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IMPROVEMENT OF CARDIAC MULTISPIRAL COMPUTED TOMOGRAPHY PROTOCOL FOR PLANNING INTERVENTIONAL ARRHYTHMIA MANAGEMENT

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Purpose. The study aimed at the comparison of computed tomography (CT) contrast enhancement (CE) protocols for optimal visualization of cardiac chambers, evaluation of their impact on results of non-invasive superficial cardiac mapping.

Methods. The study included 93 patients with heart rhythm disorders in whom catheter ablation of arrhythmia was planned. Noninvasive cardiac mapping for arrhythmia localization was performed and included multichannel ECG-registration and CT with intravenous CE (1st group - monophasic (50 patients), 2nd group - split-bolus (18 patients), 3rd group - with pre-bolus (25 patients). Qualitative and quantitative (measurement of mean blood attenuation in four chambers, calculation of ventricular-myocardial [VM] contrast-to-noise ratio VM-LV и VM-RV for the left ventricle [LV] and right ventricle [RV], respectively) parameters were compared between the groups. Fusion of ECG and CT data was carried out a semi-automatic mode with a non-invasive imaging complex.

Results. Regardless of CE technique, sufficient and homogeneous contrast attenuation was obtained for the left atrium (LA) and LV (mean blood attenuation in LA more than 278 HU, LV 250 HU, VM-LV 0,582). In most cases, the enhancement of the right heart was insufficient with the monophasic protocol; the average CT density was lower than 200 HU, VM-RV 0,256. The split-bolus protocol improved visualization of the right atrium (RA) and RV (blood density in RA 258HU, RV 227HU, VMRV 0,541); however, there was a heterogeneity of the RA cavity due to artifacts from the superior vena cava (VC) and unenhanced blood from the inferior VC. Pre-bolus administration increased the contrast ratio between RA myocardium and blood due to the improvement of blood CT density in the inferior VC (blood density 294 HU). The quality of RV CE was similar to 2nd group (blood density 264 HU, VM-RV 0,565).

Conclusion. The split-bolus and with pre-bolus CE protocols improve visualization of the RV, supporting the high-level enhancement of the left heart. The protocol with a pre-bolus is preferable for exact differentiation of the right atrial endocardial contour.

Key words: computed tomography; radiofrequency ablation; noninvasive cardiac mapping; arrhythmia

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Catheter techniques used to treat cardiac arrhythmias have been actively developed in recent years. The ablation procedure is carried out under X-ray control, intracardiac echocardiography or 3D electroanatomic mapping [1]. Since the 2000s, multichannel non-invasive cardiac mapping systems are available in addition to standard intraoperative mapping [2-4]. Key advantages of such systems include non-invasive nature, the possibility of simultaneous mapping of all four cardiac chambers, the possibility of not only endocardial, but also epicardial mapping [5]. The data of the surface non-invasive cardiac mapping contribute to faster and more precise imaging of the arrhythmogenic substrate area, selection of the optimal catheter ablation technique, as well as reduction of surgery duration [6, 7].

Global scientific sources provide detailed data on surface mapping techniques with a comparison of accuracy with invasive electrophysiological and electroanatomical mapping and the impact of preoperative data on the ablation procedure. Availability of high-quality computed tomography (CT) scans is an important factor for obtaining highly reliable anatomical data at superficial mapping. This depends not only on computed tomography machine capability and scan settings but also on the selected contrast enhancement (CE) technique that allows immediate obtaining of high contrast between the myocardium and the blood in the atrium or ventricle. Global literature describes many studies concerning the search for the optimal contrast enhancement technique for CT coronary angiography, CT of the left atrium (LA) and pulmonary veins; less material is available for the right atrium (RA) and right ventricle (RV) imaging. However, there is no scientific data concerning the impact of the quality of the computed tomography cardiac images on non-invasive mapping results.

Aim. To compare CT contrast enhancement protocols to determine the best optimal contrasting technique

for cardiac cavities and to assess its impact on the quality of 3D reconstructions based on non-invasive surface cardiac mapping.

