Development of a Protocol for SPECT/CT in the Assessment of Wrist Disorders

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J Wrist Surg 2016;5:297–305.

Abstract

Background Single-photon emission computed tomography and computed tomography (SPECT/CT) is a hybrid diagnostic imaging modality that allows clinicians to integrate their diagnostic evaluations and deliver a definitive diagnosis in musculoskeletal disorders. Specifically, in identification of osseous pathology, the conventional bone scan delivers greater specificity compared with magnetic resonance imaging (MRI). However, use of SPECT/CT enhances the sensitivity and specificity. Use of this modality denotes the possibility to specify the lesion more accurately and precisely while grading the activity according to osseous structural changes.

Purpose This study aimed to evaluate the clinical utility of SPECT/CT in the diagnoses and management of osseous wrist disorders. The objectives were to examine the value of SPECT/CT in the diagnosis of osseous-related wrist pain and whether the findings altered management.

Patients and Methods A retrospective cohort study of 20 patients with such wrist pain was conducted. SPECT/CT was used in the diagnostic process for these patients.

Results Following SPECT/CT imaging, the common final diagnoses were osteoarthritis (10; 50%) and avascular necrosis (5; 25%). Less common diagnoses included ulnar carpal impact syndrome, infection, malunion, complex regional pain syndrome, and carpal boss. Some presented with multiple pathologies. SPECT/CT changed the final diagnosis in 11 cases, resulting in nonoperative treatment (7; 63%) or surgery (4; 37%).

Conclusion Findings from this study and the literature demonstrate the clinical utility of SPECT/CT in the assessment of osseous-related wrist disorders. We present an algorithm for the assessment of wrist pain with osseous pathology. This commences with clinical assessment and plane radiographs (first-line investigation). Some cases will require a second-line investigation (ultrasound, CT, and/or MRI). If the diagnosis remains unclear, SPECT/CT is recommended as a third-line investigation.

Keywords

- ▶ SPECT/CT
- ▶ wrist
- ▶ osteoarthritis
- ▶ avascular necrosis
- ▶ ulnar impingement

The use of imaging modalities in the assessment of wrist pain is important in the diagnosis and management of wrist disorders. First-line investigations involve radiography and second-line investigations include magnetic resonance imaging (MRI), computed tomography (CT), and/or ultrasound (US).^{1,2} Metabolic

osseous changes can be difficult to detect using these standard modalities. Hybrid techniques, such as bone scan with single-photon emission computed tomography and computed tomography (SPECT/CT), enhance sensitivity and specificity for detection of osseous pathology.³ Use of this modality requires

received

October 28, 2015

accepted after revision

March 28, 2016

published online

May 2, 2016

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Tel: +1(212) 584-4662.

DOI <http://dx.doi.org/10.1055/s-0036-1583314>.
ISSN 2163-3916.

intravenous administration of an appropriate radionuclide to patients. An example is technetium-99m hydroxymethylene diphosphonate (Tc-99m HDP), which allows for identification of osteoblastic activity and active bone remodeling.^{4,5} Radio-labeled variations allow for localization of different pathologies, such as gallium radiolabeled leucocytes that localize to sites of infection.⁶

Primary application of SPECT/CT has been in malignant osseous lesions⁴ but recent evidence indicated benefits in the diagnosis of osteoarthritis (OA), fracture (stress/occult), avascular necrosis (AVN), and malunion.⁷⁻¹¹ Pathology of osseous-related wrist pain can be difficult to ascertain with no definitive diagnosis following conventional clinical examination and investigations.¹² The difficulty is associated with the intricate morphological features of this anatomical region.

Recent evidence¹² indicates the value of SPECT/CT in the diagnosis of osseous pathology. Bone scans provide greater specificity compared with MRI in detection of osseous pathology,¹³ further enhanced with CT.¹² Integration of CT provides superior anatomical resolution. The SPECT component facilitates increased sensitivity with additional information on bone turnover. Integrated SPECT/CT images supplement clinicians with invaluable additional functional and anatomical information.^{4,12} When used with conventional investigations, the precision and accuracy to localize a lesion and grade activity is significantly increased.¹² This invaluable information has potential to improve the diagnostic process and management.¹² However, parameters of its clinical applications in wider practice in the assessment of osseous-related wrist disorders are still being defined.

The study aimed to evaluate the potential applications of SPECT/CT in the diagnosis and management of osseous wrist pain. A retrospective study was conducted on patients with such wrist pain that utilized SPECT/CT. Specifically, the study evaluated (1) if SPECT/CT was of value in the diagnosis and (2) whether the findings alter the patient's management.

