LEKÁRSKE VEDY | OŠETROVATEĽSTVO | PÔRODNÁ ASISTENCIA | URGENTNÁ ZDRAVOTNÁ STAROSTLIVOSŤ | RÁDIOLOGICKÁ TECHNIKA

New Diagnostic Equipment at the Department of Nuclear Medicine in Diagnostic of Coronary Heart Disease

Nové prístrojové vybavenie na Klinike nukleárnej medicíny pri diagnostike ischemickej choroby srdca

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Summary
Introduction: In the present turbulent era, security management extends across a broad spectrum of societal life, ranging from the everyday activities of citizens to scientific and technical endeavors in many disciplines. A critical element of every social system is healthcare. Modern technologies are being introduced into this field almost on a daily basis. For accurate disease diagnostics, contemporary healthcare requires high-quality imaging methods. One of the imaging modalities is the discipline of nuclear medicine. Radioactive substances administered into the patient's body provide an accurate picture of the functional state of the internal environment. Both patients and healthcare personnel are exposed to invisible ionizing radiation, which, in doses exceeding established limits, becomes hazardous. Similar to other disciplines, nuclear medicine is continually advancing. The current standard is represented by SPECT technologies. SPECT CZT is an upgraded system in which analog detection technology has been replaced by semiconductors. Atherosclerosis plays a key role in the etiopathogenesis of cardiovascular diseases. Atherosclerosis is a generalized chronic inflammatory disease of the vascular wall, which results in anatomical and histological changes that, together with functional changes, lead to endothelial dysfunction, narrowing of the arterial lumen, and insufficient blood supply to the tissues. The high incidence of cardiovascular diseases, especially ischemic heart disease, requires early diagnosis and modern treatment.
Methodology: Using nuclear medicine methods, we try to detect these changes in time and thus prevent the occurrence of acute coronary events. In nuclear cardiology, instead of a large-area scintillation detector, a new type of cardio-gamma camera "Discovery CZT 530c" based on the principle of semiconductor detectors began to be used. The abbreviation CZT stands for semiconductor composition (Cadmium-Zinc-Tellur).
The set of respondents consisted of 6280 people examined in the years 2020-2025 by myocardial perfusion scintigraphy. There were 3140 nondiabetic patients and 3140 diabetic patients in the analysed group of the 6280 examined.
Results: In the analysed group of 3140 nondiabetic respondents, 75% had negative findings and 25% had positive findings in terms of the presence of ischemic heart disease. In the group 3140 of diabetic patients, there was a negative finding in 63% of respondents and a positive finding in 37% of the respondents in the sense of positive ischemic heart disease. Using myocardial perfusion scintigraphy in the diagnosis of functional changes, we confirmed a benefit in detecting early changes in coronary heart disease, including in the diagnosis of microvascular angina.
Conclusion: Nuclear medicine methods are of great benefit for the diagnosis of small vessel disease, diabetic cardiomyopathy and cardiac autonomic neuropathy in patients with diabetes mellitus. The new type of cardio gamma camera "Discovery CZT 530c" allows more accurate assessment of myocardial perfusion abnormalities and at the same time the reduction of the radiopharmaceutical dose reduces the patient's radiation load by 50%.

Keywords: Semiconductor Detectors for Ionizing Radiation. Cardiac CZT SPECT gamma camera 530c. SPECT/CT camera Star Guide. Coronary heart disease. Radionuclides.

Súhrn
Úvod: V dnešnej turbulentnej dobe manažérstvo bezpečnosti zasahuje do širokého spektra života spoločnosti, od bežného denného života obyvateľov až po vedecko technické aktivity z oblasti mnohých disciplín. Kritickým prvkom každého spoločenského zriadenia je zdravotníctvo. Moderné technológie vstupujú do odboru takmer na dennej báze. Pre správnu diagnostiku ochorení musí mať moderné zdravotníctvo kvalitné zobrazovacie metódy. Jednou z foriem zobrazovacích metód je aj odbor nukleárnej medicíny. Rádioaktívne látky aplikované do tela pacienta poskytujú presný obraz stavu funkčnosti vnútorného prostredia. Pacienti aj personál prichádzajú do styku s neviditeľným ionizujúcim žiarením, ktoré je v nadlimitných dávkach nebezpečné. Ako iné odbory tak aj nukleárna medicína neustále napreduje. Momentálnym štandardom sú technológie SPECT. SPECT CZT je upgradovaným systémom, kde je analógová snímacia technológia nahradená polovodičmi.
Ateroskleróza zohráva kľúčovú úlohu v etiopatogenéze kardiovaskulárnych ochorení. Ateroskleróza je generalizované chronické zápalové ochorenie cievnej steny, ktorého výsledkom sú anatomické a histologické zmeny, ktoré spolu s funkčnými zmenami vedú k dysfunkcii endotelu, zúženiu priesvitu tepien a nedostatočnému prekrveniu tkanív. Vysoký výskyt kardiovaskulárnych ochorení, najmä ischemickej choroby srdca si vyžaduje včasnú diagnostiku a modernú liečbu.
Súbor a metodika: Metódami nukleárnej medicíny sa snažíme tieto zmeny včas odhaliť a zabrániť tak vzniku akútnych koronárnych príhod. V nukleárnej kardiológii sa namiesto veľkoplošného scintilačného detektora začal používať nový typ kardio-gamakamery „Discovery CZT 530c" na princípe polovodičových detektorov. Skratka CZT znamená zloženie polovodičov (Cadmium-Zinc-Tellur).
Súbor respondentov tvorilo 6280 respondentov vyšetrených za roky 2020- 2025, u ktorých bolo vykonané vyšetrenie perfúznou scintigrafiou myokardu. V analyzovanom súbore 6280 vyšetrených bolo 3140 nediabetikov a 3140 diabetikov.
Výsledky: V analyzovanom súbore 3140 nediabetických respondentov bolo 75% negatívnych nálezov a 25% pozitívnych nálezov v zmysle prítomnosti ischemickej choroby srdca. V súbore 3140 diabetikov pri vyšetrení sme zistili negatívny nález u 63% respondentov a pozitívny nález u 37% respondentov v zmysle pozitivity ischemickej choroba srdca. Vyšetrením perfúznou scintigrafiou myokardu v diagnostike funkčných zmien

