REVIEW PAPER

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Myocardial perfusion scintigraphy – interpretation of gated imaging. Part 2

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Abstract

The first part of the review describes the basic aspects of interpreting myocardial perfusion defects in single photon emission computed tomography (SPECT) scintigraphy. It also presents indications for invasive diagnostics based on stress perfusion defects. This article provides basic information concerning the interpretation of gated SPECT imaging, including such parameters as left ventricular wall motion and thickening as well as left ventricular wall systolic and diastolic function. Gated examination combined with the assessment of myocardial perfusion reduces the rate of false positives results of myocardial perfusion scintigraphy in perfusion tests, additionally providing data on left ventricular systolic and diastolic function.

Key words: gated single photon emission computed tomography, contractility, thickening, systolic function, diastolic function.

Streszczenie

W pierwszej części pracy omówiono podstawowe aspekty interpretacji ubytków perfuzji serca w scyntygrafii wykonywanej metodą tomografii emisyjnej pojedynczych fotonów (SPECT). Przedstawiono wskazania do diagnostyki inwazyjnej na podstawie wysiłkowych ubytków perfuzji. W poniższym artykule zaprezentowano podstawowe informacje dotyczące interpretacji badania bramkowanego SPECT (*gated* SPECT), w tym takich parametrów, jak ruchomość i grubienie ścian lewej komory, funkcja skurczowa i rozkurczowa lewej komory. Łączna analiza badania bramkowanego z oceną perfuzji mięśnia sercowego zmniejsza częstość występowania wyników fałszywie dodatnich badania perfuzyjnego, a dodatkowo umożliwia uzyskanie danych dotyczących funkcji skurczowej i rozkurczowej lewej komory.

Słowa kluczowe: *gated* SPECT, kurczliwość, grubienie, funkcja skurczowa, funkcja rozkurczowa.

Introduction

Gated examination consists in summing up the counts emitted by the heart (γ radiation) in the direction of a gamma camera scintillation crystal, taking into account the division of the cardiac cycle into phases. This method of acquisition is based on summing up ECG-controlled counts – i.e. cardiac gating. The cardiac cycle is usually divided into 8 or 16 sections of equal duration referred to as "frames". The radiotracer activity counts, coming from over a dozen cardiac cycles registered for each angular change in the position of the gamma camera during its rotation around the patient's chest, are performed in accordance with the cardiac cycle, i.e., counts from every gated "frame" are summed up separately. In patients with normal heart rrhythm, this mode of acquisition enables the reconstruction of an image including: left ventricular systolic and diastolic perfusion and also the evaluation of left ventricular motion, thickening, and volume change in systole and dias-

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tole in an averaged cardiac cycle. Figure 1 shows the acquisition scheme of gated single photon emission computed tomography (SPECT).

Evaluation of regional left ventricular contractility in gated SPECT

Left ventricular (LV) contractility in gated SPECT is evaluated visually and with the use of polar maps dividing the LV into segments, walls, coronary arteries, or groups thereof, based on left ventricular wall motion deflection between the end-diastolic and end-systolic stages, measured in millimeters. The cardiac apex exhibits higher motion in comparison to the basal segments, among which the anterolateral and inferolateral segments (segments 6 and 5, respectively) are characterized by higher motion when compared to the anteroseptal and inferoseptal segments (segments 2 and 3, respectively). The division of the polar map into segments was shown in Figure 2 in the first part of this review [1].

Figure 3 shows normal contractility and systolic thickness of left ventricular walls, while Figure 4 presents an example of resting gated SPECT in a patient with advanced ischemic cardiomyopathy.

Summed score of left ventricular contractility in gated SPECT

Summed stress score for wall motion (SSSWM) in the left ventricle, with the LV divided into 17 segments, is described in Quantitative Gated SPECT software developed by the Cedars-Sinai Medical Center by the summed motion

