ORIGINAL ARTICLE — NEW METHODS

Value of rotational angiography (3D-ATG) with contrast agent administration into the right atrium during atrial fibrillation ablation procedures: a preliminary report

Artur Baszko[1], Magdalena Łanocha[2], Piotr Kałmucki[1], Marek Michalski[1], Olga Jerzykowska[3], Waldemar Elikowski[3], Anna Kociemba[2], Małgorzata Pyda[2], Tomasz Siminiak[1], Andrzej Szyszka[1]

[1]2nd Department of Cardiology, HCP Medical Centre, Poznan University of Medical Sciences, Poznan, Poland
[2]Magnetic Resonance Laboratory, University Hospital No. 1 in Poznan, Poznan, Poland
[3]Echocardiography Laboratory, Poznan General Hospital, Poznan, Poland

Abstract

Background: Efficacy and safety of radiofrequency (RF) ablation in patients with atrial fibrillation (AF) strongly depend on the possibility of three-dimensional (3D) visualisation of atria as well as the ostia of pulmonary veins. Current angiographic systems allow 3D visualisation of anatomical heart structures using rotational angiography.

Aim: To evaluate clinical usefulness of rotational angiography (3D-ATG) after contrast agent administration into the right atrium for the purpose of evaluating left atrial anatomy in patients undergoing RF ablation of AF.

Mathods: We also compared images obtained using 3D-ATG with magnetic resonance imaging (MRI). In 18 consecutive patients undergoing RF ablation of AF or left-atrial tachycardia, 3D-ATG was performed uneventfully, followed by 3D reconstruction of the left atrium and the aorta. Ablation using the CARTO 3 system was successful in 17 patients. Total ablation time was 127 ± 28 min, fluoroscopy time 31 ± 8 min, and radiation dose was 413 ± 170 mGy. Mean fluoroscopy time for 3D-ATG was 1.75 ± 0.4 min and the mean radiation dose was 159 ± 57 mGy. Appropriate 3D visualisation of the left atrium was possible in 17 patients, including 16 patients in whom all 4 pulmonary venous ostia were imaged. In 1 patient, all right-sided pulmonary veins were located outside the scan area. In 1 case, 3D-ATG did not allow visualisation of the right inferior pulmonary vein, and in another case the left-sided veins had a common ostium as shown in MRI but not visualised in 3D-ATG.

Results: Pulmonary vein diameter assessed by 3D-ATG was slightly higher than by MRI (16.6 ± 3.2 vs. 15.2 ± 3.6 mm, p = 0.28), although this was mainly related to a single nonvisualised right inferior pulmonary vein. Good agreement (< 2 mm) between the two methods for the assessment of pulmonary venous ostia was higher for the right-sided than the left-sided veins (62.5% vs. 44%, p = 0.03).

Conclusions: We conclude that 3D-ATG after contrast agent administration into the right atrium seems to be a safe and effective method to visualise pulmonary venous ostia and left atrial anatomy. It remains to be established whether it enables evaluation of anatomical anomalies.

Key words: atrial fibrillation, rotational angiography, magnetic resonance imaging

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INTRODUCTION

Atrial fibrillation (AF) ablation is one of the most difficult procedures in cardiac electrophysiology and its real-world effectiveness is still below expectations [1, 2]. Standard procedure involves pulmonary vein (PV) isolation using radiofrequency (RF) current or cryoablation [3, 4]. The most common cause of unsuccessful procedures is recurrent conduction between PVs and the atrium [5, 6]. One of important factors that limit

Address for correspondence:
Artur Baszko, MD, PhD, 2nd Department of Cardiology, Poznan University of Medical Sciences, ul. 28 Czerwca 1956r Nr 194, 61–485 Poznań, Poland, e-mail: abaszko@wp.pl
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effectiveness of ablation is varying anatomy of the left atrium [7]. As a result, modern techniques of three-dimensional (3D) cardiac imaging have been enthusiastically welcomed in cardiac electrophysiology. Established techniques include computed tomography (CT) and cardiac magnetic resonance imaging (MRI) performed before the ablation procedure [8]. The use of rotational angiography during the ablation is an attractive approach that allows obtaining a 3D image of the left atrium and navigating it during ablation [9]. Imaging is performed after administration of contrast agent into the left atrium during advanced atrioventricular block induced with a high dose of adenosine (requires general anesthesia) or during rapid ventricular pacing. Both techniques have contraindications or yield technically inadequate images in about 30% of patients [10]. Contrast agent administration into the right atrium before transseptal puncture seems more advantageous as it eliminates the need for general anaesthesia, reduces the risk of malignant ventricular arrhythmia during rapid ventricular pacing, and may facilitate transseptal puncture.

