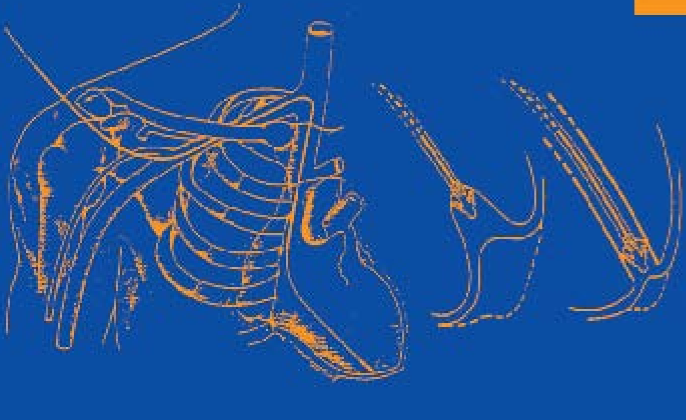
Michela Casella
Antonio Dello Russo

An Atlas of Radioscopic Catheter Placement for the Electrophysiologist



An Atlas of Radioscopic Catheter Placement for the Electrophysiologist

Michela Casella and Antonio Dello Russo

An Atlas of Radioscopic Catheter Placement for the Electrophysiologist

With the Collaboration of
Drs. Paolo Della Bella and Andrea Natale

Springer

Editors
Michela Casella, MD, PhD
Antonio Dello Russo, MD, PhD

Institute of Cardiology
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome
Italy

ISBN: 978-1-84800-226-5 e-ISBN: 978-1-84800-227-2
DOI: 10.1007/978-1-84800-227-2

British Library Cataloguing in Publication Data
An atlas of radioscopic catheter placement for the electrophysiologist
1. Cardiac catheterization 2. Radiography, Medical
I. Casella, Michela II. Dello Russo, Antonio
616.1'20754

Library of Congress Control Number: 2008930756

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

To our parents and to our little Marianna

Foreword

The training of the young cardiologist willing to join the activity of the electrophysiology laboratory is, at best, essentially theoretical and mostly focused on understanding of ECG, intracardiac tracings, and arrhythmia mechanisms. From the practical standpoint, however, the relation between specific anatomic locations within the heart chambers and the actual position of the catheter maneuvered to record and stimulate remains unclear, and a great amount of empirical training with an expert tutor, as well as years of personal experience, is required to achieve adequate confidence to reach a desired anatomical site.

The original work by Drs. Michela Casella and Antonio Dello Russo definitely fills this gap, providing a comprehensive information of the fundamentals of fluoroscopic anatomy for the electrophysiologist. Detailed information on the newer imaging techniques, with special reference to the left atrial CT anatomy, helps in acquiring confidence with the recently introduced technique of image integration, widely used for catheter ablation of atrial fibrillation.

The second part portrays a very interesting collection of the typical and, sometimes, of the less usual catheter positions for the treatment of a variety of arrhythmias. The third part, besides a complete description of permanent lead positions and positioning techniques, includes an original chapter dealing with images and suggestions on "how to" handle lead extractions. As a closing part, a short but complete and updated review of the imaging related to endomyocardial biopsy procedures is included.

Overall an interesting and pleasant to read publication. As a former mentor of Drs. Casella and Dello Russo I express my personal appreciation for their work that, I believe, many electrophysiologists at the beginning of their career or already experienced will find to be a useful companion to their daily activity.

Paolo Della Bella, M.D.
Department of Cardiology, Arrhythmia Service
Cardiologic Center "Monzino"
Milan, Italy

Foreword

The heart is a four-dimensional structure, composed of three spatial dimensions of shape and one temporal dimension of motion. Many technological advances in the field of imaging, such as intracardiac echo, CT, MRI, and three-dimensional electroanatomical image integration mapping systems, have enhanced our ability to visualize, map, and navigate in the heart. Nevertheless, fluoroscopy remains the cornerstone of all interventional electrophysiology procedures. Moreover, with the limitations of current technologies, fluoroscopy will continue to be extensively used well into the next decade.

This EP manual, *An Atlas of Radioscopic Catheter Placement for the Electrophysiologist*, is unique because it is the first book that provides a teaching tool for fellows in training, allied health professionals, and accomplished electrophysiologists on relevant x-ray views commonly encountered in different electrophysiology procedures, and how these x-ray views correlate with cardiac anatomy.

Fluoroscopy provides a two-dimensional representation of cardiac anatomy, but a skilled operator with the use of multiple projections can deduce the anatomy and catheter location with remarkable spatial detail. Because fluoroscopy provides a real-time unmodified view to the operator, there is no easy way to organize the multiple measurements taken from a moving catheter into a more clinically useful model of cardiac electrical activity. As a result, significant clinical experience with fluoroscopy is necessary to accurately position catheters at an exact intracardiac site.

This book was specifically designed to systematically address this challenging aspect of all electrophysiology procedures. It has been written in a perspicuous manner in the hopes of demystifying fluoroscopy, thus making it easier to better understand cardiac anatomy and successfully perform electrophysiology procedures. Each chapter has been assiduously authored by outstanding clinicians in their field who have brought their vast experiences to you in their chapters. The goal for this book is to be *res ipsa loquitur*. This has been a rewarding and exciting experience because it addresses a time honored electrophysiology topic in a new manner. We are confident that everyone from the aspirant electrophysiologist to the seasoned veteran will enjoy this book and find it useful in his or her clinical experience.

Dimpi Patel
Department of Cardiovascular Medicine
Cleveland Clinic
Cleveland, Ohio, USA

Andrea Natale, M.D.
Executive Medical Director of the Texas
Cardiac Arrhythmia Institute
St. David's Medical Center,
Austin, Texas, USA

Acknowledgements

Our objective with this Atlas is to pass on all the teaching, advice, and "tricks of the trade" which an experienced operator might give to less experienced colleagues in the operating theatre.

We could not have written it without the help of all those who have taught, encouraged, and supported us in this fascinating branch of cardiology. There have been so many that we can only name a few.

The years we have spent at Dr. Paolo Della Bella's Centre have been the most exciting and productive imaginable. His warmth and generosity with his knowledge have daily guided us ever deeper into the principles of electrophysiology. We will always be grateful to him, both for that as well as for the invaluable help he has given us during the writing of this book.

We also extend our heartfelt thanks to Dr. Andrea Natale for advising on English terminology and revising the text. He took us under his wing with real friendship.

Our gratitude is also particularly due to Dr. Claudio Tondo and Dr. Roberto De Ponti for their enthusiastic support which has proven constantly invaluable.

Of course, we also owe an enormous debt to many others: especially to Drs. Gemma Pelargonio and Pietro Santarelli; our Chiefs, Professors Paolo Zecchi and Fulvio Bellocci; and our Director, Professor Filippo Crea. We could not have asked for better collaboration or more help from all of them.

It should go without saying that without the help and patience of all the technicians and nurses in and around the operating theatre, this book would simply never have been written at all. Our warmest thanks are due to all of them.

Michela Casella, M.D., Ph.D.
Antonio Dello Russo, M.D., Ph.D.

Contents

Authors and Contributors

Authors

Michela Casella
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome, Italy

Antonio Dello Russo
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome, Italy

Contributors

Conor Barret
Department of Cardiovascular Medicine
Cleveland Clinic
Cleveland, Ohio USA

Fulvio Bellocci
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome, Italy

Lorenzo Bonomo
Department of Bioimaging
and Radiological Science
Catholic University of the Sacred Heart
Rome, Italy

Thomas Callahan
Department of Cardiovascular Medicine
Cleveland Clinic
Cleveland, Ohio, USA

Filippo Crea
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome, Italy

Giuseppe De Martino
Unità Operativa per la Cura delle Aritmie
e dello Scompenso
Ospedale Accreditato Santa Maria
Bari, Italy

Roberto De Ponti
Department of Cardiovascular Sciences
University of Insubria
Varese, Italy

Paolo Della Bella
Department of Cardiology
Arrhythmia Service
Cardiologic Center "Monzino"
Milan, Italy

Carmine Di Stasi
Department of Bioimaging and
Radiological Science
Catholic University of the Sacred Heart
Rome, Italy

Gaetano Fassini
Department of Cardiology
Arrhythmia Service
Cardiologic Center "Monzino"
Milan, Italy

Carlo Liguori
Department of Bioimaging and
Radiological Science
Catholic University of the Sacred Heart
Rome, Italy

Riccardo Marano
Department of Bioimaging and
Radiological Science
Catholic University of the Sacred Heart
Rome, Italy

Laura Mottola
Loyola University, Chicago
USA

Andrea Natale
Texas Cardiac Arrhythmia Institute
St. David's Medical Center
Austin, Texas, USA
Division of Cardiology
Stanford University
Palo Alto, California, USA
Case Western Reserve University
Cleveland, Ohio, USA

Dimpi Patel
Department of Cardiovascular Medicine
Cleveland Clinic
Cleveland, Ohio, USA

Gemma Pelargonio
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome, Italy

Maurizio Pieroni
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome, Italy

Pierluigi Rinaldi
Department of Bioimaging and
Radiological Science
Catholic University of the Sacred Heart
Rome, Italy

Tommaso Sanna
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome, Italy

Pietro Santarelli
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome, Italy

Giancarlo Savino
Department of Bioimaging
and Radiological Science
Catholic University of the Sacred Heart
Rome, Italy

Claudio Tondo
Division of Cardiology
Cardiac Arrhythmia Center and Heart Failure Unit
San Camillo-Forlanini Hospital
Rome, Italy

Carlo Trani
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome, Italy

Nicola Trevisi
Department of Cardiology
Arrhythmia Service
Cardiologic Center "Monzino"
Milan, Italy

John Zakaib
Department of Cardiovascular Medicine
Cleveland Clinic
Cleveland, Ohio, USA

Paolo Zecchi
Department of Cardiovascular Medicine
Catholic University of the Sacred Heart
Rome, Italy

1

X-Ray Anatomy of the Heart

The heart is a three-dimensional structure which, through fluoroscopy, may be visualized two-dimensionally (Figures 1.1–1.2). In order to have a proper view of the cardiac cavities as well as of the great vessels, fluoroscopic projections other than standard ones are required.

Electrophysiological procedures usually relay on three radioscopic projections: frontal posteroanterior (PA), right anterior oblique (RAO) (ranging between −30° and −45°), and left anterior oblique (LAO) (ranging between +30° and +45°).[1]

In the frontal PA view, the cardiac silhouettes' right border is defined, above, by the superior vena cava and, inferiorly, by the right atrium's lateral wall. In case of considerable left atrial dilatation, the left atrium may contribute to the shape of the right border of the heart shadow.

The left border, inferiorly, is shaped by the anterior wall of the left ventricle while, superiorly, a slight convexity is given by the left atrial appendage and the pulmonary artery's common trunk. Anatomically, the base of the heart is comprised primarily by the inferolateral wall of the right ventricle, while the apex represents the left ventricular apex (Figures 1.3–1.5).

In the RAO projection, the heart shadow has an oblong shape with major axis running superoinferiorly and toward the viewer so that we can see a right border, a left border, and an inferior border. The right border is shaped by the posterior wall of the right atrium and by the posterior wall of the left atrium. The left border is shaped by the superior wall of the right ventricle (though the apex is mainly shaped by the left ventricular apex) and, above, by the right ventricular outflow section; by varying the view from −45° to −60° and further, the left ventricle progressively fades away from the right edge of the heart image. The base of the heart coincides with the right ventricular inferior wall. This view shows very clearly the atrioventricular groove, viewed in length-wise direction; therefore, it allows better distinction of the atrium from the ventricle. The RAO view should be used when evaluating catheter's anterior or posterior position, for both the right and the left heart cavities (Figures 1.6–1.8).