MATERIAL AND METHODS

In the FSBI "A.V.Vishnevsky National Medical Research Center of Surgery" 93 patients with different types of cardiac arrhythmias were hospitalized for catheter ablation of arrhythmia from April 2018 until March 2020. Most patients had atrial arrhythmias - 73 patients (78.5%) and 20 patients (21.5%) had ventricular arrhythmias. Among the patients, males predominated: 57 patients (61%), the mean age was 56±12.3 years. Preprocedural all patients underwent contrast-enhanced CT of the cardiac chambers and 3D modeling of the cardiac chambers using the standard CT software: Philips Intellispace Portal. The patients were divided into 3 groups depending on the contrast enhancement technique used. Demographic characteristics were balanced between the groups (Table 1).

All patients underwent a non-contrast low-dose CT scan of the chest with capturing all surface mapping electrodes and examining the cardiac area with intravenous contrast enhancement and ECG synchronization (the arterial phase of the scan was performed to obtain anatomical data and the delayed phase of the scan was conducted to exclude intracardiac thrombosis). The scan was performed using Philips Brilliance 64 and Philips Ingenuity 64 tomographs. Three contrast enhancement techniques were used: standard monophasic, split-bolus, and pre-bolus.

Contrast agent (CA) injection technique in group 1: monophasic CA injection at the rate of 1 mL per 1 kg of body weight, then 40 mL of saline (50 patients).

CA injection technique in group 2: fractional injection using the split-bolus technique. Phase 1 - 2/3 of the undiluted CA volume, phase 2 - 1/3 of the CA volume diluted with the saline at a 1:1 ratio, phase 3 - 40 mL of the saline (18 patients).

CA injection technique in the group 3: phase 0 - 50 mL pre-bolus, then, after a 50-sec delay, phase 1 - 2/3 of the undiluted CA volume, phase 2 - 1/3 of the CA volume diluted with the saline at a 1:1 ratio, phase 3 - 40 mL of the saline (25 patients).

The contrast agent injection rate was 3.5-4 mL/sec in all three groups.

The scan starts parameters were similar in all three groups: a locator on the ascending aorta, the absolute threshold for achieving contrast was 150 HU, a minimum delay of the scan beginning from reaching the threshold was 4.2 sec; delayed phase - after 90 sec. The "bolus tracking" mode in groups 1 and 2 was started simultaneously with the CA injection initiation, in groups 3 - 50 seconds after the end of the pre-bolus injection.

Contracting of the cardiac chambers was assessed qualitatively (visual assessment of homogeneous contract filling and the quality of 3D cardiac models) and quantitatively (measurement of chamber content density at three levels, as well as calculation of the ventricular-myocardial contrast ratio for the right and left ventricles using the formula:

$VM = (HU_{ventr} - HU_{mio}) / HU_{aorta}$ [8].

Immediately before the tomography, all patients underwent synchronous ECG recording in 6 standard leads from the extremities and in 224 leads from the chest surface using the "Amycard 01K" diagnostic complex. The electrocardiographic and tomographic data were combined semi-automatically using the same diagnostic complex (Fig. 2).

To verify the arrhythmogenic substrate, isochronous activation maps (for ventricular arrhythmias) and phase maps of the right and left atria (for atrial fibrillation and flutter) were built. In the final 3D models of surface mapping, a visual assessment of the right cardiac chambers was performed using a scoring scale of 1 to 3 points, where 1 score reflected the unsatisfactory quality of reconstruction, the impossibility to obtain diagnostic information; 2 scores reflected the good quality of reconstruction, the model was close to an anatomical one with the presence of artifacts that do not interfere with the diagnostic information interpretation; 3 scores reflected the excellent quality of reconstruction. Then, an electrophysiological examination, electroanatomical invasive mapping and radiofrequency

Table 1.

