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General Review

Simultaneous dual-isotope $^{123}I/^{99m}Tc$ acquisition using CZT-based cameras: Toward a one-stop-shop SPECT in heart failure patients

Acquisition simultanée double-isotope ($^{123}I/^{99m}Tc$) avec les gamma-caméras à semi-conducteur CZT : vers un examen tout-en-un chez les patients insuffisants cardiaques

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Abstract

The CZT-cameras (DNM 530c and DSPECT) have only recently been introduced, and the impact of the increased energy resolution remains unknown. This paper summarizes the evidence on the assessment of: (i) the left ventricular function, (ii) the $^{123}I/^{99m}Tc$ mismatch, and (iii) the heart-to-mediastinum ratio (HMR) of ^{123}I-metaiodobenzylguanidine (MIBG) uptake under dual-isotope conditions (^{99m}Tc and ^{123}I) using cadmium-zinc-telluride (CZT) technology. The diagnostic accuracy of CZT cameras for myocardial sympathetic innervation imaging, left ventricular function and perfusion assessment using perfusion-gated SPECT have only been established in a few studies, under single-isotope conditions. Limited evidence is available regarding simultaneous dual-isotope acquisition using CZT-cameras. However, recently reported data have shown that CZT cameras allow, in dual-isotope (^{123}I and ^{99m}Tc) acquisitions and under routine conditions: (i) a simultaneous and accurate segmental study of myocardial innervation and perfusion (match and mismatch), (ii) the ventricular function assessment (EDV, ESV and LVEF), and (iii) the determination of the late HMR of cardiac ^{123}I-MIBG uptake in patients with heart failure. However, this latter should be performed using transaxial reconstructed images and a linear correction based on phantom data acquisitions.

Conclusion. – With an increased energy resolution, the CZT cameras should become the one-stop shop SPECT for simultaneous dual-isotope $^{123}I/^{99m}Tc$ acquisitions in heart failure patients, permitting to perform LV function, myocardial perfusion and innervation.

Keywords: CZT; HMR; MIBG; Dual-isotope; LVEF

Résumé

Les caméras à semi-conducteurs (DNM 530c et DSPECT) ont été introduites récemment, et l'impact de leur résolution en énergie accrue reste inconnu. Cette revue de la littérature porte sur l'évaluation (i) de la fonction ventriculaire gauche, (ii) de l'étude segmentaire de la fixation myocardique d'$^{123}I/^{99m}Tc$, et (iii) du rapport cardio-médiastinal (RCM) de la fixation d'^{123}I-metaiodobenzylguanidine (MIBG) en condition double-isotope (^{99m}Tc et ^{123}I) avec la technologie tellurure de cadmium-zinc (CZT). La précision diagnostique des caméras CZT dans l'évaluation de l'innervation sympathique myocardique, de la fonction ventriculaire gauche et de la perfusion utilisant la TEMP de perfusion synchronisée à l'ECG n'a été établie que par quelques études, en conditions simple-isotope. Peu d'études sont disponibles concernant les acquisitions simultanées double-isotope utilisant les caméras CZT. Cependant, des données récentes ont montré que les caméras CZT permettent, lors d'acquisition double-

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isotope (^{123}I et ^{99m}Tc) et en conditions de routine, (i) l'étude simultanée et segmentaire précises de l'innervation et de la perfusion myocardiques (concordance et discordance), (ii) l'évaluation de la fonction ventriculaire (VTD, VTS et FEVG), et (iii) la détermination du RCM tardif de la fixation cardiaque d'^{123}I-MIBG chez les patients atteints d'insuffisance cardiaque. Cette dernière doit cependant être réalisée en utilisant les images reconstruites transaxiales avec la DNM 530c et les reprojections planaires avec la DSPECT et après correction linéaire basée sur des acquisitions de données fantômes pour les deux caméras.

Conclusion. – Avec une résolution en énergie accrue, les caméras CZT devraient devenir les TEMP tout-en-un pour les acquisitions double-isotope ^{123}I/^{99m}Tc simultanées chez les patients insuffisants cardiaques, pour évaluer lors d'une seule session la fonction VG, la perfusion myocardique et son innervation.