The aim of our study was to evaluate quality of rotation angiography images obtained after administration of a contrast agent into the right atrium in patients with AF undergoing RF ablation, and to compare this method with MRI.

METHODS

We studied consecutive patients undergoing ablation of symptomatic arrhythmia originating from the left atrium, mainly AF. Patients were managed according to current clinical standards, including chronic anticoagulation therapy with regularly monitored international normalised ratio (INR). Transthoracic and transoesophageal echocardiography was performed in all patients. Cardiac chambers were measured in the long-axis parasternal view (left ventricular end-diastolic dimension and left atrial end-systolic dimension) and in 2-chamber and 4-chamber apical views (left ventricular ejection fraction, left atrial end-systolic area). The atrial appendage was evaluated using standard transoesophageal echocardiographic views.

Rotational angiography (three-dimensional atriography — 3D-ATG)

Studies were performed in patients in the supine position with upper limbs along the trunk. Diagnostic leads were placed in the area of the His bundle and in the coronary sinus (CS). A 6 F pigtail catheter was introduced into the inferior vena cava at its entry into the right atrium. The X-ray tube was placed so as to obtain a central image of the bronchial tree, using two oblique views (LAO 60^{o} and RAO 60^{o}) to image the CS catheter as a marker of the border between the left atrium and the left ventricle. Diagnostic electrodes were removed after confirming that the whole atrium is within the imaging field. The pigtail catheter was connected to an automatic syringe and, after checking for the presence of any air in the catheter, Optiray 350 contrast agent was administered (contrast volume 120 mL, flow rate 20 mL/s, administration time 5 s). Rotational angiography was performed using the Allura Xper FD10 flat detector angiographic system (Philips Medical Systems, Best, Netherlands) by a 240-degree rotational scan (from RAO 120^{o} to LAO 120^{o}) during 4.1 s at the rate of 30 frames/s. After scanning, data were automatically transmitted to an integrated working station and processed using the EP Navigator software which allows automatic detection of the bronchial tree and the left atrium, along with identification of all heart structures and vessels that are opacified by the contrast agent (e.g., aorta). A delay between contrast agent administration and initiation of scanning allows obtaining the best opacification of the region of interest, i.e. the left atrium. The obtained 3D image of the left atrium was then integrated with the fluoroscopic image. In addition, the ascending aorta was imaged to improve safety of the transseptal puncture. Following the ablation procedure, PV diameter was measured at their entry to the atrium without knowing their MRI measurements. These measurements were performed on 2-D atrial images in 3 perpendicular planes.

Based on the left atrial image reconstruction, PV isolation was performed by RF ablation using a cooled ablation catheter and the CARTO-3 electroanatomic system (Biosense Webster). We evaluated total procedure duration, fluoroscopy time, and radiation dose separately for 3D-ATG imaging and the remaining part of the ablation procedure. During image reconstruction, we evaluated the quality of left atrial appendage imaging and PV diameter.

Cardiac magnetic resonance imaging

Pulmonary veins draining to the left atrium were imaged using a Magnetom Avanto 1.5 T MRI system (Siemens). Contrast agent magnetic resonance angiography (CE-MRA) was used to obtain 3D gradient echo images. A test bolus was used to determine the contrast passage time to the left atrium, followed by administration of a full contrast agent dose and acquisition of a series of rapid angiographic sequences at the set delay. Images showing maximal opacification of the PVs draining to the atrium were chosen for further data processing. We obtained maximum intensity projection (MIP) reconstructions of CE-MRA images and their multiplane presentations to measure PVs. The superior-inferior and anterior-posterior dimensions of each PV were measured from their cross-section views on 8 mm MIP image layers. During all MRI examinations, cardiac anatomy and function was evaluated along with PVs and their dimensions.

Statistical analysis

Results are expressed as mean values ± SD or percentages. The exact Fisher test was used for small samples. Qualitative data were compared using the χ^2 test. Other parameters were analysed using the Student t test or ANOVA and the Bland-Altman test to evaluate agreement between MRI and 3D-ATG measurement. $P < 0.05$ was considered statistically significant.

