Quality Improvement Study

Medicine®

OPEN

Transseptal puncture by CTP-2 method: Results from cardiac computed tomography analysis and clinical application

Yan Wang, MD, PhD[a,*], Guangzhi Chen, MD, PhD[a], Yang Bai, MD[a], Sheng Li, MD[a], Andrea Natale, MD, PhD[b], Jianzeng Dong, MD[c], Hong Wang, MD[a], Caihua Sang, MD[c], Ronghui Yu, MD[c], Deyong Long, MD[c], Ribo Tang, MD[c], Xingpeng Liu, MD[d], Xiaopeng Zhao, MD[e], Yuanwen Jiang, MD[e], Changsheng Ma, MD, PhD[c], Dao Wen Wang, MD, PhD[a,*]

Abstract

The current used parameters for transseptal puncture (TSP) under fluoroscopic guidance is from left atriography and need to be verified by precise anatomic measurement. From February 2009 to July 2013, consecutive patients who received computed tomography (CT) were included. Landmarks and parameters were preliminary studied by right atriography, and further evaluated on the CT images of 1001 patients. A method (CTP-2) was proposed for guiding TSP. In right anterior oblique 45° view, the CTP-2 method was defined by points C, T, and P, and 2 areas: point C is in coronary sinus; point T is at a distance of dCT (usually 1.5 ± 0.2 vertebral height) over point C; then point P, the optimal puncture site, was located at 0.5 ± 0.2 vertebral body height posterior to point T; puncture should avoid the aortic root area and the rear triangle area; the aortic root area could be negatively revealed by right atriography at the orifice of inferior vena cava, and the rear triangle area is demarcated by points C, C′, and T′ (C′ and T′ are 2 points horizontally posterior to, and at dCT away from points C and T, respectively). The initial application of CTP-2 in 2820 patients showed that it might be helpful in reducing the need of left atriography and the possibility of cardiac perforation.

Abbreviations: AF = atrial fibrillation, CAD = coronary artery disease, CS = coronary sinus, CSo = coronary sinus orifice, CT = computed tomography, IVC = inferior vena cava, LA = left atrium, LAO = left anterior oblique view, RAO = right anterior oblique view, SVC = superior vena cava, TSP = transseptal puncture.

Keywords: computed tomography, fluoroscopy, transseptal puncture

Editor: Jacek Bil.

YW, GZC, YB, SL, AN, JZD, XPL, XPZ, CSM, and DWW designed the experiments, analyzed the data, and wrote the manuscript. YW, GZC, HW, CHS, RHY, and DWW performed the experiments. GZC, YB, DYL, RBT, and YWJ selected and examined the subjects. All authors reviewed and revised the first and final drafts of this manuscript.

This work was supported by the Science and Technology Department of Hubei Province (2015CFA077) and the Natural Science Foundation of China (81400369 and 81570308). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

The authors have no conflicts of interest to disclose.

[a] Department of Cardiology, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China, [b] St David's Medical Center, Austin, TX, [c] Department of Cardiology, Beijing Anzhen Hospital, Capital Medical University, [d] Heart Center, Center for Atrial Fibrillation, Beijing Chao-Yang Hospital, Capital Medical University, Beijing, [e] Karamay Central Hospital, Karamay, Xinjiang, China.

[*] Correspondence: Yan Wang and Dao Wen Wang, Department of Cardiology, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan 430030, China (e-mail: newswangyan@tjh.tjmu.edu.cn [YW] and dwwang@tjh.tjmu.edu.cn [DWW]).

Medicine (2016) 95:34(e4504)

Received: 27 April 2016 / Received in final form: 12 July 2016 / Accepted: 13 July 2016

http://dx.doi.org/10.1097/MD.0000000000004504

1. Introduction

Transseptal puncture (TSP) is now widely used in interventional cardiology.[1–3] This technique may result in life-threatening complications at times.[4–6] Proper location of the puncture site on septum is the first and also the most critical step during TSP. Various imaging modalities such as intracardiac echocardiography have been reported and may be helpful for locating the puncture site, but the needs of specific instruments limit their uses.[7–9] On the other hand, TSP guided by fluoroscopy is more convenient, and likely will be the mainstay in a considerable long period in many medical centers, especially in the developing countries. Therefore, there is much interest in improving the technique of transseptal access guided by fluoroscopy.[10–12]

Left atriography is once introduced for accurately locating the puncture site under fluoroscopy. However, this method more or less increases the procedure time and it requires the application of a high-pressure injector, which may not be a constantly standby facility in some centers.[1] The collection process may also increase the risk of contamination. Additionally, a silhouette of the left atrium (LA) is not clear in the patients with tricuspid insufficiency.[3,11–13] Moreover, the previous reported parameters to locate the puncture site for TSP under fluoroscopic guidance were mainly resulted from clinicians' experiences or measurements on cadaver heart. The accuracy of cadaver measurement would be restricted by dehydration, eversion, or dissection. As yet, there is no study offering parameters based on precise anatomic measurement.[2,3,12,14,15] The successful rate is largely depended on the clinician's experience. Hence, it is necessary to modify this method to study the landmarks and parameters for the proper location.

Recently, the development of 320 slice computed tomography (CT) allows for the precise measurement of chest 3-dimensional structures; various distances and angles can be measured accurately and repetitively.[15] Additionally, many patients had received CT angiography for visualizing the coronary artery or for guiding pulmonary isolation prior to the TSP maneuver.

By taking this advantage, we screened the landmarks by right atriography, analyzed them on CT images of 1001 patients (the first population), selected several parameters and designed a 3-step method for guiding TSP under fluoroscopy, and eventually evaluated the efficacy in CT images of 316 patients (the second population), as well as the safety of our method in 2820 patients (the third population).

2. Methods

This study was approved by institutional review board of Tongji Medical College and Karamay Central Hospital. Every patient required informed consent prior the procedure. All participants signed their name when they were arranged for screening CT scan. CT angiography images were gained from Tongji Hospital and Karamay Central Hospital. The modified method for TSP was applied in 3 hospitals including Tongji Hospital, Chao-Yang Hospital, and Anzhen Hospital.