In the LAO projection, the heart shadow appears as a globe in which we can distinguish a right border, a left border, and an inferior border. The right border is shaped by the right ventricular lateral wall and, above, by the right atrial appendage. The left border is defined by the left ventricular lateral wall and, above, by the left atrium. By rotating up to +60°, the left atrium's image progressively increases; at the same time, the ventricular section becomes smaller until it fades away completely by rotating to +90°. Atrioventricular valve rings are viewed enface. During the fluoroscopic procedure, the atrioventricular junction can be identified by the difference in the pulsation of the atrial section compared with

[1] Although in clinical practice they are named "anterior oblique," these are actually posterior projections. Posterior oblique projections give a radiological picture equivalent to those of the controlateral anterior oblique views.

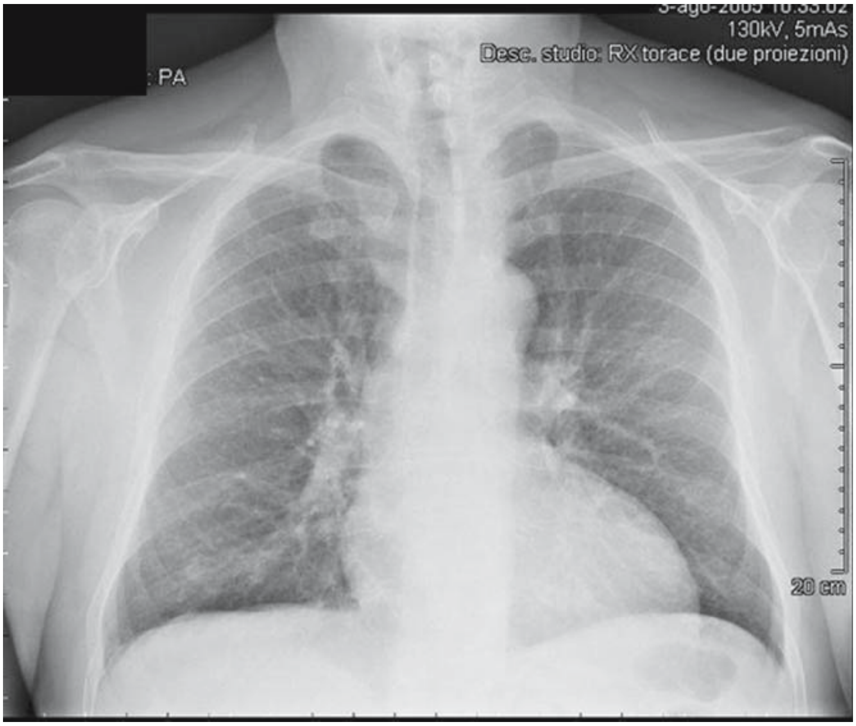


Figure 1.1 Standard thoracic radiograph obtained in the posteroanterior (*PA*) projection. Thoracic fluoroscopy enables easy visualization of both the heart and the vascular structures, as they appear white, thus distinguishing them from the lungs which are radiolucent and appear black. Electrophysiological procedures require fluoroscopic images to be carried out with the patient lying on his/her back. In this position the diaphragm tends to rise and overlap the base of the heart

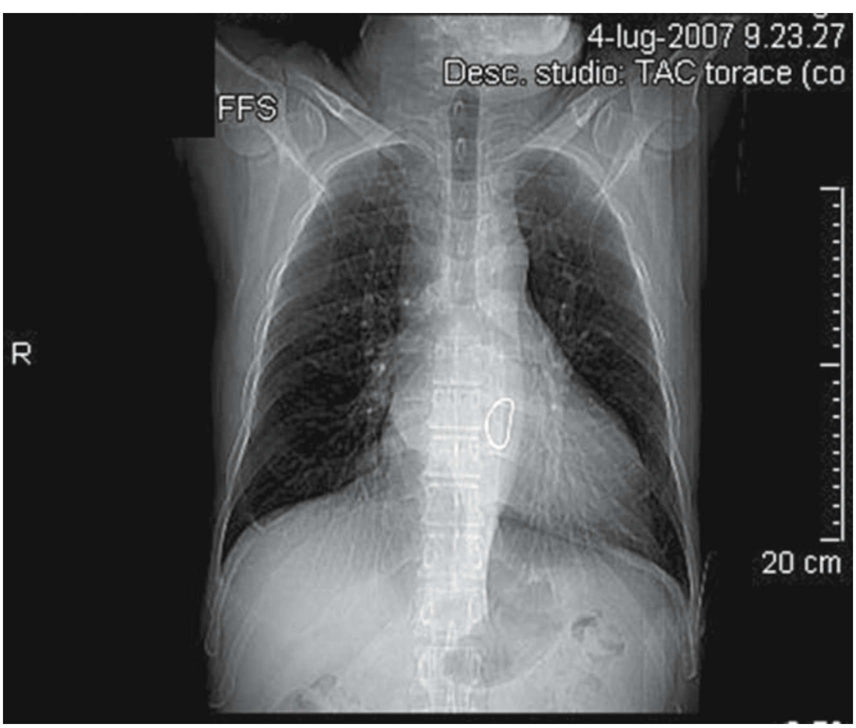


Figure 1.2 Standard thoracic radiograph obtained during deep inspiration in posteroanterior (*PA*) view. The presence of a Carpentier-Edwards Physio Ring at mitral annulus allows to visualize directly the left atrioventricular groove

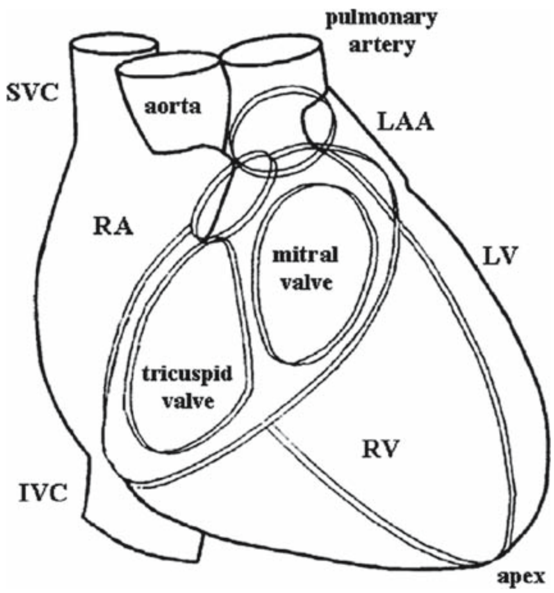


Figure 1.3 Diagram of the heart in the posteroanterior (*PA*) frontal view; right atrium (*RA*), left atrium with left atrial appendage (*LAA*), superior vena cava (*SVC*), inferior vena cava (*IVC*), right ventricle (*RV*), and left ventricle (*LV*)

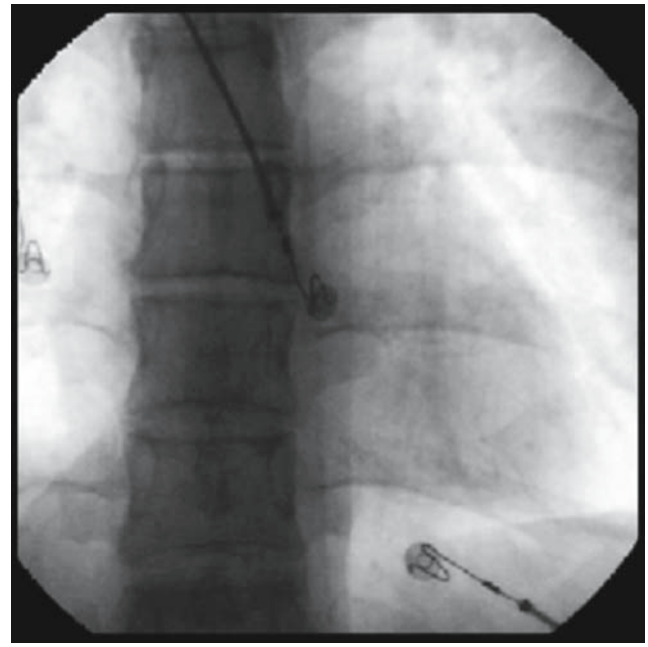


Figure 1.4 Fluoroscopic image in the posteroanterior (*PA*) frontal view showing a heart shadow of normal size and normal axis. The axis of the heart, in this projection, corresponds to the axis of the left ventricle. By definition, the axis of the left ventricle is the line joining the ventricular apex to the aortic annulus. Usually, in frontal views, the axis of the heart and the horizontal plane form an angle of about 60°. This angle is <60° in horizontal type of hearts and it is >60° in vertical ones

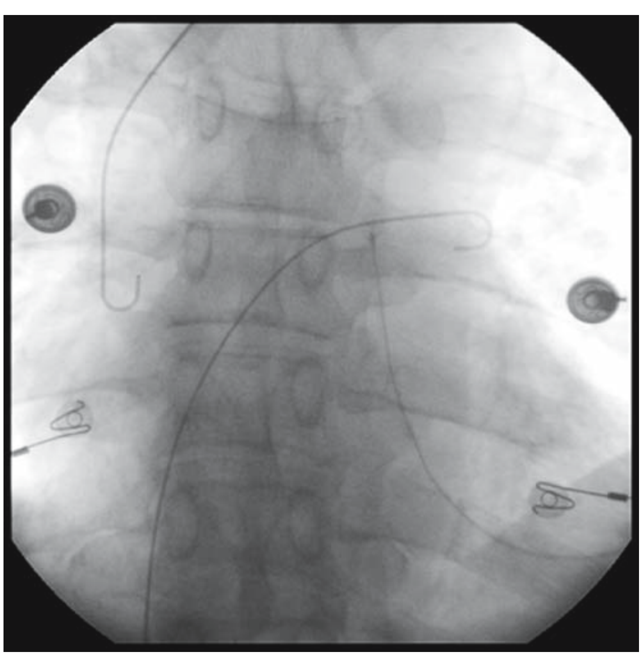


Figure 1.5 Fluoroscopic image in the posteroanterior (*PA*) frontal view. In this case, the heart shadow is enlarged. Furthermore, fluoroscopy enables visualization of two guidewires: one enters the right atrium via the superior approach, along the superior vena cava; the other enters the heart through the inferior vena cava and enters the left atrium through a patent foramen ovale

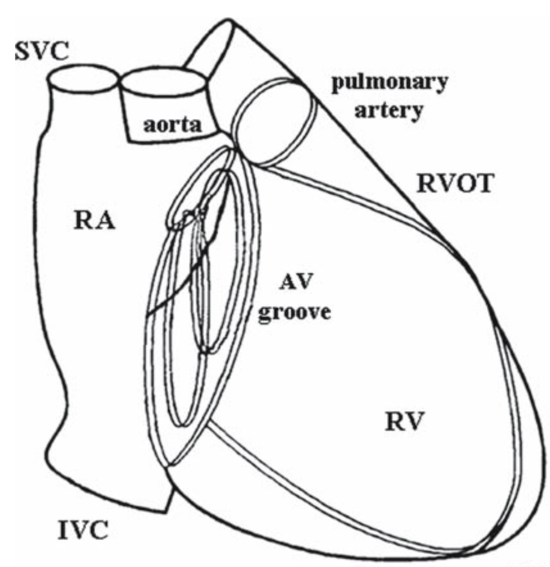


Figure 1.6 Diagram of the heart in the right anterior oblique (*RAO*) view. Right atrium (*RA*), atrioventricular (*AV*) groove, superior vena cava (*SVC*), inferior vena cava (*IVC*), and right ventricle outflow tract (*RVOT*)