Table 1. Study group characteristics

Age	57.5 ± 11.3 years
Female gender	7/18
Type of arrhythmia:	
Paroxysmal AF	8
Persistent AF	7
Coexisting atrial flutter	9
Atrial tachycardia	3
EHRA class	2.8 ± 0.4 (15 pts in class 3, 3 pts in class 2)
Previous RF ablation	7 (PVI: 3 pts, CTI: 3 pts, LAT: 1 pt)
Coexisting disease:	
Hypertension	13
Previous MI	2
Dilated cardiomyopathy	1
Ostium secundum ASD	2
Echocardiographic parameters:	
LVEDD	50 ± 5 mm
LVEF	55.6 ± 6.6%
LA_d	42 ± 6 mm
LA_a	25.1 ± 6.3 cm^2

AF — atrial fibrillation; PVI — pulmonary vein isolation; CTI — cavotricuspid isthmus ablation; LAT — left atrial tachycardia; MI — myocardial infarction; ASD — atrial septal defect; LVEDD — left ventricular end-diastolic dimension; LVEF — left ventricular ejection fraction; LA_d — left atrial end-systolic dimension; LA_a — left atrial area

RESULTS

We studied 18 consecutive patients undergoing RF ablation of AF or left-atrial tachycardia. The study group characteristics were shown in Table 1.

Rotational angiography (3D-ATG)

Reliable reconstruction of the left atrium was obtained in 17 patients. In 1 patient, both right PVs were located outside the imaging range and were not visualised. In 16 patients, 4 separate PVs were identified. In 1 patient, the right inferior PV was not identified. The base of the left atrial appendage was well seen in all patients, but the whole appendage could be visualised in 7 (39%) patients. The presence of AF or sinus rhythm was not found to have any effect of the quality of appendage imaging. Visualisation of the ascending aorta together with the left atrium facilitated transseptal puncture in 3 patients after 1–2 unsuccessful attempts of fluoroscopy-guided puncture with standard electrodes placement in the area of the His bundle and CS (Fig. 1).

Ablation using a cooled RF catheter (Thermocool Ezsteer, Biosense-Webster) and the CARTO 3 system was performed in all patients, resulting in successful PV isolation in 15 patients and successful ablation of atrial tachycardia in 2 patients (Fig. 2). The procedure was unsuccessful in 1 patient after coronary artery bypass grafting with atrial flutter originating from the left atrium. In addition, ablation of the low right atrial (cavotricuspid) isthmus was performed in 6 patients due to documented episodes of typical atrial flutter. Total ablation time was 127 ± 28 min, fluoroscopy time 31 ± 8 min, and radiation dose was 413 ± 170 mGy. Mean fluoroscopy time for 3D-ATG was 1.75 ± 0.4 min and the mean radiation dose during lamp setting and rotational scanning was 159 ± 57 mGy.

Cardiac magnetic resonance imaging

Cardiac CE-MRA was performed before ablation in 8 patients. In 7 patients, 4 separate PVs draining to the left atrium were identified. In 1 case, common drainage of the left-sided PVs was found. Significant differences between MRI and 3D-ATG images of the left atrium were noted in 2 patients. In 1 case, 3D-ATG failed to visualise the right inferior PV which had a diameter of 10 mm in MRI imaging. In the second case, MRI showed common drainage of the left-sided PVs, while