2.1. Patients and cardiac multidetector CT

From February 2009 to July 2013, 1001 patients in Tongji Hospital and Karamay Central Hospital were included in the study (the first population). Those patients received contrast-enhanced electrocardiograph-gated CT scan (320-slice, Aquilion ONE, Toshiba, Japan) for screening coronary artery disease (CAD). Independent workstations (Basic Vitrea 2) were used for analysis. A 75% phase location was used for analysis. The slice acquisition thickness and slice gap were 0.5 mm. Three-dimensional structures of LA, aorta, and spine were constructed using volume-rendered method. The location of right atrial landmarks and coronary sinus (CS) on 3-dimensional structure were often verified in axial/sagittal/coronary/oblique plane when they could not be clearly revealed by the volume-rendered method.

2.2. Definitions of directions and points

2.2.1. Direction. Front view, right anterior oblique view (RAO), and left anterior oblique view (LAO) were used for measurement and analysis. Anterior indicated that a cardiac structure or maneuver was remote from spine in an RAO maximum projecting the atrial septum. Caudal indicated that a cardiac structure was remote from the head (Fig. 1A).

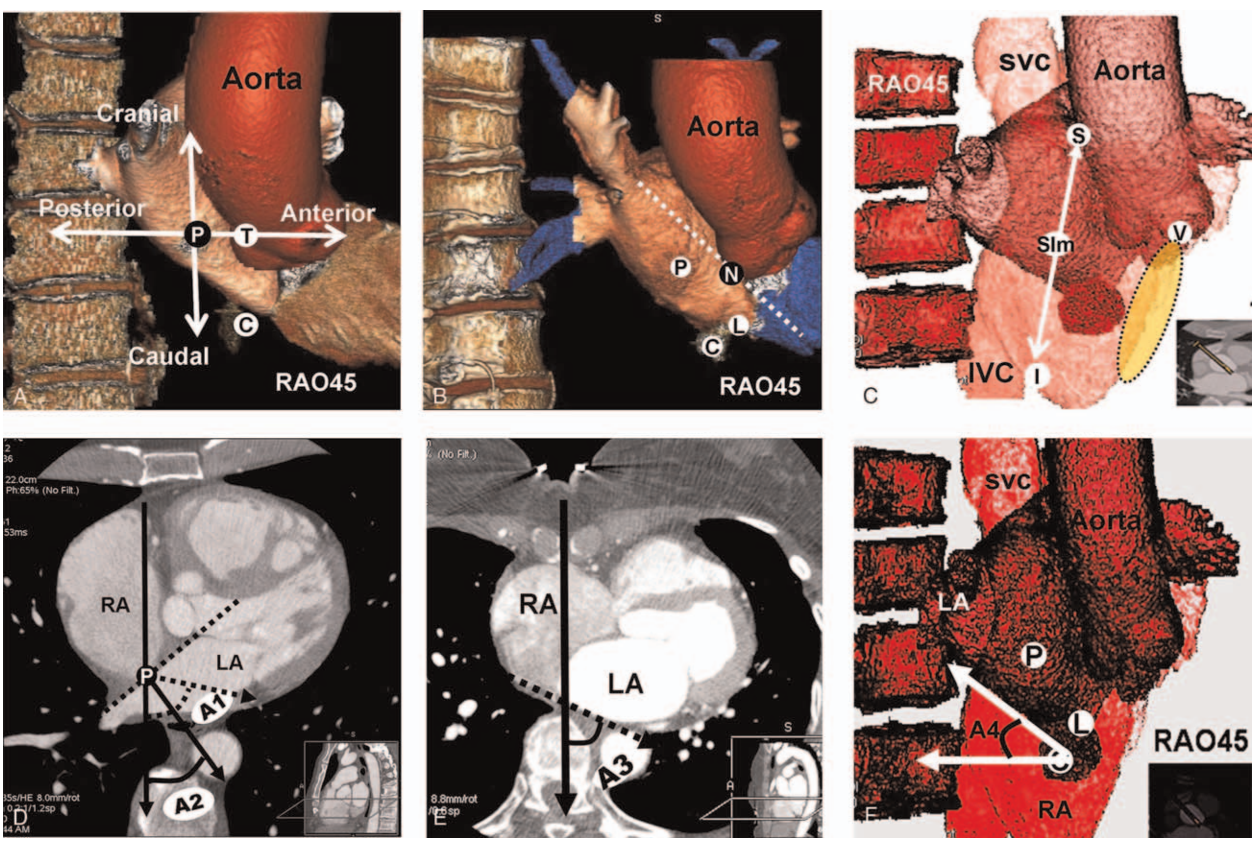

Figure 1. The directions, points, and angles were defined in the three-dimensional model in RAO (i.e. 45 degree) or axial plane. (A) Point C was in coronary sinus at the bifurcation of middle cardiac vein; point T was at the ideal level for puncturing vertically over point C; point P indicated the assumed optimal puncture site. (B) Point L was the lowest point on LA bottom; point N was at the posterior–inferior margin of noncoronary cusp touched by the line of 45° with the horizontal line. (C) Graph showed the point on anterior margin of SVC crossed by right atrial appendage (point S), the junction of anterior margin of IVC and RA (point I), and the peak of tricuspid annulus (point V), the middle point of the line linking points S and I (point SIm). (D) A1 was the best direction for advancing catheter and A2 was the best fluoroscopic view for projecting the septum. (E) A3 was the tangential view for projecting the posterior junction of the 2 atria. (F) A4 was the angle of posterior–inferior border of LA with horizontal line. IVC = inferior vena cava, LA = left atrium, LAO = left anterior oblique view, RA = right atrium, SVC = superior vena cava.

2.2.2. Point C/T/P. Point C was at the bifurcation of middle cardiac vein in CS; point T was at the ideal level for puncturing vertically over point C; point P indicated the assumed optimal puncture site. To avoid puncturing into pericardium, aortic root, or other unexpected cardiac structures, point P was identified in axial, sagittal, and coronary plane, and verified in 3-dimensional structure of CT images. It was often located at the midpoint of the atrial septum where the septum was the widest in axial plane (Fig. 1A and 1B).

2.2.3. Other points. Point L was the lowest point on LA bottom. Point N was the posterior–inferior margin of noncoronary cusp touched by the line of 45° with horizontal line. Point S indicated the anterior margin of superior vena cava (SVC) at where crossed by right atrial appendage. Point I was the junction of anterior margin of inferior vena cava (IVC) and right atrium (RA). Point SIm was the middle point of the line linking point S and I. Point V was at the peak of tricuspid valve (Fig. 1B and C).