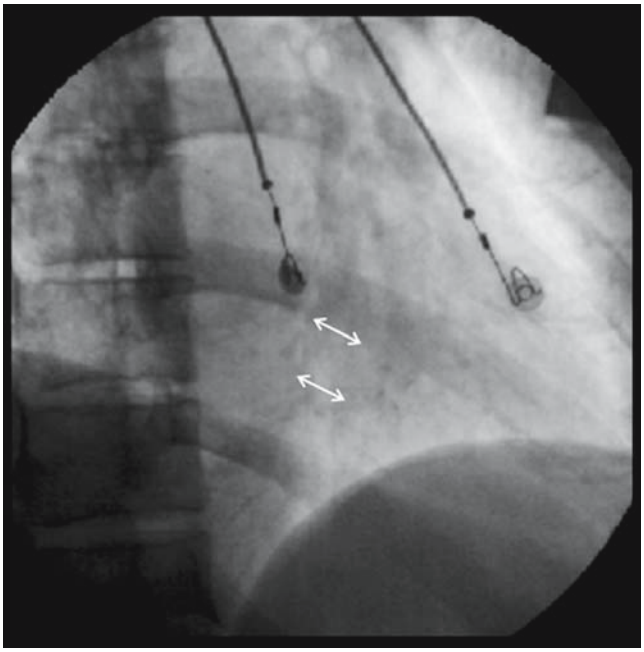


Figure 1.7 Fluoroscopic image in the right anterior oblique (*RAO*) view. In this projection, the atrioventricular valve ring appears as a radiolucent line which moves concurrently with the heart cycle (double arrows)

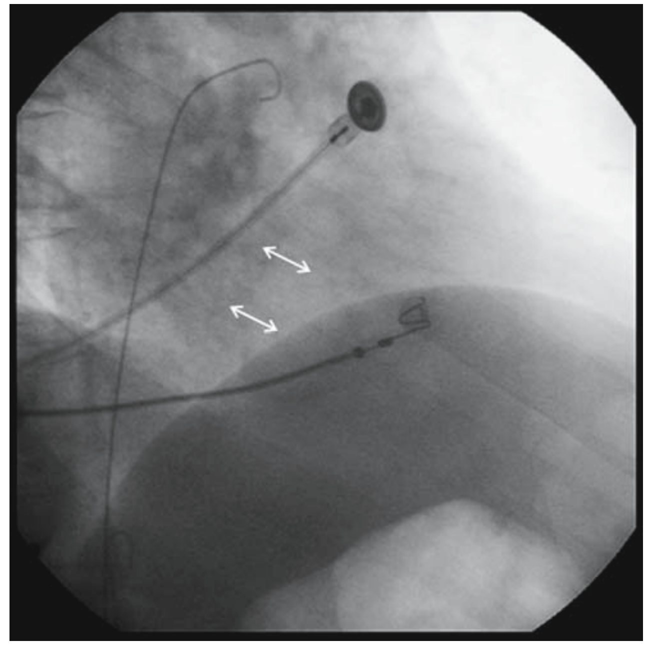


Figure 1.8 Fluoroscopic image in the right anterior oblique (*RAO*) view of a dilated heart. Fluoroscopy shows a guide in the left atrium that penetrates the atrial septum through a patent foramen ovale. In this case too it is possible to identify the atrioventricular ring as a radiolucent line which moves concurrently with the heart cycle (double arrows)

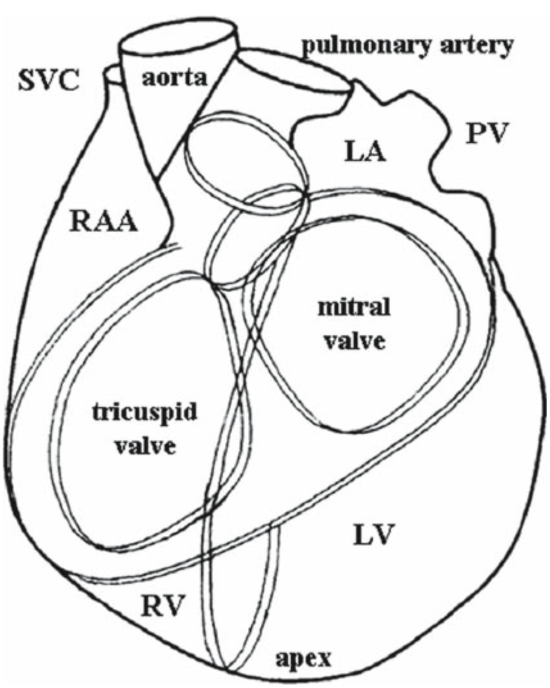


Figure 1.9 Diagram of the heart in the left anterior oblique (*LAO*) projection; right atrium with right atrial appendage (*RAA*), left atrium (*LA*), superior vena cava (*SVC*), inferior vena cava (*IVC*), right ventricle (*RV*), left ventricle (*LV*), and pulmonary vein (*PV*)

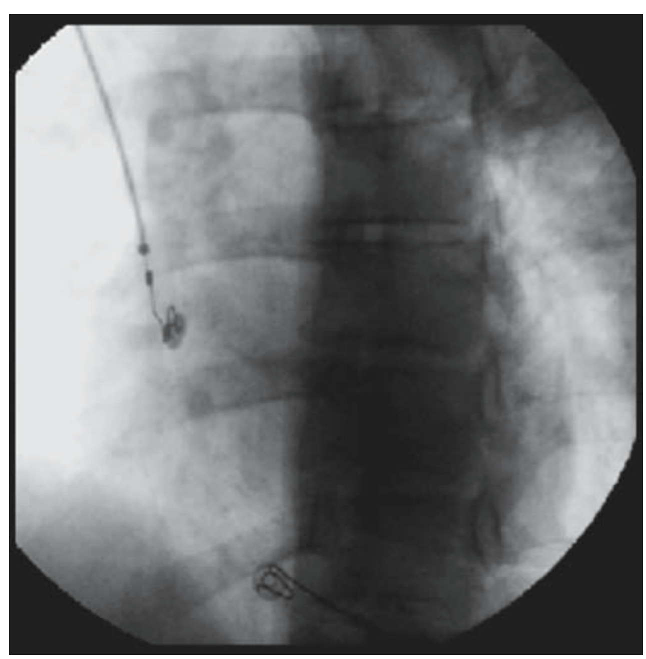


Figure 1.10 Fluoroscopic image in the left anterior oblique (*LAO*) view; with this projection, the typical globular shape of the heart is seen

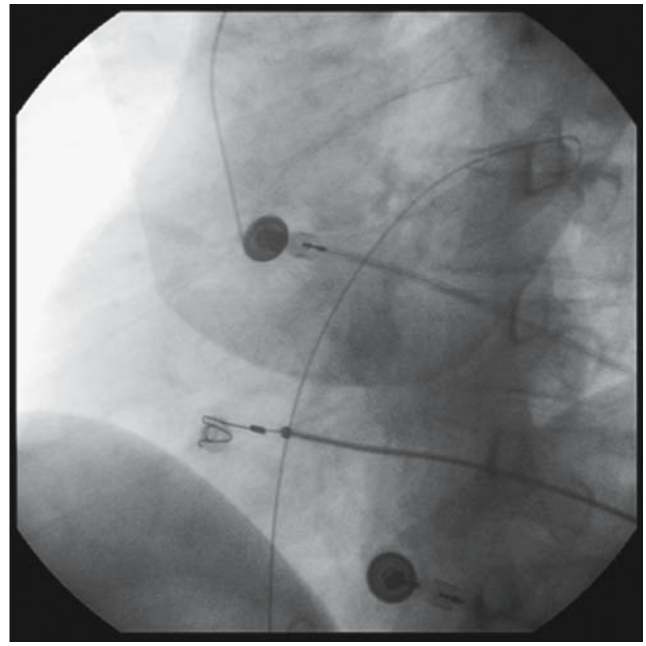


Figure 1.11 Fluoroscopic image in the left anterior oblique (*LAO*) view of a dilated heart. Fluoroscopy shows a guidewire in the left atrium which passes through the patent foramen ovale as well as a guidewire in the right atrium coming down from the superior vena cava

that of the ventricular one. The LAO view should be used to evaluate the lateral or medial catheter position and allows better distinction of the right heart cavities from the left heart cavities and, for each cavity, the free walls from the septal ones (Figures. 1.9–1.11).

It is useful to remember that, in oblique projections, shadow of the spine is always found opposite to the type of used projection. In the right oblique view, the spine will be found on the left, whereas in the left oblique view it will be seen on the right.

2

Computed Tomography of Anatomy of the Heart

In order for cardiologists to plan and accurately perform an ablation procedure, it is absolutely necessary to have anatomic-radiological knowledge of the heart. In this chapter, we will describe the technical-radiological bases of the heart computed tomography (CT) study as well as the obtained anatomic images.

2.1 CT Anatomy of the Heart

The heart is a hollow, muscular egg-shaped organ which lies within median mediastinum between the two arterious series circles, that is, pulmonary and systemic circles. It consists of two separate sections: the right section connected with the pulmonary circle and filled with venous blood and the left section connected with the systemic circle and filled with arterious blood. Moreover, each section is subdivided into two cavities, the atrium and the ventricle, separated from each other by a special valve apparatus. According to the heart axis direction, anteriorly and leftwards caudally obliqued, the right atrium (RA) and the right ventricle (RV) are located anteriorly in relation to the left atrium (LA) and the left ventricle (LV). LA is the more cranial and posteriorly located cardiac chamber. The heart within the mediastinum is contiguous to large vessels (aorta, pulmonary artery, and venae cavae) and its pericardial sac presents adherences to diaphragm, sternum, dorsal column, and mediastinal pleura.

The heart surface is "carved" by grooves outlining the four cavities; the atrioventricular groove, perpendicular to the longitudinal axis, separates atrial from ventricular cavities, whereas the anterior and the posterior longitudinal grooves define the border line between the two ventricles. A surface limit between the two atria is recognizable at the diaphragm level. Here one can recognize the interatrial groove. The two ventricles, characterized by a pyramidal shape and based on the atrioventricular groove, represent a major part of the surface of the heart. The most dorsal region, instead, represents a smaller portion of the heart. This is posteriorly convex and has an irregular outline due to systemic venous structures (venae cavae draining into RA) joining pulmonary ones (pulmonary veins draining into LA).

Figure 2.1 Three-dimensional (*3-D*) volume rendering (*VR*) image. The figure depicts the left atrium with contiguous mediastinal structures. *SCV* superior caval vein, *DAO* descending aorta, *PA* pulmonary artery, *LA* left atrium, *LV* left ventricle

The atria have a "dome-like" shape with appendages projecting forward and partially surrounding the aorta origin, on the right, and the pulmonary artery, on the left. RA, covering the omolateral ventricular base, from which it is separated by the tricuspid valve, hosts the venae cavae sinus in its posterior and median portion. The coronary sinus (CS) outlet, draining blood flowing back from coronary circulation, is located relatively to RA

a **b**

Figure 2.2 **a** 3-D VR image. *LA* posterior surface. Atrial anatomy and venous branching by reformatted images with external surface visualization. **b** 3-D maximum intensity project (*MIP*) image. *LA* posterior surface. Atrial anatomy and venous branching by reformatted images with high-density pixel exaltation (angiographic view) diaphragmatic wall and anteromedially on the left of the inferior vena cava opening. LA, overlapping the omolateral ventricular base, shows, instead, a morphology that stretches out crosswise while receiving pulmonary veins (PVs) outlet into its posterosuperior wall (Figs. 2.1 and 2.2). The two atria show thin walls, with a common wall defined as interatrial septum (IAS), about 2.5 mm thick. It is made of a muscular and a membranous portion, the latter of which is located within the fossa ovalis region where thickness is lower.