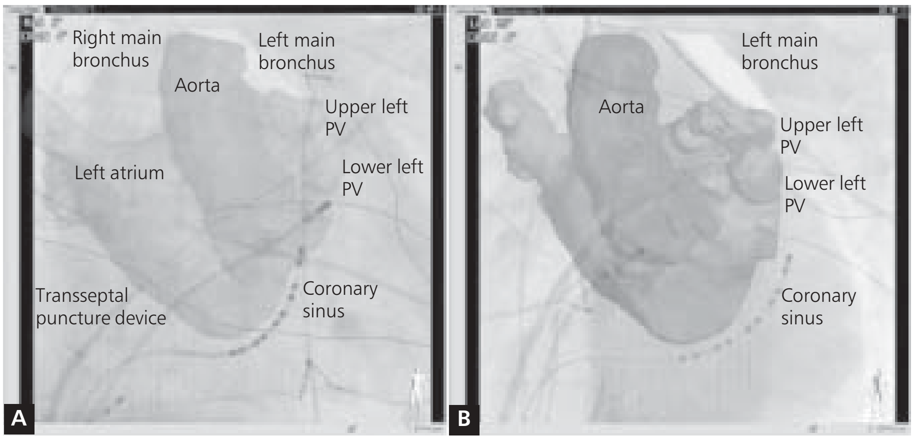


Figure 1. Images obtained after rotational scanning and reconstruction of the left atrium and the ascending aorta. 3D-ATG-guided transseptal puncture in AP and LAO views. Superimposed image of the ascending aorta and the left atrium reduces the risk of puncturing the aorta or the posterior wall of the left atrium; PV — pulmonary vein

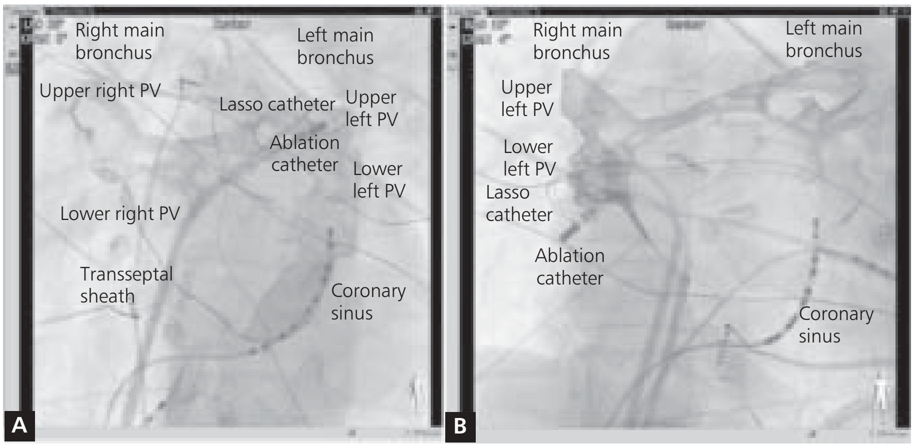
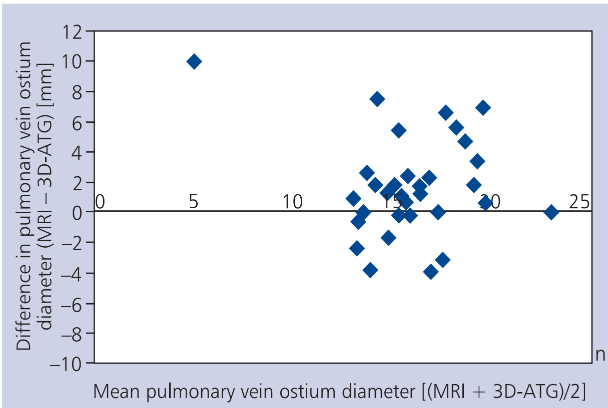


Figure 2. A three-dimensional image of the left atrium superimposed on a two-dimensional fluoroscopy view. **A.** LAO 30° view. The ablation catheter and Lasso catheter are in the ostium of the upper left pulmonary vein (PV); **B.** The ablation catheter and Lasso catheter are in the ostium of the upper right PV. In both cases, the Lasso catheter well identifies the PV ostium. Position of the left atrial reconstruction model is controlled using the image of the trachea, bronchi, and a lead introduced into the coronary sinus

3D-ATG images did not differ from those in patients with separate venous drainage. Pulmonary venous ostia were measured in all patients. Table 2 shows PV dimensions obtained using both methods. Mean PV diameter assessed by 3D-ATG differed slightly compared to MRI (16.6 ± 3.2 vs. 15.2 ± 3.6 mm, p = 0.28), although this was mainly related to a single nonvisualised right inferior PV with a diameter of 10 mm. The graph on Figure 3 shows differences in PV diameter measurements using both methods (3D-ATG and MRI) in relation to the mean measured diameter of these vessels (Bland-Altman test). A difference of ≥ 2 mm was found for measurements of 14 out of 35 PVs (40%). Good agreement (< 2 mm) between the two methods for the assessment of pulmonary venous ostia was higher for the right-sided than the left-sided veins (62.5% vs. 44%, p = 0.03).