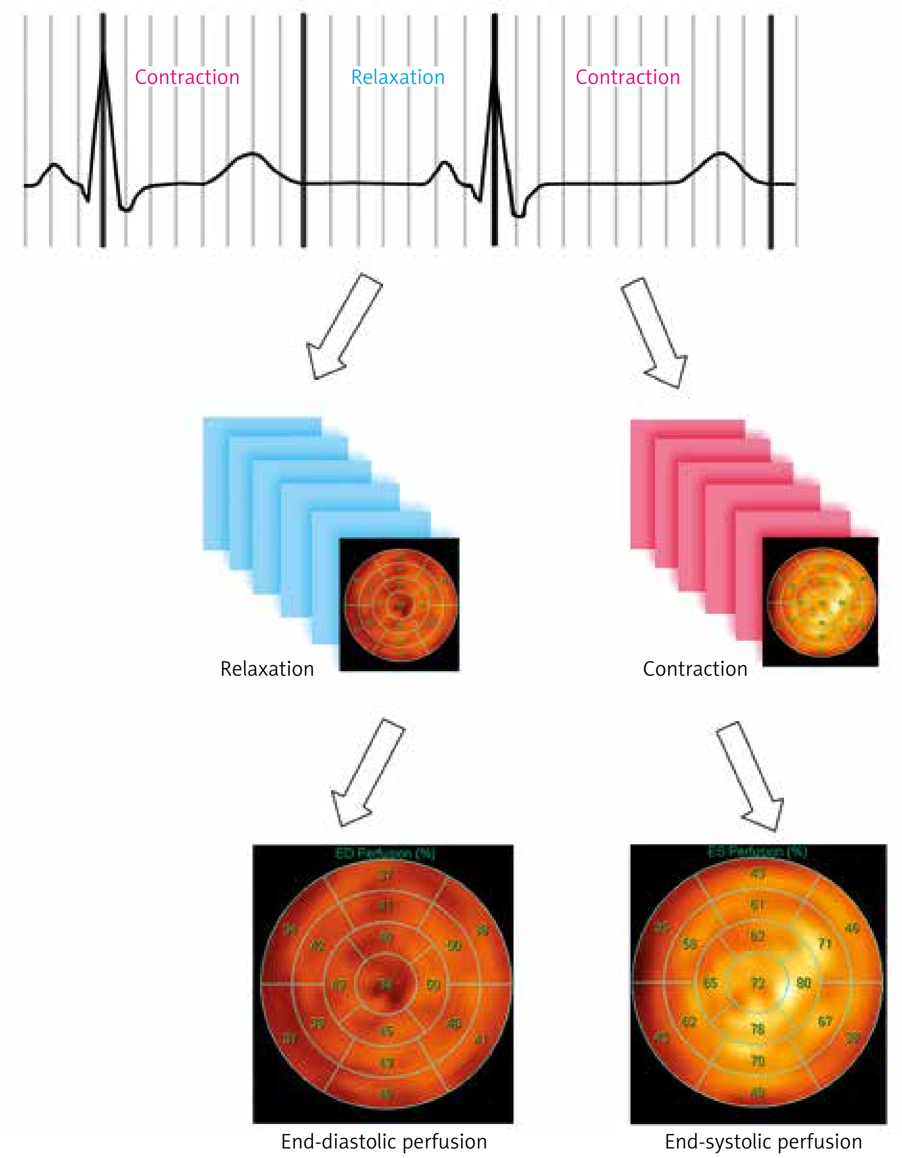


Fig. 1. Scheme of gated SPECT acquisition. After the cardiac cycle is divided into 8 or 16 “frames” of equal duration based on ECG, counts are summed separately in subsequent gated “frames”. This enables the evaluation of such parameters as regional wall motion and thickening as well as systolic and diastolic function of the left ventricle. The division of the cardiac cycle into 16 “frames” instead of 8 increases the precision of the parametric assessment of left ventricular function

