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# SECT and DECT coronarography: a comparison of two techniques

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## Abstract

Coronary artery disease is an atherosclerotic disease of the coronary arteries with consequent development of ischemic heart disease and is one of the leading causes of death in developed and developing countries. The "*golden*" standard in the diagnosis of coronary disease is invasive coronarography, but with the development of coronary CT angiography, a sub-millimetre precise assessment of the anatomy of coronary arteries and heart has been made possible. While in the earlier stages, SECT devices were used for the needs of coronary CT angiography with synchronization with the ECG, the development of DECT devices enabled a significant rise in the performance of coronary CT angiography in the form of a better assessment of anatomy and stenoses of the coronary arteries caused by plaque, the possibility of assessing heart perfusion, obtaining an image with a minimal amount of artifacts, a smaller amount of applied iodine contrast agent, better characterization of the atherosclerotic plaque and its components, and all of the above with a lower radiation dose for the patient. While most of the conducted research speaks in favour of DECT devices versus SECT devices, the issue of inadequate utilization of the numerous possibilities of DECT devices in everyday clinical practice remains. The DECT technique can be implemented in several ways, depending on the structure of the DECT device (on the number of radiation sources, the structure/arrangement of detectors, or the use of filters), but the question of which type of DECT technique/device to use depends on the disadvantages and advantages of individual devices as well as on the final goal of diagnostic procedures.

**Keywords:** invasive coronarography, coronary CT angiography, DECT, SECT

## Introduction

Ischemic heart disease is a term interchangeably used with coronary disease (atherosclerotic disease of the coronary arteries), which is also its main cause. Mortality rates are declining due to improved prevention, wider availability of heart catheterization laboratories, and overall improvement of the health care system [1]. The main diagnostic method for CAD (*CAD – Coronary Artery Disease*), is coronary angiography or coronarography, which enables, further treatment in the form of PTCA (*PTCA – Percutaneous Transluminal Coronary Angioplasty*) and/or PCI (*PCI – Percutaneous Coronary Intervention*) [2]. PCI includes verification of an artery lesion utilizing coronarography, followed by application of a *stent*, while PTCA implies an expansion of a balloon at the point of narrowing caused by an atherosclerotic plaque and removal of the balloon after widening the narrowed part of the artery [3]. Using FFR (*FFR- Fractional Flow Reserve*) as part of coronarography, the need for further treatment in the form of PCI/PTCA is assessed. FFR is a method of assessment of the hemodynamic significance of CAD in the development of ischemia, and represents the ratio of distal coronary blood pressure (distally from the site of atherosclerotic plaque) and proximal coronary pressure during hyperaemia (induced by adenosine), with the normal value being 1 [4,5]. Patients with FFR values ≥ 0.75 can have their PCI/PTCA postponed [6]. Coronarography is regarded as the "*golden*" standard in CAD diagnosis, although it evaluates the presence and extent of atherosclerotic plaque indirectly through the visualization of stenosis or obstruction of the lumen of the artery [7].

## CT Coronarography

The problem of continuous heart contractions and small diameter of coronary arteries has been resolved with the development of CT (*CT – Computed Tomography*) technology which enables better spatial and temporal resolution with faster image acquisition [7]. FFR can be assessed using non-invasive CT coronary angiography/ CT coronarography/ CTCA or CCTA (*CTCA – CT Coronary Angiography; CCTA – Coronary CT Angiography*) [8]. CCTA represents a non-invasive alternative to the assessment of arteries compared to invasive coronarography. Nowadays, ≥ 64-layer MSCT devices are used as the standard for CCTA [9,10]. The main role of CCTA is the detection of calcium deposits in the coronary arteries and assessment of stenosis or occlusion. Until the entry of MSCT (*MSCT – Multi-Slice Computed Tomography*) devices into widespread use, EBCT devices (*EBCT – Electron Beam Computed Tomography*) were used to determine calcium deposits or CACS (*CACS – Coronary Artery Calcium Scoring*). CACS is considered a CAD indicator and is the standard in determining risk for future cardiac incidents [11,12]. CACS is determined using Agatston's method or AS (*AS – Agatston Score*), calculating deposit volume, indirectly calculating total calcium mass, or calculating the percentage of coronary artery calcium coverage [12,13]. In AS, depending on the density of calcium deposits in coronary artery plaques (130-199 HU, 200-299 HU, 300-399 HU, and ≥ 400HU; *HU – Hounsfield Units*), 1, 2, 3, or 4 points are given, respectively. When determining the maximum density of an individual plaque, an area of at least 1 $mm^2$ is considered. The total AS of an individual is obtained by adding the points of all plaques within coronary arteries, and the final sum describes the probability of significant CAD (Table 1) [12,13].