2.3. Measurements and analyses

2.3.1. Related angles. Various related angles for guiding TSP were determined in axial plane (A1–A3) or on 3-dimensional images in RAO45 (A4) at the optimal puncture level. A1 to A3 were expressed as fluoroscopic views, which were the angles of a direction with sagittal axis.

The best view for advancing catheter (A1): A1, the best direction for advancing catheter, would allow the catheter tip to have the largest space for inserting into the LA; hence, it could minimize the risk of perforation on the anterior or posterior wall of the LA (Fig. 1D).

The best fluoroscopic view for projecting the atrial septum (A2): The best fluoroscopic view should enable the operator to view the maximum size of the septum on X-ray screen and accurately locate the puncture site. A2 was also the best angle for puncturing but it was not the best angle for advancing catheter (Fig. 1D).

The tangential view for projecting the posterior junction of both LA and RA (A3): At the level of optimal puncture site in axial plane, a tangent line was given at the posterior junction of both atria. A3 was the angle of the tangent line with sagittal axis. In this fluoroscopic view, the most posterior border that the catheter could reach in the RA was almost consistent with the posterior border of the LA on the monitor screen (Fig. 1E).

The angle of posterior–inferior border of LA with horizontal line in RAO45 (A4): A line was drawn from point C to the most posterior point of LA (the junction of left and right atria) on septum at the optimal puncture level. The line approximately demarcated the posterior–inferior border of LA. A4 was the angle of this line with horizontal line and was measured on 3-dimensional image (Fig. 1F).

2.3.2. Caudal–cranial location. The optimal level for puncture (H1/H2): H1 and H2 were the vertical distance from the optimal level to the left atrial bottom (point L) and to point C, respectively (Fig. 2A).

The maximum level for puncture (H3): H3 was the vertical distance from optimal and maximum level to the left atrial bottom (point L). The maximum level for puncturing was assumed at where the length of the atrial septum was $<$1.0 cm in the axial plane of CT image (Fig. 2A).

2.3.3. Anterior–posterior location. D1 to D4 were the horizontal distances from point P to the posterior border of the LA under various fluoroscopic views. D1 (in front view), D2 (in the best fluoroscopic view for projecting the septum), and D3 (in the tangential view of the posterior intersection of 2 atria) were measured in the axial plane. D4 was measured on 3-dimensional images in RAO45 (Fig. 2B–D). P1 and P2 were measured on 3-dimensional images and were the horizontal distances from point P to the vertical line passing points C and L, respectively (Fig. 2D).

2.3.4. Right atrial landmarks for guiding TSP. Various distances related right atrial landmarks were determined on 3-dimensional images in RAO45. D_S, D_I, and D_T were the horizontal vectors started from point P to vertical line passing points S, I, and T, respectively, and were defined to be positive if the vector pointed anteriorly (Fig. 2E). H_S and H_V were the vertical vectors started from point P to horizontal line passing points S, and V, respectively, and were defined to be positive if the vector pointed cranially (Fig. 2F).

2.3.5. Value of aortic root for guiding TSP. Classification: According to the anatomic relation of the aorta with the LA, the position of the aortic root was classified as superior (S), central (C), and inferior (I) types in the caudal–cranial direction, and as anterior (A), middle (M), and posterior (P) types in the anterior–posterior direction in 433 patients (Fig. 2G).

Distances: D_N and H_N were measured in the 3-dimensional images in RAO45. D_N was the horizontal distance from point P to the vertical line passing point N. H_N was the vertical vector from point P to the horizontal line passing point N, and was defined positive if the vector pointed cranially (Fig. 2H).

2.3.6. General measurements. The atrial volume of 2 atria, the vertebral height at the level of the optimal puncture site along the middle line, and the diameter of the aortic root at the level just over aortic cusp were measured. In the section of the maximum area, the longitudinal and transverse diameter, and the height of the both atria were measured in the axial or sagittal plane.

2.4. Simplified angiography

To clearly visualize various landmarks for guiding TSP under fluoroscopy, right atriography was attempted at SVC, CS orifice (CSo), and IVC without the use of high-pressure injector.

Angiography was performed for 1 to 2 s with 10 to 15 mL of contrast injected manually through dilator. Fluoroscopic view included right anterior oblique 45° view (RAO45) or left anterior oblique 45° view (LAO45). The detailed maneuver was as follows: IVC: the dilator was placed just within the IVC orifice and was directed toward atrial septum; SVC: the dilator was placed below the SVC orifice and was directed toward right atrial appendage; CSo: JR4.0 was directed toward slightly posterior to the CS electrode in RAO45; occasionally, straight-tip hydrophilic guide wire (0.035 in) was used for introducing JR4.0 into the CS (Fig. 3A–3F).

2.5. Preliminary evaluation of the landmarks/parameters and the new method

The landmarks/parameters were chosen on the accuracy and reproducibility to locate the optimal puncture point. The promising landmarks and parameters were selected for further evaluation. The best fluoroscopic view for guiding TSP: the best fluoroscopic view should be helpful for locating the posterior border of the atrial septum and gaining the maximum projectile length of the atrial septum. The influence of various factors on the