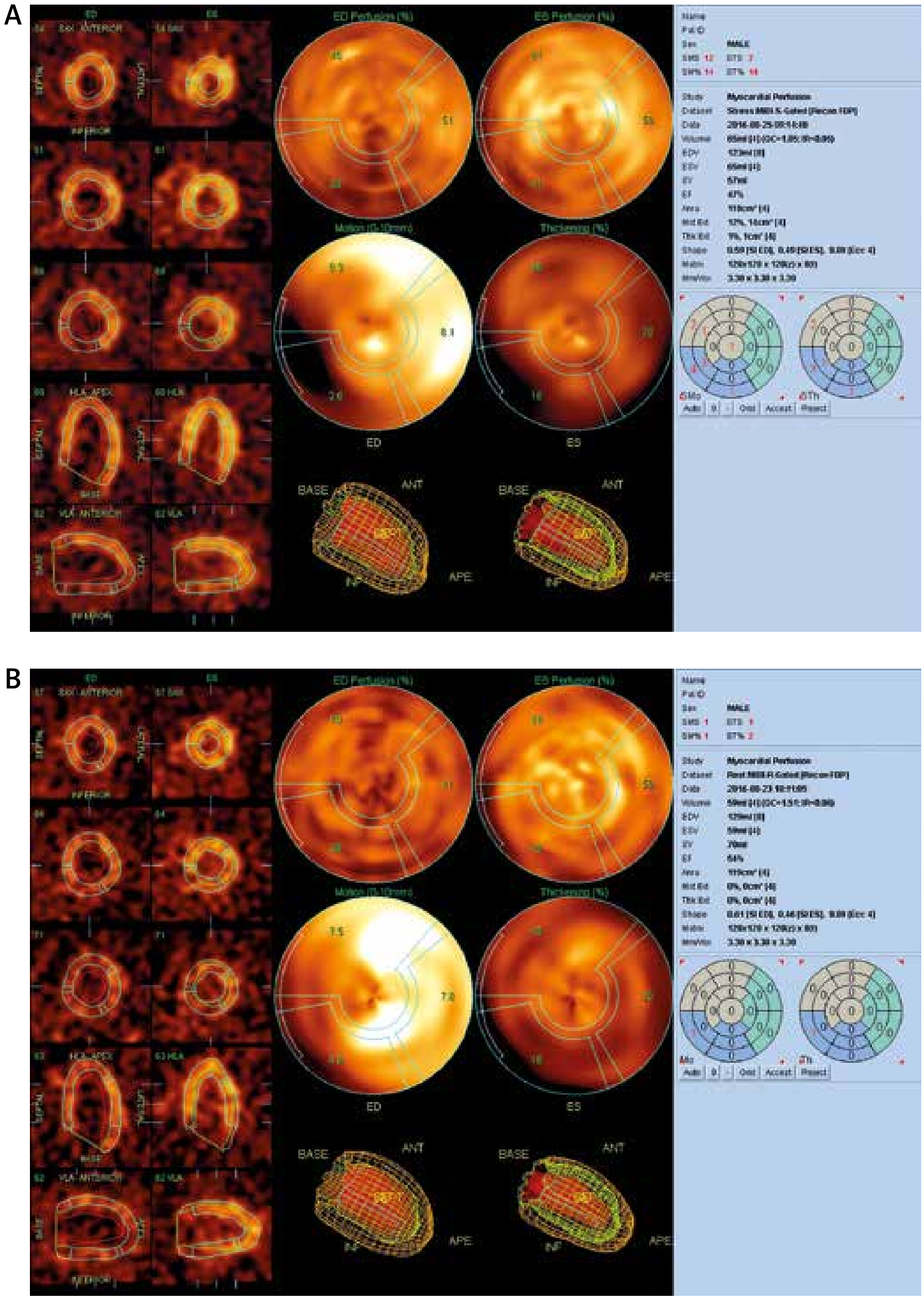


Fig. 2. A – Stunned myocardium. Stress examination revealed contractility abnormalities and impaired thickening of the septum. Perfusion scintigraphy showed a stress perfusion defects in this area. The polar map includes a division into coronary arteries. The examination was conducted at the Laboratory of Nuclear Medicine of the Silesian Center for Heart Diseases in Zabrze (QGS software). **B** – The same patient. Resting examination revealed normal left ventricular wall motion and thickening. The polar map includes a division into coronary arteries. The examination was conducted at the Laboratory of Nuclear Medicine of the Silesian Center for Heart Diseases in Zabrze (QGS software)

score – SMS. It constitutes a summed score of semi-quantitative evaluation of left ventricular wall motion in 17 segments on a 6-point scale presented in Table I. This score is obtained by comparing the acquired data with a set of averaged respective values from a healthy population. The SMS index is calculated for registrations after stress and at rest. The difference between the SMS calculated for registrations after stress and at rest reflects the severity of left ventricular wall contractility abnormalities after stress.

New contractility abnormalities in examinations conducted after stress in comparison to examinations at rest suggest stunned myocardium (Figs. 2 A, B), which confirms