CCTA requires minimization of artifacts caused by cardiac activity, which is why the ideal moment of cardiac activity, suitable for CCTA, is the middle or end of diastole. CCTA is performed either prospectively synchronized with ECG (*prospective triggering*), where the phase of the cardiac cycle in which the scan takes place is determined beforehand, or retrospectively synchronized with ECG (*retrospective gating*), in which the scan takes place during entire cardiac activity, and only sections with a minimal number of artifacts are used for post-procedural reconstruction. Recently, the prospective method has been used more often due to lower radiation doses [9].

CCTA provides information on the morphological characteristics of plaques and coronary artery stenoses, but cannot directly assess their influence on hemodynamics. This problem is addressed using CT-FFR or FFRCT (*CT-FFR – CT-Fractional Flow Reserve*) as a supplement to CCTA. FFRCT is not invasive, as is the case with invasive coronarography [14]. The use of FFRCT alongside CCTA leads to better planning for revascularization with a reduction in the use of invasive angiography in patients without signs of obstructive CAD [15]. FFRCT correlates well with FFR obtained by invasive coronarography and reduces the number of patients who were initially recommended invasive angiography due to stenosis by ≥ 50%. Also, FFRCT lower than 0.80 is a better indicator of the need for revascularization or the risk of future cardiac incidents than the confirmation of severe stenosis by CCTA alone [16]. Thus, FFRCT value of 0.80 is a threshold value above which no further diagnosis is required, while coronary artery stenoses with FFRCT values between 0.76 and 0.80 require further invasive coronarography in the case of presence of high-risk features of atherosclerotic plaques, significant burden of atherosclerotic disease or greater number of stenoses. If FFRCT value is ≤ 0.75, invasive coronarography is required. CCTA and invasive coronarography have similar diagnostic values in detecting hemodynamically significant CAD, comparing FFR in both techniques. Therefore, CCTA is useful for excluding significant coronary stenosis and avoiding unnecessary invasive procedures [17,18].

CCTA enables differentiation of contrast in the lumen of arteries and calcification deposits as well as implanted stents. Although it is possible to differentiate certain types of plaques using CCTA, unfortunately, it is still not possible to distinguish which plaques are vulnerable and which are stable. Plaque composition itself has a greater predictive value in prognosticating future cardiac incidents compared to the degree of stenosis, but differentiating plaques rich in lipids from those with a predominantly connective component is extremely demanding [11]. Compared to invasive coronarography, effective dose radiation is higher in CCTA with retrospective ECG gating, while in CCTA with prospective ECG control, it is the same as in invasive coronarography [19]. Doses < 1 mSv can be achieved in patients whose BMI is < 30 $kg/m^2$, heart rate < 70/min, and with the use of the prospective ECG method [11]. An effective radiation dose of 0.2 mSv can be achieved using 30 ml of iodine contrast medium, with

Table 1. Probability of significant stenosis depending on AS. *Source: https://pubmed.ncbi.nlm.nih.gov/33016506/*

| Agatston score | Plaque burden | Probability of significant CAD |
|---|---|---|
| 0 | No plaque | Very low |
| 1-10 | Minimal plaque | Low |
| 11-100 | At least mild atherosclerotic plaque | Mild or minimal coronary artery stenosis |
| 101-400 | At least moderate atherosclerotic plaque | Nonobstructive CAD likely, although obstructive disease possible |
| >400 | Extensive atherosclerotic plaque | High likelihood of at least one significant coronary artery stenosis |

an X-ray tube voltage of 70 kVp (*peak kilovoltage*) with prospective ECG synchronized CCTA [20].