sme potvrdili prínos pri záchyte včasných zmien pri koronárnej chorobe srdca a to aj pri diagnostike mikrovaskulárnej angíny.
Záver: Metódy nukleárnej medicíny sú veľkým prínosom pre diagnostiku choroby malých ciev, diabetickej kardiomyopatie aj kardiálnej autonómnej neuropatie u pacientov s diabetes mellitus. Nový typ kardiogamakamery „Discovery CZT 530c" umožňuje presnejšie hodnotiť abnormality perfúzie myokardu, zároveň redukcia dávky rádiofarmaka znižuje o 50% radiačnú záťaž pacienta.

Kľúčové slová: Polovodičový detektor. Kardiogamakamera CZT 530c. SPECT/CT kamera Star Guide. Ischemická choroba srdca. Rádionuklidy.

1 New Diagnostic Equipment at the Department of Nuclear Medicine

An ionizing radiation detector (gamma camera) is a device capable of detecting ionizing radiation. According to the principle, there are two main types of detectors that form the basic unit for imaging devices (gamma camera):

- Scintillation detector of ionizing radiation on a conventional SPECT gamma camera (scintillation in the crystal).
- Semiconductor detector of ionizing radiation (ionization in a solid substance in a semiconductor).

Semiconductor Detectors for Ionizing Radiation

Semiconductors are solid substances whose electrical conductivity is higher than that of insulators but lower than that of metals. The electric current is carried by electron–hole pairs. Radiation particles are capable of directly or indirectly ionizing the atoms of the semiconductor, thereby generating free charge carriers. The resulting electron (–)–hole (0) pairs increase the current flow, the value of which provides information about the energy spectrum of the incident particles.

- The electric current is carried by electron–hole pairs.
- One detection unit of the semiconductor corresponds to one aperture on the collimator (pinhole), representing one image point (pixel).
- Sensitivity is increased (by a factor of 4) and resolution is improved.

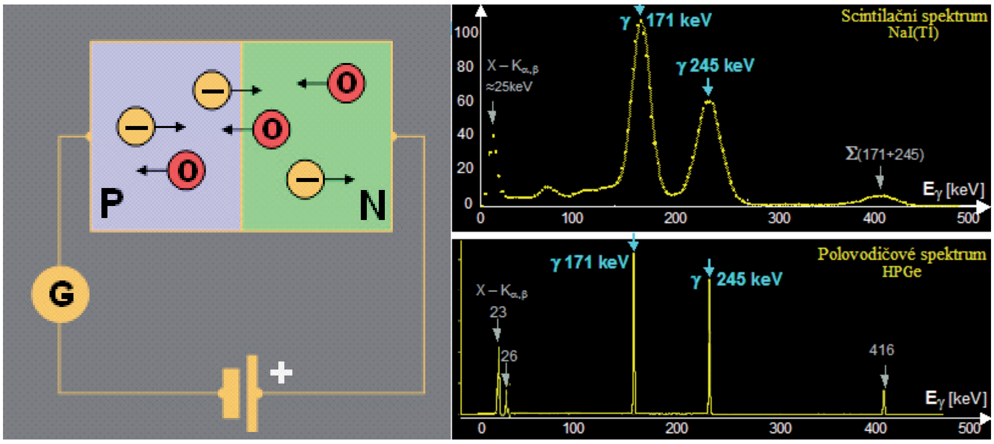

Figure 1 *Principle of a semiconductor detector (SD) – comparison of the energy spectrum obtained from a semiconductor detector demonstrates significantly higher resolution in contrast to the spectrum from a scintillation detector (1,4).*

When comparing semiconductor detectors with gas-filled ionization detectors, their advantage lies in the tenfold lower energy (2.96 eV–Ge) required to create a single ion pair, which results in higher resolution capability. In comparison with scintillation detectors, they provide substantially more precise energy resolution and exhibit significantly (20×) higher sensitivity.

Classical semiconductor detectors are constructed from highly purified monocrystals of germanium (Ge) or silicon (Si), enriched with trace amounts of lithium (Li). Semiconductor detectors have found application not only in smaller detectors but also in gamma cameras and PET scanners (1,2).

The spatial resolution of new semiconductor cameras (defined by a single pixel) is 2.5 mm, which is twice as good as that of conventional scintillation cameras. This technology, in terms of image quality, approaches that of PET technology.