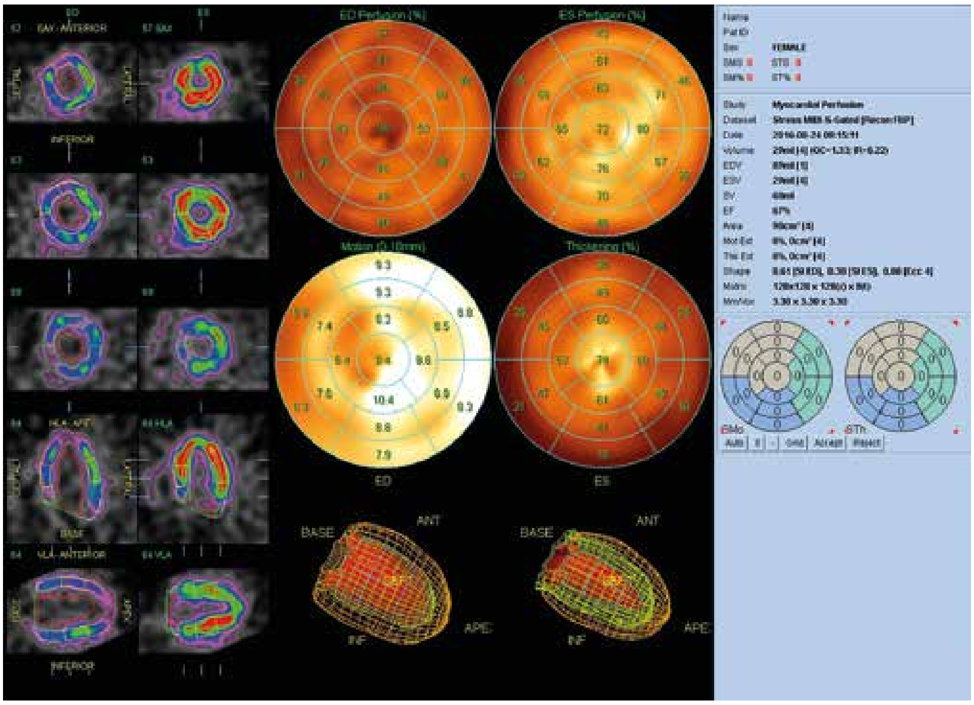


Fig. 3. Normal left ventricular wall motion and systolic thickening. The polar map at the bottom left shows left ventricular contractility (motion) with its value expressed in mm. The polar map on the right shows the systolic thickening of the left ventricular muscle (thickening), expressed as a percentage increase in radiotracer activity in the end-systolic phase in comparison to the end-diastolic phase. The motion and thickening scores were presented on the right (on the blue background) and described at the top of the field with the following indices: SMo (motion) and STh (thickening). The polar map presented is divided into 17 segments. The examination was conducted at the Laboratory of Nuclear Medicine of the Silesian Center for Heart Diseases in Zabrze (QGS software – Quantitative Gated SPECT)