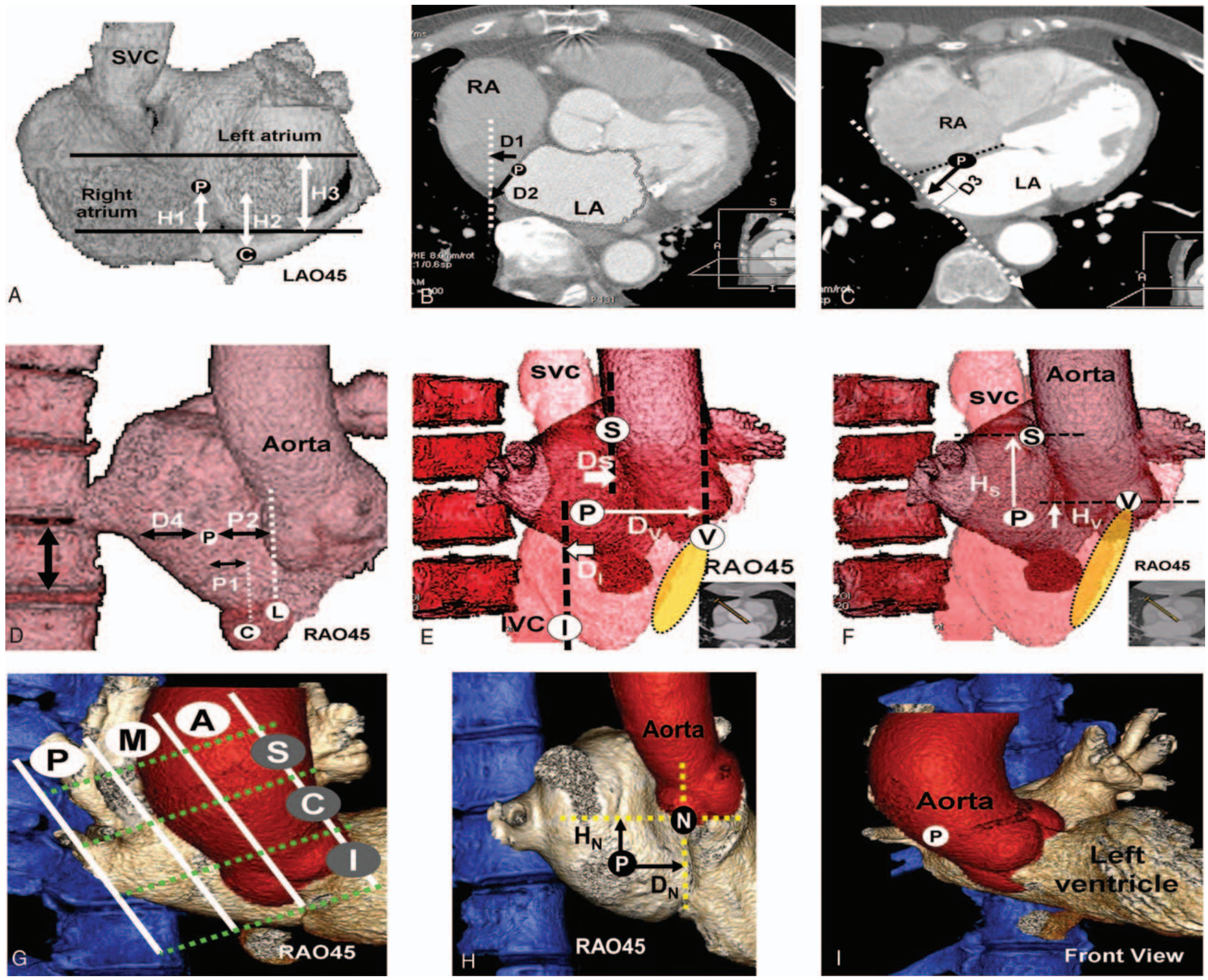

Figure 2. Various parameters for the proper location during transseptal puncture were defined. (A) H1 and H2 indicated the vertical distance from optimal level to the left atrial bottom or point C, respectively; H3 was the vertical distance from maximum level to the left atrial bottom. (B–D) D1 to D4 were the distances from point P to the posterior border of LA under various fluoroscopic view; P1 and P2 were the horizontal distance from point P to the vertical line passing points C and L, respectively. (E) D_S, D_I, and D_V were the horizontal vectors started from point P to vertical line passing points S, I, and V, respectively. (F) H_S and H_V were the vertical vectors started from point P to horizontal line passing points S, and V, respectively. (G) The position of aortic root was classified as anterior (A), middle (M), and posterior (P) types in anterior-posterior direction, and as superior (S), central (C), and inferior (I) types in caudal–cranial direction. (H) D_N and H_N were the vectors from point P to the vertical and horizontal lines passing point N, respectively. (I) The cardiac image shown in front view was of the same patient shown in (G). Other abbreviations and definitions were the same as in Fig. 1.

parameters for locating the puncture site under fluoroscopic view was analyzed. These factors included the left atrial volume, left atrial and right atrial diameters in the axial, sagittal, and coronary plane. A new compound method was proposed for the location.

2.6. Evaluation of landmarks/parameters and the proposed new method

Selected landmarks/parameters and the proposed new method were evaluated and graded by 3 other independent observers on CT images of 316 patients (the second population). The criteria for grading were as follows: the site located by the assessed method was at the ideal position (Good); the site located by the method was not at the ideal position, but it could be accepted (Medium); the site located by the method would likely result in a cardiac perforation (Bad).

2.7. Clinical application

The selected method was independently re-confirmed by experienced clinicians in consecutive patients (the third population) undergoing TSP in 3 medical centers including Tongji Hospital, Chao-Yang Hospital, and Anzhen Hospital. Every patient required informed consent prior the procedure. Data were collected and successful TSP was defined as described previously.[11] Briefly, TSP was considered to be successful if it was accomplished without any severe complications such as cardiac perforation, arterial thromboembolism, arterial air embolism, pericarditis, death, and any other complications secondary to TSP that required further intervention (such as iatrogenic atrial septal defect). As the operator's experience is an important factor involving the procedure success, only those operators who had performed more than 50 cases of TSP independently were included in our analysis.

2.8. Statistical analysis

Continuous data were expressed as mean ± standard deviation. Two-way analysis of variance was used to examine differences between groups, with post hoc analyses performed by Student–-Newman–Keuls method. Linear regression was used for the correlation analysis. Chi-squared test was used for categorical data. All data were analyzed with SPSS 13.0 for Windows. $P < 0.05$ was considered statistically significant.

3. Results

3.1. Simplified angiography

Right atriography without the use of high-pressure injector succeeded in all the patients. In RAO45, the angiography at SVC orifice clearly revealed the profile of SVC, point S, and indirectly delineated the posterior margin of the aortic root (Fig. 3A). In RAO45, the angiography at IVC orifice clearly revealed all the anatomic structures relevant to TSP such as point I, the angle of the IVC with the RA, and importantly, negatively revealed the contour of the aortic root (Fig. 3B); whereas the angiography at the lower part of the RA and toward the aorta also could visualize the aortic root (Fig. 3C). The CT image (Fig. 3D) and fluoroscopic image (Fig. 3C) were from the same patient.

Retrograde CS angiography could be used to visualize the superior wall of the CS, which was closer to the LA bottom than the electrode placed in CS, especially in the case of enlarged CSo (Fig. 3E).

Retrograde angiography of the CS can be omitted during ablation procedure.[14] In this occasion, the position of the electrode at 1 cm inside the CS can be used as reference for the location, and it is always 4 mm over point C (Fig. 3E). Of note, the part of the electrode outside the CSo should not be used as a landmark for the location (Fig. 3F).