The cadmium–zinc–telluride (CZT) semiconductor detector, used in digital semiconductor gamma cameras with direct gamma radiation conversion, is designed so that one aperture on the collimator corresponds to one semiconductor detection unit and simultaneously to one resulting image point (pixel) (3,4).

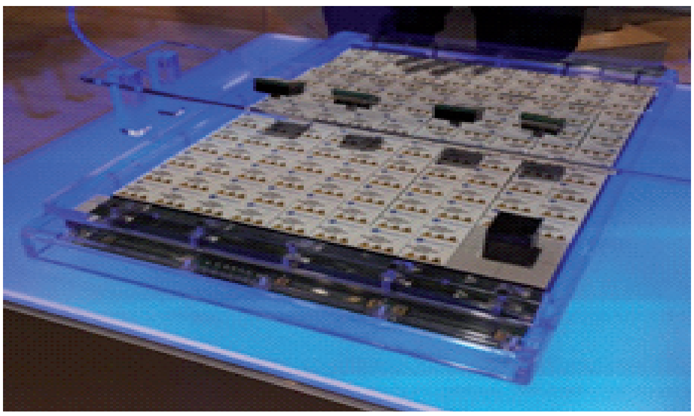

Figure 2 *Semiconductor detector (4)*

***Cardiac CZT SPECT gamma camera 530c by GE with** Semiconductor Detectors for Ionizing Radiation*

At the Nuclear medicine clinic at ÚVN Ružomberok, we have been working with a CZT 530c cardio camera with semiconductor detectors since September 2019 (Figure 5).

A gamma camera based on the principle of a semiconductor detector employs, instead of a large planar scintillation detector, a semiconductor cadmium–zinc–telluride (CZT) detector equipped with a greater number of pinhole collimators. The semiconductor cadmium–zinc–telluride detector (CZT) incorporates multiple pinhole collimators arranged in a semicircle, capturing data simultaneously from several angles without the need for rotation around the patient (5).

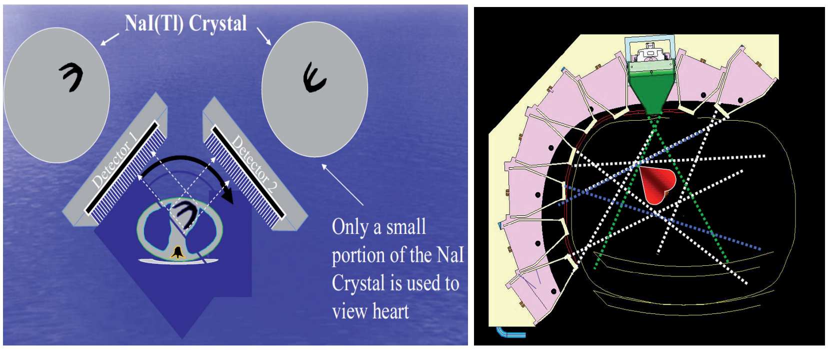

***Figure 3** Diagram of a conventional SPECT device (Vitola, J. V., 2004)*

Advantages:

- Shortened examination time, resulting in increased work efficiency;
- Acquisition of the final scan within 5–7–10 minutes;
- Fourfold higher sensitivity with improved resolution;
- Reduction of the radiopharmaceutical dose by 50% (decreasing the patient's radiation burden by 50%);
- Improved flexibility and higher efficiency in radiopharmaceutical preparation;
- Enhanced evaluation of hemodynamic parameters;
- Possibility of dynamic imaging in 3D projection;
- Capability of assessing coronary flow reserve;
- Obtained scan demonstrates more valid results in comparison with coronary angiography.

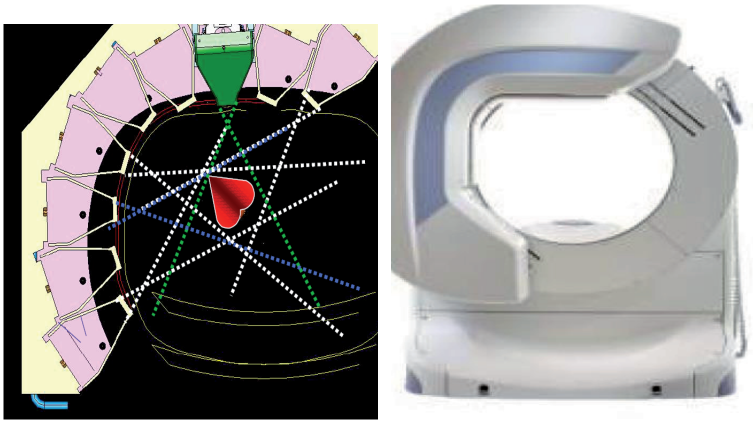

***Figure 4** Cadmium–zinc–telluride semiconductor detector. In digital semiconductor gamma cameras with direct gamma radiation conversion, one aperture on the collimator corresponds to one semiconductor detection unit and simultaneously to one resulting image point (pixel).*

Figure 5 *Semiconductor cardiac gamma camera "Discovery CZT 530c" by GE (Central Military Hospital – University Hospital Ružomberok).*

SPECT/CT camera with 12 radially arranged CZT detectors – StarGuide by GE

The SPECT/CT gamma camera StarGuide by GE is equipped with 12 independent digital detectors positioned on a special gantry-mounted ring. The larger number of fixed cadmium–zinc–telluride (CZT) semiconductor detectors, arranged in a circle around the patient, enables simultaneous acquisition from multiple angles (6).