Materials and Methods

This retrospective cohort study was performed from 2013 to 2015. The analysis included 20 patients (12 men and 8 women; mean age, 45.8 years; range, 17.2–70.1 years) with osseous-related wrist pain (right side, 9; left side, 9; both, 2), in whom SPECT/CT using Tc-99m HDP was applied. None of the participants experienced adverse reactions during the procedure and did not have bone malignancy diagnoses pre- or post-SPECT/CT.

Imaging Techniques

All bone scans performed were incorporated with SPECT/CT that utilized hybridized gamma cameras/CT scanner (Siemens Symbia T SPECT/CT scanner, Adelaide, South Australia, Australia).

Patients were administered Tc-99m HDP intravenously. Doses ranged from 800 to 900 MBq, dependent on whether single joint to full body scans were required. Tc-99m HDP is renally cleared and has a half-life ($t_{1/2}$) of 4 to 12 hours.³

Scans required patients to be seated and positioned in a "superman position" (supine with the hand/hands forward to the head) and wrists planted on the imaging platform. A three-

phase bone scan was conducted. The initial phase involved acquisition of a dynamic blood flow image recorded using a 256×256 matrix with full field of view, at a 5-second frame rate for the first 1.5 to 2 minutes following radionuclide administration. Static blood pool images were acquired in the following 4 minutes. 2 minutes with the hands palmar planted and 2 minutes dorsal planted. These initial images relayed distributional information of the radionuclide with areas of hypervascularization appearing with greater intensity.

Approximately 2 to 4 hours later, delayed static images were acquired. The delayed static images were acquired in the same view over 3 to 5 minutes. Subsequently, SPECT was performed using two gamma cameras (128×128 matrix; 130 keV) to give 64 views at 15 seconds/view over 360 degrees. This was followed by CT that provided an anatomical map for SPECT attenuation (1.25-mm slices; 30 mA) conducted over 1.5 minutes. The registered SPECT/CT data are additionally processed into reconstructed images of localized pathological uptake, interfaced with the anatomical map of the CT. The resultant images are multiplanar (transverse, coronal, and sagittal). Whole body SPECT/CT scans were performed where systemic conditions were suspected.

Risk and Contraindications

Pregnant and breastfeeding women are contraindicated from undergoing a SPECT/CT scan, due to risk of radiation exposure to the fetus and child.³ The isotope is renally cleared. However, renal impairment does not preclude its use. Adverse reactions may include a rash. The table used for the scans can support a maximum weight of 227 kg.

Outcomes Measured

An upper limb orthopedic surgeon performed the clinical assessment. Patient demographics, clinical data, and results of standard imaging modalities (radiographs, US, CT, and MRI) and provisional diagnoses were assessed. The provisional diagnoses (before the SPECT/CT) included OA, infection, AVN, ulnar carpal impact syndrome (UCIS), and malunion.

The SPECT/CT scan was performed, and the final clinical diagnosis was made. From review of the record, we identified the following:

- Were the conclusions from SPECT/CT corroborative of the provisional diagnosis?
- Did SPECT/CT aid in the diagnosis?
- Did SPECT/CT change the management plan for patients?

Data collection and statistical analysis were conducted by an independent observer. All data were expressed as mean $\pm$ standard deviation, which were calculated with BiostaTGV.

Results

Following the SPECT/CT imaging, the final diagnosis was OA (10; 50%), AVN (5; 25%), UCIS (2; 10%), infection (1; 5%), malunion,¹ complex regional pain syndrome,¹ carpal boss,¹ dorsal intertarsal ligament,¹ and no abnormality.¹ This included patients with multiple pathologies in the affected wrist: OA + AVN (2; 10%) and OA + UCIS.¹ The