3.2. Measurements and analyses

Among the 1001 patients for measurement and parameter analysis, 508 were scanned for preprocedural planning before atrial fibrillation (AF) ablation and the remaining 493 patients were scanned for screening of CAD. The population characteristics are presented in Table 1.

3.2.1. Related angles. The measurements of angles were shown in Table 2. Since A4 was 34 ± 6.6° and none of them was >45°, a right-angled isosceles triangle could be drawn to demarcate the rear blank area, which was only consisted of right atrial tissue and had no left atrial tissue. The hypotenuse is the posterior–inferior border of LA and the right-angled sides equal the defined height for puncturing. Generally, puncture should avoid this area (Fig. 1F, Table 2).

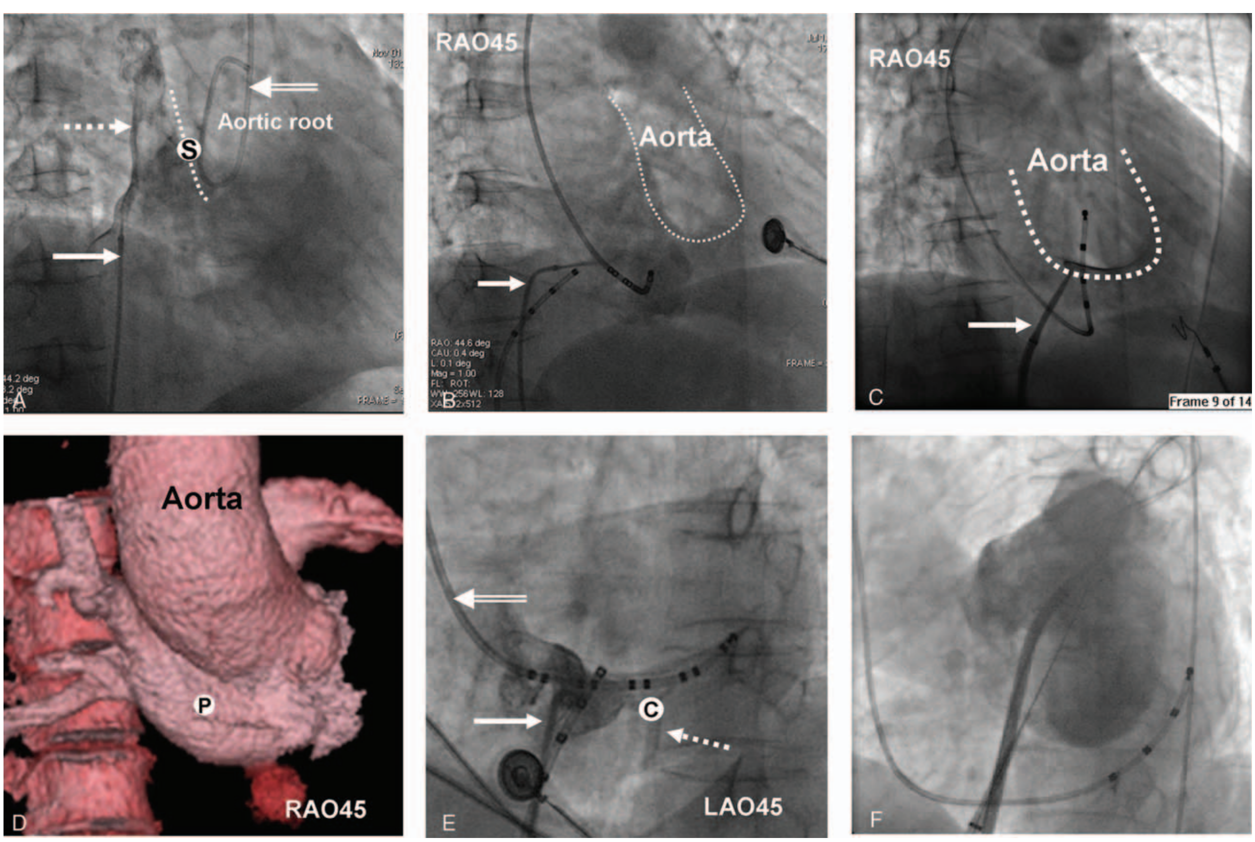

Figure 3. Right atrial angiography was performed at upper (A), lower (B), and middle (C) part of the RA in RAO45, and at the coronary sinus orifice (E) in LAO45. Left atrial angiography was performed in LAO45 (F). Solid arrow showed the catheter used for angiography. Dashed arrow showed the silhouette of SVC (A) or middle cardiac vein (E). Hollow arrow showed the catheter (A) placed at noncoronary cusp in aortic root or the electrode (E) placed in coronary sinus. The black line (C) within the dashed line revealed the posterior–inferior margin of the aortic root. The image shown in (C) and in (D) was from the same patient. Other abbreviations and definitions were the same as in Fig. 1 and 2. LAO45 = left anterior oblique 45° view.

Table 1

Baseline characteristics of the population.

	AF group (n=508)	CAD screening (n=493)	Total (n=1001)
Gender: male, n (%)	373 (73)	306 (62)	679 (68)
Age, y	62±11	55±12	58±11
Weight, kg	94±20	74±16	84±18
Height, cm	177±11	168±8	173±9
LVEF, %	58±9	63±8	61±9
LA diameter, mm	42±8	34±5	38±7
Comorbidity, n (%)			
Hypertension	285 (56)	162 (33)	447 (45)
CAD	107 (21)	139 (28)	246 (25)
Diabetes	46 (9)	54 (11)	100 (10)
CHF	45 (9)	29 (6)	74 (7)
Other*	112 (22)	44 (9)	156 (16)

Caucasian and African American patients comprised 95.5% of the AF group; whereas Asian patients comprised 74.2% of the CAD screening group.
AF=atrial fibrillation, CAD=coronary artery disease, CHF=chronic heart failure, LA=left atrium, LVEF=left ventricular ejection fraction.
* Included patients with hyperthyroidism, cardiomyopathy, sick sinus syndrome, myocardial infarction, patent foramen ovale, chronic obstructive disease, aortic insufficiency, etc.

3.2.2. Caudal–cranial location. The results were shown in Table 3. The optimal level was at 0.9±0.2 vertebral height over the LA bottom and 1.5±0.2 vertebral height over point C if vertebral height (20.2 mm) was used for normalization under fluoroscopy (Fig. 2D, Table 3).