A standard distance between the detectors and the patient's body surface, positioned on a movable table, is maintained by optical sensors. The detectors are capable of moving toward the patient's body from all angles, approaching to very close proximity. Furthermore, the detector plates in the apical part of the segments can rotate and adjust the imaging angle.

The acquisition process from all angles supports all types of imaging: planar, static, dynamic, whole-body, tomographic, and dynamic reconstruction in 3D imaging. Following software processing, image rotation, precise localization, and visualization of lesions that would otherwise be superimposed in 2D projection are made possible. The coordination of detector movements and positioning achieves exceptional volumetric sensitivity and resolution.

The sharpness of the image and the visualization of very small pathological and anatomical details are of major significance for diagnostics. The reconstructed image in many respects approaches the quality of PET scanners. Moreover, it is possible to calculate SUV (standardized uptake value) – the absorbed dose, and MIP (maximum intensity projection) – the maximum display intensity (1).

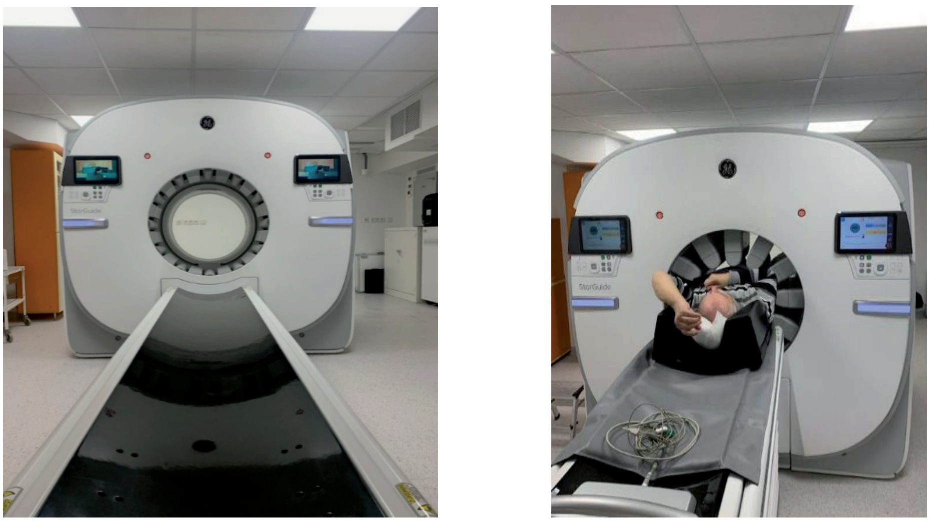

Figure 6 *StarGuide camera with 12 independent detectors (Central Military Hospital – University Hospital Ružomberok, Slovakia)*

The directly integrated CT enables the acquisition of both functional and anatomical images within a single system, in immediate sequence, with the patient remaining in one position. For CT imaging, the "low dose" option (localization CT imaging) is typically selected. In certain cases (e.g., oncological diagnostics), a full diagnostic multi-slice CT is required. The hybrid SPECT/CT system thus provides both functional and anatomical images simultaneously. In addition to precise anatomical information used for more accurate localization of findings, the acquired CT data also provide a density map, which is applied for attenuation correction (7).

2 Examination methods

Several methods are used in the diagnosis of CHD (ECG, exercise ECG examination, ECHO, biochemical and haematological examinations etc.). Important methods include MSCT coronary angiography and classic selective coronary angiography (SCA), which is also a treatment method. Diagnostic methods include perfusion scintigraphy of the myocardium, which is important for early diagnosis of coronary artery disease (8,9,10).

It allows determining the extent and severity of the disorder, provides information on the state of the macrocirculation, as well as the state of the microcirculation. Selective coronary angiography primarily shows changes in the main coronary vessels and their branches. It can also indirectly indicate a disease of small vessels (*for example, atherosclerotic changes on the coronary arteries may not be visible, but a slow flow of contrast material is present*). Selective coronary angiography and perfusion scintigraphy are complementary examinations.

In myocardial perfusion scintigraphy, most often used radiopharmaceuticals are **^{99m}Tc sestamibi** *(MIBI-methoxy-isobutyl-isonitril)* **and ^{99m}Tc tetrofosmin** *(Myoview-ethoxyethylfosfino-ethan)*.

With normal blood flow through the coronary vessels, the deposition of radioactivity in the myocardium is homogeneous. When the blood flow in the myocardium changes, defects in the deposition of radioactivity appear in the affected area. We usually use a two-day protocol with ^{99m}Tc tetrofosmin,(Myoview) starting with a stress examination, if necessary, we will do a rest examination with the application of ^{99m}Tc tetrofosmin on another day (10).