Table 1 Management changes in SPECT/CT wrist cases

Patient	Gender	Age (y)	History	Radio graph	US	CT	MRI	Initial investigations	SPECT/CT	Benefit	Management
1	Male	17	"Teenbock"	x		x	x	"Teenbock"	OA distal radius + KD	Decision made	Surgery
2	Male	68	Atypical pain	x	x			Inflammatory disease	Pan carpal OA	Diagnosis	Nonoperative
3	Male	70	Atypical swelling	x			x	Atypical synovitis	No tumor	Diagnosis	Surgery
5	Male	20	Ulnar wrist pain	x	x			Normal	Normal	Diagnosis	Nonoperative
8	Male	53	Pain post-CTR	x			x	Normal	OA CMC3	Localization	Nonoperative
12	Male	55	Posttrauma pain	x			x	No fracture	RC OA + radius malunion	Diagnosis	Surgery
15	Male	51	Dorsal pain	x	x		x	Synovial cyst	Inflammatory arthropathy	Diagnosis	Surgery
16	Male	61	Dorsal pain	x	x		x	Normal	Dorsal lig tear	Diagnosis	Nonoperative
17	Female	26	Wrist pain	x		x	x	Kienbocks	OA RC + KD	Localisation	Surgery
18	Male	57	Ulnar wrist pain	x	x	x	x	Kienbocks	OA DRUJ + KD	Localisation	Nonoperative
19	Male	26	Posttrauma pain	x		x		Normal	OA from lunate fracture	Diagnosis	Nonoperative

Abbreviations: CMC3, third carpometacarpal joint; CT, computed tomography; CTR, carpal tunnel release; DRUJ, distal radioulnar joint; KD, Kienböck disease; MRI, magnetic resonance imaging; OA, osteoarthritis; PRC, proximal row carpectomy; RDJ, radiocarpal joint; SPECT/CT, single-photon emission computed tomography/computed tomography; US, ultrasound.

main symptom was pain in all cases with hand clicking (4; 20%) and prior surgery (3; 15%). Agreement in diagnosis between the standard modalities and SPECT/CT was observed in seven cases.

SPECT/CT changed the diagnosis in 11 cases. Management changed to nonoperative treatment in six (54.5%) and operative treatment in five (45.5%) cases, as shown in ▶Table 1. In the remaining two cases, there was inconclusive evidence for the leading diagnosis of ulnar impingement as the cause for wrist pain. Use of SPECT/CT as a third-line investigation aided elimination of possible differential diagnoses.

Sample Clinical Cases

We present some notable clinical cases where SPECT/CT aided in the diagnostic process and management.

Osteoarthritis

Patient no. 18 presented with chronic right ulnar wrist pain. Radiograph (▶Fig. 1) and CT were suggestive of Kienböck disease, while US and MRI appeared to suggest tenosynovitis. These first- and second-line imaging modalities pointed to a likely clinical diagnosis of Kienböck disease; however, uncertainty remained over whether there was further pathology. SPECT/CT (▶Fig. 2) demonstrated marked osteoblastic activity at the distal radioulnar joint (DRUJ) and facilitated the diagnosis of Kienböck disease and OA of the DRUJ. These constellations of findings lead to a recommendation of nonoperative treatment.

Infection and Malunion

Patient no. 7 had a wrist fusion 5 years ago, following a comminuted open fracture/dislocation of the lunate. Debris was removed from the wrist 3 years postsurgery. However, pain persisted and a radiograph demonstrated a malunion (▶Fig. 3). SPECT/CT provided further details, demonstrating

osteoblastic activity and the malunion remaining active (▶Fig. 4). Blood flow images showed increasing blood flow, suggestive of infection (▶Fig. 5).

Avascular Necrosis

Patient no. 9 presented with central wrist pain with no history of trauma. Radiograph and MRI were suggestive of AVN of the capitate (▶Figs. 6 and 7). A SPECT/CT confirmed

Fig. 1 Patient no. 18: 57-year-old man with chronic right ulnar wrist pain. Posterior–anterior radiograph.

Fig. 2 Patient no. 18: 57-year-old man with chronic right ulnar wrist pain. SPECT/CT coronal view.

AVN of the capitate, with a cold proximal pole of the capitate and hot revascularization distal zone (► **Fig. 8**).

Ulnar Impingement

Patient no. 10 presented with ulnar-sided wrist pain. Radiographs showed changes in the distal radius and the ulnar styloid (► **Fig. 9**). A CT and MRI scan did not provide a definitive diagnosis. SPECT/CT (► **Fig. 10**) showed substantial osteoblastic activity, consistent with ulnar carpal impaction.

Discussion

SPECT/CT is a diagnostic imaging technique that provides additional anatomical and functional information. In the diagnosis of nonspecific wrist pain, it provides greater specificity than MRI (1.00 vs. 0.20) but lower sensitivity (0.71 vs.

Fig. 4 Patient no. 7: 60-year-old man with a surgical history of wrist fusion. SPECT/CT coronal view.

0.86).¹³ However, the sensitivity of SPECT/CT is potentiated (0.94–1.00) when utilized together with MRI.¹² This has seen the use of SPECT/CT to aid the decision-making process when determining the management, particularly in cases where standard imaging modalities have not provided a clear diagnosis.³ The concept of a SPECT/CT is comparable to a conventional bone scan; however, it is considerably superior at

Fig. 3 Patient no. 7: 60-year-old man with a surgical history of wrist fusion. Posterior-anterior radiograph.