2.2 Multidetector Computerized Tomography

Multidetector computerized tomography (MDCT) is able to distinguish among small density differences in structures attenuation. In order to discriminate between two adjacent structures of sufficiently large sizes, in conventional radiology, a 5% radiations differential absorption is necessary, whereas with CT 0.5% is enough. The advent of MDCT, therefore, represented a turning point in diagnostic imaging.

CT images are constructed by measuring the attenuation of a pencil of X-rays obtained into innumerable paths through the bodily layer under study and calculating the attenuation component in single voxels of the examined layer. The result is a bidimensional digital image. In it a higher electronic density voxel shows a lighter grey shade in the corresponding pixel in contrast with a lower density voxel.

As time went by, several generations of computerized tomographs followed. Each was capable of better performance in terms of scanning swiftness and image resolution power. As a result, we moved from traditional tomographs, utilizing a “fan-shaped” pencil of X-rays, to new scanners enabling continuous acquisition of images instead of one layer at a time. In these tomographs, the patient supporting table is subject to a longitudinal uniform running movement, so that detectors describe a spiral along the patient’s longitudinal axis. This helical scanning enables acquisition of images within a breath hold. In more evolved tomographs, more series of detectors are present, which further reduce procedural times. This allows to acquire simultaneously data relative to large volumes; we mean multilayered or multidetector tomographs that, up to these days, can be provided with 4, 8, 16, and 64 series of detectors. Devices provided with double radiogenic source (CT dual source) and with further increase of performance have just been put on sale. For heart study, by now, equipments must be furnished with at least 16 series of detectors.

CT investigation begins by first acquiring a scout-image (guide) of the area to be studied. This topogram is necessary to define the upper and the lower level of tomographic scanning. Then we pass to the basic tomographic scanning after organ-iodated nonionic contrast material has been infused, according to requirement of the district to examine. Upon the acquired images, so-called source images, with thickness and intervals among very thin and, maybe, overlapping sections (thickness below 1 mm), some immediate elaborations are possible. An example is definition of densitometric value in any point of image for a rough characterization of the observed finding and for the window’s adjustment, which allows to graduate the image contrast. Then one decides the window’s center, that is to say the densitometric value to which one makes the medium shade of grey correspond as well as the width of window, that is to say the interval of densitometric values above and under the central one that one wants to represent with the available shades of grey. All structures with densitometric value higher than the chosen one as interval’s superior limit will appear white, while all structures with densitometric value lower than the inferior limit of the chosen interval will appear black. The greater the window’s width, the smaller will be the contrast. This expedient is necessary since our eye can discriminate among 20 different shades of grey, approximately and, if all densitometric values, varying among −1000 (air), 0 (water), and +1000 (bone), were represented with a different shade of grey on the image, this would result in an image that is extremely “flattened” and lacks contrast.

In studying the heart, we utilize a suitable technique of CT, the angiographic technique, at times using electrocardiography synchronization, also utilized for evaluation of the bodily vessels. Here the image is acquired during the phase of maximum vascular opacification due to the contrast material, before the contrast material diffuses through the majority of capillary vessels and parenchyma. Particularly, acquisition is carried out when the contrast material is in phase of maximum opacification within LA and PVs' proximal branches. Cardiac angio-CT exams can, therefore, be carried out with cardiac gating, synchronizing images' acquisition with the various phases of the cardiac cycle, in order to avoid incidental artifacts due to the cardiac movement. While this is fundamental for the CT study of coronary arteries, which are much affected by cardiac contraction, the same seems to be less important for the PVs and LA study, due to the minor contractility of examined structures depending on myocardium's lower thickness. Axial images, obtained with definitely quick acquisition times (an average of 10–12 s without cardiac gating for 16 layered devices and even more than halved for 64 layered devices), are not burdened with artifacts caused by the thin atrial wall contraction (certainly weaker than the ventricular wall, which, as it is well known, calls for the use of cardiac synchronization for the coronaries' study); therefore, even without using cardiac synchronization, three-dimensional (3-D) and multiplanar reconstructions, or endocavitary browsing, appear qualitatively diagnostic.

MDCT and magnetic resonance imaging (MRI) have been applied as imaging techniques for the PVs, with excellent spatial resolution. These techniques have a low inter- and intraobserver variability and give an accurate imaging of the PVs and LA. The greatest advantage of these methods is the size of the diameter of the lumen and visualization not only of PVs superior and inferior walls but also of the anterior and posterior ones. Reconstruction of acquired images can be carried out on three planes (transversal, sagittal, and coronal) using different postprocessing techniques (MPR, multiplanar reconstructions, 3-D VR, volume rendering, and MIP, maximum intensity projection, images). A volume's adequate technique allows a 3-D panoramic visualization of PVs anatomy as well as an evaluation of PVs' anatomic connections with nearby structures. Virtual endoscopic images can be reconstructed, enabling endoluminal evaluation of the venous–atrial junction and the PVs branches. Moreover, morphologic information provided by CT and MRI is used as a stereotactic guide during the procedure, and also to navigate and to make the catheter steady for ablation. Systems which can integrate MRI or CT high-resolution images with 3-D images coming from electroanatomic mapping have been developed. By utilizing the 3-D anatomic information coming from the MRI/CT image, the electroanatomic

a b

Figure 2.3 **a** Some modalities of atrial visualization. a Endocavitary view. **b** Virtual endovascular view. *RSPV* right superior pulmonary vein, *RIPV* right inferior pulmonary vein, *RMPV* right middle pulmonary vein, *LSPV* left superior pulmonary vein, *LIPV* left inferior pulmonary vein, IS intervenous septum, *LAA* left atrial appendage, S left appendage/pulmonary vein saddle, *MI* mitralic isthmus, *AO* aorta mapping sequence with catheter can be planned before starting the procedure, reducing considerably procedural times and increasing the level of accuracy bound to the easier way of reaching particular anatomic structures or structures which are difficult to pinpoint. During the whole procedural phase, one gets, in real time, the visualization of the mapping catheter moving within a complete and accurate anatomic structure, ensuring the reaching of particularly complex anatomic structures too. The ability to section MRI/CT along different planes (sagittal, coronal, frontal) allows visualization in real time of the veins, providing a direct representation of the inside walls with them correlated (Fig. 2.3)

2.3 CT Study of Target Structures in Atrial Fibrillation Ablation

Structures representing the target for atrial fibrillation (AF) ablation are the following: PV ostia (Fig. 2.4), including the intervenous septum between the left superior pulmonary vein and the left atrium appendage (LAA), and the LA posterior wall.

Other additional ablation sites are the septum between the left inferior PV and the mitral annulus, also called the mitral isthmus (MI); the LA roof; intervenous septum(s) between the right middle PV (RMPV) and the right inferior PV; other foci spread within atrial walls' thickness.

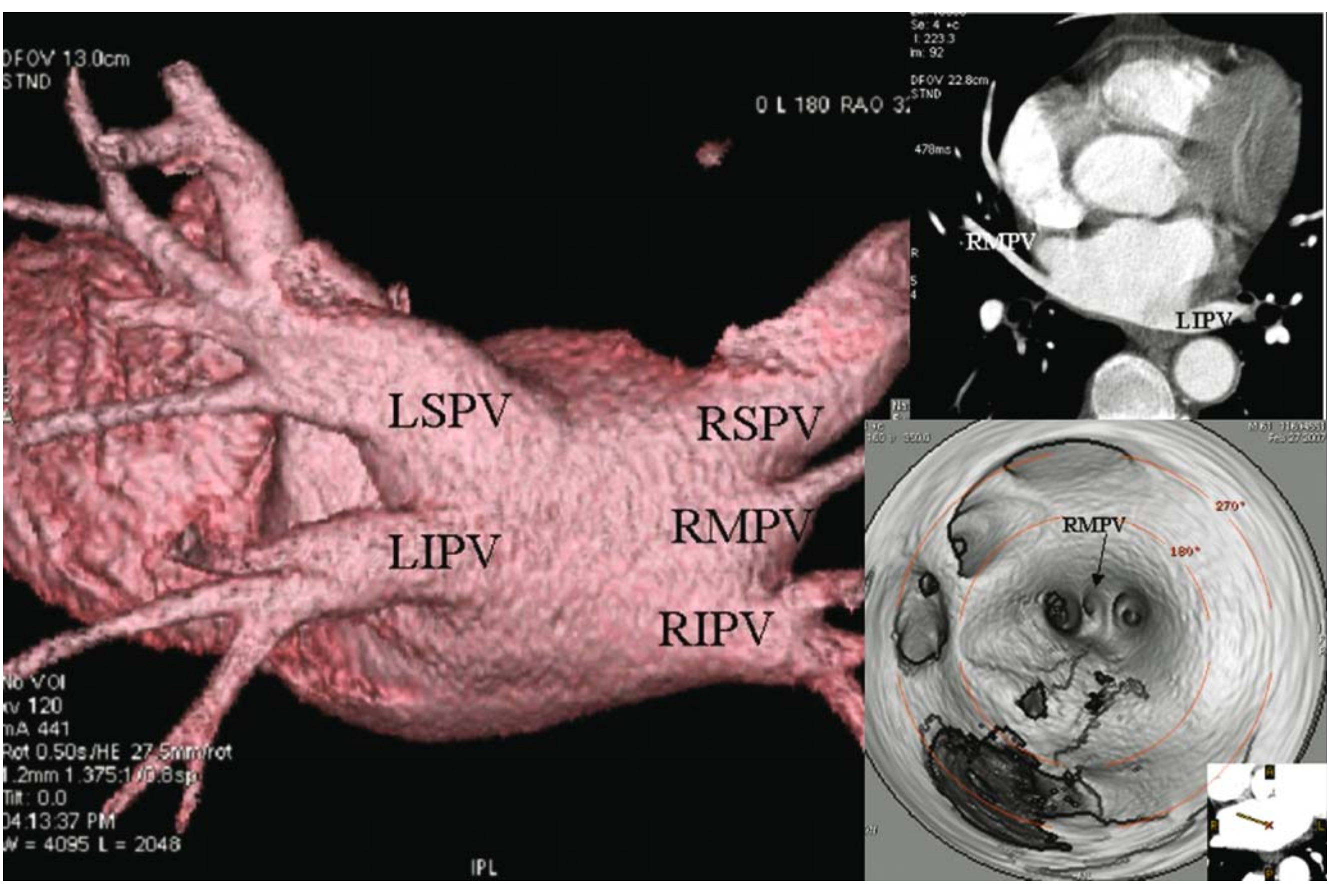
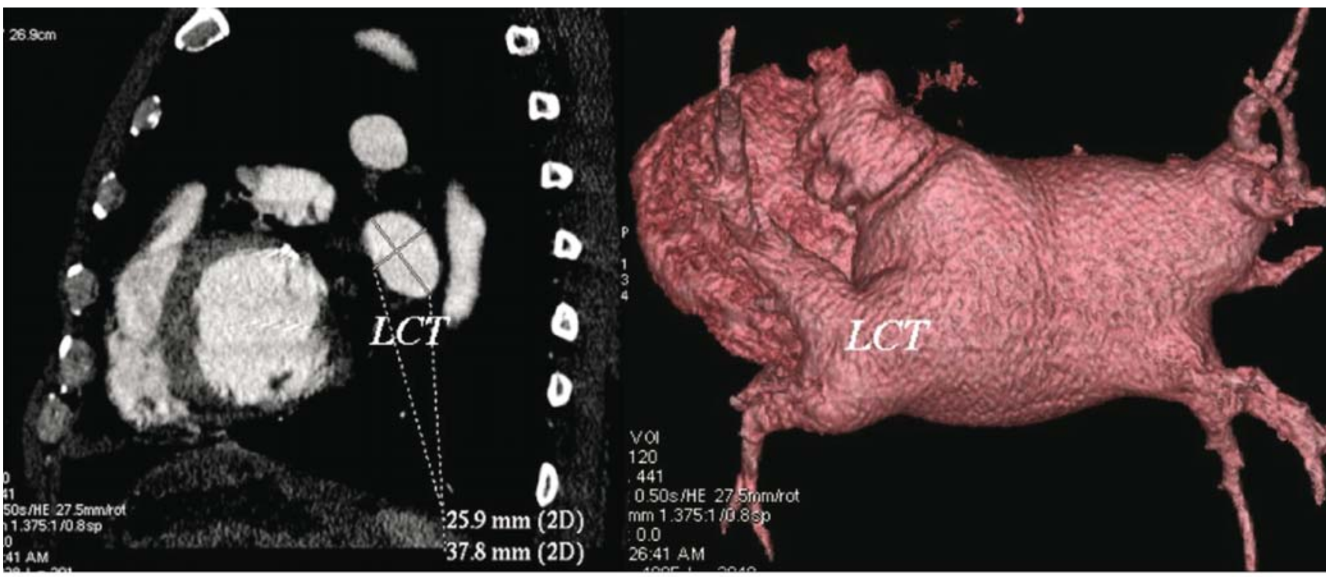


