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Types of anatomic relationship between left main coronary artery and pulmonary sinus of Valsalva: Implications for balloon pulmonary angioplasty and catheter ablation in the pulmonary root

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ABSTRACT

Background: Concerns have been raised upon the risk of left main coronary artery (LMCA) injury when balloon angioplasty or ablation is performed within the pulmonary sinus of Valsalva (PSV).
Objective: To investigate the LMCA and PSV anatomic relationship (LMCA-PSV_{ar}) variants potentially susceptible to procedure complication.
Methods: We retrospectively studied 100 consecutive patients undergoing computed tomography coronary angiography (CTCA). Three types of LMCA-PSV_{ar} were observed on the basis of the relative location between the LMCA ostium and left pulmonary sinus of Valsalva (LPSV): type 1, intimate contact between the LMCA ostium and LSPV; type 2, LMCA ostium opposite to LPSV and the proximal part coursing anteriorly around LSPV; and type 3, no contact between LMCA ostium and LSPV.
Results: LMCA-PSV_{ar} types 1, 2, and 3 were present in 20(20%), 43(43%), and 37(37%) patients, respectively. For the three types of LMCA-PSV_{ar}, the minimal distance between LMCA and LPSV was 1.66 ± 0.53 mm, 4.63 ± 1.64 mm and 8.24 ± 1.65 mm, and the distance ≤5 mm were in 100%, 87% and 9% patients, respectively. Additionally, the distance from right coronary artery (RCA) to right pulmonary sinus of Valsalva (RPSV)/RVOT was ≤5 mm in 71 patients (71%).
Conclusion: The LMCA is intimately related to LPSV in majority of patients (mainly involving the types 1 and 2), whereas the RCA is often close to RPSV/RVOT. These anatomic features pose potential vulnerability to coronary injury, and should be heightened to avoid complications in this area.

1. Introduction

Balloon pulmonary angioplasty (BPA) has been an attractive strategy for pulmonary artery stenosis (PAS) and pulmonary hypertension [1,2]. Recently, studies also reported the successful ablation of certain outflow tract ventricular arrhythmia (VA) within the pulmonary sinus of Valsalva (PSV) [3–5]. Due to the special anatomical structure of pulmonary valves, RFCA of PSV-derived VA is of great challenge for clinicians. Therefore, Liao et al. and Yang et al. both recommended that PSV-derived VA could be successfully ablated via a reversed-U curve technique, which could provide better catheter-tissue stability and contact force (CF) much higher in the pulmonary sinus [3,5].

However, such procedures mentioned above may increase the risk of left main coronary artery (LMCA) injury. As LMCA damage is a severe complication and life-threatening emergency presenting acutely [6,7], procedures within the pulmonary valves necessitated us to have knowledge of the precise relationship of these structures to each other. So far, the type of anatomic relationship between the coronary arteries to PSV has not been fully delineated. Therefore, in this manuscript, we aimed to describe the LMCA-PSV_{ar} variants including the right coronary artery (RCA) in order to facilitate procedural success and minimize complications when BPA or RFCA was performed in this area.

2. Methods

2.1. Study population

We retrospectively studied the computed tomographic coronary angiograms (CTCA) of 112 consecutive outpatients (56 males, age 47 ± 18 years) with suspected coronary artery disease (CAD) without a prior history of CAD. Patients with previous coronary revascularization or obstructive CAD documented as >50% diameter stenosis by invasive angiography, as well as the patients who underwent PET-CT to study the etiology of cardiomyopathy or heart failure, were not included. 3

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patients with a coronary artery (CA) necrosis was excluded, as were 9 others with suboptimal scan quality, leaving 100 patients who compose the study population. Each patient was given written informed consent, and the study was approved by independent Ethics Committee.