Mots clés : CZT ; RCM ; MIBG ; Double-isotope ; FEVG

1. Introduction

Impairment of cardiac sympathetic innervation assessed with the late heart-to-mediastinum ratio (HMR) of ^{123}I-meta-iodobenzylguanidine (^{123}I-MIBG) is recognized as an independent prognostic factor in patients with heart failure [1–6]. An HMR of less than 1.6 is associated with an increased risk [6]. Currently, the calculation of HMR requires a planar static image of the thorax. This technique is well-standardized and reproducible using a conventional Anger camera [7,8].

Recently, dedicated cardiac single photon emission computed tomography (SPECT) cameras using cadmium-zinc-telluride (CZT) detectors have dramatically transformed the routine practice of myocardial perfusion and innervation imaging in patients with known or suspected coronary artery disease [9]. The available dedicated cardiac CZT cameras (DNM 530c: GE Healthcare, Milwaukee, WI, USA, and DSPECT: Biosensors International, Caesarea, Israel) have a better count detection sensitivity resulting in decreased acquisition times and injected radiopharmaceutical doses, and an improved energy resolution, permitting better photon energy discrimination for dual-isotope imaging. However, these cameras differ in sensitivity (4-fold improved with DNM 530c, and nearly 7-fold with DSPECT), and spatial resolution (6.7 mm with DNM 530c, and 8.6 mm with DSPECT) (Table 1) leading to images with different sharpness and contrast-to-noise ratios [10–12].

Despite their increased energy resolution, the scatter fraction remains high with CZT cameras (30% vs. 34% with conventional Anger gamma cameras) [13]. In addition, the tailing effect in the energy spectrum towards lower energies due to incomplete charge collection [14] may specifically affect count statistics with CZT cameras. These two phenomena may impact image acquisition within the ^{99m}Tc photopeak during ^{123}I/^{99m}Tc dual-isotope acquisition, further compromising the accuracy of left ventricular function and perfusion assessment using the ^{99m}Tc-labelled tracer.

However, only a few reported studies have evaluated their accuracy for myocardial sympathetic innervation imaging [15–18] and left ventricular function and perfusion assessment using perfusion-gated SPECT [12,19,20].

As previously emphasized [21,22], quantification of HMR is influenced by the type of collimators used and the number of scattered photons. Consequently, the value of HMR is expected to depend on the type of CZT camera used. Bellevre et al. [18] using ^{99m}Tc-tetrofosmin to localize the heart within the thorax, recently demonstrated the feasibility of determining the late HMR of ^{123}I-MIBG uptake using dual-isotope imaging with a CZT camera (DSPECT) in patients with heart failure.

There is a lack of data regarding the use of CZT SPECT cameras for simultaneous assessment of left ventricular innervation, function and perfusion using ^{123}I/^{99m}Tc dual-isotope acquisition. In several studies performed using both DNM 530c and DSPECT, we examined (i) the impact of simultaneous dual-isotope (^{123}I/^{99m}Tc) acquisition on the assessment of global and regional left ventricular function in the ^{99m}Tc photopeak, (ii) the comparison of perfusion/innervation mismatch using simultaneous and serial dual-isotope imaging, and (iii) the feasibility of late HMR of ^{123}I-MIBG uptake using simultaneous dual-isotope CZT acquisition (DNM 530c) in patients with heart failure.

2. Simultaneous ^{123}I/^{99m}Tc dual isotope imaging do not impact on left ventricular function assessment

Using a dynamic phantom, we demonstrated the feasibility of left ventricle ejection fraction (LVEF) evaluation using gated perfusion SPECT with CZT cameras [23] (Fig. 1). The results from the latter study showed that the type of camera (DSPECT or DNM 530c) but not the acquisition mode (i.e. single- or dual-isotope) impacted on volume measurements. In addition, an almost perfect agreement was found between single- and dual-isotope acquisitions for assessing segmental wall motion and thickening with ^{99m}Tc with both CZT cameras. On simultaneous dual radionuclide acquisitions, the ^{99m}Tc photopeak was unaffected by ^{123}I scatter and crosstalk.