Patients' characteristics

	Total	Group I	Group II	Group III
Number of patients, n	93	50	18	25
The mean age, years	56,4±12,3	55,1±12,3	59,2±10,8	54,8±13,7
Male, n (%)	57 (61)	35 (70)	8 (44,4)	14 (56)
Females, n (%)	36 (39)	15 (30)	10 (55,6)	11 (44)
Atrial arrhythmias, n (%)	73 (78,5)	43 (86)	13 (72,2)	17 (68)
Ventricular arrhythmias, n (%)	20 (21,5)	7 (14)	5 (27,8)	8 (32)

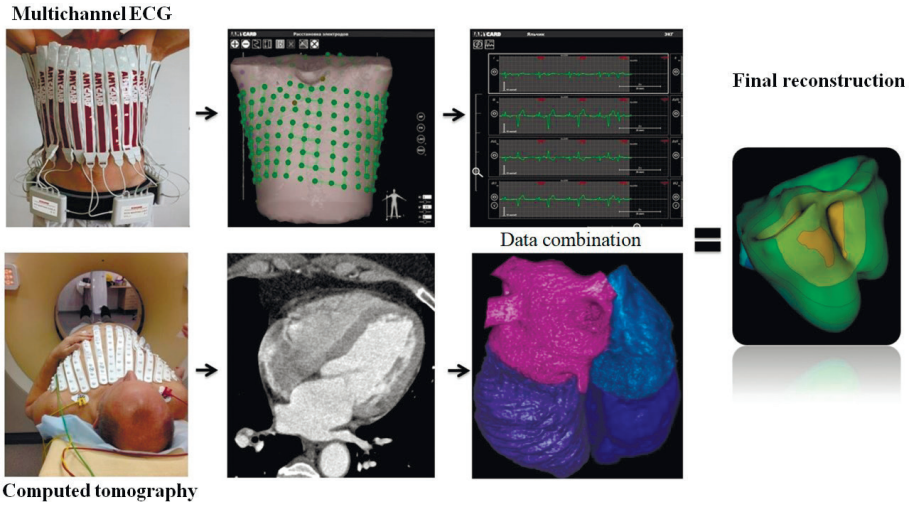

Fig. 1. Stages of non-invasive surface cardiac mapping.

ablation of arrhythmia were conducted in the X-ray operating room.

RESULTS

Table 2 shows the quantitative analysis results for the contrast enhancement of cardiac chambers.

The parameters of the mean contrasted blood density in the LA lumen were significantly higher in group 1 and were similar in group 2 and group 3. There was no significant difference in density in the left ventricle (LV) cavity between groups. Ventricular-myocardial contrast ratio shows the extent of cardiac cavity contrasting in relation to the wall. The larger the ratio, the better the contrasting difference between the ventricular wall and the blood filling its lumen, which makes it easier to identify the endocardial contour when building 3D images. For the LV, this parameter was comparable and did not differ significantly between groups. Regardless of the contrast enhancement technique, there was sufficient contrasting of the coronary arteries, high contrast between the myocardium and the blood in the left cardiac chambers, with good visualization of papillary muscles, aortic and mitral valves, additional septa, mass lesions and thrombotic masses.

With the monophasic contrast enhancement protocol (group 1), the contrasting of the right cardiac chambers was not sufficient to obtain diagnostic information: mean blood density in the RA was 176±102 HU, in the RV 172±86 HU. Nearly in all cases, mean density of the contrasted blood in the chamber cavity was below 200 HU, a minimum threshold value allowing differentiation of the myocardium internal contour from low-contrasted blood filling the right ventricle and atrium [17]. This is due to the flow of a new portion of non-contrasted blood from the inferior vena cava (IVC) with each cardiac cycle. Subsequently, this led to inaccurate automatic identification of the RV and RV endocardium borders when constructing epi-endocardial cardiac models, their distortion, and required manual processing of 3D reconstructions during surface mapping (Fig. 2).