## Principles of CCTA clinical use

The patient lies on a movable table in a supination position with ECG monitoring, while the recording method is determined depending on the heart rate [21]. CCTA is a swift procedure that scans the heart during the first arterial passage of iodine contrast (intravenous application of 50 to 100 ml of iodine contrast agent with a concentration between 320 and 400 mgI/ml for 10 to 20 seconds at a speed of about 4 ml/s) through the left heart chambers and coronary arteries [9,21,22]. After iodine contrast medium is administered, the application system is washed with saline solution [21]. CCTA involves the acquisition of native and post-contrast CT images. The optimal condition for a CCTA is a heart rate ≤ 60/min, which is achieved by the application of a beta-blocker an hour before the examination or by the sublingual application of nitroglycerin [10]. It is important to precisely time the application of the contrast agent, for which there are two timing methods: *bolus tracking method* and *test bolus method*. With the bolus tracking method, after the start of the contrast injection, the region of interest (ascending aorta) is selected and it is continuously scanned. CCTA starts at the moment when the attenuation in the region of interest is > 200 HU. The test bolus method includes an injection of a small amount of contrast medium (approx. 12 ml), after which the TDC (*TDC – Time-Density Curve*) in the region of interest is monitored with a continuous scan. By using the prediction formula for peak contrast enhancement, the time of the optimal scan delay (start of the scan) is obtained [21,23]. Possible complications in the form of kidney failure, contrast-induced nephropathy, and cardiovascular incidents are avoided by minimizing iodine contrast medium and keeping the patient well hydrated [23,24].

CCTA can be deficient in the presence of severe coronary calcification, which can be coped with DECT (*DECT – Dual Energy Computed Tomography*). Unlike conventional SECT (*SECT – Single Energy Computed Tomography*), DECT has the possibility of better characterization of atherosclerotic plaque, displaying myocardial perfusion during single imaging, and non-contrast quantification of calcium with the possibility of subtracting calcium from the atherosclerotic plaque and thereby improving the visualization of the artery.

## The aim of this article

This article aims to provide a description and interpretation of work principles and the use of SECT and DECT coronarography in everyday clinical practice, with an emphasis on comparison of the mentioned two techniques. The article is supported by the available scientific literature on the *Pubmed.gov* database, published from 2012 onwards.

## Discussion

SECT generates a polychromatic X-ray beam of different energies (keV) with a maximum energy equal to the peak voltage of the X-ray tube emitted from a single radiation source. The passage of an X-ray beam through an object creates images that represent attenuation of photons of all energies in each voxel [25]. The attenuation caused by the passage of X-rays through the object is displayed as different levels of gray colour, the quantification of which is expressed in HU. SECT gives only morphological and anatomical information, while information about the material through which the rays passes is limited, since the basis of SECT is the calculation of the linear attenuation coefficient of each component material, regardless of its density [26,27]. On the other hand, DECT technology enables differentiation of materials/tissues by evaluating the attenuation of two different radiation energies/photons [28,29]. DECT technology implies obtaining two groups of image data of the same anatomical region, which are obtained with two different X-ray spectra. This in turn enables a more detailed analysis of the material and better tissue characterization, depending on the absorption of different energy X-rays (Figure 1) [27]. DECT improves CCTA examination through better identification of the lumen of arteries, reduction of the administered amount of contrast agent, easier characterization of atherosclerotic plaques, and elimination of the need for the native part of CCTA, which is required in the SECT technique for the calculation of CACS [30]. Conventional SECT performs tests under a constant peak voltage of the X-ray tube (120 kVp to 140 kVp), while the photon energies created in the DECT device are under the influence of a voltage of 80 kVp for the acquisition of low-energy attenuation profiles of tissues and the voltage of 140 kVp for the acquisition of high-energy attenuation profiles of tissues [28].