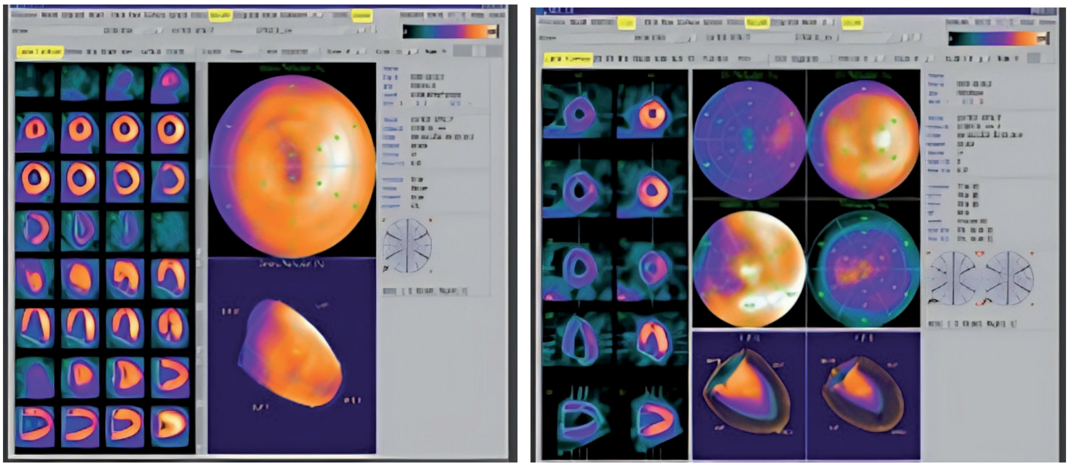

Figure 7 *Normal scintigraphic finding. The upper image shows myocardial perfusion. In the lower panel: the upper images depict the end-diastolic and end-systolic phases. The lower left image demonstrates wall motion (kinetics), and the lower right image shows myocardial contractility.*

A perfusion defect appears in the basin of the narrowed vessel on scintigrams. A defect present only after exercise, regressing at rest, indicates the reversibility of perfusion in ischemia (10). After an MI, a permanent perfusion defect may be present. The effect of coronary stenosis on the blood supply to the myocardium, especially during exercise and at rest, is evaluated as a coronary flow reserve.

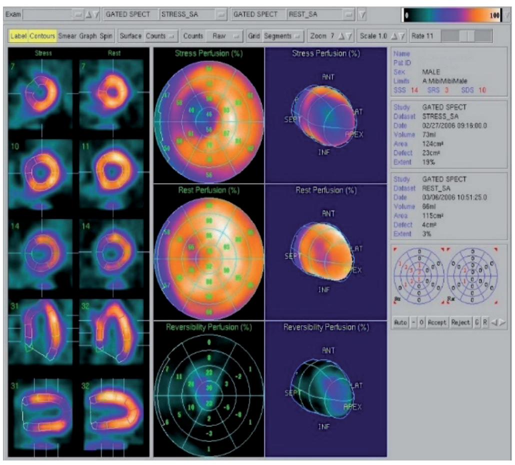

Figure 8 *Upper image: positive scintigraphic finding during stress. Middle image: rest perfusion imaging with resolution of perfusion abnormalities. Lower image: difference in perfusion abnormalities between stress and rest. Clinically, the patient reported stabbing interscapular pain during exertion. ECG and exercise testing were within normal limits. Echocardiography showed no current abnormalities and no wall motion abnormalities. Coronary angiography revealed a 90% stenosis of the left anterior descending artery (LAD). Percutaneous coronary intervention with stent implantation was performed. Follow-up examination after treatment showed a normal finding.*

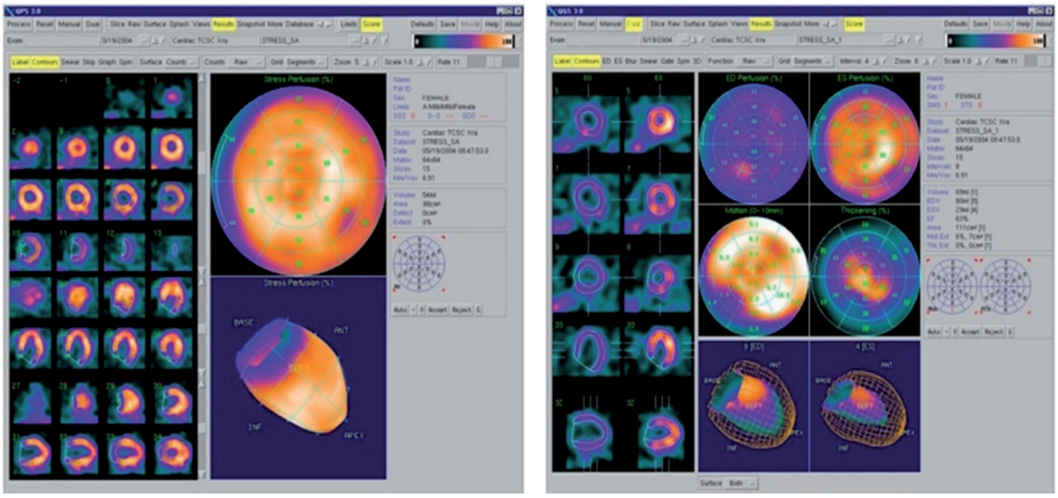

Figure 9 *Left image: minimal posterolateral hypoperfusion. Right image: no wall motion abnormality detected. Clinically, the patient reported morning chest pressure without exertional angina and dyspnea. Resting ECG was within normal limits; during stress, ST-segment depressions were present in leads II, III, aVF, and V4–V6. Coronary angiography revealed an ostial occlusion of the left anterior descending artery (LAD), with complete filling via heterocollaterals. The circumflex artery (LCx) showed a 40% stenosis distal to the obtuse marginal branch (OM); conservative management was chosen. Myocardial perfusion scintigraphy (MPS) with ^{99}mTc Myoview.*

Dysfunctional segments with a fixed defect accumulating **< 50%** of maximum radioactivity are considered to be a post-MI scar, with accumulation of **radioactivity > 50%** of maximum, it may be a **chronically hypoperfused "hibernating" myocardium.** The finding of normal perfusion in a dysfunctional hypokinetic or even akinetic segment usually indicates a **"stunning" myocardium** (11).