Figure 2.4 3-D VR image, axial image, virtual endovascolar view of the left atrium. In this case a right middle pulmonary vein (*RMPV*) has a separated ostium in LA

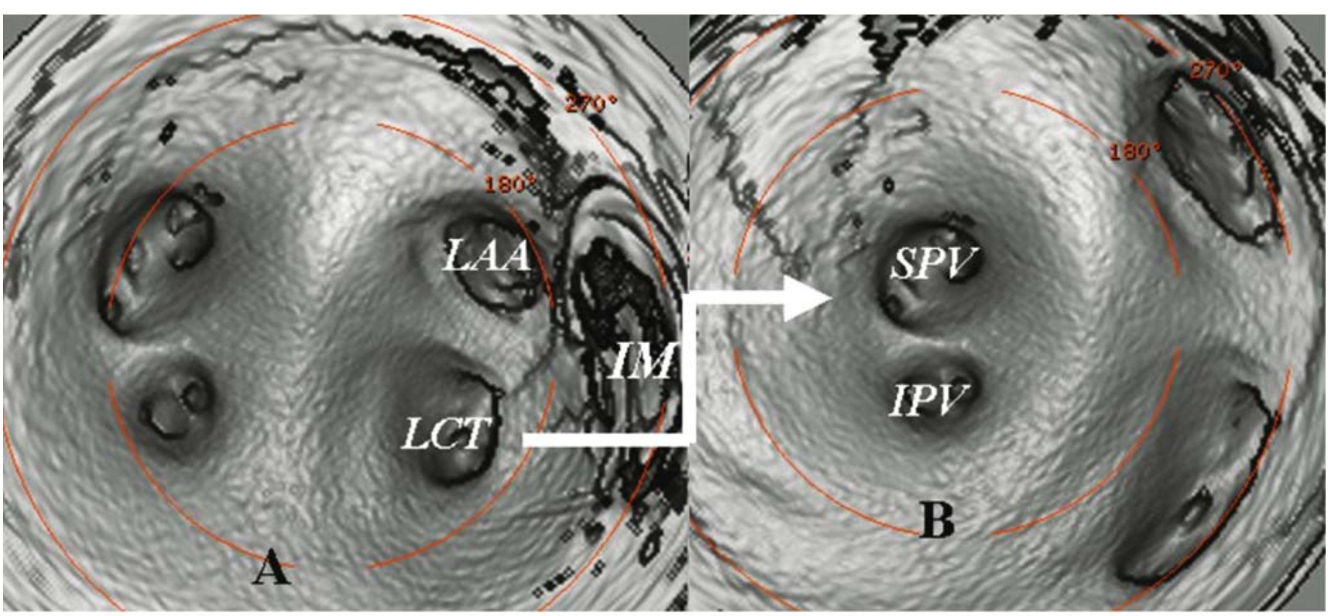
2.3.1 CT Study of Pulmonary Veins

Pulmonary veins show complex anatomy greatly varying among different individuals in terms of number, shape, size, bifurcation, and branching out.

Usually there are two main PVs for each side; the left superior PV (LSPV) and the left inferior PV (LIPV) on the left; the right superior PV (RSPV) and the right inferior PV (RIPV) on the right. Venous ostia, usually two on each side, show a flute mouthpiece-like oval-shaped morphology, with axial diameter ranging, approximately, between 11 mm and 16 mm, without valve structures.



a



b

Figure 2.5 **a** Common left venous trunk. A multiplanar reconstructions (*MPR*) image (oblique) on the left; 3-D VR image on the right. The images depict a left common trunk (*LCT*) with separated ostia and its dimensions. **b** Virtual endoscopic image. On endoscopic view (a), the apparent presence of only two ostia on the left (ostium of left appendage and a single venous ostium). A deep endoscopic view (b) into common trunk demonstrates the separated confluence of the left superior and inferior pulmonary veins

Intervenous septum (between ipsilateral PVs and left PVs with LAA) can be thin or thick relatively to how much the size mean value draws away defectively or excessively. Its sizes vary in patients with AF and are approximately: LSPV – LIPV: 7 ± 5 mm; RSPV – RIPV: 8 ± 4 mm.

Different variants and anomalies are numbered. With regard to number and morphology, PVs confluence into LA is variable; as a matter of fact, it is possible to find, on each side, a higher number of pulmonary venous structures flowing together into LA, as well as one single venous trunk on each side. Most common variants are, on the left, existence of common trunk draining both pulmonary lobes (Figs. 2.5 and 2.6); on the right, ostia separated from veins by pulmonary inferior lobe apical segment and by middle lobe.

Frequent is the existence of overlap among segmental veins coming from separate branches which distally overlap. In case of venous branching, the branching distance relatively to the main venous ostium, considerably higher on the left than on the right, should be evaluated. Branching occurs in almost 90% of subjects within 15 mm from the main venous ostium (and among these ones in 50% within 5 mm). In cases where the outlet occurs within 15 mm, it is necessary to evaluate, very often bilaterally, each vein's venous tree and veins' angulations degree.

Finally, for correct anatomic interpretation, it is necessary to pinpoint some of anatomic structures' definitions (Table 2.1).

With regard to CT study, the size measurement of pulmonary ostia is greatly important in order to allow their monitoring during follow-up. Measurements are carried out on different planes, rectified according to minor or major ostium axis, and on different reconstruction planes (axial, coronal, and sagittal plane). Native axial TC images are "reformatted," on a dedicated console, employing some suitable postprocessing software, thus getting multiplanar, tridimensional, and endoscopic images, which enable the radiologist

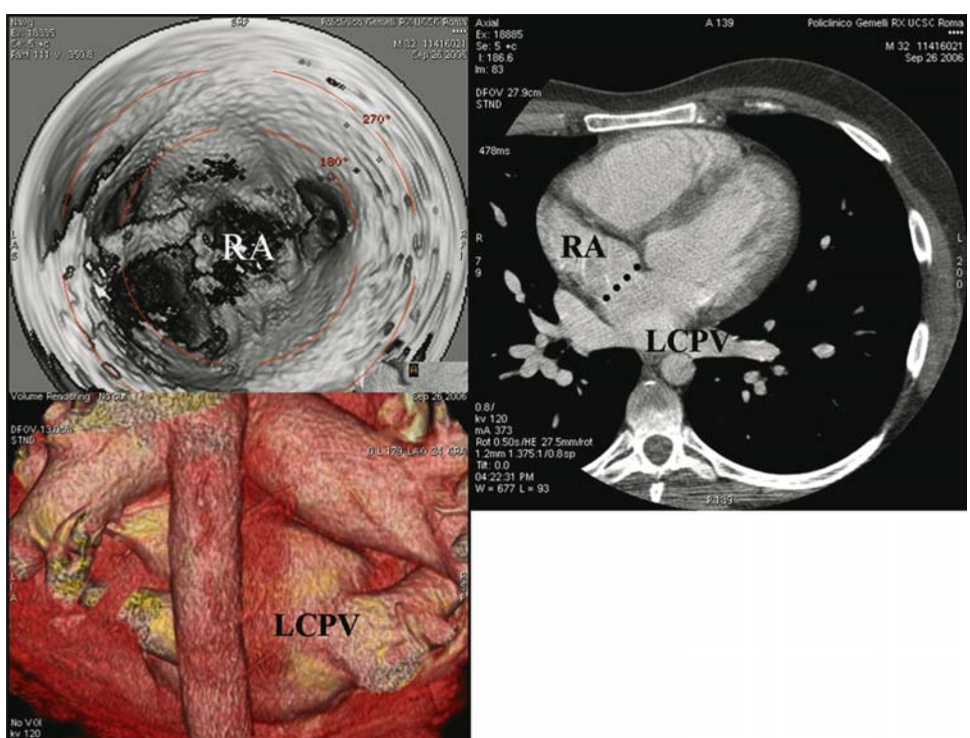
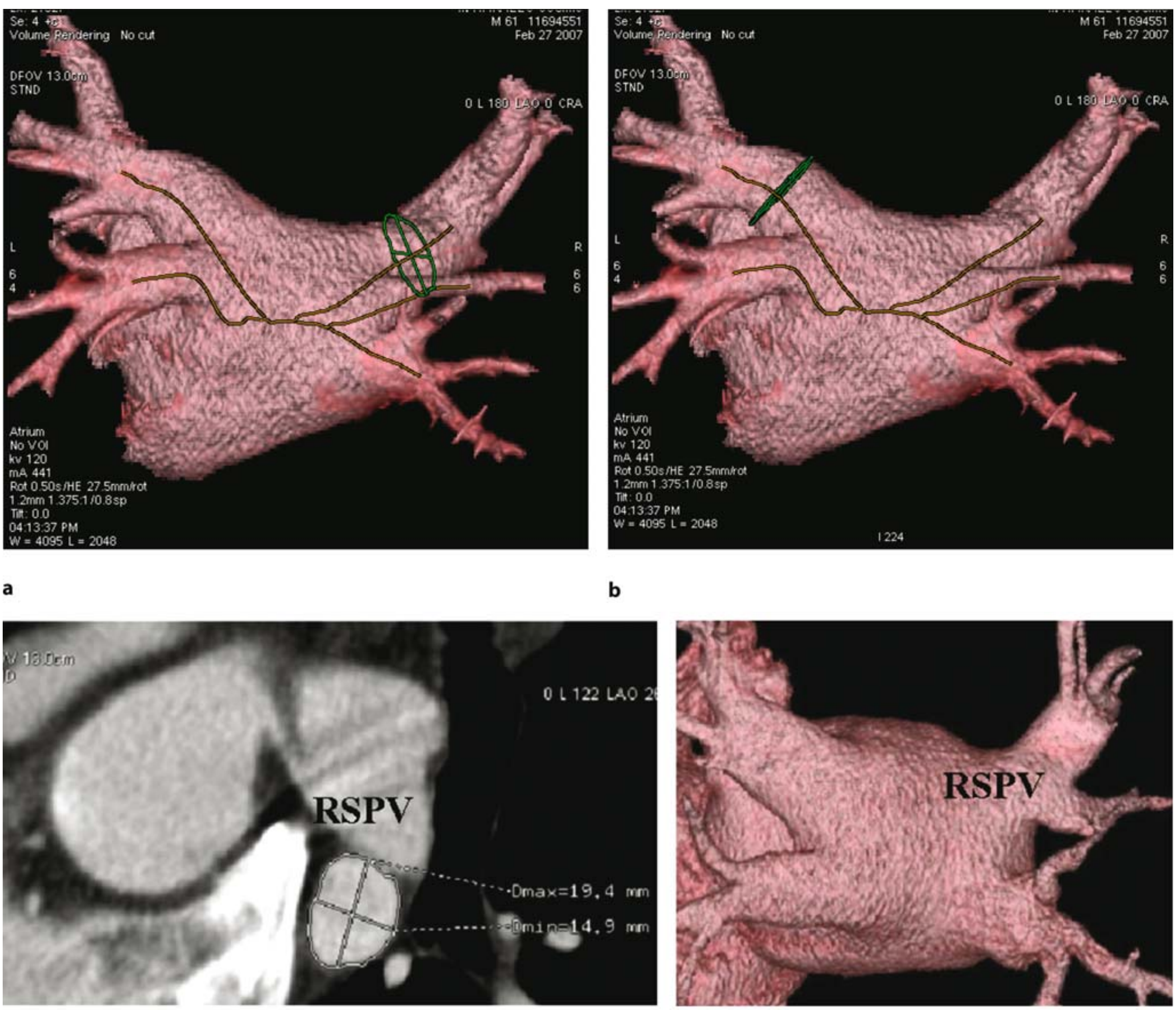