The measurement of LV function is a key step of prognosis assessment and may potentially be altered when using CZT cameras with a simultaneous dual-isotope protocol due to the down-scatter, crosstalk, and tailing effect of ^{123}I in the ^{99m}Tc photopeak. It was previously demonstrated that the DNM 530c provides higher systolic volumes compared to the DSPECT camera. This camera impact on volume assessment is likely related to spatial resolution. Imbert et al. [11] reported the following classification of measured central spatial resolution: DNM 530c (6.7 mm) and DSPECT (8.6 mm). These results are

Table 1
DNM 530c and DSPECT characteristics.
Caractéristiques de la DNM 530c et de la DSPECT.

	DNM 530c	DSPECT
Number of CZT detectors	19, no motion	9, mobile
Collimation systems [10,11]	Multi-pinhole collimation, focusing the heart	Wide-angle parallel hole collimation
Energy resolution (%)	4 to 5	4 to 5
Central spatial resolution (mm)	6.7	8.6
Count sensitivity (compared to conventional Anger camera) [11]	× 4	× 7
Reconstructed voxel size (mm)	4 × 4 × 4	4.92 × 4.92 × 4.92
Scatter, cross-talk, and tailing effect corrections [26]	No	Only for dual-isotope acquisitions
Non-uniformity and truncation artefact (compared to Anger) [27]	Observed	No

concordant with previous findings by Bailliez et al. [12] showing in both phantom and patients that LV volumes were higher using the DNM 530c model compared to DSPECT and to Anger camera equipped with cardiofocal collimators.

3. Simultaneous ^{123}I/^{99m}Tc dual isotope imaging do not impact on the assessment of perfusion/innervation mismatch

The size of both ^{123}I and ^{99m}Tc defects as well as their mismatch was not impacted either by the type of camera (DSPECT vs. DNM 530c), or by the acquisition mode (single vs. dual) or by the acquisition time [24] (Fig. 2). D'Estanque et al. [25] recently reported the impact of scatter correction in dual-isotope (^{201}Tl/^{123}I-MIBG) cardiac SPECT protocols for trigger zone assessment with the DNM 530c. This correction improved the accuracy of myocardial SPECT for mapping the segmental myocardial sympathetic denervation. In their study, perfusion was assessed using ^{201}Tl, where the energy window was centered at 67 keV ± 10%, right in the ^{123}I down-scatter and crosstalk window. The contribution of tailing and down-scatter photons from the photopeak of ^{123}I, detected as primary photons in the ^{99m}Tc energy window is less important than in the ^{201}Tl energy window, as depicted in Fig. 3. According to D'Estanque et al. [25], scatter correction is required when using ^{201}Tl/^{123}I-MIBG.

Although only the possible evaluation with and without scatter correction could help to better understand the need to use scatter for the DNM 530c, the published results suggested that correction for crosstalk, scatter and tailing effect of ^{123}I in the ^{99m}Tc photopeak may likely have only limited clinical relevance in patients with ischemic heart disease. The amount of ^{99m}Tc activity had an impact on ^{99m}Tc/^{123}I ratio but did not interfere with the energy resolution of the detector, only