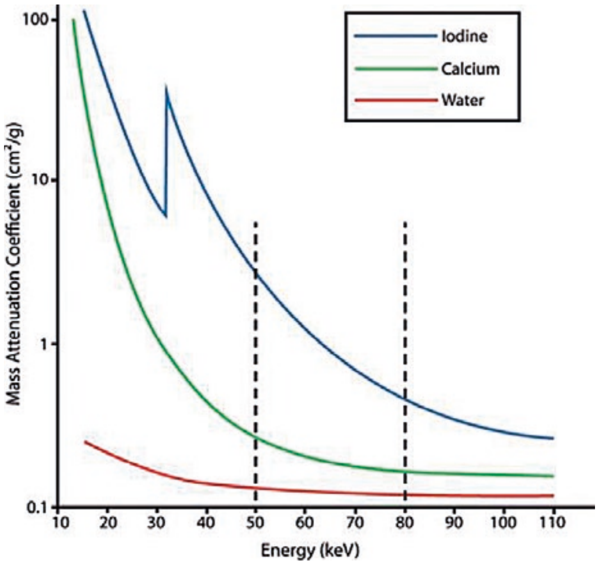

**Figure 1.** Attenuation coefficients for iodine (blue), water (red), and calcium (green) obtained with two different energy X-rays (vertically dashed lines). Iodine attenuation at higher energies (80 keV) has a larger drop than calcium attenuation. Also, the difference in iodine and calcium attenuations is greater at lower energies (50 keV).
*Source: https://pubmed.ncbi.nlm.nih.gov/22411937/*

The attenuation is the result of two physical phenomena, *photoelectric effect*, which depends on the energy of the photon and atomic number of the element through which the photon passes, and *Compton effect*, independ-

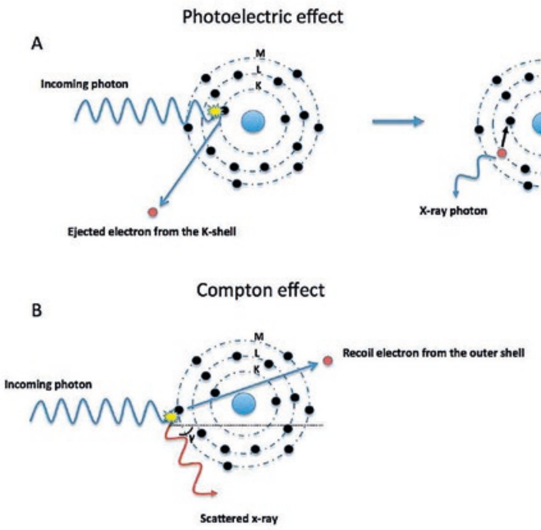

**Figure 2.** A) Photoelectric effect: photon collides with an electron and is completely absorbed. The electron from K-shell is ejected if the photon has higher kinetic energy than the binding energy of the electron. B) Compton effect: an X-ray photon knocks out an electron from the outer shell and then scatters. *Source: https://pubmed.ncbi.nlm.nih.gov/26068288/*