3.2.3. Anterior–posterior location. As shown in Fig. 2 and Table 4, projection in RAO45 was apparent better than that in front view. Figure 2G and I was CT images from the same patient, which also showed the advantage of RAO45 for guiding TSP. P1 was 10.5±4.3 mm; thus, the optimal puncture site was located at 0.5±0.2 vertebral height posterior to the vertical line passing point C.

The difference between the distances for location in RAO36 and RAO45 was very small. RAO45 was apparently better than front view for projecting the atrial septum (Fig. 2G and I, Table 4).

3.2.4. Right atrial landmarks for guiding TSP. As shown in Table 5, the peak point of tricuspid valve was not an ideal landmark for the location due to the larger distance and variation compared with other landmarks. Also point S could be used as a landmark for anterior–posterior location, but it was not ideal for caudal–cranial location (Fig. 2F, Table 5).

3.2.5. Parameters relevant to aortic root. The anterior, middle, and posterior types of the aortic root were 12%, 86%, and 2% in 433 patients, respectively. The superior, central, and inferior types of the aortic root were 2%, 90%, and 8% in 433 patients, respectively. The aortic root was at the same level of left atrial bottom in 0.7% of the patients (Fig. 2G and I). D_N was 13.6±3.5 mm and H_N was 2.4±5.8 mm (Fig. 2H, Table 5).

3.2.6. Other parameters. The effect of left atrial volume on the localization parameters was shown in Tables 2 to 4. The effect of left atrial size on optimal puncture height (H1) showed similar results. However, right atrial size had no apparent effect on the above parameters for locating the puncture site.

3.3. Preliminary evaluation and the new method

Landmarks/parameters were selected for further evaluation according to their proximity to the optimal puncture site and the variation. Landmarks including spine, CSo, and the peak of tricuspid valve are not suitable for the proper location because they are far away from and not tightly associated with the target septum. IVC is also not an ideal landmark for the location due to the relative large variation (Fig. 1A–C).

The landmarks selected for further evaluation were points S, C, I, and N for anterior–posterior location, and points SIm, C, L, and N for caudal–cranial location. The distances relevant to those points for locating the optimal puncture site were based on the averages of measurement mentioned above.

The CTP-2 method was also evaluated. It was defined by points C, T, and P, and 2 areas in RAO45: point T, the ideal puncture level, was at a distance of dCT (usually 1.5±0.2 vertebral height) over point C; then point P, the optimal puncture site, was located at 0.5±0.2 vertebral body height posterior to point T; if C′ or T′ indicated the point at dCT (usually 1.5±0.2 vertebral height) horizontally posterior to point C or T, respectively, the rear triangle area was demarcated by points C, C′, and T′; puncture should avoid the aortic root area and the rear triangle area (Fig. 4A and B).

The measurements were performed on CT images of 75% phase; since the catheter showed that the position changed dramatically between systolic and diastolic phase (Fig. 4C and D). Thus, the parameters defined here for the location should be based on the position of landmarks in diastolic phase.

Table 2

Angles for guiding transseptal puncture under fluoroscopy ($\bar{x} \pm s$, degree).

	A1	A2	A3	A4
Total (n=252)	55.0±9.4	36.2±9.7	44.8±7.7	34.0±6.6
Small left atrium (n=84)	58.8±10.7	36.2±10.1	45.8±8.1	40.1±4.2
Large left atrium (n=84)	50.2±8.1*	33.9±9.7	42.2±7.5	29.3±3.9*

Definitions as in the text and in Fig. 1.
* $P<0.05$ compared with small left atrium group.

Table 3

Distances for caudal–cranial location ($\bar{x} \pm s$, mm).

	Aorta diameter	Vertebral height	H1	H2	H3
Total (n=252)	23.8±2.8	20.2±1.7	19.0±4.0	30.4±4.0	33.8±6.5
Small left atrium (n=84)	22.7±2.7	20.0±1.8	16.7±3.6	28.3±3.8	31.8±6.5
Large left atrium (n=84)	25.7±2.4*	20.4±1.6	21.3±4.4*	32.3±4.3	35.7±8.8*

Definitions as in the text and in Fig. 2.
* $P < 0.05$ compared with small left atrium group.

3.4. Evaluation of the landmarks/parameters and CTP-2 method

The compound method CTP-2, point C, and point S were apparently better than point N for anterior–posterior location ($P < 0.05$) (Fig. 5A). The CTP-2 method, point C, and point L were apparently better than points N for caudal–cranial location (Fig. 5B). Among those objects for comparison, the percentage of "Good" in CTP-2 was the highest whereas the percentage of "Medium" plus "Bad" in CTP-2 method was the lowest.

3.5. Clinical application of the CTP-2 method

The CTP-2 method and our right atriography were applied for locating the proper TSP site in 2820 patients. Although, many operators also took typical second catheter movement as the optimal TSP site on the X-ray screen.[1–3] The CTP-2 method was generally used as reference in their final decision. Additionally, many patients might have no second typical jump due to the lack of apparent prominence in anterior–inferior aspect of fossa ovalis. Thus, our method was used for the location in this situation. The procedures included the ablation of AF and left accessory pathway, and percutaneous balloon mitral valvuloplasty. Two cases finally gave up the puncture because of straight back syndrome or small atrial septum revealed by CT angiography. Seven cases (0.25%) had inadvertent cardiac puncture revealed by contrast injection: 3 of them completed the procedure without any complication; 3 cases suspended the procedure without further interventions and finally completed the procedure about 1 month later; only 1 case (0.04%) had cardiac tamponade and required catheter drainage. Actually, the patient who had cardiac tamponade also showed an extremely small atrial septum in the retrospectively analysis of the CT angiography. No other severe complications were found.

4. Discussion

Fluoroscopy is the basic and essential modality for guiding TSP in many medical centers at present and likely will be used in a considerable period.[2,3,9,11,16,17] Traditionally, left atriography was used for determine the optimal puncture site. It is a relatively safe method. However, it may be inconvenient and inefficient sometimes or in some special situation as described above.

In this study, we reported a novel and effective 3-step method, which can be used for locating the proper TSP site under fluoroscopic guidance. We used images acquired by ECG-gated 320-slice CT. The scan only needs a single 0.35-s rotation. Thus, the effect of respiratory and cardiac motion on the images can be controlled very well with this technique, and other image modalities could hardly achieve this goal in the near future.