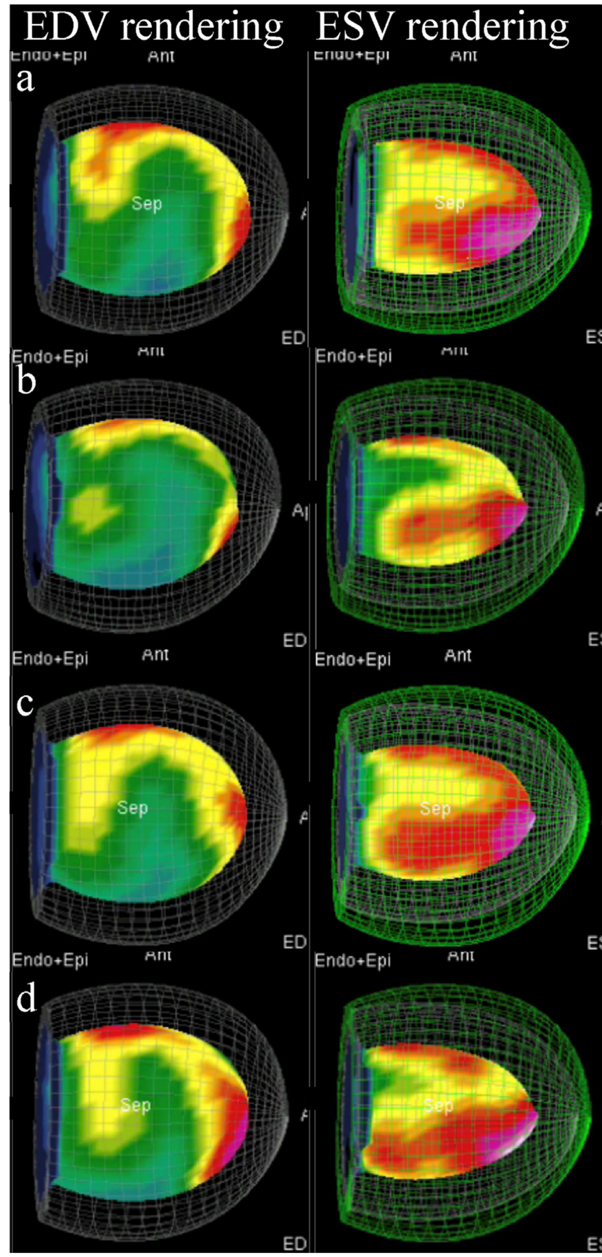

Fig. 1. End-diastolic and end-systolic volume rendering in single ^{99m}Tc (a), single ^{123}I (b), dual ^{99m}Tc (c) and dual ^{123}I (d) condition using DNM 530c, and LVEF set to 45%.
Rendu volumique télé-diastolique et télé-systolique en condition simple-isotope ^{99m}Tc (a), simple-isotope ^{123}I (b), double-isotope ^{99m}Tc (c), et double isotope ^{123}I (d) avec la DNM 530c, et la FEVG réglée à 45 %.

modifying the magnitude and not the width of the photopeak (Fig. 4).

A higher image contrast for both ^{123}I and ^{99m}Tc images was observed when using a simultaneous dual-isotope acquisition with the DSPECT compared to single isotope acquisition. The availability of tailing effect, scatter, and crosstalk corrections using the DSPECT camera only for dual (and not single) isotope acquisitions [26], may explain the difference in terms of image contrast between single-isotope (separate ^{123}I and ^{99m}Tc acquisitions) and simultaneous dual-isotope (^{123}I and ^{99m}Tc) acquisitions with the DSPECT. ^{99m}Tc crosstalk into the ^{123}I