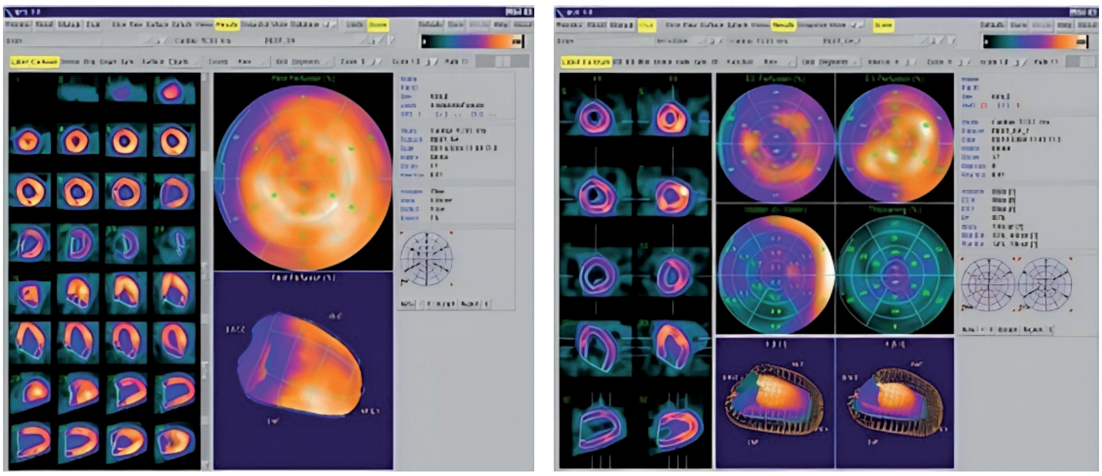

Figure 10 *Left: normal perfusion on stress imaging. Upper right: end-diastolic image with mild abnormalities and normal end-systolic image. Middle: wall motion imaging showing a marked abnormality in the septal and inferior wall regions. Lower right: impaired wall thickening (contractility), consistent with viable but stunned myocardium on 99mTc Myoview imaging.*

Patients with diabetes are a specific group for the diagnosis of cardiac complications. Cardiac complications of diabetes include:

- Coronary heart disease (CHD) based on atherosclerosis of the coronary arteries.
- Small vessels disease.
- Diabetic cardiomyopathy.
- Cardiac autonomic neuropathy (CAN) (12).

The prevalence of **coronary heart disease** in patients with diabetes is approximately 45%, in non-diabetics approximately 25%. The occurrence of silent ischemia is more frequent in approximately 10-20% of diabetic patients, compared to 1-4% of non-diabetics (13,14,15). Coronary heart disease in patients with diabetes is more severe than in non-diabetics. The occurrence of inflammation in vulnerable atherosclerotic plaques is more common. In diabetes, the collateral circulation is formed more slowly. In diabetes, the protective effect of estrogens on the vascular wall decreases in women, atherosclerotic changes are more pronounced in women with diabetes and occur at a younger age (16,17). The development of new medicaments (e.g. *SGLT2 inhibitors, GLP-1 receptor agonists*), improving the morbidity and mortality of patients with diabetes, shows that an ill diabetic must be detected as soon as possible (18,19).