Due to prolonged CA injection time the split-bolus contrast enhancement technique (group 2) prevented its rapid washout from the right cardiac chambers; this improved the images of the tricuspid and pulmonary valve, papillary muscles, myocardium of the right atrium and ventricle (mean blood density in RA was 258±59 HU, in RV - 227±45 HU). However, the heterogeneity of the RA cavity contrast enhancement was maintained due to artifacts from the CA bolus tail and lowdensity blood from the IVC. This also resulted in less accurate identification of the RA endocardium borders and sometimes required manual correction of reconstructions (Fig. 3).

The CE technique with pre-bolus injection (group 3) increased the contrast between the RA myocardium and the blood (mean blood density in the RA was 294±88 HU, in the RV 264±74 HU, (Fig. 4).

The homogeneity of the RV contrast enhancement was like that in group 2. The VM-RV values for the 2nd and 3rd types of protocols were more than 2 times higher than the values for the monophasic protocol. Atrial mapping using a pre-bolus protocol subjectively required the least amount of time (Fig. 5).

The operator noted that ventricular mapping in the patients from groups 2 and 3 was easier and took less time than in the patients from group 1.

As stated above, the qualitative analysis of the reconstructions was carried out based on the ability of imaging to provide diagnostic information from the final isochronous activation and phase maps of the right cardiac chambers. According to the data obtained, shown in the diagram (Fig. 6), in the monophasic contrast enhancement group, only 18% of cases (9 patients) had "good" quality of the right cardiac chambers' reconstruction and the other cases of reconstruction were scored 1. On the contrary, in the split-bolus contrasting group, only 16.7% of reconstructions (3 patients) were considered "unsatisfactory". In the pre-bolus contrasting group, all 100% of the right cardiac chambers reconstructions were scored 2 or 3, without unsatisfactory results ($p < 0.001$).

Table 2.

Results of quantitative analysis of the heart chambers contrast enhancement (HU)

Measurement level	Group I	Group II	Group III	P-value*
LA	305.9±75.4	260.3±72.3	277.6±40.8	0.044
LV	293.8±72.2	248.1±64.2	269.7±40.3	0.051
RA	176.0±101.8	257.6±58.7	293.7±88.0	< 0.001
RV	171.6±86.0	227.1±45.1	263.6±73.5	< 0.001
VM-LV	0.628±0.13	0.582±0.09	0.586±0.131	0.312
VM-RV	0.256±0.265	0.541±0.236	0.565±0.267	< 0.001

Notes: LA - left atrium, LV - left ventricle, RA - right atrium, RV - right ventricle, VM-LV - ventricular-myocardial contrast ratio for the left ventricle, VM-RV - ventricular-myocardial contrast ratio for the right ventricle, * - significance at $p < 0.05$.

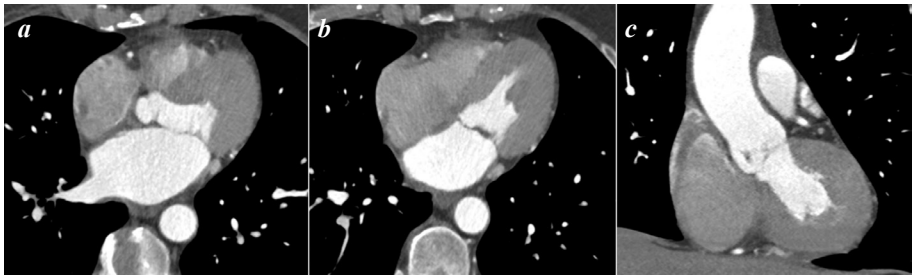

Fig. 2. Cardiac CT, monophasic contrast enhancement, arterial phase (a, b - axial reconstructions, c - coronal reconstruction). High contrast between the myocardium and the blood in the left cardiac chambers. Contrasting of the right cardiac chambers insufficient for surface mapping due to the constant flow of non-contrasted blood from the IVC.