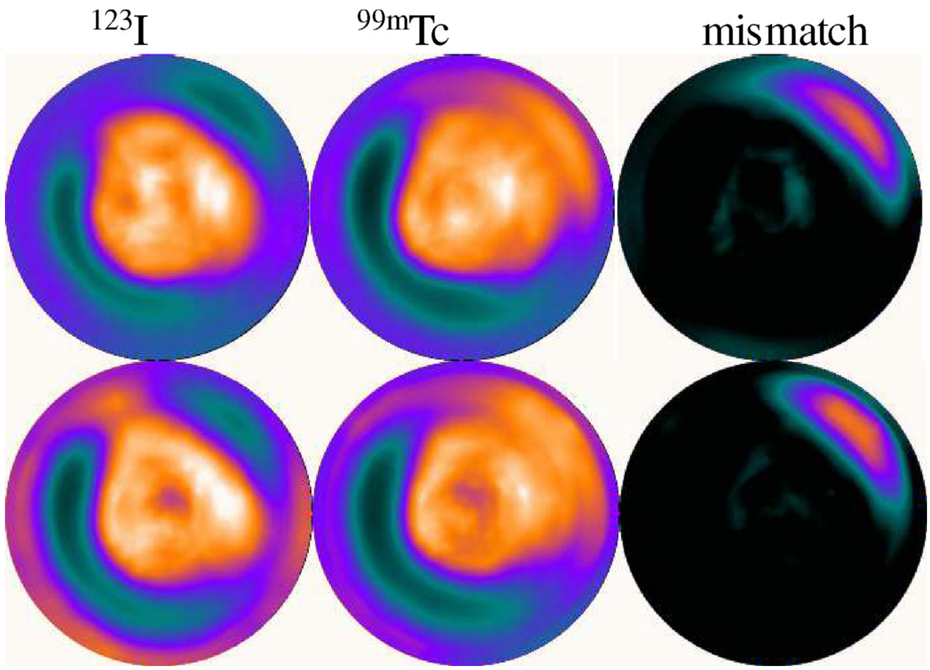

Fig. 2. Single-isotope (separate ^{123}I and ^{99m}Tc) acquisitions and mismatch (upper row) and simultaneous dual-isotope (^{123}I and ^{99m}Tc) acquisitions and mismatch (lower row) presented as the bull's eye polar maps of the 22-min acquisitions using DSPECT.
Représentation polaire sur les acquisitions 22 min des zones hypofixantes et de leurs discordances en mode simple-isotope (^{123}I puis ^{99m}Tc, ligne supérieure) effectuées sur la DSPECT, puis en mode double-isotope (^{123}I/^{99m}Tc, ligne inférieure) respectivement (b et d).

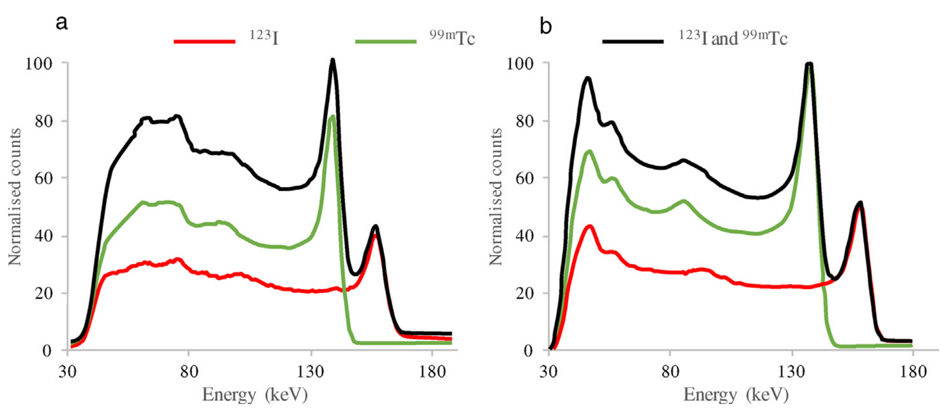

Fig. 3. Single-isotope (separate ^{123}I and ^{99m}Tc) and simultaneous dual-isotope (^{123}I and ^{99m}Tc) acquisitions on DNM 530c (a) and DSPECT (b) presented as the energy spectra of the 7 min acquisitions.
Spectre énergétique d'un fantôme (7 min) avec diffusé intra-objet en acquisitions simple-isotope (^{123}I puis ^{99m}Tc) et double-isotope (^{123}I et ^{99m}Tc) sur la DNM 530c. Remarquer l'effet de trainée et le diffusé de l'^{123}I vers le ^{99m}Tc en condition double-isotope.

window is negligible when performing a simultaneous CZT acquisition [26].

4. Simultaneous ^{123}I/^{99m}Tc dual-isotope imaging allows HMR of MIBG uptake

In the Adrecard study combining ^{123}I-MIBG and ^{99m}Tc-tetrofosmin using a DSPECT CZT camera, we demonstrated the feasibility of the assessment of cardiac neuronal function using simultaneous dual imaging in patients with heart failure [18]. Impaired myocardial innervation leads to low myocardial ^{123}I-mIBG uptake, requiring a dual isotope protocol to localize the heart. Due to the small field-of-view of the dedicated CZT cardiac cameras, a scout view is mandatory to localize the heart and correctly center the field-of-view prior to SPECT acquisition. In addition, most of the patients referred for ^{123}I-mIBG assessment have an ischemic cardiomyopathy with heart failure (66% in the ADMIRE-HF study [6]). In this clinical setting, the dual-isotope protocol allows a simple and efficient co-registration of innervation and perfusion studies, and thus a robust assessment of innervation-perfusion mismatch, and add perfusion information to the prognosis assessment.