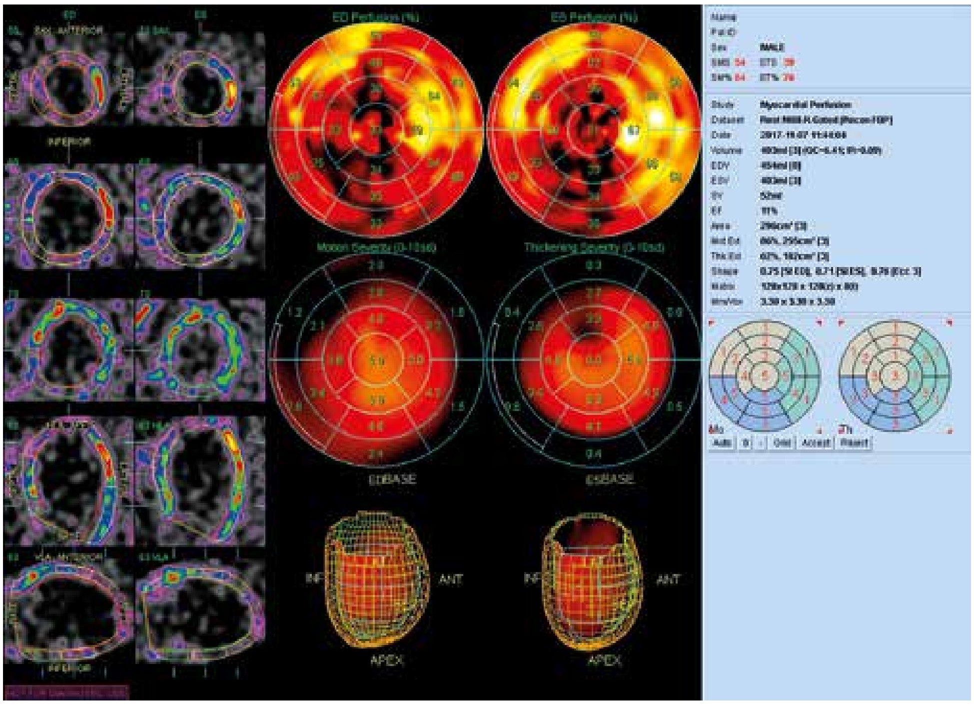


Fig. 4. Severe left ventricular wall contractility and thickening abnormalities in a patient with ischemic cardiomyopathy. Generalized left ventricular wall contractility abnormalities, including dyskinesis of the apex, inferior wall, and apical lateral segment (segments 9, 10, 15, 16, 17). Contractility abnormalities are accompanied by systolic thickening abnormality. Patient after transmural infarction of the inferior wall. Contractility abnormalities are accompanied by systolic thickening disorder. Amputation of the right coronary artery, significant stenosis of the trunk of the left coronary artery, anterior descending branch, and circumflex branch. The assessment of myocardial viability was conducted at the Laboratory of Nuclear Medicine of the Silesian Center for Heart Diseases in Zabrze (QGS software)

the presence of significant ischemia in a given location in patients with być hypoperfusion in the same area [2, 3].

QGS software additionally calculates the SM% index, which constitutes a normalized SMS value with a division of the left ventricle into 17 segments, and the extent of abnormal motion (*Mot Ext*) expressed in cm^2 and, additionally, in % with respect to the surface of the left ventricle.

Evaluation of the systolic thickening of left ventricular wall in gated SPECT

Left ventricular wall thickening is calculated on the basis of "partial volume effect". Thickening is presented on a polar map as a percentage increase in the thickness of left ventricular wall [4, 5] or on a point scale on a polar map divided into 17 segments (summed thickening score – STS). The STS index is based on a 4-point scale of left ventricular wall thickening (Table II). QGS software additionally calculates the ST% index, which constitutes a normalized STS value and takes into account the division of the left ventricle into 17 segments, and the Thk Ext index, which (similarly to the Mot Ext index) is expressed in cm^2 and % with respect to the surface of the left ventricle.

Regional contractility abnormalities should generally co-occur with left ventricular thickening abnormalities (Fig. 4) [6, 7]. Patients after coronary artery bypass grafting (Fig. 5), with right ventricular stimulation or right bundle branch block constitute an exception. In such cases contractility abnormalities are usually accompanied by normal left ventricular wall thickening.

In other cases, if a myocardial perfusion abnormalities is accompanied by normal motion and thickening, it is most likely an artifact associated with the uptake of radiation by extracardiac tissue. Therefore, perfusion abnormalities should be evaluated together with the regional motion and thickening of left ventricular walls. Combining SPECT with cardiac gating (gated SPECT) to assess myocardial perfusion reduces the percentage of false positives results in the diagnosis of hypoperfusion [8].

Left bundle branch block in SPECT – "false perfusion defects" in the septum

Stress myocardial perfusion scintigraphy is often recommended for patients with His bundle branch block. In cases of left bundle branch block (LBBB), 2/3 of patients exhibited permanent or reversible perfusion defects in septal segments. These are largely "false" defects without any significant ischemia in territory of the left anterior descending artery (LAD) [9–12]. The etiology of this phenomenon is unclear, but it is most likely caused by delayed septal diastole in relation to left ventricular diastole, which has a negative impact on septal perfusion [13]. This means that blood flows through the LAD during diastole while septal branches are still in systole, which cause impair blood flow in septal segments.

Gated examination is useful in differentiating between real ischemia and "false" defects in patients with LBBB. If a perfusion defects is accompanied by normal septal thickening in gated SPECT, it is most likely an artifact associated with LBBB. It is also useful to evaluate septal perfusion during end-diastole; normal perfusion in this phase of the cardiac cycle suggests that the perfusion defects is most likely "false" [14].

Table I. Six-point scale for scoring left ventricular motion abnormalities. The number of points is a result of comparing LV wall motion to the averaged data of a population with normal LV motion. The scale serves as a basis for calculating the SMS index, with the polar map divided into 17 segments

Motion	Score
Normokinesis	0
Mild hypokinesis	1
Moderate hypokinesis	2
Severe hypokinesis	3
Akinesis	4
Dyskinesis	5

Real ischemia in the LAD area is indicated by a blood supply defects in the apex and segments of the anterior wall (segments 17 and 1, 7, 13, respectively). Researchers believe that normal perfusion of the apex does not co-occur with significant LAD stenosis, but it is not a rule [13]. An example of perfusion scintigraphy in a patient with LBBB is presented on Figures 6 A–C.