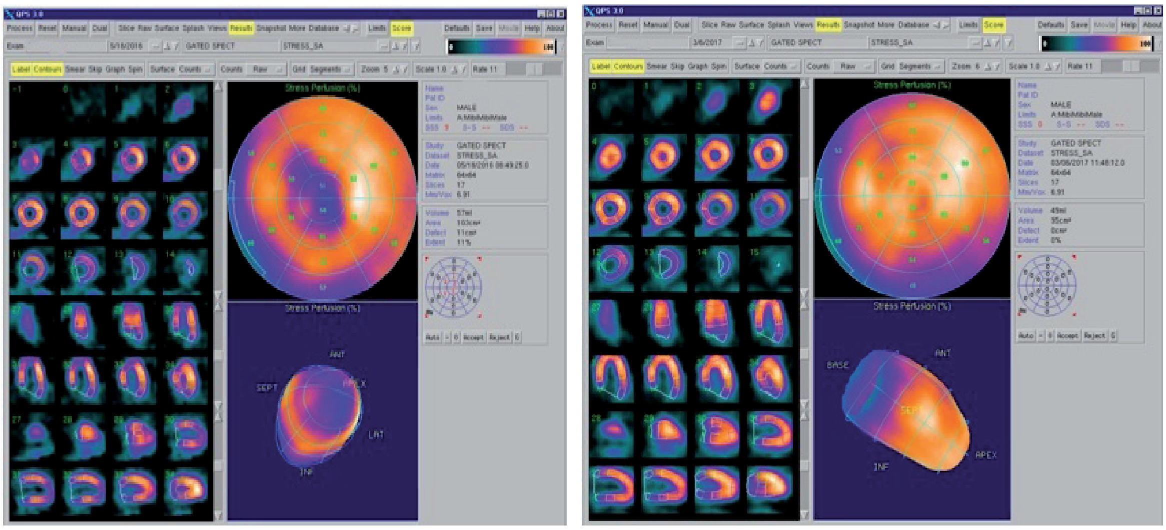

***Figure 11** Silent ischemia in a patient with diabetes mellitus. The patient had a 10-year history of diabetes mellitus and was clinically asymptomatic for ischemia. Resting ECG and exercise stress testing were within normal limits. Echocardiography revealed no pathological findings. Myocardial perfusion scintigraphy demonstrated hypoperfusion of the anterior wall (left). Coronary angiography identified a 75% stenosis of the left anterior descending artery (LAD); percutaneous coronary intervention (PCI) with stent implantation was performed. Right: follow-up myocardial perfusion scintigraphy after the invasive procedure.*

Small vessel disease is a functional and structural abnormality of the coronary microcirculation. The structural abnormality is caused by a change in the basement membrane, mainly by its thickening and endothelial proliferation of arterioles, which limits the vasodilation reserve of the coronary blood flow. Clinically, they can be manifested by angina pectoris, ischemic changes on the ECG at rest or during exertion. Non-invasive and invasive diagnostic methods help in differential diagnosis (20,21).

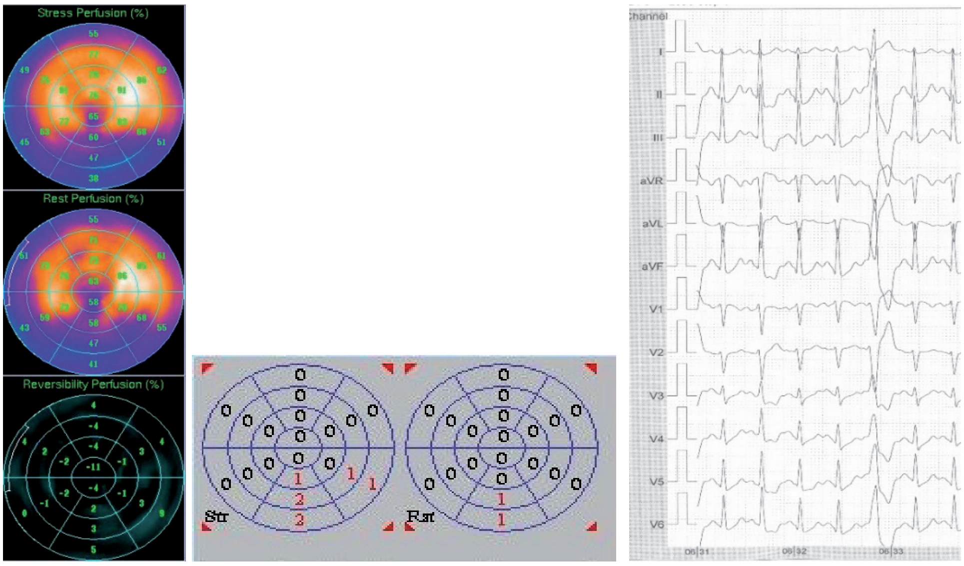

***Figure 12** Small vessel disease. Hypoperfusion of the inferior and posterolateral walls. Coronary angiography without significant findings. ECG showed pathological changes.*

3 A set of examined patients

On the cardiology gamma camera CZT 530c (GE), over a five-year period (2020–2025), myocardial perfusion scintigraphy was performed in 6,280 individuals. In a subgroup of 3,140 nondiabetic respondents, negative findings were observed in 75% of individuals, while positive findings were present in 25%. Among the positive findings suggestive of coronary artery disease, coronary angiography (CAG) was recommended in 5% of patients and multislice CT (MSCT) in 8%. In the remaining 12% of patients, medical therapy was recommended due to metabolic–microcirculatory abnormalities, including wall motion abnormalities, increased left ventricular (LV) volume, perfusion abnormalities present only in end-diastole, impaired LV diastolic function, and reduced LV systolic function.