Using the DSPECT camera, an anterior reprojection of reconstructed tomographic images offers a pseudo-planar suitable for the assessment of the heart-to-mediastinum ratio

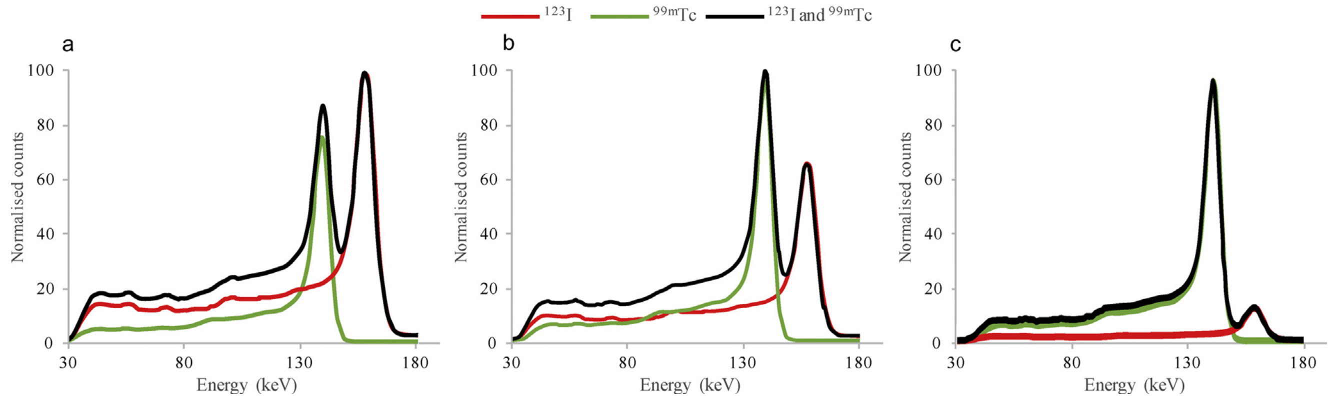

Fig. 4. Single ^{123}I (24 MBq), single ^{99m}Tc, and simultaneous (^{123}I and ^{99m}Tc) energy spectra using linear sources and DNM 530c. Low tailing effect and down-scatter of ^{123}I toward ^{99m}Tc (and absence of ^{99m}Tc scatter toward ^{123}I) were observed in dual-isotope condition, whatever the ratio of ^{99m}Tc activity to ^{123}I activity: 0.5:1 (a), 1:1 (b), or 5:1 (c).

Spectres énergétiques effectués avec des sources linéaires sur la DNM 530c en acquisitions simple-isotope : ^{123}I (24 MBq), ^{99m}Tc, puis double-isotope (^{123}I et ^{99m}Tc). Les effets de trainée et de contamination de l'^{123}I vers le ^{99m}Tc (et absence de diffusé du ^{99m}Tc vers l'^{123}I) sont présents en condition double-isotope, quel que soit le ratio d'activité ^{99m}Tc/^{123}I : 0.5/1 (a), 1/1 (b), et 5/1 (c) respectivement.

(HMR) of mIBG uptake. After normalization using phantom measurements, the ^{123}I-mIBG HMR is concordant to planar measurement using conventional Anger camera.

Using the DNM 530c with multi-pinhole collimation, the situation is quite different, the reprojection of pseudo-planar images providing a fair agreement to planar techniques. This weakness is related to the multi-pinhole collimation, which is responsible for a truncation artifact [27] that interferes with the mean counts of the myocardial ROI, and for a larger nonuniformity with DNM 530c than with the Anger camera [27]. This phenomenon was overcome through the use of reconstructed transaxial images instead of reprojection images for the measurement of corrected ^{123}I-MIBG HMR with the DNM 530c [28].

Finally, acquisition of both SPECT and planar images using the Anger camera usually requires 30–45 min. In contrast, acquisition with CZT cameras usually requires only 10 min, an acquisition duration that is much more convenient in patients with heart failure.

5. Conclusion

With an increased energy resolution, simultaneous dual isotope perfusion/innervation imaging using CZT cameras (i) does not compromise the assessment of left ventricular function (EDV, ESV and LVEF) under dual acquisition condition, (ii) allows the segmental study of myocardial innervation and perfusion mismatch, and (iii) permits the determination of the late HMR of cardiac ^{123}I-MIBG uptake in patients with heart failure. However, this latter procedure should be performed using anterior reprojection images with the DSPECT camera and transaxial reconstructed images using the DNM 530c, after correction based on phantom data acquisitions for both cameras.

Disclosure of interest

The authors declare that they have no competing interest.

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