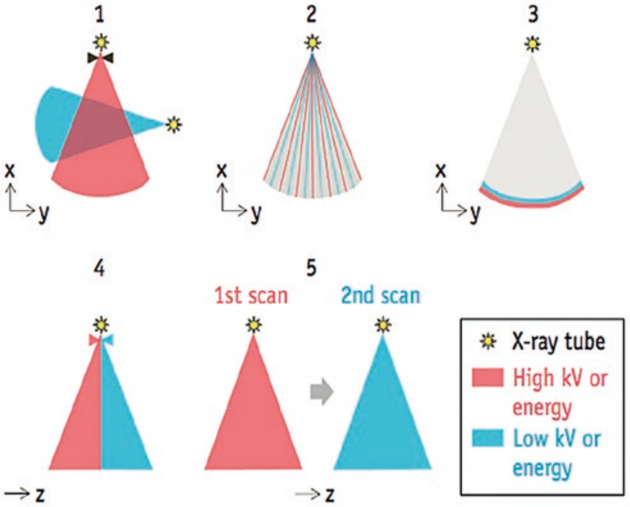

**Figure 3.** Different types of DECT. 1= DSCT with two X-ray tubes and two detectors (dsDECT); 2= rapid alternating voltage on one X-ray tube (rsDECT); 3= double detector layer ("*sandwich*") with one X-ray tube (dlDECT); 4= one X-ray tube with filters that divide the radiation spectrum into two beams (tbDECT); 5= one x-ray tube performs a search under high voltage and then under low voltage (seqDECT). *Source: https://pubmed.ncbi.nlm.nih.gov/28670151/*

ent of the photon energy, but depending on the density of the material through which the photon passes (Figure 2). Photoelectric effect is created by the ejection of an electron from the inner electron K-shell by a photon that has a higher energy than the binding energy of the aforementioned electron [25,28]. While iodine and calcium show similar attenuation on SECT, on DECT with an emphasis on low-energy scans, it is possible to distinguish iodine and calcium due to different attenuations at low X-ray energies [26]. Compton effect represents a collision of photons with electrons of the outer shell of the atom, where the incoming photon is not completely absorbed, but a *photon scattering* occurs, which depends on the electron density. DECT is based on the photoelectric effect, which is obtained through energy-dependent attenuation of materials when they are exposed to two different photon energy levels. Two materials can be distinguished from each other, as long as their attenuation profiles are different. Therefore, DECT enables definition of tissue composition using differences in tissue attenuation, which is not possible using conventional SECT techniques [31].

It is important to distinguish SECT from SSCT (*SSCT – Single-Source Computed Tomography*), which represents CT devices with a single source of radiation, but which can be conventional SECT devices as well as DECT devices (by rapidly changing voltage of one X-ray tube that produces X-rays/photons of two energies). DSCT is an abbreviation for *Dual-Source Computed Tomography*. Simplified, DECT is divided into DECT based on source change and DECT based on detector change (Figure 3). DECT based on source change are seqDECT, dsDECT, rsDECT, tbDECT, while DECT based on detector modifications are dlDECT and CT with a photon counter. Only dlDECT and dsDECT enable almost simultaneous acquisition of data, while with other techniques a smaller lag in co-registration is still possible, leading to appearance of minor artifacts [27].

DECT enables calculation of substance concentration by subtracting a certain substance such as iodine or calcium. Iodine enhancement creates perfusion maps, while iodine subtraction creates images most similar to non-contrast images, so-called VNC (*VNC – virtual non-contrast*) [25,27]. It is possible to calculate AS without prior recording of native TNC (*TNC – true non-contrast*) images, which reduces radiation dose of the entire examination. Although it is known for its great potential in replacing TNC in the calculation of CACS, further studies are needed to determine the conversion algorithms that will enable the conversion of VNC recordings into the TNC equivalent, which is still considered the standard in calculating AS [27,30]. DECT has the possibility of reconstructing images that represent the attenuation of photons of a certain energy level in each voxel, which is called a virtual monoenergetic image/VMI (*VMI – Virtual Monoenergetic Image*), unlike SECT, which represents the attenuation of the entire spectrum of emitted photons [25,27]. VMI can be of high and low energies, where high-energy VMI enables us to reduce artifacts created under the influence of implanted stents or calcifications within plaques, thereby reducing the overestimation of the degree of coronary artery stenosis, while low-energy VMI is more sensitive to iodine and is better for evaluating stenosis caused by soft/non-calcified plaques. This reduces the amount of contrast agents and improves visualization of arteries, which ultimately brings great advantage for patients prone to allergic reactions and nephrological diseases [25,27].