According to our analysis, the aortic root is a suitable landmark for anterior–posterior location but not for caudal–-cranial location, especially when the aortic root is very close to, or posterior to the CS electrode, or is very close to the spine under fluoroscopy.

Our analysis showed that the best angle for projecting the septum is RAO36, and for tangentially viewing of the posterior junction of the 2 atria is RAO45. The difference was only 1 to 2 mm between the distances in the above 2 views, and the latter angle is more convenient for calculation; hence, RAO45 was finally chosen for guiding TSP in our study.

There is a rear blank triangle area posterior to the border of the LA and often anterior to the spine in RAO45. Since the angle of posterior–inferior border of LA with horizontal line was always <45°, the triangle can be simplified as a right-angled isosceles. Thus, the CTP-2 method was proposed for the proper location.

The initial application of our method in 2820 patients showed that it was an effective and safe method to locate the TSP site under fluoroscopic guidance. In the present study, only 1 case (0.04%) had cardiac tamponade, and no other severe complications according to our definition. We have no parallel data for comparison; however, our historic controls showed a 0.33% TSP-related severe complications.[11] We believe that the improved outcome is not only due to the modified method but also due to more image data available prior to the TSP.

5. Summary

(1) The CTP-2 method for TSP was defined by 3 crucial points (C, T, and P) and 2 areas in RAO45.
(A)

Table 4

Distances for anterior–posterior location ($\bar{x} \pm s$, mm).

	D1	D3	D4	P1	P2
Total (n=256)	13.1±4.1	19.7±3.8*	18.7±3.6*	10.5±4.3	15.4±4.5
Small left atrium (n=84)	10.2±3.6	17.8±2.7	16.7±3.3	7.7±4.9	14.8±5.6
Large left atrium (n=84)	16.1±4.5†	21.5±3.5†	20.6±5.1†	12.4±2.3†	16.0±4.5

Definitions as in the text and in Fig. 2.
* $P < 0.05$ compared with D1.
† $P < 0.05$ compared with small left atrium group.

Table 5

Parameters relevant to right atrial landmarks for anterior–posterior or caudal–cranial location in RAO45 (n=256, mm).

	Anterior–posterior location				
	SIm	D_S	D_I	D_N	D_V
$\bar{x} \pm s$	−1.6±3.1	2.1±4.1	−1.0±4.8	13.6±3.5	30.3±5.6

	Caudal–cranial location			
	H_V	H_N	SIm	H_S
$\bar{x} \pm s$	2.3±6.9	2.4±5.8	1.5±5.7	28.8±6.3

All the parameters were vectors started from point P to the target point, and defined to be positive if the vector pointed anteriorly or cranially. Definitions as in the text and in Fig. 2.
RAO45 = right anterior oblique 45° view.

The optimal puncture point (P) was determined as follows: point C, which could be visualized by retrograde CS angiography, was in CS at the bifurcation of middle cardiac vein; point T, the ideal puncture level, was at a distance of dCT (usually 1.5±0.2 vertebral height) over point C; then point P was located at 0.5±0.2 vertebral body height posterior to point T.

(B) TSP should avoid the aortic root area and the rear triangle area: the aortic root area could be negatively revealed by right atriography at the orifice of IVC; the rear triangle area was demarcated by points C, C′, and T′; C′ or T′ was defined as the points at dCT (usually 1.5±0.2 vertebral height) horizontally posterior to point C or T, respectively.

(C) For caudal–cranial location, point T could also be alternatively located by the following methods in specific clinical situations: during ablation procedure, point T is at 1.3±0.2 vertebral height over the position of the electrode placed at 1 cm inside the coronary orifice; in patients receiving LA angiography, point T is at 0.9±0.2 vertebral body heights over the LA bottom.

(2) The parameters for location should be based on the position of landmarks in diastolic phase, and should be adjusted according to the left atrial size.

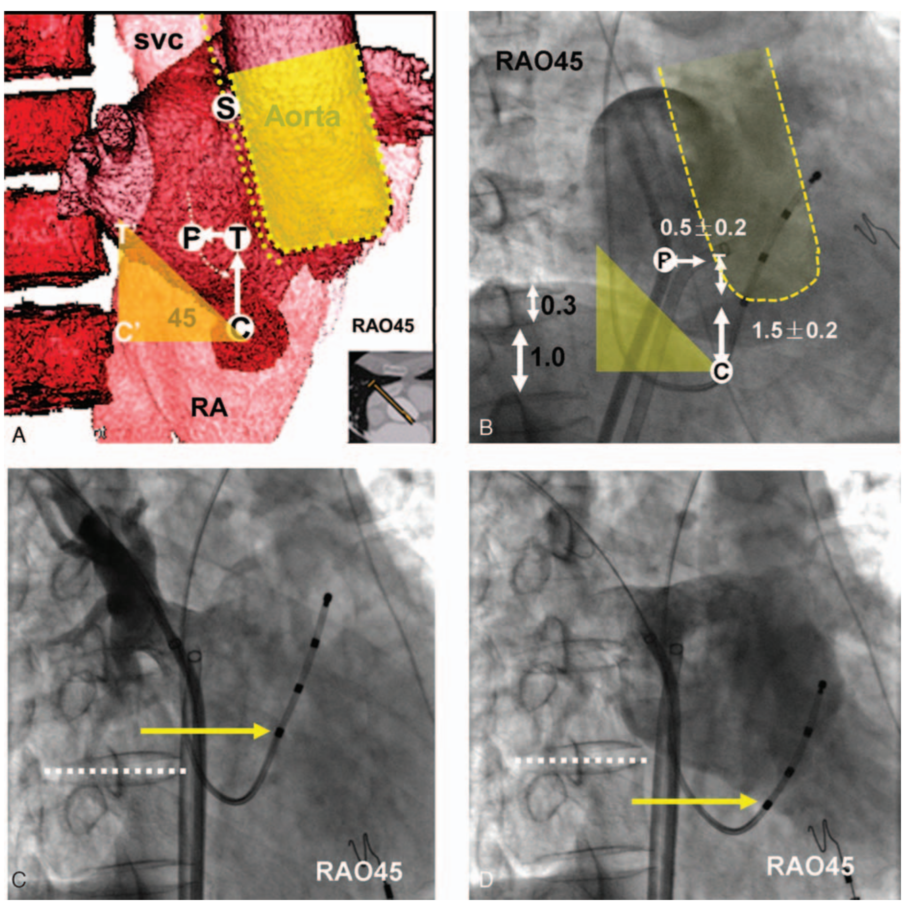

Figure 4. CTP-2 method was revealed in RAO45 in diastolic phase on 3-dimensional computed tomography image (A) or on fluoroscopic images (B–D) for the proper location during transseptal puncture. The optimal puncture site was named as point P; Point C was in coronary sinus at the bifurcation of middle cardiac vein; puncture should avoid the aortic root area and the rear triangle area (demarcated by points C, C′, and T′). Solid arrow showed that the position of proximal electrode in coronary sinus changed dramatically in systolic (C) and diastolic (D) phase in the same patient when the same vertebral space was used as reference (dashed line). Other abbreviations and definitions were the same as in Fig. 1 and 2. RAO45 = right anterior oblique 45° view.