Table 2. Comparison of mean pulmonary vein (PV) diameter in magnetic resonance imaging (MRI) and three-dimensional atriography (3D-ATG)

	MRI [mm]	3D-ATG [mm]	P
All pulmonary veins	16.6 ± 3.2	15.2 ± 3.6	0.028
Left-sided veins	16.3 ± 3.1	15.6 ± 2.2	0.39
Right-sided veins	16.9 ± 3.4	14.8 ± 4.8	0.02
Upper left PV	17.3 ± 3.5	16.9 ± 1.8	0.24
Lower left PV	15.3 ± 2.4	15.1 ± 2.2	0.88
Upper right PV	18.3 ± 2.9	17.6 ± 2.4	0.15
Lower right PV	15.3 ± 2.9	14.4 ± 4.7	0.09



Rycina 3. Evaluation of the pulmonary vein diameter in relation to its size (Bland-Altman test). The graph depicts the difference in pulmonary vein ostium diameter measured using magnetic resonance imaging (MRI) and three-dimensional atriography (3D-ATG) in relation to the average diameter measured using both these methods

DISCUSSION

Technological advances in AF treatment lead to integration of anatomy and electrophysiology. Earlier approach was based on previously performed CT or cardiac MRI. First attempts to integrate a 3-D image of the atrium with fluoroscopy were made for CT images and electroanatomic systems (CartoMerge, Biosense-Webster, and Ensite, St. Jude Medical) [9, 11, 12]. The next step was an integration of CT images with 2-D fluoroscopy that improved precision of the evaluation of specific cardiac structures and decreased fluoroscopy time [11]. Three-dimensional rotational angiography performed during the ablation procedure has become the next step in the evaluation of complex left atrial anatomy. In an early study in a group of 30 patients with AF, Li et al. [13] confirmed high reliability of 3D-ATG images as compared to CT. Quality of 3D-ATG images depends on the degree and uniformity of contrast opacification of the left atrium. To this end, two approaches are used. The first one includes contrast agent administration directly to the left atrium after transseptal puncture. In addition, a large adenosine dose is administered intravenously to reduce cardiac output by inducing a relatively long-lasting (for about 8–10 s) atrioventricular block. Adenosine is contraindicated in patients with asthma or obstructive lung disease, and in some patients duration of block is too short despite a large dose, or arrhythmia ensues, resulting in a significant deterioration of image quality [14, 15]. The presence of pacemaker may also be problematic, as the device has to be reprogrammed. In all cases, anaesthesia is required, also to reduce inadvertent body movements that might occur during atrioventricular block. Hadid et al. [15] evaluated the value of rotational angiography in consecutive patients referred for AF ablation. From the original group of 22 patients, the study was ultimately performed in 17, and good quality images were obtained in 14 patients. Reasons for not performing rotational angiography included obesity in 2 patients, asthma in 1 patient, renal failure in 1 patient, and failure of transseptal puncture attempts in 1 patient. An alternative approach to obtain good contrast opacification of the atrium is rapid ventricular pacing [16]. It reduces cardiac output, thus limiting atrial emptying, but is also associated with a risk of inducing ventricular tachycardia or fibrillation in patients with coexisting cardiomyopathy [17]. Administration of contrast agent into the right atrium or pulmonary artery is associated with fewer problems, but image quality may be reduced.