The problem of plaque differentiation in invasive coronarography is settled by using DECT, which enables better resolution of the necrotic core and fibrous plaque [25,32]. Vulnerable plaques can be analysed by evaluation of effective atomic numbers of elements/EAN (*EAN – Effective Atomic Number*), which potentially enables the characterization of plaque [33,34]. There are promising studies that confirm that by analysing the atomic (*Z*) number, DECT can provide more information than the density of the plaque alone, which is important since it is known that plaques with a thin fibrous cap or a large necrotic nucleus rupture more easily [25].

The development of prospectively synchronized operation with ECG and the reduction of X-ray tube voltage depending on the patient's BMI enabled the reduction of doses when performing SECT coronarography. While earlier studies spoke in favour of higher radiation doses during DECT compared to SECT, in the further course almost equal radiation doses were confirmed in both techniques [35]. Subsequent studies even confirm a reduction in radiation dose using DECT when compared to SECT in patients with regular heart rhythms [31]. The use of post-procedural VNC images in DECT further reduces the radiation dose, cost, and time spent on the diagnostic procedure, through the exclusion of acquisition of previous non-contrast images for calculating calcium load, such as the case with SECT [31]. The study by Yamada et al. confirmed the effective radiation dose during DECT coronarography of 4.3±0.3 mSv, in contrast to the SECT protocol (first acquisition of a non-contrast image for calculating calcium load, and then SECT coronarography) where the effective radiation dose is 5.4±0.7 mSv [36].

Reducing the amount of applied contrast agent leads to a lower risk of damaging renal function, but it brings a reduction in the quality of the final image due to the appearance of noise (*SNR – signal-to-noise ratio*) and disturbance of the contrast and noise ratio (*CNR – contrast-to-noise ratio*). Using low-energy VMI images, it is possible to improve CNR and SNR [37]. Raju et al. confirmed the feasibility of DECT coronarography with a reduction of iodine contrast agent by > 50%, where the use of low-energy VMI images improved the value of SNR and CNR, comparable to SECT coronarography [38]. Similar studies have confirmed the reduction of contrast agents by up to 60% using low-energy VMI reconstructions [31]. In SECT, the only countermeasure to inadequate opacification of blood vessels with iodine contrast agent is the reduction of X-ray tube voltage to increase the attenuation of the contrast agent, which leads to noise and reduced accuracy of the performed examination [39]. DECT enables acquisition of images with fewer artifacts, even with faster frequencies or irregular heart rhythms. Invasive coronarography is still superior to DECT technology in terms of temporal resolution, which is why beta-blockers are needed in pre-diagnostic preparation. Similarly, spatial resolution in newer CT devices is about 0.4 to 0.5 mm, but is still inferior to invasive coronarography (0.1 to 0.2 mm) [40]. With DECT, it is possible to display the scanned region of the patient with X-rays of one photon energy level which is why the obtained images are less sensitive to *beam hardening* artifacts and the so-called *blooming* effect/artifacts occurring in smaller high-density structures (metal stents, calcifications), making them appear larger than they are [31].

Beam hardening artifacts occur when a polychromatic X-ray beam (used by SECT) passes through areas of high density, leading to enhanced absorption of low-energy photons versus high-energy photons and resulting in hypodense and hyperdense streaks [25]. Blooming artifacts caused by the presence of stents and calcified plaques lead to overestimation of the degree of coronary artery stenosis, and they can be reduced, as well as beam hardening artifacts, by high-energy VMI images (110 keV to 120 keV) [31,39,41]. At the same time, high-energy VMI images are poorly sensitive to iodine contrast agents, which is the reason that the assessment of the arterial lumen is performed using high-energy and low-energy VMI [25]. Thus, VMI images at 80 keV energy are optimal for DECT coronarography in patients with stents (42). The use of dlDECT leads to better visualization of the artery lumen, while high-energy VMI images lead to a significant reduction of artifacts caused by metal implants (stents, sternal cerclages, or bypass clips) or concentrated contrast in the *vena cava* [31]. DECT in CCTA assesses myocardial perfusion (by calculating the concentration of the iodine contrast agent in the myocardium distal to the site of the stenosis) and coronary artery anatomy in the same scan, provides assessment of myocarditis and myocardial fibrosis (in patients with contraindications for MRI with gadolinium), differentiates tumours and thrombi, provides better quality images, provides better visualization of atherosclerotic plaques, lumen of coronary arteries and coronary stents, and uses smaller amount of iodine contrast agent (reduces iodine contrast agent volume by > 50%, which is of great importance in patients with acute kidney damage or reduced glomerular filtration) [25,38,43].