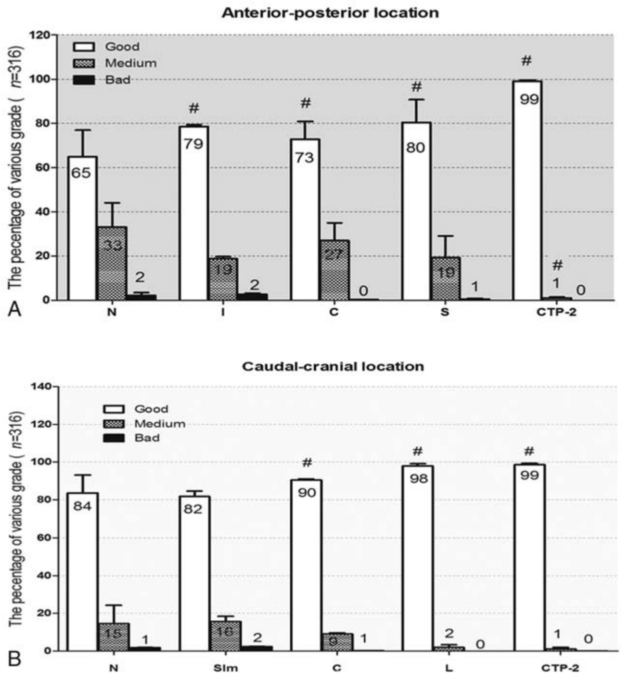

Figure 5. Three independent observers evaluated the superiority of landmarks and the CTP-2 method for anterior–posterior location (A) or caudal–cranial (B) location on 3-dimensional images. Among those objects for comparison, the percentage of "Good" in CTP-2 was the highest whereas the percentage of "Medium" plus "Bad" in CTP-2 method was the lowest. Abbreviations and definitions were the same as in Fig. 1 and 2. $^{\#}P<0.05$ compared with landmark N.

6. Study limitations

Multirow cardiac CT may be insufficient to visualize the fossa ovalis. This study also did not utilize the fossa ovalis as the target for puncture site. However, to acquire more space for manipulating the catheter in AF, many operators intentionally performed the second puncture at other site than at fossa ovalis, even if the first puncture was located at fossa ovalis.[18]

References

[1] Marcus GM, Ren X, Tseng ZH, et al. Repeat transseptal catheterization after ablation for atrial fibrillation. J Cardiovasc Electrophysiol 2007;18:55–9.
[2] Earley MJ. How to perform a transseptal puncture. Heart 2009; 95:85–92.
[3] Ross JJr. Transseptal left heart catheterization a 50-year odyssey. J Am Coll Cardiol 2008;51:2107–15.
[4] Babaliaros VC, Green JT, Lerakis S, et al. Emerging applications for transseptal left heart catheterization old techniques for new procedures. J Am Coll Cardiol 2008;51:2116–22.
[5] De Ponti R, Cappato R, Curnis A, et al. Trans-septal catheterization in the electrophysiology laboratory: data from a multicenter survey spanning 12 years. J Am Coll Cardiol 2006;47:1037–42.
[6] Hartono B, Razakjr OA, Munawar M. Amplatzer septal occluder sealed the complicating aortic root perforation during transseptal procedure. JACC Cardiovasc Interv 2012;5:450–1.
[7] Thiagalingam A, D'Avila A, Foley L, et al. Full-color direct visualization of the atrial septum to guide transseptal puncture. J Cardiovasc Electrophysiol 2008;19:1310–5.
[8] Alaeddini J, Ellenbogen KA. Transseptal catheterization using a nonfluoroscopic mapping system. J Invasive Cardiol 2006;18:328–9.
[9] Shaw TR. Anterior staircase manoeuvre for atrial transseptal puncture. Br Heart J 1994;71:297–301.
[10] De Ponti R, Marazzi R, Picciolo G, et al. Use of a novel sharp-tip, J-shaped guidewire to facilitate transseptal catheterization. Europace 2010;12:668–73.
[11] Wang Y, Xue YM, Mohanty P, et al. Dilator method and needle method for atrial transseptal puncture: a retrospective study from a cohort of 4443 patients. Europace 2012;14:1450–6.
[12] Rogers DP, Lambiase PD, Dhinoja M, et al. Right atrial angiography facilitates transseptal puncture for complex ablation in patients with unusual anatomy. J Interv Card Electrophysiol 2006;17:29–34.
[13] Wadehra V, Buxton AE, Antoniadis AP, et al. The use of a novel nitinol guidewire to facilitate transseptal puncture and left atrial catheterization for catheter ablation procedures. Europace 2011;13:1401–5.
[14] Subinas A, Montero V, Ormaetxe JM, et al. Transseptal catheterization using electrophysiological landmarks in ablation procedures. Rev Esp Cardiol 2007;60:80–3.
[15] Wagdi P, Alkadhi H. Can computer tomography help predict feasibility of transseptal puncture after percutaneous closure of an interatrial septal communication? J Interv Card Electrophysiol 2012;34:167–72.
[16] Daoud EG. Transseptal catheterization. Heart Rhythm 2005;2:212–4.
[17] Kong XQ, Wang L, Xue YZ, et al. A new approach for transseptal catheterization in patients undergoing percutaneous balloon mitral valvuloplasty. Cardiology 2002;98:46–9.
[18] Haegeli LM, Wolber T, Ercin E, et al. Double transseptal puncture for catheter ablation of atrial fibrillation: safety of the technique and its use in the outpatient setting. Cardiol Res Pract 2010;2010:295–7.