In our study in a group of 18 consecutive patients referred for ablation, no patient was withdrawn due to asthma, obesity, cardiac enlargement, or failure to perform transseptal puncture. In 3 cases, transseptal puncture was made possible by visualisation of the ascending aorta and the left atrium. Our findings confirm that 3D-ATG is highly useful during ablation procedures targeted at left atrial arrhythmia. Very good image quality allowing precise identification of pulmonary venous ostia was obtained in 94.4% of patients. Concordance of the morphological evaluation of pulmonary venous ostia was acceptable, although anomalies of pulmonary venous return were noted in only 2 patients in our study group (including 1 patient with common left-sided drainage, and 1 patient with a very small lower right PV). In both cases, 3D-ATG failed to identify the actual pulmonary venous anatomy in these patients. This might have resulted from the approach we used, which included contrast agent administration into the right atrium and delayed imaging after contrast passage to the left atrium. At that time, some contrast agent is still present within the right heart, and the left atrium is well opacified, but some amount of the contrast agent has already passed to the left ventricle and the aorta. In these circumstances, left atrial image reconstruction may be hindered, but commercially available software allowed good identification of the left atrium and PVs virtually without any need for manual corrections. The presence of the contrast agent in the aorta also allows its visualisation without the need for any additional contrast administration, and thus it may be used as an anatomic landmark in technically more challenging instances of transseptal puncture (Fig. 1). In earlier studies involving contrast agent administration into the left atrium, identification of common pulmonary venous drainage or accessory PVs was very precise. Hadid et al. [15] compared 3D-ATG and MRI images in 10 patients and found that in 1 case, rotational angiography failed to identify an intermediary left PV with a diameter of 14 mm (as measured by MRI). Hilbert et al. [16] found common left-sided pulmonary venous drainage in 9 out of 24 patients. Rotational angiography failed to provide adequate images of this vascular anomaly in only 1 patient [16]. Li et al. [13] also reported good results by administering contrast agent into the right atrium in 30 patients, with optimal image quality in 28 (93%) patients. Common pulmonary venous drainage was identified in all 6 patients with this anomaly, and the presence of an intermediary right PV in all 5 patients. However, the lower left PV was not visualised in a few cases due to inadequate positioning of the imaging system before rotational scanning [13]. It remains to be established which of these rotational angiography techniques proves optimal, although these data should be interpreted in the context of overall safety of ablation procedures, as 3D-ATG is only meant to facilitate ablation and not to replace CT or MRI.

Another important aim of our study was to compare PV ostia measurements in 3D-ATG and MRI. We confirmed quite good but not ideal concordance of these measurements. In our study group, the mean difference in PV diameter measured using the two methods was 1.4 mm. 3D-ATG measurements were not found to overestimate vein diameter as compared to MRI, as it was noted with contrast agent administration directly to the left atrium during ventricular asystole. Acceptable concordance between the two methods (difference of the measured diameter < 2 mm) was found in 60% of cases. The observed differences may have resulted from different approaches to these measurements. In MRI, PVs were measured after performing 3-D reconstructions that allowed precise evaluation of the size of a vein, including its long-axis and transverse dimensions at the ostium. In 3D-ATG, measurement were performed in three perpendicular planes (vertical, horizontal, and sagittal). This allowed choosing an axis that was perpendicular to the venous ostium, but not necessarily identified its actual largest and smallest dimensions. Lower concordance of measured left-sided PV dimensions might have also been related to the vicinity of the left atrial appendage which could obscure precise evaluation of the PV ostia. Somewhat larger dimensions of PVs were noted in investigations performed after adenosine administration, which was likely related to atrial overfilling due to asystole, although the actual difference was only 0.1–0.8 mm [15, 18]. Tang et al. [10] performed rotational angiography after contrast agent administration into the left atrium during rapid ventricular pacing in 46 patients and obtained optimal atrial images in 95.7% of investigation. The measured PV ostium diameter was increased compared to MRI measurements by 1.1 ± 0.7 mm, 2.0 ± 0.9 mm, 1.6 ± 0.8 mm, and 2.3 ± 0.8 mm for the upper right, lower right, upper left, and lower left PV, respectively [10]. In our study, PV diameter in 3D-ATG was not consistently increased compared to MRI measurements, likely due to the fact that measurements in our study were performed at a time when cardiac systolic function was preserved.

CONCLUSIONS

Rotational angiography (3D-ATG) after contrast agent administration into the right atrium seems to be a safe and effective method to visualise pulmonary venous ostia and left atrial anatomy. Our study confirmed good concordance of MRI and 3D-ATG images. It remains to be established whether 3D-ATG enables evaluation of anatomical anomalies of pulmonary venous return (common drainage, accessory veins, particularly of small diameter). Short duration of the diagnostic procedure and atrial image reconstruction, along with short fluoroscopy time and low radiation dose make this technique a promising tool that may facilitate ablation procedures in the treatment of left atrial arrhythmias.