2.2. Image acquisition and reconstruction

Patients took metoprolol 50 mg PO 12 h and 2 h before CTCA using a 64-slice CT scanner (Discovery CT 750 HD, GE Healthcare, Waukesha WI) using prospective ECG gating with images acquired at 75% of the R-R interval during a single breath-hold with slice thickness of 0.625 mm from arch of aorta to below the inferior surface of heart. A bolus of up to 100 mL iohexol 350 was injected intravenously at 6 mL/s, followed by 26 mL saline flush after a timing bolus. Images were reconstructed and analyzed using an OsiriX open-source DICOM viewer (OsiriX, Pixmeo, Geneva, Switzerland).

Structures were described according to their attitudinal position [8]. The pulmonary root consists of three sinuses of Valsalva that are confined by the semilunar attachments of the valvular leaflets proximally and the sinutubular junction distally. Different nomenclatures, left, right, and anterior sinus were used to define the anatomic location of the pulmonary valve sinuses according to their spatial location in relation to the body of the heart itself [6,7,9].

2.3. Classification of the LMCA-PSV_{ar} and relationship between the PSV and LMCA

The anatomic relationship between the PSV and LMCA ostium (LMCA-PSV_{ar}) was described by analysis of 2-dimensional images and 3-dimensional reconstructions. As tissue necrosis can occur within 5 mm of radiofrequency (RF) energy application [10], we classified the LMCA-PSV_{ar} into 3 contact types on the basis of the sinus relative location, and the minimal distance between the LMCA ostium and the LPSV: type 1, intimate contact between the LMCA ostium and LSPV; type 2, LMCA ostium was opposite to LPSV with the proximal part coursing anteriorly around LSPV; and type 3, no contact between LMCA ostium and LSPV. The distance from each PSV to the nearest coronary artery (regional analysis including LMCA, LAD for LPSV and APSV, and RCA for RPSV) was also calculated.

2.4. Data analysis

Continuous variables are presented as mean ± SD, and categorical variables are presented as number (percentage) of patients within each group. Continuous and categorical variables were compared using the Student *t*-test and χ2 test, respectively, with the SPSS (Version 21 for Apple Macintosh, SPSS Inc., Chicago, IL). The level of significance for all analyses was $P < 0.05$ (2-tailed).

3. Results

Baseline characteristics of the 100 patients are given in Table 1.

3.1. Prevalence of LMCA-PSV types

Representative cases of the 3 LMCA-PSV_{ar} types and their prevalence are shown in Figs. 1 and 2. LMCA-PSV_{ar} types 1, 2, and 3 were present in 20 (20%), 43 (43%), and 37 (37%) patients, respectively. A secondary analysis using ≤2 mm, 2–5 mm and >5 mm distance between the LMCA ostia and LPSV lumens as the cutoff for the definition of contact between these 2 structures did not result in a significant change in the distribution of LMCA-PSV_{ar} types (types 1, 2, and 3 in 19%, 45%, and 36%, respectively).

Table 1
Patient characteristics.

	n = 100
Age (years)	46.4 ± 14.8
Females (%)	48 (48)
Body mass index (kg/m^2)	25 ± 3.9
Left ventricular ejection fraction (%)	58.6 ± 9.4
Left ventricular end-diastolic diameter (mm)	50.8 ± 6.7
PA diameter, mean ± SD (mm)	23.2 ± 3.5
Patients with PA enlargement (%)	0
Anatomic ventriculoarterial junction diameter (mm)	26.79 ± 3.08
Pulmonary sinus of Valsalva diameter (mm)	35.23 ± 2.93
Aortic annulus diameter (mm)	21.2 ± 1.8
Ascending aorta diameter (mm)	31 ± 4.6
Patients with other obstructive coronary artery disease (%)	15.7
Data are given as n ± SD or n (%).	

Aortic enlargement defined as aortic diameter at sinutubular junction (STJ) > 2 SD from mean.
Pulmonary artery (PA) enlargement defined as PA diameter >2 SD from mean.
Computed tomographic evidence of obstructive stenosis (>70%) of coronary arteries other than the left main coronary artery (LMCA).

