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Review article

Cadmium–zinc–telluride SPECT scanners – New perspectives in nuclear cardiology

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ABSTRACT

Nuclear cardiology is one of the most important non-invasive imaging methods in cardiac imaging. It makes possible primarily functional assessment of the heart with quantification of perfusion and systolic function. Development of new types of scanners for nuclear cardiology brings more possibilities in research and clinical practice. This paper describes a brief review of some applications of cadmium-zinc–telluride (CZT) scanners in comparison with conventional cameras.

Contents

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Introduction

Nuclear cardiology is an established and well proved method in non-invasive cardiac imaging. Its sensitivity and specificity for diagnosis of myocardial ischaemia and viability assessment have been reported in many studies [1–4]. For several decades, the single-photon emission tomography (SPECT) scanners used for cardiac imaging were the same as for general nuclear medicine purposes. The conventional type of scanner (Fig. 1) consists of a scintillation detector, using natrium iodide crystal activated by thallium (NaI [Tl]). It works on principle of luminescence, when impact of gamma radiation photon on NaI [Tl] crystal causes a flash of visible light. This flash is detected by photomultiplier tube (PMT), multiplied and transformed to electric signal. The average spatial resolution of scintillation scanners is about 1–2 cm and acquisition time varies between approx. 10and 20 min according to administered activity of radiopharmaceutics. The cadmium–zinc–telluride (CZT) SPECT scanners have been introduced in the first decade of 21st century [5]. The CZT detector works as a semiconductor with direct conversion of gamma radiation to electric signal. This mechanism results in better spatial resolution and sensitivity, what means lower administered dose of radiopharmaceutics and/or shorter acquisition time. One of the most frequently used systems is D-SPECT (Spectrum Dynamics, Haifa, Israel), which uses pixelated CZT detector arrays in 9 vertical columns mounted in a 90° gantry geometry. The parallel hole high sensitivity collimators are made of tungsten. Another commercially available CZT camera is Discovery 530c (SPECT alone – Fig. 2) or 570c (SPECT/CT) manufactured by GE Healthcare (Haifa, Israel). This system is based on multi-pinhole collimator system and an array of nineteen CZT pixelated detectors. Spatial resolution was reported better in GE Discovery (6.7 vs 8.6 mm); count sensitivity is higher in D-SPECT (850 vs 460 counts per second per MBq). Both parameters are better than the mean values for conventional SPECT (15.3 mm of spatial resolution and sensitivity of 130 counts per second per Mbq) [6]. This paper brings a brief review of previously performed studies with CZT SPECT scanners.

Radiation dose reduction

Lowering of radiation doses is currently one of the most frequent issues in diagnostic procedures. However, the

Fig. 1 – Conventional two-detector SPECT camera (Discovery NM 630, GE Healthcare).

Fig. 2 – CZT camera with 90° arch of detectors (Discovery 530c, GE Healthcare).

nuclear medicine methods are not the main source of radiation exposure in healthcare in comparison with e.g. computed tomography, the reduction of administered doses of radiopharmaceutics is beneficial for patients and for nuclear cardiology staff as well. First clinical experience with CZT scanner and dose reduction was described by Duvall et al. [7]. Authors retrospectively analysed 717 patients, using GE Discovery 530c. The examinations were performed during four months, and patients were divided into three groups: stress-only protocol with high dose, stress-only with low dose and rest-stress protocol with standard dose of isotope. The stress dose for low-dose protocol was 462.5 MBq, high dose was 925–1332 MBq according to patient's weight. The low-dose rest dose was 296–481 MBq also adjusted to weight. The administered activity was reduced by 70% in the low-dose and 30% in the high-dose stress-only group in comparison with usually used doses. This results also in lower mean effective doses – 4.2 mSv, 8.0 mSv and 11.8 mSv in low-dose stress-only, high-dose stress-only and rest-stress group respectively. The image quality was assessed as good or excellent in more than 90% in all groups. In another study, the shortening of acquisition time with low administered dose did not affect image quality and diagnostic accuracy in comparison with scintillation camera [8]. Acquisition times were 5 and 8 min for rest, 3 and 5 min for stress images on CZT camera and 15 min for stress on conventional SPECT. There was no significant difference between mean perfusion deficit, ejection fraction or left ventricular volumes measured by shorter or longer acquisition time on CZT camera and between CZT and conventional camera. The images obtained by CZT SPECT showed significantly better quality despite shorter time and lower total impulse count. Radiation exposure in rest-stress low-dose protocol was almost one-half of that in conventional protocol with Tc-99 m sestamibi. Also ultra low-dose protocol (with radiation exposure about 1 mSv) proved good correlation between image quality, ejection fraction and total perfusion deficit obtained by conventional and CZT camera [9].