Assessment of systolic function in gated SPECT

Gated examination provides additional data describing the systolic and diastolic function of the left ventricle. The data is derived from the curve that shows the changes in left ventricular volume during an averaged cardiac cycle. On this basis, the following parameters can be established: left ventricular end-systolic volume (ESV) and end-diastolic volume (EDV), stroke volume (SV), as well as ejection fraction (EF), which is calculated from the previous parameters (Fig. 7). The typical resting ESV and EDV values for an adult of a standard stature (height of 170 cm, weight of 70 kg) are 70 ml and 120 ml, respectively. In clinical practice any EF value in gated SPECT equal to 50% or higher is considered normal. These values may change depending on the software used and the ethnicity of the population studied, e.g., EDV and EF measured using QGS software in the Japanese population were, respectively, 53–116 ml and 54–79% for women and 40–88 ml and 61–83% for men [15].

An additional parameter used to evaluate left ventricular systolic function is peak ejection rate (PER), i.e., the indicator of the maximum ejection of the left ventricle expressed in normalized form as end-diastolic volume per second (EDV/s). According to the Frank-Starling law, it reflects not only the systolic function, but also, indirectly, the diastolic function of the left ventricle.

Diastolic function in gated SPECT

Similarly to echocardiographic examination, gated SPECT does not have a single parameter providing a defini-

Table II. Four-point scale for scoring left ventricular thickening abnormalities. The scale serves as a basis for calculating the SMS index, with the polar map divided into 17 segments

Thickening	Score
Normal	0
Mildly reduced	1
Significantly reduced	2
No thickening	3

tive diagnosis of left ventricular diastolic dysfunction. The following parameters describe diastolic function in gated SPECT: peak filling rate (PFR) – indicator of the maximum filling of the left ventricle, time to peak filling (TTPF) – time necessary for the blood volume in the left ventricle to reach its maximum after the end of systole, and mean filling rate (MFR) – indicator of the average filling rate of the left ventricle. Mean filling rate constitutes the average filling rate of the left ventricle normalized by dividing the result by the end-diastolic volume of a patient. Normal MFR should not be lower than 1.55 EDV/s [16]. Peak filling rate represents the highest filling value in early diastole. It is normalized in the same way like MFR, so the unit of PFR is EDV/s. In QGS software, with acquisition dividing the cardiac cycle into 16 "frames", the average PFR is approximately 2.62 or 2.5 EDV/s according to a different study [16, 17]. Time to peak filling represents the time required to reach the maximum filling of the left ventricle (i.e., reach PFR); normally it is approximately 164.6 ms and should not exceed 208 ms or, according to other authors 180 ms (values entered into QGS software with a division of the cardiac cycle into 16 "frames") [16, 17]. The threshold values usually assumed for PFR and TTPF are 1.70 EDV/s and 208 ms, respectively. In cases of left ventricular diastolic dysfunction a PFR drop is observed (the peak of the E wave is marked with a green arrow on Figure 7) with accompanying TTFR prolongation (yellow arrow in Figure 7).

Sphericity index

Gated SPECT enables the estimation of the shape of the heart. The sphericity index of the left ventricle is calculated by dividing the maximum LV short-axis length by the LV long-axis length in the end-diastolic phase. The normal shape of the heart is an ellipsoid (the maximum LV short-axis length is much shorter than the long-axis length). Higher heart sphericity was demonstrated to be associated with higher risk of heart failure in the future [8].

Conclusions

Myocardial scintigraphy conducted with gated data acquisition significantly complements perfusion imaging. Comparing the results of perfusion scintigraphy with LV wall contractility and thickening makes it easier to distinguish perfusion defects associated with "false" radiotracer uptake abnormalities from hypoperfusion, e.g., in patients with LBBB. Moreover, gated SPECT enables additional evaluation of left ventricular systolic and diastolic function.

There is also the issue of evaluating contraction dyssynchrony in candidates for resynchronization therapy and assessing myocardial viability, which is based on