3.2. Anatomic features of the LMCA-PSV_{ar} types

For the LMCA-PSV_{ar} type 1, the commissural point of two arterial roots was identified between LPSV and the LMCA ostium, while the LMCA/left anterior descending artery (LAD) courses anteriorly around the LPSV and APSV for types 2 and 3, respectively. Notably, the LPSV was spatially related to LASV in type 2, but was close to the commissure between RASV and LASV in type 3. The distance from the 3 pulmonary sinuses to LMCA, LAD, RCA were for the three types of anatomic relations are presented in Table 2.

3.2.1. Relationship of LMCA to LPSV

For the three types of LMCA-PSV_{ar}, the mean minimal distance between LMCA and LPSV was significantly different (1.66 ± 0.53 mm, 4.63 ± 1.64 mm and 8.24 ± 1.65 mm, respectively; $P < 0.001$). The LMCA-LPSV distance ≤5 mm were in 100%, 87% and 9% patients for LMCA-PSV_{ar} types 1, 2 and 3, respectively. And the part of LMCA closest to the LPSV was most commonly its ostial and distal third. For the LAD and LPSV anatomic relation, the minimum distance from LPSV to LAD was 3.09 ± 1.64 mm, 2.00 ± 0.71 mm and 3.5 ± 2.30 mm, respectively and showed no significant difference between each type. Specifically, LMCA/LAD in 74 (74%) patients was identified within 5 mm from the LPSV, including 23 (23%) within 2 mm and 51 (51%) patients between 2 and 5 mm.

3.2.2. Relationship of LMCA to APSV

As shown in Table 2, the minimum distance from APSV to LMCA showed no significant difference among three anatomic types (19.04 ± 5.43 mm, 22.47 ± 3.53 mm and 23.32 ± 5.38 mm for types 1, 2 and 3, respectively; $P = 0.15$). But the mean minimal distance between LAD and APSV was significantly shorter in types 1 and 2 (4.77 ± 1.17 mm, 4.27 ± 1.32 mm, and 7.28 ± 2.25 mm for types 1, 2, and 3, respectively; $P < 0.001$). In 34% cases, pulmonary APSV was within 5 mm from the LMCA/LAD, among them APSV within 2 mm was 5%. The point of LMCA closest to APSV was the distal third in all cases.

3.2.3. Relationship of RCA to RPSV

The RPSV was often related to the RCA, their anatomic relation also showed 3 types of contact according to the anatomic distance. The mean minimum distance from the RCA to RPSV/RVOT was 4.37 ± 2.2 mm (range 1–13 mm). As presented in Table 2 and Fig. 2, RCA was ≤2 mm in 10 (10%) patients, >2 to ≤5 mm in 61 (61%) patients, and >5 mm in 29 (29%) patients. The proximal and middle part of RCA (4.9 ± 2.45 mm from the ostium of RCA) were identified as the closest sites to RPSV/RVOT in 76% and 24% cases, respectively.