DISCUSSION

The standard CE protocols in cardiac studies (in particular, CT coronary angiography, as the most performed tomographic

procedure) have been optimized for the left cardiac chambers and are applicable when imaging of the LA and the pulmonary veins is required prior to ablation of atrial fibrillation. This protocol is a monophasic contrast agent injection at the rate of 1 ml per kg of patient body weight or the addition of a second phase with injection of small saline volume [9]. However, in this case the amount of CA being injected, and the infusion duration have not been optimized to assess abnormalities of the right chambers, the constant flow of non-contrasting blood from the IVC and the extension of the CA bolus tail in the superior vena cava (SVC) leads to significant inhomogeneity of the chamber contents and low contrast in relation to the myocardium; besides a significant part of the CA has time to leave the right chambers. The contrast enhancement of the right atrium and ventricle varies widely, which we observed in arm 1 (Fig. 2).

When planning catheter ablation, it is important to obtain sufficient and homogeneous contrasting of the left and right cardiac cavities, since the arrhythmogenic activity areas may be localized in any myocardial area [1, 10]. The imaging of right cardiac chambers can be improved by adjusting the amount and rate of CA injections to prolong the duration of CA flow and maintain adequate contrast of the whole heart during scanning [11]. However, monophasic injection of the CA only at a constant rate does not allow sufficient homogeneous contrasting of the right cardiac chambers and often leads to the emergence of linear artifacts from high-density blood in the SVC, shading adjacent structures and distorting 3D reconstructions [12-14].

The use of dual volume contrast media injectors allowing simultaneous injections of the CA and the saline allowed significant changes in the approach to the intravenous contrasting technique [15]. It has been demonstrated that the use of a bolus chaser, i.e. the saline, reduces the frequency of streak artifacts from highly contrasted blood and also reduces the total CA amount required for optimal contrasting [12, 14, 16, 17], while maintaining high and homogeneous contrasting of the arterial system [12, 18]. On the other hand, in many cases, the bolus chaser and the accompanying decrease in the volume of the CA injected and the modernization of the scanning duration leads to an accelerated CA washout from the right cardiac chambers and reduce the attenuation ratio in the RA and RV. This makes it difficult to trace the endocardium contours, to analyze the anatomy and abnormal changes in the right cardiac chambers and the pulmonary trunk [12, 14].

Clinical tasks have stimulated a discussion about a switch from the monophasic contrast protocol to more complex combinations of the CA, saline, and their mixture for adequate contrast enhancement of the cardiac chambers of interest during the scanning.

The fractional contrast agent injection, i.e. split bolus, was initially applied for imaging the urinary system [19], then researchers began to use it to improve cardiac imaging. This protocol is currently used with the following stages included: 1) CA injection, 2) CA-saline mixture injection in various ratios, 3) saline solution injection. In our study, the split-bolus technique used allowed improving right ventricle imaging quality by increasing the contrast of the myocardium-chamber cavity border (Fig. 3).

D.Utsunomiya et al. were among the first to compare monophasic contrast enhancement, with (group B) and without a bolus chaser (group C), and a split-bolus protocol (group A) for imaging the cardiac chambers and the coronary arteries. The split bolus included a CA: saline dilution in a 50:50 ratio in the second phase and a slow injection at a rate of 1.5 ml/sec. It was observed that the highest attenuation ratio in the RV cavity was obtained with the split-bolus protocol; however, the differences were not statistically significant. The difference between the maximum and minimum attenuation values in the LV cavity for all three protocols varied slightly; it was comparable in the RV and the LV when protocol A was used and varied significantly for protocols B and C. Thus, the best contrast enhancement of the LV and RV chambers with clear imaging of the endocardial contour of the interventricular septum was observed with a prolonged fractional CA injection. In the case of a monophasic injection with or without a bolus chaser in half of the patients, precise identification of the interventricular