Figure 2.6 Axial image, endoscopic image, 3-D VR image. A case of severe interatrial defect in association with a single left venous trunk. *RA* right atrium, *LCPV* left common pulmonary vein

Table 2.1 Anatomic structures' definitions

Pulmonary venous ostium	Junction point of PV and LA, where parietal pericardium reflection occurs, well recognizable in multiplanar reformatted images
Common venous ostium common vein	Common confluence of two ipsilateral PVs into LA with coalescence of ipsilateral superior and inferior PVs; the distance between the internal virtual line of venous walls relative to outlet into atrium, measured in axial or oblique plane, and the line following the external border of the vein walls, must be 5 mm
Intervenous septum	The portion of tissue lying between separate ipsilateral PVs or between venous ostium and LAA ostium
Ostium branch	Venous branch joining the main vein within 5 mm from the venous–atrial junction
Intravenous septum	The portion of tissue lying between ipsilateral ostial branches
Outnumbering vein	An outnumbering PV with separate junction at atrium, as for example, vein for inferior lobe apical segment or middle lobar vein

LA left atrium, *PV* pulmonary vein, *LAA* left atrial appendage



c

Figure 2.7 **a** 3-D VR image with 3-D evaluation of the left superior pulmonary vein ostium. **b** 3-D VR image. 3-D evaluation of the right superior pulmonary vein ostium. **c** 3-D VR image and multiplanar reconstructions (*MPR*)-sagittal image. Computerized analysis of ostial diameters. *RSPV* right superior pulmonary vein to give anatomic, morphologic, and dimensional pictures of ostia, as it is required by the electrophysiologist; the most employed softwares are "Vessel Analysis" and "CardEp" GE-Healtcare (Fig. 2.7). TCMD allows, therefore, to get in a noninvasive way precise information about the number and seat of pulmonary veins; number/course anomalies of pulmonary veins; angulation of veins and their relative ostia; veins' branching within 1 cm from antrum; type of ostium (separate/common); diameters and morphology of ostia; and anatomic ostium/antrum distance for each vein.

2.3.2 CT Study of Left Atrium

CT study of the left atrium should be including LA measurement and exclusion of endocavitary thrombosis, LA/PVs/LAA connections, and LA single walls evaluation.

By literature, LA capacity, lesser than the right atrium, ranges between 80 cc and 130 cc (Fig. 2.8). LA volume varies in patients with or without AF (patients with AF: 134 ± 52 cc; patients without AF: 73 ± 37 cc); in male (140 ± 55 cc) and female (116 ± 37 cc) patients; and in patients with paroxysmal (121 ± 38 cc) or persistent (150 ± 61 cc) AF.

Endocavitary thrombosis should always be excluded remembering that thrombi are mainly located in LAA, and the larger the atrium appendage size, the higher the occurrence of thrombosis.

About LA/PVs/LAA connections, it is important to evaluate superior and inferior PVs distance along the roof and the posterior wall; superior and inferior ipsilateral PVs distance; distance among various antra; distance between LIPV and MI; location and morphology of LAA ostium; definition of atrium appendage-venous ridge (expressed as an angle) and its length (with LSPV).

Regarding LAA, its location as well as the anatomic outline of its ostium and of the interatrium-appendage-venous septum is fundamental for thorough isolation of venous ostia. The LAA ostium (Figs. 2.9 and 2.10) can be located at different levels relative to the LSPV ostium and it can exist in three different positions: above the LSPV ostium (type I); in the same plane (type II); or underneath it (type III). Furthermore, in cases where

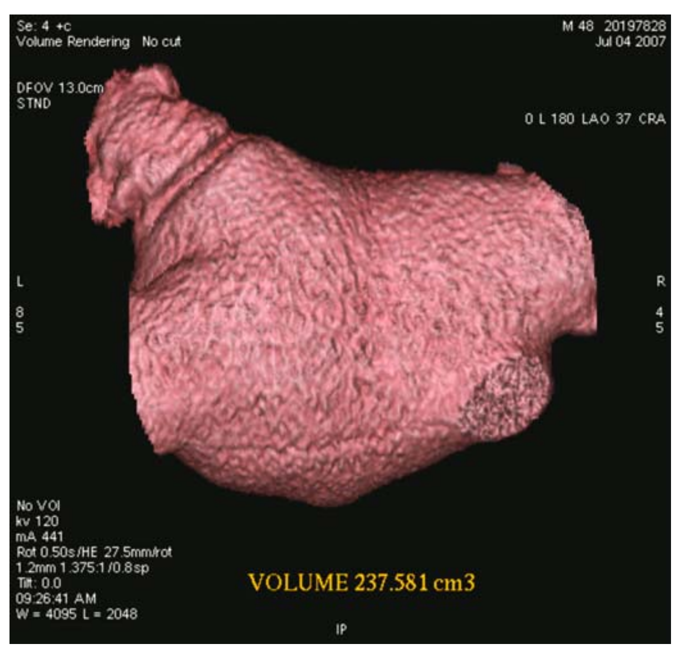
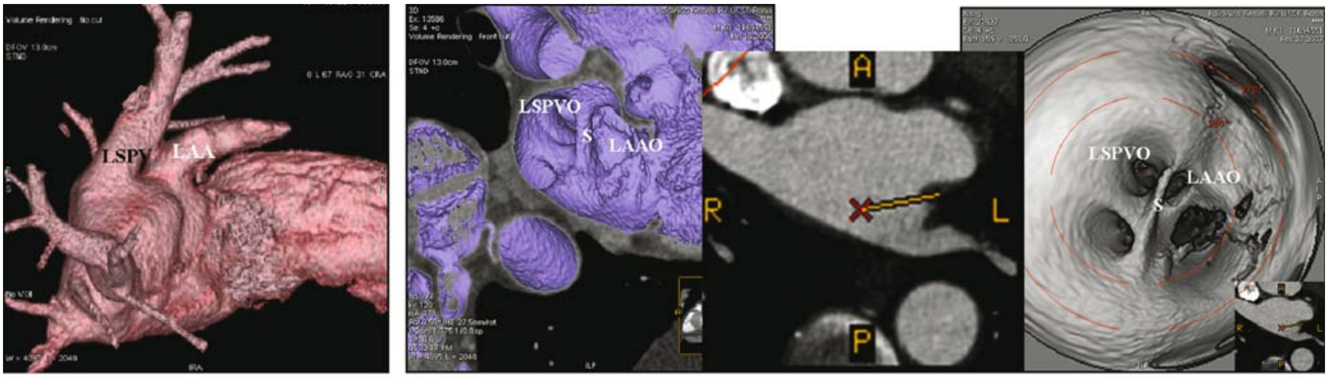


Figure 2.8 3-D VR image. Computerized measurements of left atrial volume before radiofrequency ablation



a b

Figure 2.9 **a** 3-D VR image. Relationship between the left atrial appendage (*LAA*) and the left superior pulmonary vein (*LSPV*). **b** Endoscopic image. Relationship between the *LAA* ostium and the *LSPV* ostium. *LAAO* left atrium appendage ostium, *LSPVO* left superior pulmonary vein ostium, *S* septum between the LAA and the LSPV

ablation is pushed as far as proximity of CS, lesions of circumflex distal segments have been described as well as lesions, following ablations within the LAA ostium, of proximal tract of the circumflex artery itself, as this one runs very close to the anteroinferior wall of the atrium appendage. In particular, the distance between LAA and circumflex artery, almost in all cases, ranges between 2 mm and 5 mm. It is hardly ever above the higher limit of 5 mm. The type of atrium appendage getting into the closest contact with the circumflex is type III. In other cases, LAA is close to left coronary's distal tract.

Figure 2.10 3-D VR image. In this case, the left atrial appendage (*LAA*) is developed medially

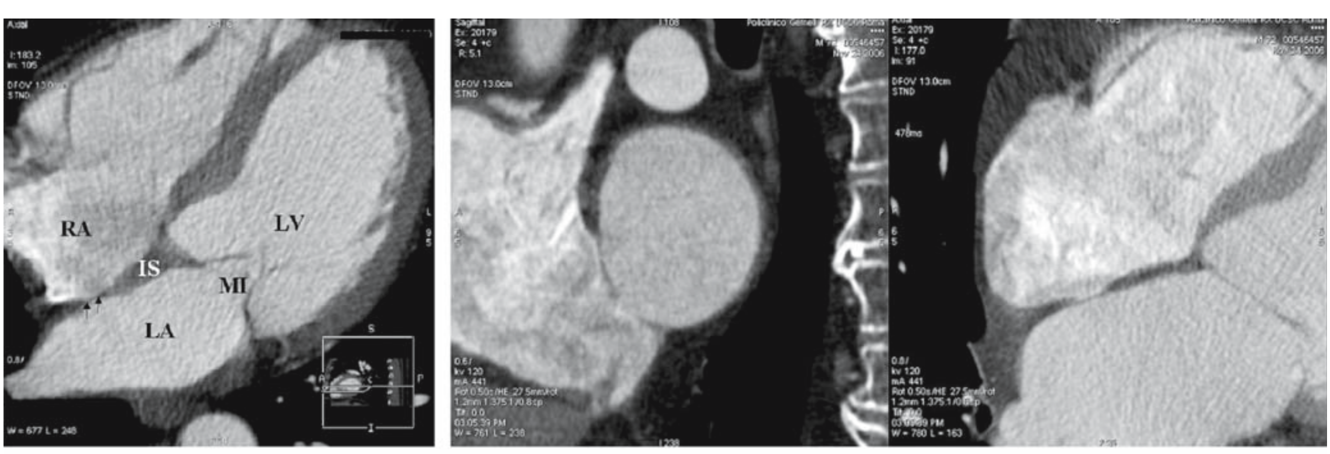
Particularly important is the evaluation of the posterior atrial wall and of its correlation with esophagus course. Myocardial posterior atrial wall's thickness is larger in the median portion, whereas there are no significant thickness differences relatively to right and left venous–atrial junctions. The inferior wall, correspondingly to the level right over coronary sinus and between 6 mm and 15 mm from mitral annulus, shows the greatest myocardial thickness, as well as amount of adipose tissue. On the contrary, the level above, defined by the superior border of superior venous ostia, shows the least amount of adipose tissue. Within posterior atrial wall's thickness there exist discontinuity areas represented by fibrous tissue, having no connection whatsoever with age, sex, population, etc.