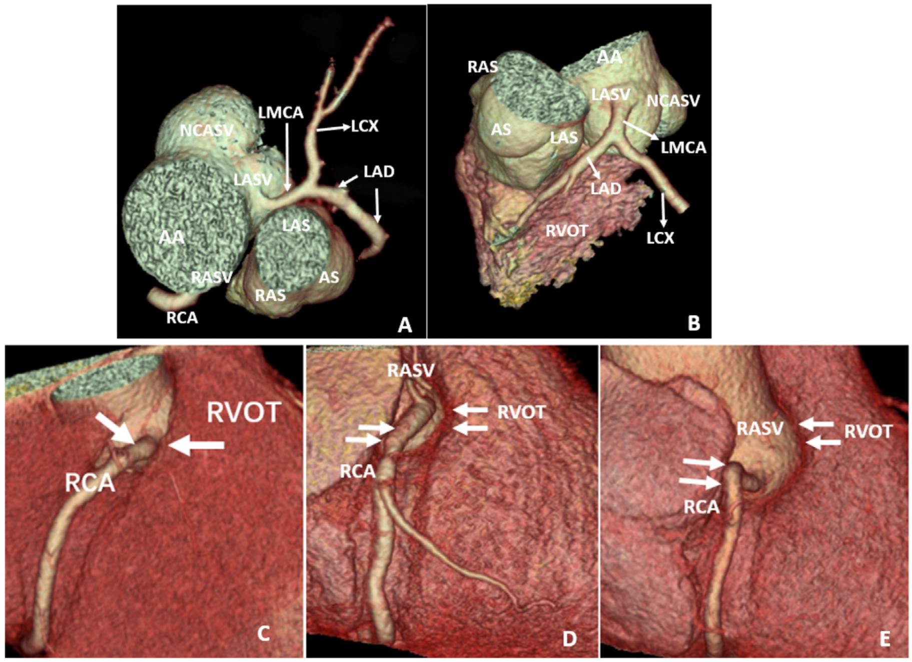

Fig. 1. CT 3D reconstructions of pulmonary root. A, B) Superior and left anterior view showing the relationship between the LMCA and pulmonary valves and related structures. C–E) Right lateral view showing three relationships between the RCA and RVOT in ≤2 mm, 2–5 mm and >5 mm, respectively. LMCA = left main coronary artery; LAD = left anterior descending artery; LCX = left circumflex coronary artery; RCA = right coronary artery; LPSV = left pulmonary sinus of Valsalva; APSV = anterior pulmonary sinus of Valsalva; NCASV = noncoronary aortic sinus of Valsalva; RPSV = right pulmonary sinus of Valsalva; LASV = left aortic sinus of Valsalva; RASV = right aortic sinus of Valsalva; RVOT = right ventricular outflow tract.

3.3. Comparison between systolic and diastolic phases

For the three types of LMCA-PSV$_{ar,}$ the mean minimal distance in systole between LMCA and LPSV was found significantly shorter than that of diastole only in type 3 (19.51 ± 6.24 mm vs. 23.32 ± 5.38 mm, $P < 0.001$) (Fig. 2C). While for types 1 and 2, the distances in systole showed no differences compared with those in diastole (Fig. 2A and B). No other alterations were observed between systole and diastole for the anatomical relationships of coronary artery and APSV and RPSV, respectively (Fig. 2).

4. Discussion

LMCA injury due to BPA rarely occurs, some may require respiratory management with a ventilator [11,12]. In recent years, VA arising from the PA or PSV is confirmed not uncommon with unique electrocardiographic characteristics [3,5]. Meanwhile, the newly adopted reversed-U curve technique is frequently used in RFCA of VAs from the RVOT and PSV due to its better ablation efficiency and higher contact force. In this context, the anatomic relationship between PSV and the related CA structures is of clinical importance.

