, wrist and ankle joints because the flat panel CT part of our SPECT/CT device offers limited image quality for larger joints as hip and shoulder. With the newest generation of high-end SPECT/CT machines, excellent diagnostic CT quality with low radiation exposure (iterative reconstruction) will become reality also for larger joints.^{41,42} CT acquisition (increase tube current or voltage, reduction of section thickness) and reconstruction (adaption of deconvolution kernel, iterative reconstruction, use of extended Hounsfield unit scale) techniques to reduce metal artefacts, including dual energy, will be increasingly available for the CT part of SPECT/CT.⁴³ Owing to several possibilities for reduction of radiation exposure like limited volume acquisition, small field collimation, automatic modulation of tube current, iterative reconstruction the additional radiation burden obtained by diagnostic CT as part of SPECT/CT arthrography is insignificant.^{41,42,44} With this technical improvement, SPECT/CT arthrography has the potential to serve as a valuable alternative to MR arthrography or CT arthrography alone for the assessment of internal derangements of the shoulder and hip joint.

CONCLUSION

In conclusion, SPECT/CT arthrography is a promising imaging combination to evaluate joint pathologies in patients with MR contraindications.

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