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Conflict of interest: *none declared*

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Wartość angiografii rotacyjnej z systemem 3D-ATG z podaniem kontrastu do prawego przedsionka w zabiegach ablacji migotania przedsionków: doniesienie wstępne

Artur Baszko[1], Magdalena Łanocha[2], Piotr Kałmucki[1], Marek Michalski[1], Olga Jerzykowska[3], Waldemar Elikowski[3], Anna Kociemba[2], Małgorzata Pyda[2], Tomasz Siminiak[1], Andrzej Szyszka[1]

[1]II Klinika Kardiologii, Centrum Medyczne HCP, Uniwersytet Medyczny im. K. Marcinkowskiego, Poznań

[2]Pracownia Rezonansu Magnetycznego, Szpital Kliniczny Nr 1, Poznań

[3]Pracownia Echokardiografii, Wielospecjalistyczny Szpital Miejski, Poznań

Streszczenie

Wstęp: Skuteczność zabiegów ablacji migotania przedsionków (AF) w znacznym stopniu zależy od możliwości trójwymiarowej wizualizacji struktur anatomicznych przedsionków i oceny morfologii spływu żył płucnych u pacjentów poddawanych tym zabiegom. Współczesne systemy angiograficzne umożliwiają rejestrację obrazu również w trakcie rotacji toru wizyjnego, co umożliwia trójwymiarowe odwzorowanie badanych struktur anatomicznych.

Cel: Celem pracy była ocena przydatności angiografii rotacyjnej z 3D-ATG i podaniem środka kontrastowego do prawego przedsionka u pacjentów poddawanych ablacji AF, a także porównanie trójwymiarowych obrazów otrzymanych tą metodą z wynikami rezonansu magnetycznego (MRI).

Metody: U kolejnych 18 pacjentów wykonano angiografię rotacyjną z zastosowaniem 3D-ATG, a następnie rekonstrukcję trójwymiarową lewego przedsionka i aorty bezpośrednio przed zabiegiem ablacji. Zabieg ablacji z zastosowaniem CARTO 3 był skuteczny u 17 pacjentów. Całkowity czas zabiegu ablacji wyniósł 127 ± 28 min, czas fluoroskopii 31 ± 8 min, a pochłonięta dawka 413 ± 170 mGy. Czas fluoroskopii niezbędny do wykonania 3D-ATG wyniósł średnio 1,75 ± 0,4 min, a dawka pochłonięta w czasie ustawienia lampy rentgenowskiej oraz skanu rotacyjnego wyniosła 159 ± 57mGy. Wiarygodną rekonstrukcję lewego przedsionka uzyskano u 17 pacjentów, w tym u 16 uwidoczniono 4 osobno odchodzące żyły płucne. W 1 przypadku nie uwidoczniono żył płucnych prawostronnych, które zostały poza obszarem skanu. W 1 przypadku nie uwidoczniono w 3D-ATG żyły płucnej dolnej prawej, natomiast w kolejnym wynik MRI sugerował osobne odejście żył lewostronnych, czego nie uwidoczniono w 3D-ATG.

Wyniki: Różnice średnich wymiarów odejścia żył płucnych uzyskane z rekonstrukcji 3D-ATG oraz MRI różniły się nieznacznie (16,6 ± 3,2 *v.* 15,2 ± 3,6; p = 0,28), na co wpływał głównie brak wizualizacji 1 żyły płucnej dolnej prawej o kalibrze 10 mm. Zgodność oceny spływu żył płucnych (< 2 mm) była większa dla żył prawostronnych niż lewostronnych (62,5% *v.* 44%; p = 0,03).

Wnioski: Obserwacje sugerują, że angiografia rotacyjna z zastosowaniem systemu 3D-ATG, wykonana po podaniu kontrastu do prawego przedsionka jest bezpieczną i efektywną metodą wizualizacji lewego przedsionka oraz odchodzących żył płucnych. Potwierdzono dużą zgodność obrazów uzyskanych w MRI i 3D-ATG. Krótki czas wykonania rekonstrukcji przedsionka, a także krótki czas fluoroskopii i mała dawka promieniowania czynią z tej techniki bardzo obiecującą metodę wspomagającą wykonywanie zabiegu ablacji arytmii lewoprzedsionkowej. Możliwość oceny anomalii ujścia żył płucnych przy użyciu 3D-ATG wymaga przeprowadzenia dalszych badań.

Słowa kluczowe: migotanie przedsionków, angiografia rotacyjna, rezonans magnetyczny

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Adres do korespondencji:
dr n. med. Artur Baszko, II Klinika Kardiologii, Uniwersytet Medyczny im. Karola Marcinkowskiego, 28 Czerwca 1956 r Nr 194, 61–485 Poznań, e-mail: abaszko@wp.pl

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