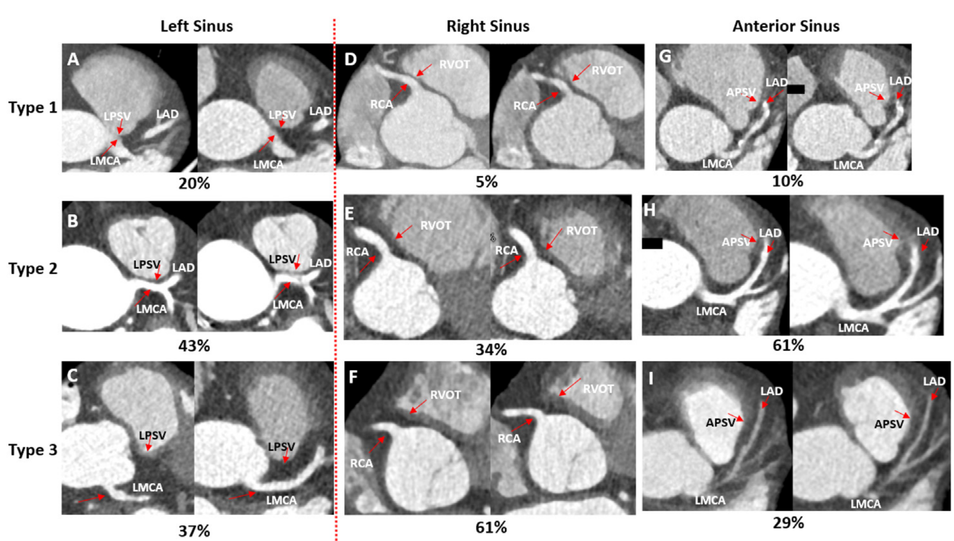

Fig. 2. CT Axial plane images (left panel: diastolic phase; right panel: systolic phase). A–C) Types of LMCA-PSV anatomic relation and their prevalence. D, E, F) Three relationships between the RCA and RVOT in ≤2 mm, 2–5 mm and >5 mm and their prevalence, respectively. Three relationships between APSV and LAD in G) ≤2 mm, H) 2–5 mm and I) >5 mm, and their prevalence. LMCA = left main coronary artery; LAD = left anterior descending artery; RCA = right coronary artery; LPSV = left pulmonary sinus of Valsalva; APSV = anterior pulmonary sinus of Valsalva; RVOT = right ventricular outflow tract.

Table 2
Measurements of three LMCA-PSV anatomic relations.

	Type 1 (n = 20)	Type 2 (n = 43)	Type 3 (n = 37)	P
Distance from CA to sinus				
LMCA-LPSV	1.66 ± 0.53	4.63 ± 1.64	8.24 ± 1.65	<0.001
LMCA-APSV	19.04 ± 5.43	22.47 ± 3.53	23.32 ± 5.38	0.15
LAD-LPSV	3.09 ± 1.64	2.00 ± 0.71	3.5 ± 2.30	0.23
LAD-APSV	4.77 ± 1.17	4.27 ± 1.32	7.28 ± 2.25	<0.001
LMCA < 5 mm from LPSV	20 (100%)	38 (88%)	4 (9%)	
LMCA closest portion				
Ostia/proximal	20 (100%)	20 (46%)	0	
Middle	0	17 (38%)	8 (21%)	
Distal	0	6 (17%)	29 (79%)	

Data are given as n ± SD or n (%).
CA = coronary artery; LMCA = left main coronary artery; PSV = pulmonary sinus of Valsalva; LPSV = left pulmonary sinus of Valsalva; APSV = anterior pulmonary sinus of Valsalva; LAD = left anterior descending artery.

The principal finding of the present study, using CCTA to analyze the LMCA-PSV_{ar}, is that in patients with types 1 and 2 anatomic relation, the proximal portion of the LMCA came in ≤5 mm from LPSV to LMCA. And for the three types of LMCA-PSV_{ar}, the distance ≤5 mm between LPSV and LMCA/LAD was found in 74% patients, among them 23% patients were <2 mm. Additionally, the distance from RPSV to RCA was ≤2 mm or >2 to ≤5 mm in 10% and 61% patients, respectively.

CTCA enables the accurate and highly detailed definition of the LMCA-PSV_{ar}. To our knowledge, this study is the first to comprehensively classify the anatomic type between these vascular structures. We described the presence of LMCA-PSV_{ar} between sinuses of 2 arterial roots and found that the attachment points of the adjacent leaflets of the two arterial roots are not always opposite each other. Such commissural mismatch between LMCA ostium and LPSV may carry important clinical implications and the extent of such mismatch could significantly influence the adjacency of the LPSV to the LMCA and its branches, which should be taken good care of when ablation or BPA was performed.

Pulmonary stenosis is common in children with complex congenital heart diseases [1]. For interventions in the pulmonary artery (PA) during balloon sizing of the PA, simultaneous coronary injections were performed in order to evaluate the risk of compression, and the proximity of the LMCA is often a predictor of compression but does not always correlate with true compression due to the dynamic nature of the PA, as the LMCA dilates in ventricular systole and the thickness of surrounding structures. In this study, we found that the anatomic relationship between coronary artery and PA/RVOT showed no significant alterations during diastole and systole.