The space between the esophagus and the posterior atrial wall is differently filled with adipose tissue and pericardial connective tissue. Furthermore, in its context, periesophageal lymph nodes are present varying in number; besides, within its thickness run vagus and periesophageal plexus' nervous terminations. "Fat pad" thickness is larger superiorly, corresponding to superior veins' ostia (2.4 mm on an average), whereas it is lower corresponding to inferior ostia (0.5 mm as an average).

Some CT/Carto integrated studies have been carried out assessing the possibility of different situations (variables, however, are to be considered due to heart rhythm, peristalsis of esophagus, free during procedure), such as no connection with atrial wall nor with veins or present connection (<3 mm in 87% of patients). When a connection is present, it may be relative to the following tracts: on the axial plane (horizontal): third septal level; third median level; third lateral level; on the coronal plane (vertical): floor level; third median level; superior portion level. The distance and the contact area (length × width) should also be evaluated. The most frequent position (almost one half of the subjects) is represented by the course of the esophagus along the atrial wall intermediate portion, followed by a more lateral course however far from the venous ostia. Less frequent is the course adjacent to the left ostia, while rare is that adjacent to the right ostia. Another important region in AF ablation is mitral isthmus. Its morphology can change showing the following shapes: concave, flat, or "bowl-like."

CT study should also evaluate the LA roof. The LA roof takes a type of morphology that, besides its constitution, is also determined by relation to the left ventricular outflow portion and the aortic bulb; the latter rests above and in front of the atrium, making a more or less emphasized "print" on the roof, depending on its sizes. With regard to the roof, one must measure its length, depth, and curvature, in direct relation to the atrium volume. Therefore, it can be either flat, convex, or concave. It is of paramount importance to find the existence of possible roof pouches, which might interrupt the virtual ablation line, if not recognized.

Regarding IAS (Figs. 2.11–2.14), it is necessary to consider its orientation, expressed as an angle relative to the dorsal column/sternum line, and its level, measured relative to dorsal



a

b

Figure 2.11 Axial (panel a) and sagittal (panel b) views. The region of fossa ovalis (arrows) presents a thinner thickness with respect to the rest of the wall. *RA* right atrium, *LA* left atrium, *LV* left ventricule, *IS* interatrial septum

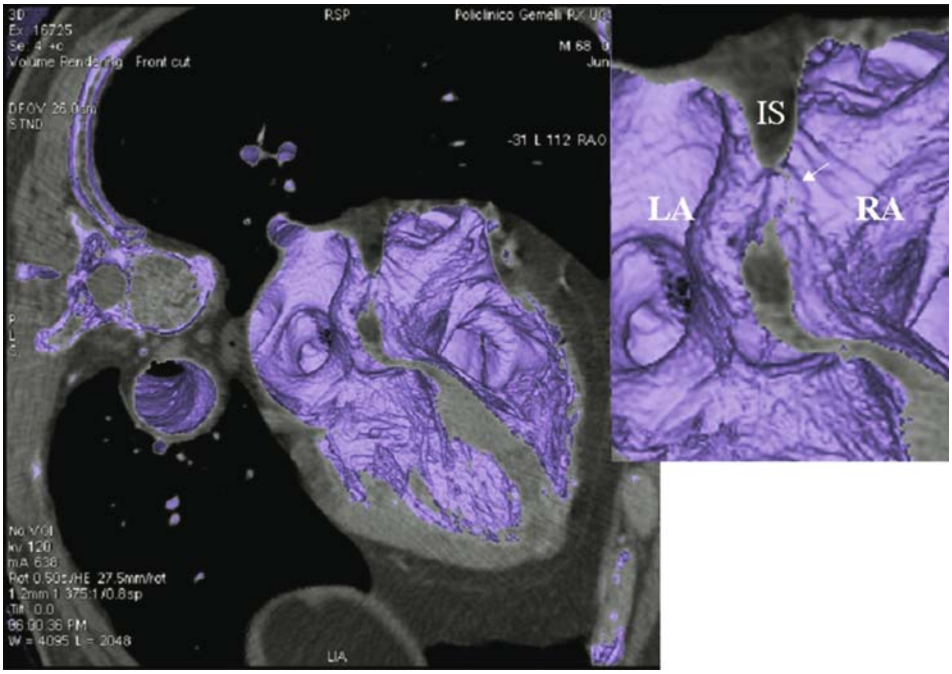


Figure 2.12 Endocavitary images. The region of fossa ovalis

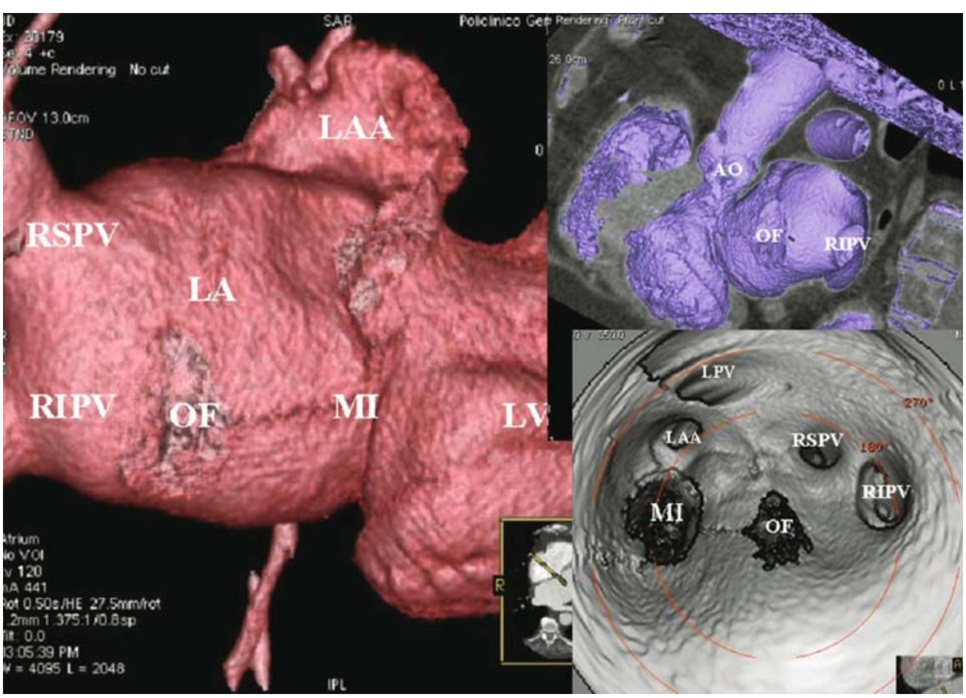


Figure 2.13 3-D VR image, endocavitary image, endoscopic image. 3-D VR image: septal continuity solution. Endoscopic and endocavitary views: the interatrial septum continuity solution is correlated to the patency of oval foramen. *OF* patent ovalis foramen, *AO* aorta

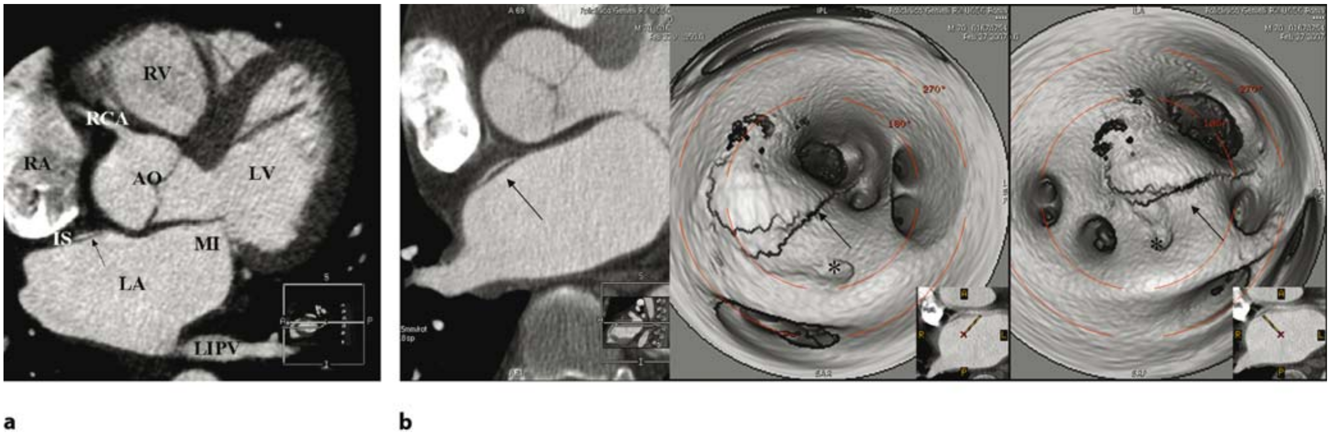


Figure 2.14 **a** Axial image. The arrow indicates the aspect of "bilaminated interatrial septum," represented by a twofold line of wall, with a contrast layer inside. This condition is not emodinamically significant. *RCA* right coronary artery, *RV* right ventricle. **b** endoscopic image.The arrow indicates the hypodense oblique line that seems to interrupt the interatrial wall and represents the aspect of bilaminated interatrial septum

vertebrae (usually, at the level of D7-D8). IAS originates from septum primum adhering to septum secundum. One of its variants could be important during procedures, that is to say, finding the so-called bilayered septum, resulting from an imperfect adherence of the two septa. This sets up, in adults, communication between the upper portion of fossa ovalis and the LA. It is visualized as a septal wall splitting, with a thin channel inside, represented by blood (opacified by contrast medium during angio-CT); it has no hemodynamic importance, as it does not allow blood to flow through. However, it has been proved in section room on anatomic piece, in some cases (about 25%), it is being passed through by a probe inserted under the semilunar fold (delimiting fossa ovalis), with direct passing into LA; such finding might be useful during procedures with direct catheter insertion, thus avoiding transseptal puncture. Fossa ovalis also has to be examined as it is a structure located in a crucial position for transseptal puncture. One has to evaluate the size, existence, and amount of adipose tissue, and the patency of foramen ovalis. It is also important to find out interatrial defects, which, if noteworthy, might contraindicate carrying out of the procedure. Finally, CT study must evaluate connections with aortic bulb, as it can be more or less strict according to atrium and aorta sizes and connections with other structures such as bronchial arteries and veins, nerve structures (vagus, phrenic nerve), Marshall ligament, right pulmonary artery (connection with VPSD and with atrial roof of type III), and with venous sinus.

2.3.3 Other Evaluations to Carry Out

During CT study performed for AF ablation, other structures such as the right atrium (volume, intercaval space, superior vena cava ostium's diameter), connections with extracardiac structures (e.g., coarse lymphoadenomegalies along the atrial wall), and collateral extracardiac findings (pulmonary parenchyma) should be evaluated.

During follow-up CT studies, complications should be excluded or confirmed (ostium stenosis, extracardiac complications such as pulmonary or esophageal complications) (Figs. 2.15–2.17) and any collateral extracardiac findings (i.e., pulmonary parenchyma nodule) should be followed-up in 6 and 12 months.