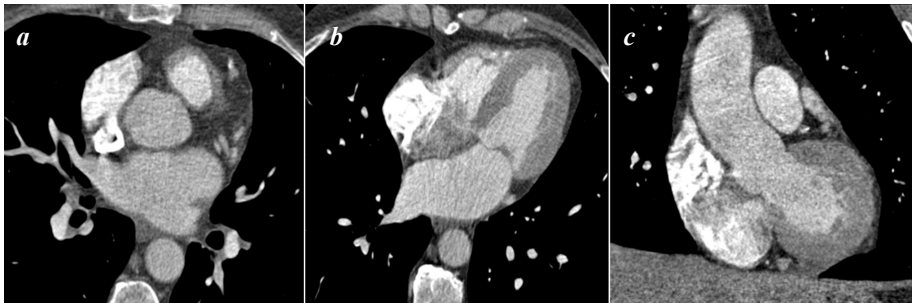

Fig. 3. Cardiac CT, split-bolus contrast enhancement, arterial phase (a, b - axial reconstruction, c - coronal reconstruction). Sufficient and homogeneous contrasting of the left cardiac chambers and the right ventricle. Heterogeneity of contrast agent filling in the RA is maintained due to artifacts from the bolus "tail" in the SVC and non-contrasted blood flow from the IVC.

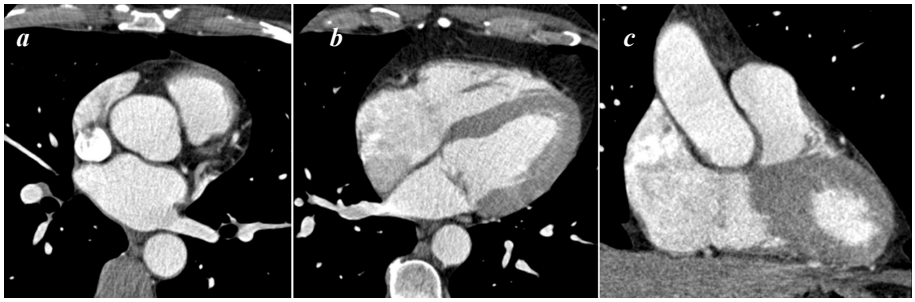

Fig. 4. Cardiac CT, pre-bolus contrast enhancement, arterial phase (a, b - axial reconstruction, c - coronal reconstruction). Increased extent of contrasting and homogeneity of the right cardiac chambers. Sufficient and homogeneous CA filling is maintained in the left cardiac chambers.

septum borders is challenging due to the low contrast of the myocardium/RV cavity [8].

J.M.Kerl et al. retrospectively analyzed data of cardiac CT scan in 75 patients obtained using three contrast enhancement protocols similar to those of Utsunomiya [8], but the split-bolus protocol included a CA: saline mixture injection in a 70:30 ratio, at a rate of 5 ml/sec. Although a monophasic CA injection without saline resulted in a high level of contrast enhancement of the left and right cardiac chambers (which may be associated with the application of the test-bolus technique to determine the scan start delay time), the frequency of artifacts reached 100% in the SVC and 94% in the RA. In the bolus chaser and split-bolus groups, the incidence of SVC/RA artifacts accounted for 34%/59% and 91%/67%, respectively. The image of the left cardiac chamber structures (papillary muscles, aortic valve, LV myocardium) and the coronary arteries generally had similar quality between the three arms. The right cardiac structures (papillary muscles, moderator band, tricuspid and pulmonary valves, RV myocardium) were visualized much better in the split-bolus group [12].

Due to variation in the contrasting extent for the right cardiac chambers depending on the CA dilution ratio for fractional injection, J.G.Lu et al. compared different versions of the split-bolus protocol with each other, changing the CA concentration in the mixture from 30% to 70%, as well as with a monophasic injection to establish the optimal technique. As a result, the mean blood density in the coronary arteries was significantly higher for monophasic injection with a saline chaser and was not significantly different for split-bolus protocols, and this did not affect the quality of vascular imaging. The saline chaser used also minimized the incidence of streak SVC artifacts (2.1%) in contrast to the monophasic CE without any saline (41.7%). With the split-bolus protocols, artifacts emerged in 12.5-23%, the incidence was not significantly different when the CA dilution ratio was changed. When assessing the intracardiac structures, the researchers noted that fractional CA injections lead to a more prolonged contrast enhancement of the RA, RV, and LA cavities; clear imaging of the right chambers structures was obtained with all split-bolus protocols. However, the greater the CA dilution ratio is in the second phase, the lower the attenuation ratio is in these chambers, while the blood density in the LV and the ascending aorta did not differ significantly [14].