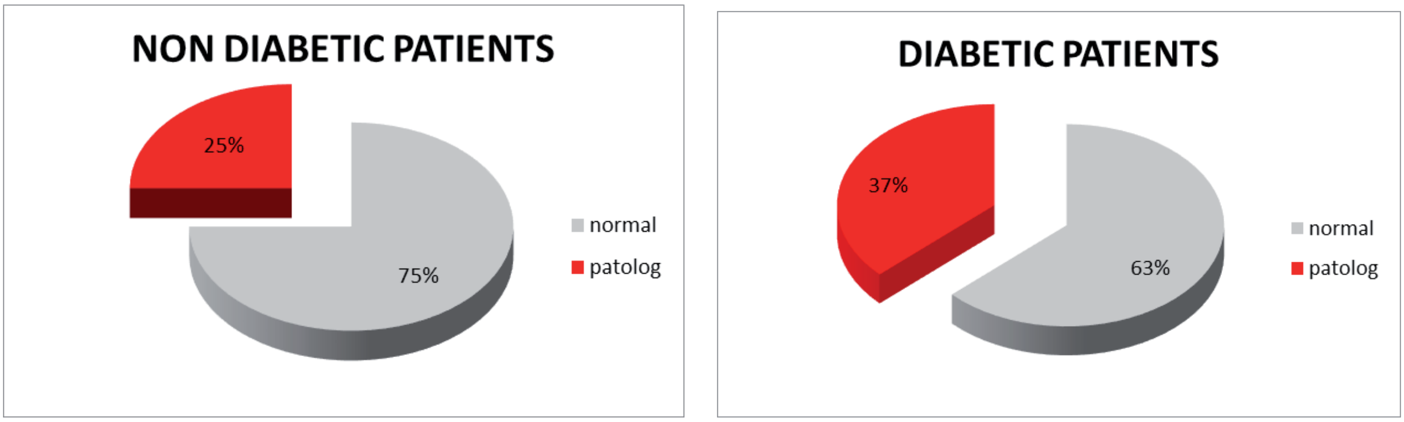

Figure 13 *Analysis of a cohort of 3140 nondiabetic and 3140 diabetic patients with negative and positive findings.*

In the analysed set of 6280 examined there were 3140 patients with diabetes (1. and 2. Type, bez rozlíšenia veku a pohlavia) . In this group, when examined by perfusion scintigraphy of the myocardium, we found a negative finding in 63% and a positive finding, indicative of ischemia, in 37% of diabetics.

With a positive finding, we recommended coronary angiography (SCA) in 8% of diabetics and MSCT in 12%. In 17% of the pathological findings, the detected changes indicated a change in metabolic-microcirculation (there were changes in kinetics, increased LV volume, perfusion changes only in end diastole, changed LV diastolic function, reduced LV systolic function. In the analyzed cohort of 6,280 examined individuals, 3,140 patients had diabetes mellitus (type 1 and type 2, without stratification by age or sex).

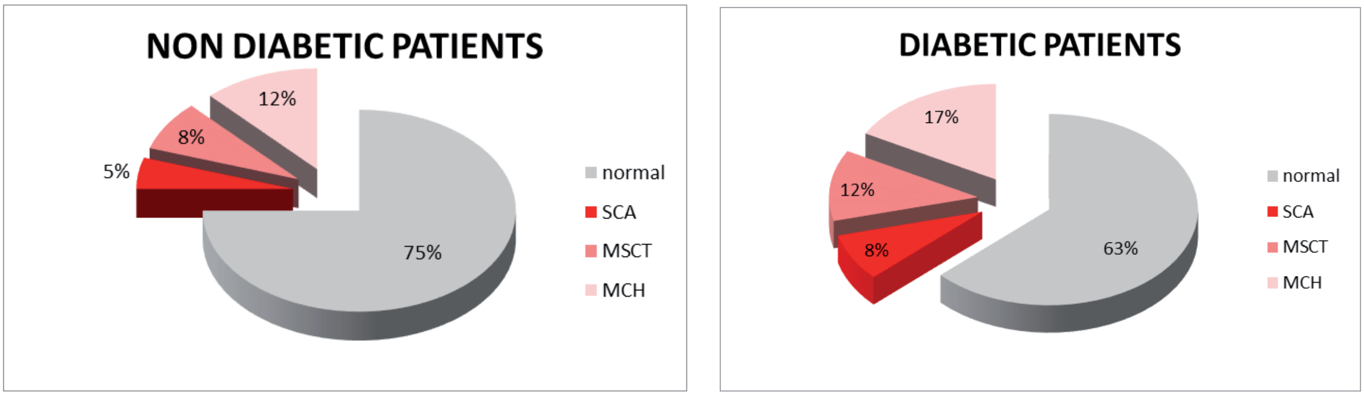

Figure 14 *Analysis of pathological scintigraphic findings according to indications for coronary angiography (CAG), multislice CT (MSCT), and metabolic changes in a cohort of 3,140 nondiabetic patients (CAG 5%, MSCT 8%, metabolic changes 12%) and 3,140 diabetic patients (CAG 8%, MSCT 12%, metabolic changes 17%).*

Statistical analysis

We statistically evaluated the significance of the difference in the presence of coronary artery disease between nondiabetic and diabetic patients using myocardial perfusion scintigraphy. In the first group (nondiabetic patients), 2,355 individuals had negative findings and 785 had positive findings. In the second group (diabetic patients), 1,978 individuals had negative findings and 1,162 had positive findings. In total, 6,280 subjects were analyzed. A comparison between the two groups with respect to two outcome categories (negative vs. positive findings) was performed using the chi-square (χ^2) test. The observed difference was statistically significant, confirming that diabetic patients have a significantly higher risk of coronary artery disease compared to nondiabetic individuals ($p < 0.00001$). When comparing the distribution of patients according to indications for coronary angiography (CAG), multislice CT (MSCT), and scintigraphically detected metabolic changes between the nondiabetic and diabetic groups, no statistically significant differences were found. Although a higher prevalence of coronary artery disease in diabetic patients was confirmed, our analysis of 3,140 diabetic subjects did not demonstrate a statistically significant increase in disease severity.

4 Conclusion

The new type of cardio-gamma camera “Discovery CZT 530c” based on the principle of semiconductor detectors gives a possibility to significantly increase their resolution, enabling more accurate assessment of myocardial perfusion abnormalities. Reducing the dose of the radiopharmaceutical reduces the radiation burden for a patient by 50%.

The importance of perfusion scintigraphy of the myocardium in the diagnosis of functional changes of the myocardium is of benefit in the detection of early changes in coronary heart disease and also in the diagnosis of microvascular angina pectoris.

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