We found that the majority of patients (types 1 and 2) in this series had intimate or close contact between the LMCA ostium and the LPSV, with the lumens of these 2 structures separated by ≤5 mm tissue. As tissue necrosis can occur within 5 mm of RF energy application, these anatomic features indicated that the vulnerability to coronary injury when ablation was performed in these areas. Of note, in patients with type 1 and 2 anatomy, the contact distance was significantly shorter, some LMCA ostia closely attached to the LPSV in type 1, than patients with type 3, thus the LMCA is potentially more prone to injury by RF application. This observation implies that LMCA-PSV_{ar} can represent the LPSV-LMCA distance variation with specific kind of LMCA coursing and morphology, which is a useful classifier of coronary injury risk by BPA or RF energy within LPSV.

Additionally, the RCA rather than the LMCA/LAD was close to the RPSV/RVOT. Therefore, if ablating in the RPSV/RVOT, it is unlikely that damage will occur to the LMCA, but the RCA damage is possible. According the findings regarding to RCA, the major cases presented the distance ≤ 5 mm from RVOT/RPSV, that were well within the possible radius of necrosis from an RF source, and the proximal portion was the most likely vulnerable to injury by BPA or RF energy.

So far, the LMCA-PSV_{ar} has received little attention during percutaneous pulmonary valve implantation [13] and in patients with severe pulmonary hypertension [11]. However, with improved techniques and wider applications, balloon angioplasty for pulmonary artery stenosis has become a reliable alternative to in many centers around the world [14,15]. Meanwhile, RFCA of certain RVOT-VA within PSV also raised the concern of coronary injury. From this point of view, the LMCA-PSV_{ar} should receive sufficient attention in order to avoid the catastrophic complications.

For RFCA within the PSV, injury to LMCA is rarely reported up to now. This may be due in part to underreporting and that the LMCA is protected from damage because of the heat sink effect of high blood flow through it and the presence of fat between it and surrounding structures [11,16]. Even a 1-mm layer of epicardial fat appears to protect the myocardium from RF-induced damage [16]. Only 3 cases of LMCA damage caused by RF-induced thermal injury have been reported [13,17]. More subtle arterial injury may be more common and may present much later after ablation [18]. Other cases of LMCA damage were ascribed to LMCA ostial trauma during catheter passage across the aortic valve [18].

4.1. Study limitations

Individuals enrolled in this study were not ablation candidates, but rather patients undergoing coronary test. This patient population might differ from patients undergoing ablation in characteristics such as age, ventricular contraction burden, and comorbidities (e.g., congestive heart failure and pulmonary disease). These could impact the LMCA-PSV ar due to, for example, prevalence of pulmonary hypertension, or the measurements of the PSV. There were no anomalous coronary arteries or congenital anomalies affecting the analysis in our series, and therefore, comments regarding coronary arterial proximity, and relative position were not evaluated.

In addition, the computed tomographic images were acquired with breath held during ventricular diastole, but RF energy is applied continuously throughout the cardiac and respiratory cycles. There is considerable movement of the PSV and other structures during these cycles, but we did not acquire cine runs and therefore did not study any associated changes of the relationship between the PSV and its surrounding aortic root structures.

5. Conclusion

The LMCA is intimately related to LPSV in majority of patients (mainly involving the types 1 and 2), whereas the RCA is often close to RPSV/RVOT. These anatomic features pose potential vulnerability to coronary injury, and should be heightened to avoid complications in this area.

Conflict of interest

None.

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None.