Fig. 5 Patient no. 7: 60-year-old man with a surgical history of wrist fusion. Blood pool confirms infection.

localizing the lesion due to the better anatomical resolution, offered by reconstructed multiplanar SPECT images interposed on CT images.¹² As the wrist joint is a complex articulation, this superior resolution is a significant advantage. Until now, much of the evidence to support the clinical utility of SPECT/CT is based on findings from cardiac, neurologic, and oncologic conditions.³ This study demonstrates that the SPECT/CT scan is of value in the assessment and management of disorders of the wrist with osseous pathology.

A limitation of this study is that this is a retrospective review of the experience of one surgeon limited to 20 cases. However, the study has demonstrated that use of SPECT/CT

has clinical value in the assessment of patients with wrist pain with osseous pathology.

SPECT/CT is a technique that has recently been applied to investigations involving the wrist.^{12,13} The integration of SPECT/CT into wider clinical practice will better define its exact role in the assessment of wrist disorders. Consideration was given to the role of the SPECT/CT scan to facilitate diagnosis and alter the clinical management.

Review of the literature demonstrates the application of SPECT/CT in a variety of conditions and clinical settings.⁷⁻¹¹ This includes OA, fracture (stress/occult), AVN, malunion, UCIS, infection, and tumor.^{7-11,14} In this study, the use of SPECT/CT facilitated the following:

Fig. 6 Patient no. 9: 22-year-old woman with avascular necrosis of capitate. Posterior-anterior radiograph.

Fig. 7 Patient no. 9: 22-year-old woman, T1-weighted sequence without fat suppression postcontrast sagittal MRI of the wrist showing avascular necrosis of the capitate.

- Diagnosis of conditions such as AVN, OA, infection, and UCIS
- Localizing the zone of osteoblastic activity
- Eliminating certain differential diagnoses (e.g., scaphoid fracture)
- Directing management, especially when the aforementioned factors were considered with the clinical assessment and other imaging modalities

In our study, we had no tumors; however, we expect it would be useful in the diagnosis of metastatic lesions and osteoid osteomas.^{12,15}

Fig. 8 Patient no. 9: 22-year-old woman. SPECT/CT eliminates diagnosis of tumor and confirms avascular necrosis.

The literature has also stated that in evaluation of occult wrist fractures, particularly of the scaphoid, SPECT/CT was found to be beneficial in the diagnosis when combined with standard imaging modalities.⁹ Therefore, suspicion of scaphoid pathology whereby diagnosis remains unclear despite undertaking conventional investigations, SPECT/CT may then prove beneficial. Using the findings from the study and the literature, ► **Table 2** highlights the conditions and pathologies where SPECT/CT proved beneficial in the diagnostic process

Fig. 9 Patient no.10: Posterior-anterior radiograph.

Fig. 10 Patient no. 10: SPECT/CT revealing osteoblastic activity consistent with ulnar carpal impaction.

and management of wrist disorders. Findings from this study also revealed that presentations that have normal findings with first- and second-line modalities can in fact have pathology, or vice versa, as demonstrated by the use of SPECT/CT. ►**Table 1** demonstrates that certain presentations require the combination of multiple modalities for diagnosis. Importantly, the use of SPECT/CT is not usually recommended in isolation due to its lower sensitivity when used as the sole modality.¹⁶ If the wrist pain is due to a soft tissue abnormality (e.g., scapholunate instability), the lesion could be missed when SPECT/CT is used as a standalone technique.

The second purpose of this study was to evaluate whether the SPECT/CT altered management. This study demonstrated changes in the management based on SPECT/CT findings—specifically, whether operative or nonoperative treatment was indicated.

Table 2 Conditions where SPECT/CT facilitated diagnosis

Condition	Possible etiologies positive with SPECT/CT
Trauma-induced	Fracture (occult or stress) ^{8,9}
Tumor	Metastases ⁴
	Osteoid/osteoma ¹⁵
Infection	Osteomyelitis ⁵
AVN	Cold ischemic segment
	Revascularization ¹⁰
	Remodeling
OA	Impingement ¹⁴

Abbreviations: AVN, avascular necrosis; OA, osteoarthritis; SPECT/CT, single-photon emission computed tomography/computed tomography.