Diagnosis of coronary artery disease

The invasive coronary angiography is considered as a "gold standard" in diagnosis of coronary artery disease (CAD). Conventional SPECT systems proved good sensitivity and specificity in many studies; the values are about 73–92% for sensitivity and 63–87% for specificity [10]. Comparison of myocardial perfusion imaging using CZT SPECT and invasive coronary angiography showed more than 90% sensitivity for detection ≥70% stenosis of epicardial artery [11]. The specificity was lower, according to patients' selection it varied between 36.9 and 55.6% and diagnostic accuracy varied between 68.7 and 71.6%. Better results can be achieved with hybrid imaging (SPECT/CT) and attenuation correction [12]. This may improve image quality particularly in obese patients, and reported sensitivity, specificity, positive and negative predictive values and diagnostic accuracy were 87, 67, 92, 53 and 83% respectively. The assessment of specificity of SPECT is problematic, because patients with negative perfusion imaging are mostly not referred for coronary angiography. Some studies predict sensitivity and specificity from normalcy rate in cohorts of patient with very low pre-test probability of CAD, but current guidelines for CAD diagnosis and treatment [10] do not recommend performing stress testing in patients with very low pre-test probability (<15%). Furthermore, the higher sensitivity and better spatial resolution can lead to imaging of smaller and non-severe perfusion defects due to endothelial dysfunction in patients without significant epicardial coronary artery stenosis, and it may also affect specificity of CZT cameras [12]. The assessment of left ventricular function and volumes is also more accurate using CZT camera in comparison with conventional devices [13]. Use of invasive coronary angiography as a reference method may produce another bias, because it is comparison of anatomical and functional method. Fractional flow reserve can provide relevant information about significance of stenosis and this method was used by Mouden et al. [14] in group of patients with intermediate coronary artery stenosis (40–80%). The cut-off value of <0.75 was set for FFR as abnormal. Myocardial perfusion imaging with CZT camera showed ischaemia in 31%, FFR was <0.75 in 20%, and patients with positive SPECT had significantly lower FFR value (0.77 ± 0.12 vs 0.83 ± 0.07; $p = 0.001$). Concordance between SPECT and FFR was 73%, 8% of SPECT were false negative, and 19% false positive. The benefit of CZT technology is also presented in patients with coronary multivessel disease. In the study of Gimelli et al. [15], CZT SPECT from 20 patients with 2- or 3-vessel disease identified correctly all significant coronary artery stenosis in 17 patients versus 6 by standard system, so use of CZT SPECT is favourable in these patients due to better sensitivity.

Sympathetic innervation imaging

The importance of assessment of myocardial sympathetic innervation using ^{123}I-metaiodobenzylguanidine (MIBG) was reported in several papers [16–18], but all these studies were performed on scintillation gamma cameras. Most frequently used parameters were heart-to-mediastinum ratio (H/M) and MIBG myocardial washout rate.