M.Kok et al. have also obtained high quality of RV contrasting using the split-bolus protocol: the mean attenuation ratio of more than 200 HU was recorded in almost 80% of cases (372/472 scans). The contrasting was conducted with an individual selection of the amount of CA injected (108±24 mL) and the injection rate (6.1±2.2 ml/sec) based on the body weight and the proposed scan duration, the CA: saline ratio accounted for 20:80 [20].

D.Gopalan has highlighted the key factors allowing the optimal contrast enhancement of the right ventricle. They include: 1) use of a contrast agent with a high concentration of iodine (320-370 mg/ml); 2) split-bolus CA injection. If simultaneous contrasting of the pulmonary trunk is required, the injection of the bolus chaser should be skipped; 3) maintaining a high injection rate (at least 5 ml/sec) during the entire infusion period to reduce the effect of a venous return from the IVC; 4) coordination of the saline solution and contrast agent injection rates in multiphase protocols to reduce the phenomenon of "dead space" (a small portion of the CA, lingering between the brachiocephalic and superior vena cava, especially with decreased injection rate at the second stage of the split-bolus) [13].

The pre-bolus technique was introduced relatively recently. Initially, it was intended to optimize the radiation exposure on the patient during examinations of the pulmonary veins and the left atrium, namely, to exclude intracardiac thrombosis. Filling pseudo defects arising from incomplete mixing of the CA and the blood at impaired atrial contractility, increased trabeculation and large pectineus muscles can mimic thrombotic masses [21, 22]. A delayed scan with high sensitivity allows differentiating these changes, but increases the patient's radiation exposure [23, 24]. J.Hur et al. have used this technique to detect left appendage thrombosis in patients with ischemic stroke, as well as before catheter ablation for atrial fibrillation. Two CA boluses were used: 1) 50 ml test bolus; 2) 70 ml main bolus injected 180 seconds after the test bolus injection. The scan started simultaneously with the start of the main bolus injection; thus, in one scan cycle, an

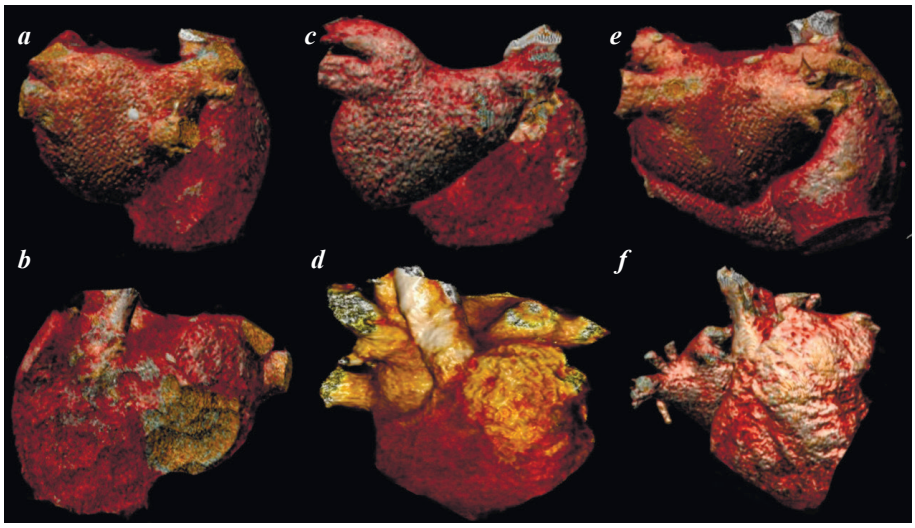

Fig. 5. Intermediate result of non-invasive cardiac mapping: volumetric epicardial atrial models (a, c, e - left atrium, b, d, f - right atrium) at monophasic contrast enhancement (a, b), split-bolus (c, d), with a pre-bolus technique (e, f). With the monophasic protocol, the right atrium (5b) is not contrasted, which is why it is displayed as non-volumetric in the final reconstructions. With the split-bolus and pre-bolus protocols, the right atrium is more contrasted (5d and 5f). However, with the pre-bolus protocol (5f), a more homogeneous contrast filling (by a lower difference in color spectrum) and a more detailed display of the right atrium structures are reflected.

arterial phase was obtained for imaging the LA cavity and the pulmonary vein ostia, and a delayed one - for the LA appendage [25, 26].