Among the study cohort, 11 (55.0%) received modifications to management. Of these patients, seven (63.4%) were managed nonoperatively and four (36.6%) had surgery. These results suggest that the application of SPECT/CT in wrist disorders, with unknown pathology, can change management.

Further Considerations When Using SPECT/CT

As mentioned earlier, if the patient is pregnant, breastfeeding,³ or weighs more than 227 kg, then the use of SPECT/CT is unsuitable. The value of SPECT/CT may also be limited if the patient has had wrist surgery in the previous 12 months.¹⁶

In addition, it was noted that SPECT/CT can be demanding on the patient. It requires an intravenous injection followed by a dynamic blood flow and/or blood pool scan. For acquisition of the delayed static and SPECT/CT images, duration of this process is ~30 minutes and the patient is restricted from moving.¹⁷ The entire process requires 4 hours.

Moreover, while SPECT/CT can facilitate diagnosis and alter management, the greater cost of using SPECT/CT may discourage its widespread use. A comparison of imaging modalities is presented in ►**Table 3**. Based on our findings and the literature, the SPECT/CT when applied in selected conditions (►**Table 2**) may offset increased cost associated with an indeterminate diagnosis. However, when considering the cost of the imaging modality alone, SPECT/CT is relatively more expensive (costs reported in Australian dollars). The cost of imaging 1 joint is \$847, while a full body scan costs \$960. Contrastingly, radiograph is \$79, US \$285, CT \$327, and MRI \$614. A further drawback is the additional ionizing exposure associated with the use of SPECT/CT, and the risk of this, particularly to select patient cohorts, needs to be considered.¹⁸

Protocol for the Use of SPECT/CT in Wrist Disorders

The findings from this study and the literature demonstrate the value of the SPECT/CT scan in aiding diagnosis and management. We have developed an algorithm for the assessment of wrist pain with osseous pathology (►**Fig. 11**), which outlines the role of imaging modalities in acquisition of a definitive diagnosis in wrist disorders that involve soft tissue, osseous, or malignancy pathology.

In conclusion, this study and a review of the literature demonstrate the value of SPECT/CT in clinical practice. SPECT/CT scans provide additional anatomical and functional information. A normal scan can eliminate particular differential diagnoses, allow a positive scan localization of pathology, and assist in the diagnosis. Cumulative findings from the clinical assessment and other conventional imaging modalities aid the decision-making process and management. This is in part due to its high sensitivity and specificity in localization of pathology, and when used in adjunct with other modalities, its clinical utility remarkably increases. The clinical role of the SPECT/CT scan is as a third-line investigation, and an algorithm has been provided to assist in defining this. As with any technique, there are limitations that need to be considered in how it is applied to clinical practice. This preliminary study demonstrates the clinical utility of SPECT/CT in the diagnosis and management of wrist disorders with an element of osseous pathology.

Table 3 Comparison of imaging modalities

	Radiograph	Ultrasound	CT scan	MRI	SPECT/CT
Advantages	Available	Available	Available	Available	Less accessible
	Cheap	Dynamic study	Osseous resolution	Multiplanar	Multiplanar reformatting
		No radiation	Multiplanar reformatting	Soft tissue resolution	Osteoblast activity
			3D and 4D imaging	No radiation	Osseous resolution
Disadvantages	2D images	Operator dependent	Radiation	Metal artifacts	Radiation
	Occult fractures	Dynamic views not available for clinician	Metal artifacts	Fracture healing	Procedure duration (4 h)
	Soft tissues		Soft tissue resolution	Postsurgery	Postsurgery
				Claustrophobia	
Indication	First-line Screening	Second line	Second line	Second line	Third line
		Superficial soft tissue	Osseous conditions	Soft tissue and osseous	Osseous
		Tendons	Fractures	Ligament, articular	Trauma
		Tenosynovitis	OA, tumor	Tumor, AVN	AVN, OA
		Ganglion		Vascularization	
Cost	\$79 AUD	\$285 AUD	\$327 AUD	\$614 AUD	\$847/\$960 AUD

Abbreviations: AVN, avascular necrosis; CT, computed tomography; MRI, magnetic resonance imaging; OA, osteoarthritis; SPECT/CT, single-positron emission computed tomography/computed tomography; US, ultrasound.
Note: Costs of imaging as reported by the Australian Department of Health. Cost of SPECT scan is given for both wrist only and full body.

Fig. 11 Wrist pain assessment protocol.

Conflict of Interest

None.

Acknowledgment

The authors thank Dr. Andrew Biggs, nuclear medicine specialist, for his assistance in conducting the study.

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