References

[1] J.M. Wilson, J.W. Mack, K. Turley, P.A. Ebert, Persistent stenosis and deformity of the right pulmonary artery after correction of the Waterston anastomosis, J. Thorac. Cardiovasc. Surg. 82 (1981) 169–175.
[2] D. Kalfa, Postoperative pulmonary artery stenosis: current options and future directions, Transl. Pediatr. 6 (2017) 57–58.
[3] Z. Liao, X. Zhan, S. Wu, et al., Idiopathic ventricular arrhythmias originating from the pulmonary sinus cusp: prevalence, electrocardiographic/electrophysiological characteristics, and catheter ablation, J. Am. Coll. Cardiol. 66 (2015) 2633–2644.
[4] J. Zhang, C. Tang, Y. Zhang, X. Su, Pulmonary sinus cusps mapping and ablation: a new concept and approach for idiopathic right ventricular outflow tract arrhythmias, Heart Rhythm. 15 (1) (2017) 38–45.
[5] Y. Yang, Q. Liu, Z. Liu, S. Zhou, Treatment of pulmonary sinus cusp derived ventricular arrhythmia with reversed U-curve catheter ablation, J. Cardiovasc. Electrophysiol. 28 (7) (2017) 768–775.
[6] A. D'Avila, P. Gutierrez, M. Scanavacca, V. Reddy, D.L. Lustgarten, E. Sosa, J.A. Ramires, Effects of radiofrequency pulses delivered in the vicinity of the coronary arteries: implications for nonsurgical transthoracic epicardial catheter ablation to treat ventricular tachycardia, Pacing Clin. Electrophysiol. 25 (2002) 1488–1495.
[7] R.G. Demaria, P. Pagé, T.K. Leung, M. Dubuc, O. Malo, M. Carrier, L.P. Perrault, Surgical radiofrequency ablation induces coronary endothelial dysfunction in porcine coronary arteries, Eur. J. Cardiothorac. Surg. 23 (2003) 277–282.
[8] R.H. Anderson, M. Loukas, The importance of attitudinally appropriate description of cardiac anatomy, Clin. Anat. 22 (2009) 47–51.
[9] F. Saremi, G. Atul, S. Yen Ho, et al., CT and MR imaging of the pulmonary valve, RadioGraphics 34 (2014) 51–71.
[10] M. Vaseghi, D.A. Cesario, A. Mahajan, I. Wiener, N.G. Boyle, M.C. Fishbein, B.N. Horowitz, K. Shivkumar, Catheter ablation of right ventricular outflow tract tachycardia: value of defining coronary anatomy, J. Cardiovasc. Electrophysiol. 17 (2006) 632–637.
[11] M.S. Lee, J. Oyama, R. Bhatia, Y.H. Kim, S.J. Park, Left main coronary artery compression from pulmonary artery enlargement due to pulmonary hypertension: a contemporary review and argument for percutaneous revascularization, Catheter. Cardiovasc. Interv. 76 (2010) 543–550.
[12] K. Hosokawa, K. Abe, K. Oi, et al., Balloon pulmonary angioplasty-related complications and therapeutic strategy in patients with chronic thromboembolic pulmonary hypertension, Int. J. Cardiol. 197 (2015) 224–226.
[13] A. Fraisse, A. Assaidi, L. Mauri, S. Malekzadeh-Milani, J.-B. Thambo, D. Bonnet, L. Iserin, J. Mancini, Y. Boudjemline, Coronary artery compression during intention to treat right ventricular outflow with percutaneous pulmonary valve implantation: incidence, diagnosis and outcome, Catheter. Cardiovasc. Interv. 83 (2014) 260–268.
[14] J.S. Kan, W.J. Marvin Jr., J.L. Bass, A.J. Muster, J. Murphy, Balloon angioplasty–branch pulmonary artery stenosis: results from the valvuloplasty and angioplasty of congenital anomalies registry, Am. J. Cardiol. 65 (1990) 798–801.
[15] L. Bergersen, K. Gauvreau, J.E. Lock, K.J. Jenkins, Recent results of pulmonary arterial angioplasty: the differences between proximal and distal lesions, Cardiol. Young 15 (2005) 597–604.
[16] E.J. Hope, M.C. Haigney, H. Calkins, J.R. Resar, Left main coronary thrombosis after radiofrequency ablation: successful treatment with percutaneous transluminal angioplasty, Am. Heart J. 129 (1995) 1217–1219.
[17] M. Pons, L. Beck, F. Leclercq, M. Ferriere, B. Albat, J.M. Davy, Chronic left main coronary artery occlusion: a complication of radiofrequency ablation of idiopathic left ventricular tachycardia, Pacing Clin. Electrophysiol. 20 (1997) 1874–1876.
[18] B. Desjardins, F. Morady, F. Bogun, Effect of epicardial fat on electroanatomical mapping and epicardial catheter ablation, J. Am. Coll. Cardiol. 56 (2010) 1320–1327.