W.Staab et al. have also used the protocol with a pre-bolus of 30 mL CA at a slow injection rate (2 mL/sec), and then, after 20 seconds pause, the injection of 70 mL CA at a normal rate (4 mL/sec) to examine patients before AF ablation. In all studies, almost 100% values of sensitivity, specificity, positive and negative predictive values for imaging of thrombotic masses were obtained. However, the impact of this contrast enhancement technique on the imaging quality of right chambers has not been assessed [27].

Our previous study assessed the RA contrasting quality before atrial fibrillation catheter ablation using a pre-bolus technique. Since the main problem preventing homogeneous contrast enhancement of the RA is a hypodense blood flow from the IVC, we assumed that due to recirculation during the pause the pre-bolus would increase the IVC density at the start of the main bolus injection, as well as at the start of the scanning. The study results demonstrated increased homogeneity of the RA contents resulting from mixing of the contrasted blood from the SVC and IVC in the cavity. By reducing the CA volume in the main bolus injection, the risk of artifacts from SVC is minimized with a sufficient quality of left cardiac chambers contrasting preserved [28].

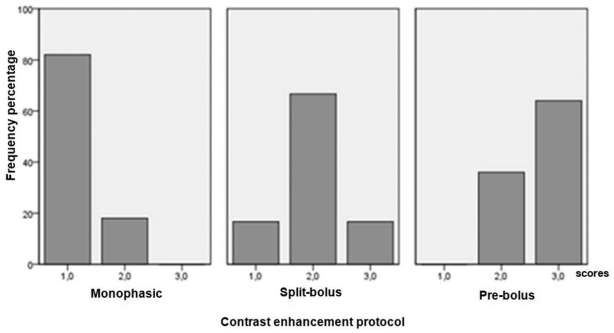

Fig. 6. Bar chart reflecting the qualitative scoring of the final surface mapping reconstructions and the distribution of the results in each arm (in percentage).

This study is an extension of the previous one. For a more detailed assessment of the modified contrast enhancement protocol and its impact on the surface mapping results, it was necessary to compare it with the split-bolus technique. Both protocols provided a high contrast between the myocardium and the blood in the right ventricular cavity; the quality of 3D surface mapping models did not differ significantly. However, the pre-bolus significantly increased the right atrial cavity homogeneity and the contrast of the myocardial-chamber cavity border; this allowed obtaining more detailed anatomical models and the time spent on mapping was subjectively lower with this type of contrast enhancement.

Thus, the protocols of prolonged fractional injection of the contrast agent using the split-bolus technique and with a pre-bolus increase the quality of right ventricle structures imaging, with a high level of CE maintained in the left cardiac chambers. In clinical cases, when precise differentiation of the internal contours of the right atrium is required for the surface mapping of the atrial arrhythmia sources, it is preferable to use a pre-bolus technique, ensuring higher homogeneity of cavity contrasting compared to the monophasic and split-bolus protocols. If reduced contrast agent exposure is required in patients with a high risk of acute renal injury or other contrast-induced conditions, it is possible to use the contrasting protocol with the split-bolus technique for preoperative topical diagnosis of the atrial arrhythmia due to a smaller volume of the contrast agent required.

CONCLUSION

Split bolus and pre-bolus contrast enhancement protocols improve right ventricle imaging while maintaining high contrasting levels of the left chambers. This ensures a precise and reproducible assessment of the volume and function of the right and left ventricles, anatomical structures, and pathological changes. However, in case when precise differentiation of the internal contours of the right atrium is required at surface mapping of the atrial arrhythmia, it is preferable to use a pre-bolus.

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