Initial experience with use of CZT camera in myocardial sympathetic innervation imaging was described by Gimelli et al. [19]. The authors used MIBG defect score, calculated from 17 segment left ventricular model and five-point scale (0 = normal, 4 = absence of tracer uptake) and segmental radiotracer uptake calculated as percentage of peak tracer uptake. Furthermore, the mechanical dyssynchrony of the left ventricle was evaluated, using regional time to peak contraction (TTP) measurements. The regional TTP is the maximum heart wall contraction expressed as percentage of the cardiac cycle [20]. This study showed independent association of regional MIBG uptake and left ventricular dyssynchrony, patients with the presence of dyssynchrony had higher mean MIBG early defect score (29 vs 18, $p = 0.014$) and authors implicate it represents significant relation between myocardial contraction synchronicity and degree of sympathetic denervation. Also direct comparison of MIBG uptake and myocardial perfusion assessed by 99mTc tetrofosmin SPECT confirmed association of impaired sympathetic innervation and perfusion defects expressed as summed rest score [21].

Other applications

One of the main problems of perfusion SPECT is that it shows only relative perfusion. That may produce diagnostic bias especially in patients with multiple coronary stenoses, e.g. balanced triple vessel disease. The fast data acquisition of the CZT scanners makes it possible to assess the myocardial perfusion reserve at rest and during vasodilator stress. Ben-Haim et al. [22] described experimental protocol using dynamic SPECT images acquired at rest and then during pharmacological stress with list-mode acquisition. After dynamic images, the standard rest and stress images were recorded as well. Regional and global activity curves were obtained from dynamic images and myocardial perfusion reserve index (MPR) was calculated as ratio of the stress and rest values. Patients with normal perfusion scans had higher MPR index (1.61. vs 1.27, $p = 0.0002$). In regional analysis, coronary territories with abnormal total perfusion deficit (TPD ≥5% calculated by QPS software) had lower MPR index (1.27 vs 1.45, $p = 0.003$) and significant association between regional TPD and MPR index was confirmed by multivariable analysis. The CZT technology also brings new possibilities using dual-isotope imaging. In a study with 214 patients [23], the stress 201-thallium and rest 99m-technetium imaging was used, and this study showed sensitivity 94%, specificity 50% (normalcy rate 92%), and diagnostic accuracy 83%, with reported mean estimated effective dose 12 ± 9 mSv. Authors presented advantages of dual isotope imaging, as better extraction fraction of thallium that improves myocardial ischaemia detection. Shortening of examination time (whole stress-rest protocol in this study was performed within 1 h) can lead to higher patient flow in nuclear cardiology department and better efficiency in CZT camera utilization. Radionuclide ventriculography can also be performed by CZT SPECT. Jensen et al. [13] reported better inter- and intraobserver variability in left ventricular ejection fraction assessment using CZT SPECT versus conventional NaI planar or SPECT camera. The mean LVEF values obtained by NaI SPECT were significantly higher than those from CZT SPECT or NaI planar imaging. This was caused by higher end diastolic volumes measured by NaI SPECT when end-systolic volumes did not significantly differ. These findings were also confirmed in another study [24], but authors also mentioned limitations of this system – e.g. small field of view (FOV) with approximately 19 cm diameter [25], and in subgroup of obese patients it is not possible to get good position of the heart in FOV, so use of CZT SPECT in these patients is not recommended. Also financial issues are important and purchasing prices can be almost twice as higher (with respect to local additional taxes) than in conventional system, so CZT SPECT is useful mainly in larger centres with high number of patients.

Conclusion

The cadmium–zinc–telluride SPECT scanners bring new possibilities to non-invasive cardiac functional imaging and the data from previously published studies are very promising. However, it is necessary to mention some pitfalls such as high purchase costs, smaller field of view and absence of real specificity data because only selected patients are subsequently sent for a reference method as coronary angiography. Also use of coronary angiography as a reference method is problematic, because is not a functional but an anatomical imaging method, so assessment of coronary artery stenosis by FFR is better to compare with myocardial perfusion imaging data.

Conflict of interest statement

None declared.

Ethical statement

Authors hereby declare this article was written according to ethical standards.

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