## Conclusion

CAD is an atherosclerotic disease of the coronary arteries leading to a consequent ischemic heart disease. Although invasive coronarography is considered the "*golden*" standard in the assessment of coronary disease, coronary CT angiography (CCTA) is becoming more important as a screening method in CAD patients, allowing for prediction of disease outcome and planning interventions for patients in whom PCI is indicated. The development of >64-layer MSCT and its implementation in performing CCTA in synchronization with ECG, modulation of X-ray tube voltage, and the development of DECT itself enabled significantly greater diagnostic possibilities and reduction of issues caused by large radiation doses and artifacts. CCTA performed with the SECT enables assessment of the anatomy of coronary arteries and the degree of stenosis caused by atherosclerotic plaques, while DECT also enables assessment of the hemodynamic effect of stenosis or myocardial perfusion, assessment of myocarditis in patients with contraindications for MRI, differentiation of a thrombus from a tumour, acquisition of images with fewer artifacts than SECT (even in the case of arrhythmias or faster heart rates), evaluation of the lumen of coronary arteries (even in the presence of significant calcifications or metal stents), reduction of the amount of applied iodine contrast agent, reduction of radiation dose, as well as better characterization of atherosclerotic plaque and its components. Ignorance of DECT possibilities, financial challenges and complicated software, are some of the many reasons this technique is not used more often. Further research is needed to confirm the usefulness of the clinical everyday application of DECT, especially since numerous, yet insufficiently used possibilities of DECT already exceed those of SECT. In addition to further research, protocols for adequate characterization of atherosclerotic plaques will be verified, which will enable differentiation of vulnerable plaques and therefore recognition of patients in need of further interventions in terms of preventing the consequences of ischemic heart disease.

All data in this paper are part of the results of the master's thesis "SECT and DECT coronarography comparison" written at the University Department of Health Studies, University of Split [44]. ■

## Sažetak

Koronarna bolest je aterosklerotska bolest koronarnih arterija s posljedičnim razvojem ishemijske bolesti srca te je jedan od vodećih uzroka smrti u razvijenim zemljama i zemljama u razvoju. *''Zlatni''* standard u dijagnostici koronarne bolesti je invazivna koronarografija, no razvojem koronarne CT angiografije omogućena je submilimetarski precizna procjena anatomije koronarnih arterija i srca. Dok su u ranijim fazama za potrebe koronarne CT angiografije korišteni SECT uređaji uz sinkronizaciju s EKG-om, razvoj DECT uređaja je omogućio značajan uzlet u izvođenju koronarne CT angiografije u vidu bolje procjene anatomije i stenoza koronarnih arterija uzrokovanih plakom, mogućnosti procjene perfuzije srca, dobivanja slika s minimalnom količinom artefakata, manje količine apliciranog jodnog kontrastnog sredstva, bolje karakterizacije aterosklerotskog plaka i njegovih komponenti, a sve navedeno uz manje doze zračenja za pacijenta. Dok većina provedenih istraživanja govori u prilog DECT uređaja spram SECT uređaja, nadalje ostaje pitanje neadekvatne utilizacije mnogobrojnih mogućnosti DECT uređaja u svakodnevnoj kliničkoj praksi. DECT tehniku moguće je ostvariti na više načina, ovisno o strukturi DECT uređaja (o broju izvora zračenja, strukturi/ rasporedu detektora ili korištenju filtera), no pitanje kojom se vrstom DECT tehnike/ uređaja koristiti ovisi o nedostacima i prednostima pojedinih uređaja kao i o konačnom cilju dijagnostičke procedure.

**Ključne riječi:** invazivna koronarografija, koronarna CT angiografija, DECT, SECT

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