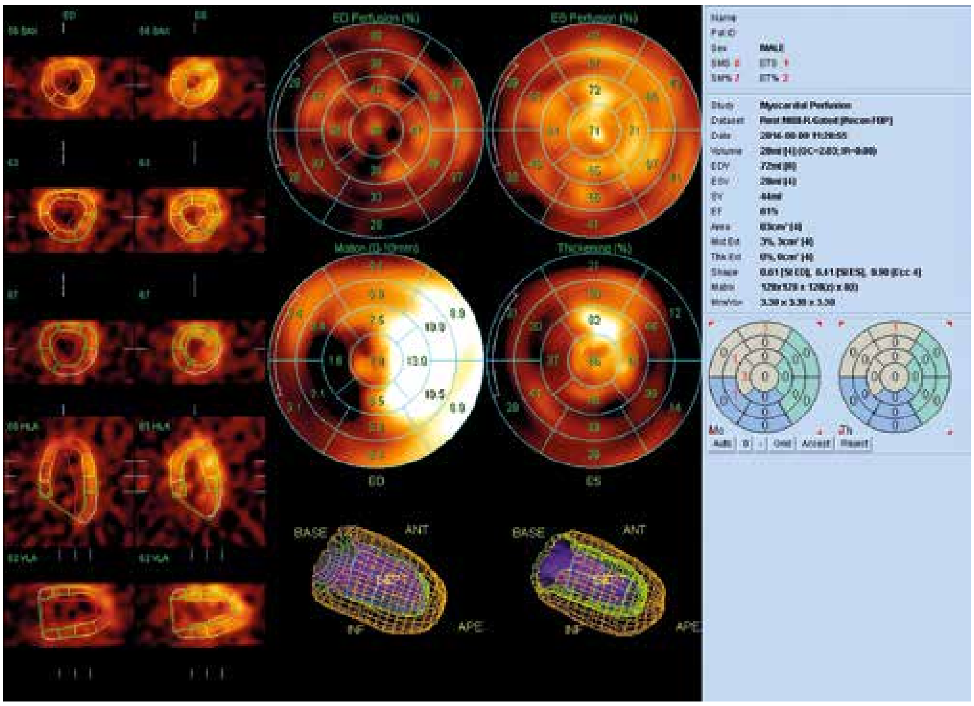


Fig. 5. Patient after coronary artery bypass grafting (CABG). Septal hypokinesis (segments 8, 9, and 14) and normal left ventricular thickening in this area. Patients after CABG frequently exhibit septal hypokinesis with normal anterior wall motion and increased lateral wall contractility. The examination was conducted at the Laboratory of Nuclear Medicine of the Silesian Center for Heart Diseases in Zabrze (QGS software)

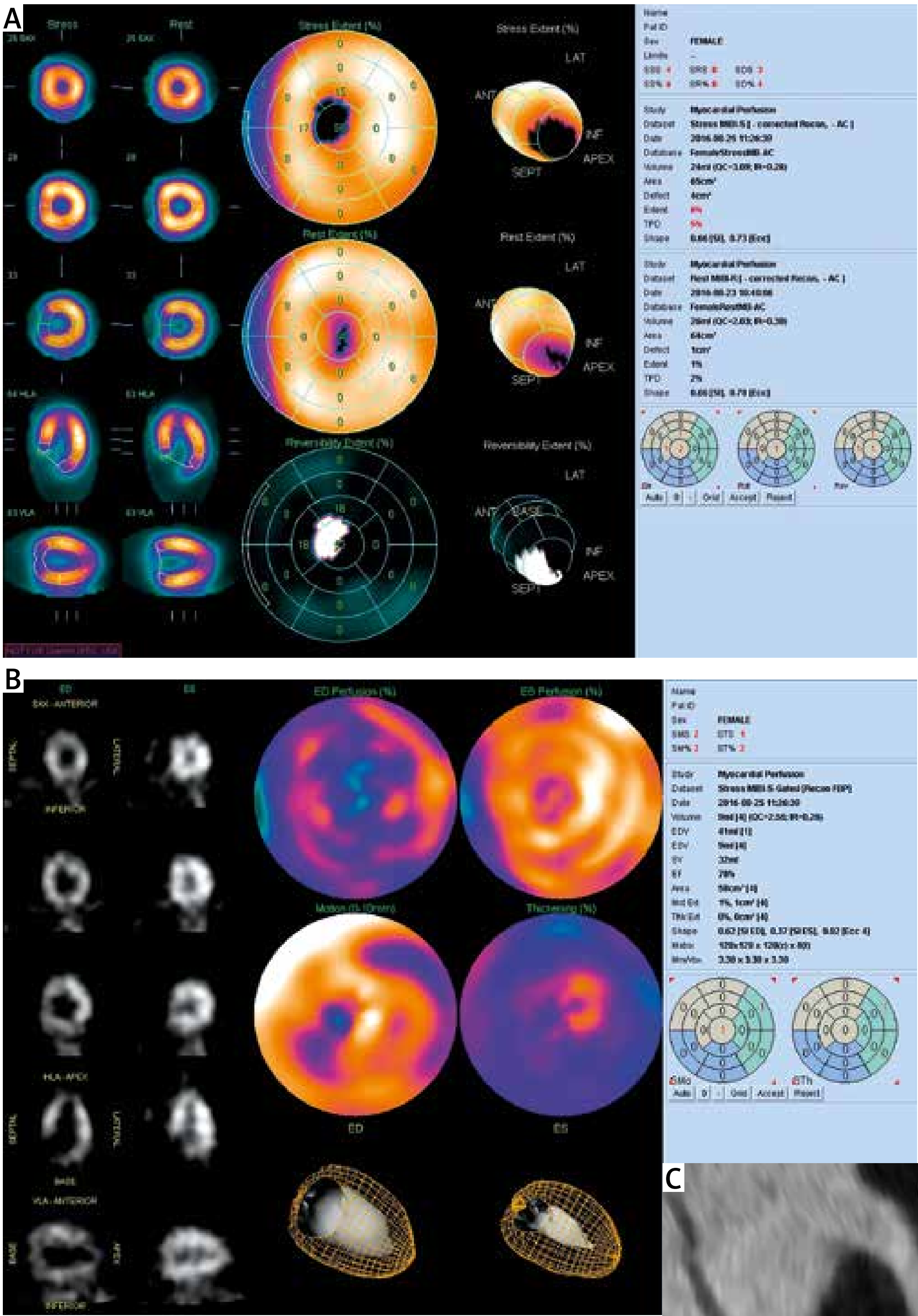
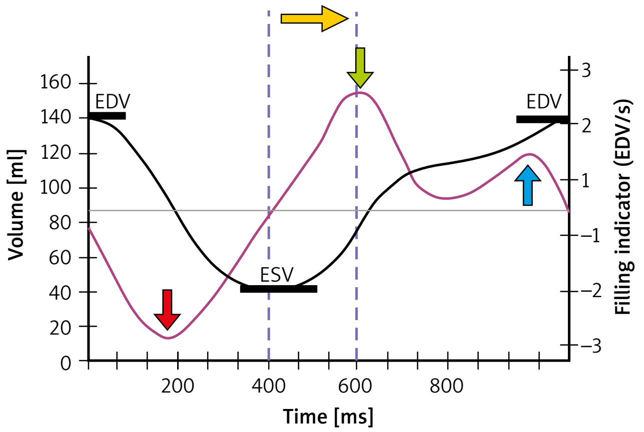


Fig. 6. A – Perfusion scintigraphy revealed a small reversible perfusion defects in the apex and the apical anterior and apical septal segments (segments 13, 14, and 17). The examination was conducted at the Laboratory of Nuclear Medicine of the Silesian Center for Heart Diseases in Zabrze (QPS software). **B** – Gated stress examination revealed normal left ventricular wall thickening in these segments. The examination was conducted at the Laboratory of Nuclear Medicine of the Silesian Center for Heart Diseases in Zabrze (QGS software). **C** – Angio-CT of the same patient as shown in Figures 6 A and B, confirming the lack of hemodynamically significant stenosis of the left coronary artery. A calcified lesion (approx. 20%) is visible in the anterior descending branch in segment 6. The examination was conducted at the Computed Tomography Laboratory of the Silesian Center for Heart Diseases in Zabrze (QGS software)



EDV – end-diastolic volume, ESV – end-systolic volume, PER – peak ejection rate, PFR – peak filling rate of the left ventricle, TTPF – time necessary for the blood volume in the left ventricle to reach its maximum after the end of systole.

Fig. 7. Figure showing the calculation of EDV, ESV, and PER (parameters of LV systolic function) as well as PFR and TTPF (parameters of LV diastolic function) during a cardiac cycle for a heart rate of 60/min. The black curve shows the ratio of LV volume change to time (dV/dt), while the violet curve – the ratio of LV filling indicator to filling time (dV/dt). The green arrow marks the E wave (early filling phase) – its peak is the maximum filling rate, i.e., PFR. The blue arrow shows phase A (atrial contraction). The red arrow shows PER, while the yellow arrow – TTPF

both perfusion imaging and left ventricular wall motion and thickening indices. In both cases the interpretation of results requires comprehensive assessment of perfusion imaging and gated examination. Additional gated SPECT phase analysis enables the selection of patients in whom resynchronization therapy may actually be effective. These issues will be discussed in part three of the study.

Disclosure

Authors report no conflict of interest.

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