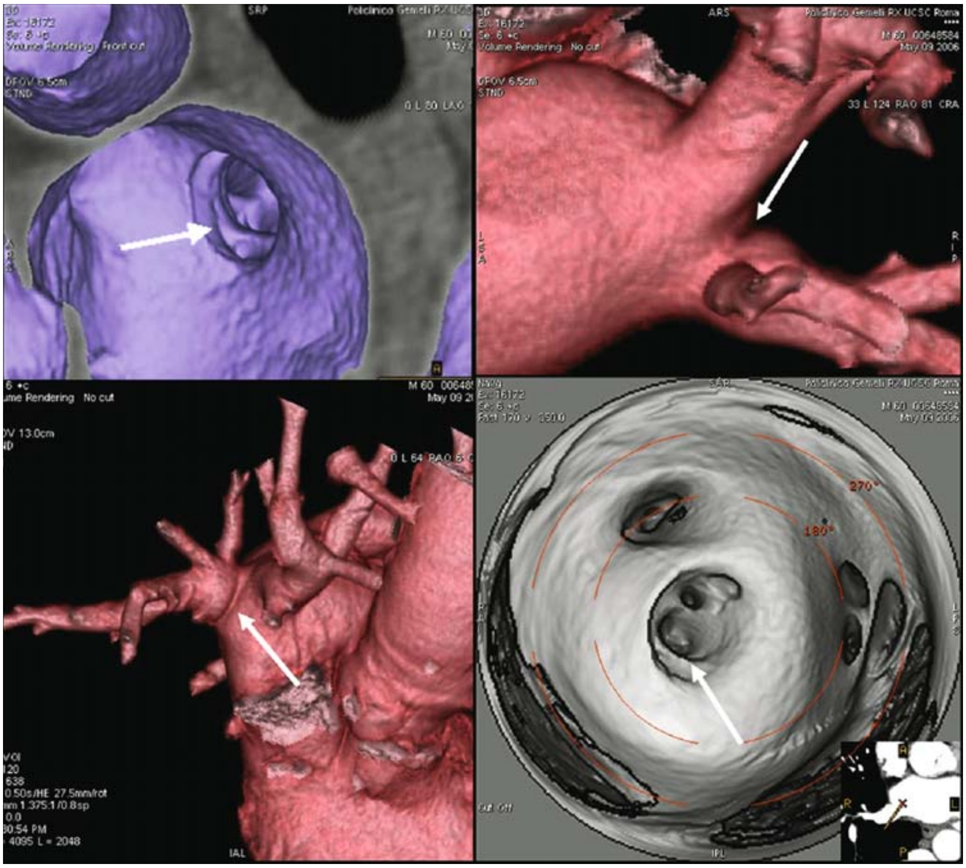


Figure 2.15 3-D VR image, endocavitary image, endoscopic image. Not significant stenosis of the right inferior pulmonary vein (*RIPV*) ostium. The arrow indicates a relief on the inferior wall

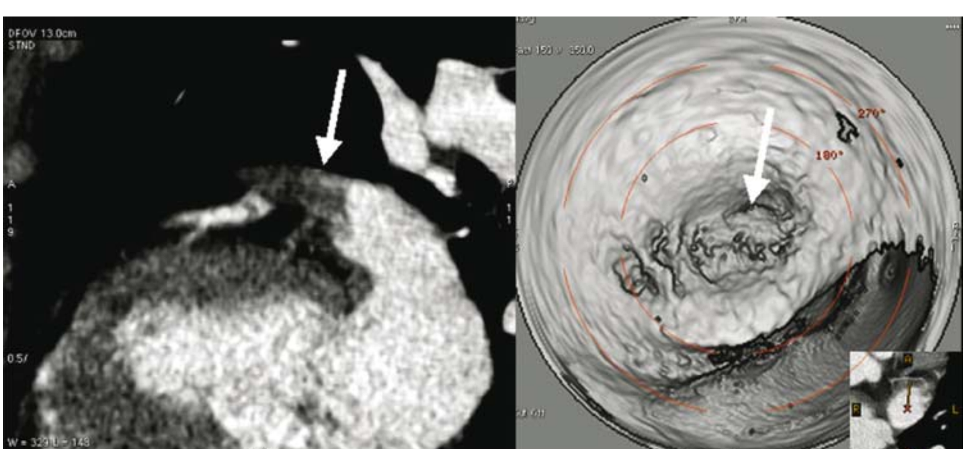


Figure 2.16 Multiplanar reconstructions (*MPR*) image and endoscopic image. Stratified thrombosis sight-like intraluminal hypodensity

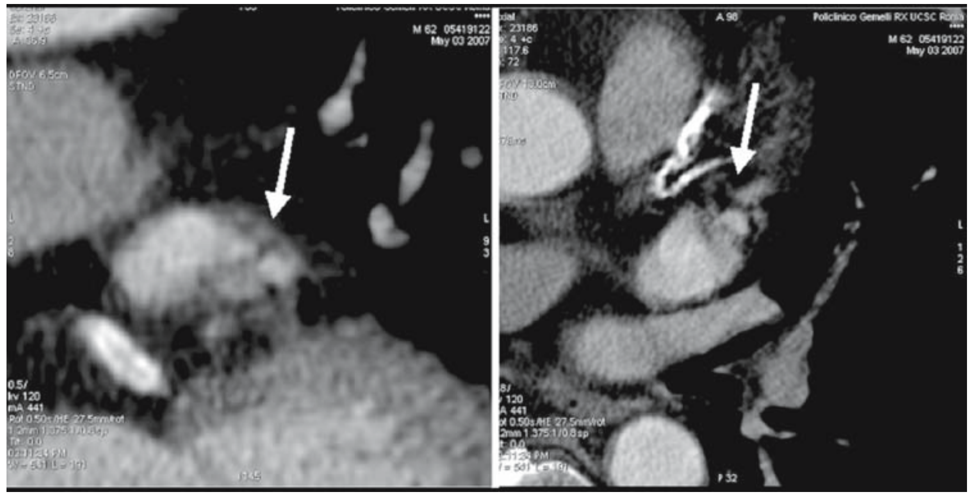


Figure 2.17 Multiplanar reconstructions (*MPR*) sagittal and axial images. Floating thrombosis

2.4 Final Remarks

Comparison with MRI, at present, poses some sure questions. If it is true that MRI does not employ ionizing radiations, it is also true that most modern sequences and now available equipment do not enable to do studies within short terms; furthermore, the MRI equipment circulation is surely less wide than the CT equipment, also considering the most modern equipment. As for our cases, we have proved also the validity of radiological studying of heart surrounding structures (pulmonary parenchyma and pleura, mediastinum with pulmonary and aortic vascular structures), for which CT nowadays is gold standard. In claustrophobic patients as well as pacemaker or metallic prostheses carriers, contraindication to the exam is obviously known. Therefore, at present, MRI study undoubtedly enables us to avoid supplying ionizing radiations and in cases of intolerance to iodated-organ media of contrast and/or kidney function deficit it allows us to use a medium of contrast that does not have contraindications of media employed in CT. Diagnostic yield, according to literature data, is absolutely the same as the one resulting from studies carried out with CT.

Furthermore, we evaluated diagnostic contribution of tri-dimensional and multiplanar reconstructions, besides virtual endoscopy, in examined anatomic structures' evaluation.

Transcatheter ablation by radiofrequency is certainly an effective procedure when treating atrial fibrillation, whether paroxysmal or persistent; besides, it is associated with a low occurrence of complications during procedure and subsequent follow-up.

The new integrated electroanatomic reconstruction technologies CT images allow more aimed procedures at the patient's anatomy, ensuring good effectiveness in the long run, minimizing procedural risks.

Imaging methods' evolution enables at present to carry out a thorough preprocedural preparatory study, taking into account PVs anatomic situation (number, course, angulation's variants of venous–atrial junction, type of ostium), thus avoiding preablation angiographic procedure of all anatomic LA components (IAS evaluation enables us to suspect the existence of pervious foramen ovalis, certained by echocardiography, consequently saving transseptal puncture).

Preprocedural imaging, moreover, enables us to evaluate even those structures that could be involved into the procedure itself, such as the esophagus and the LAA, allowing to plan in time therapeutic act in order to avoid complications made heavier by adverse outcome, such as atrioesophageal fistulas, which occurs rarely.

Accessory findings can also be numerous. For example, tomodensitometric alterations on pulmonary parenchyma's portion can be seen in the carried out slices (among our cases we found out existence of a minute pulmonary nodule of diskaryokinetic nature) or on some structures and superior abdominal organs' portions. These are visible in the most caudal slices carried out at the height of the heart base (among our cases we have found out a giant hepatic angioma).

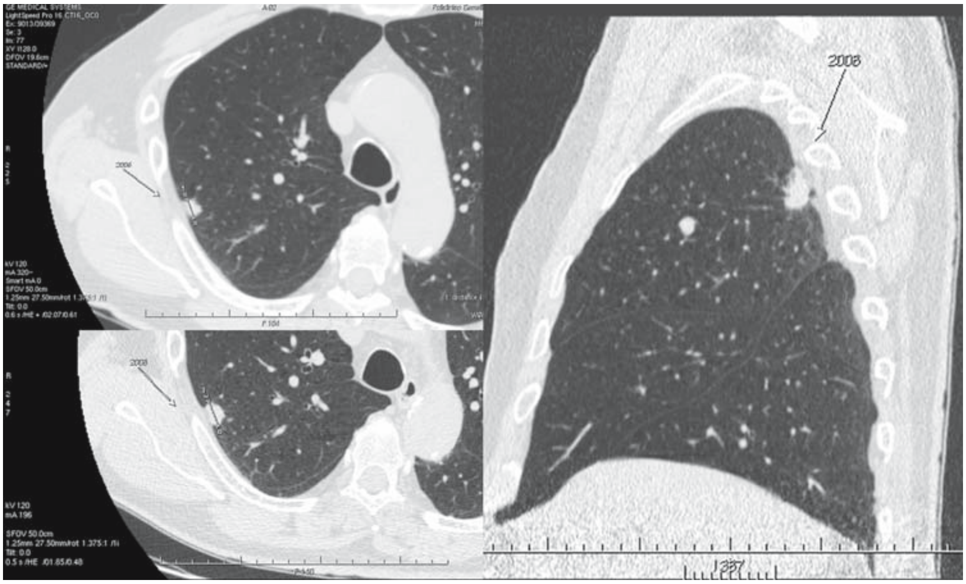


Figure 2.18 Accessory findings. Axial and sagittal images. The nodule increased its dimension in 1 year (Dec. 2005–Dec. 2006), under *CT* surveillance; a new lesion is visible. The patologic diagnosis after surgery was adenocarcinoma

Follow-up by means of CT allows to precociously evaluate possible complications represented, for instance, by venous ostium stenoses uprising, with consequent extension toward pulmonary hypertension (among the cases of stenosis we have come across, caliber's reduction has never been significant). The necessary distant monitoring enables, at last, to prevent pulmonary hypertension uprising, certifying when stenosis is reaching the critical threshold and the need of surgery or endovascular methods (i.e., stenting).

Knowledge of normal cardiac anatomy and its numerous variants has significant importance as it aids radiologists to carefully evaluate such structures also when carrying out CT exams with different clinical questions and, therefore, recognize possible pathologic alterations of the structures (for instance, thorax CT exams carried out under suspicion of pulmonary lesions), furnishing the clinical specialist with useful information for the subsequent diagnostic and therapeutic planning.

Therefore, close cooperation between clinical specialists, in this specific case, cardiologists and radiologists, seems necessary to a successful ablation procedure. Lack of information acquired with radiological imaging, in numerous cases, would cause the procedure to last longer (in the same way, radioscopy and dosimetry). In conclusion, we must not undervalue that collateral findings are not rarely encountered, in some cases life-saving (Figs. 2.18 and 2.19).

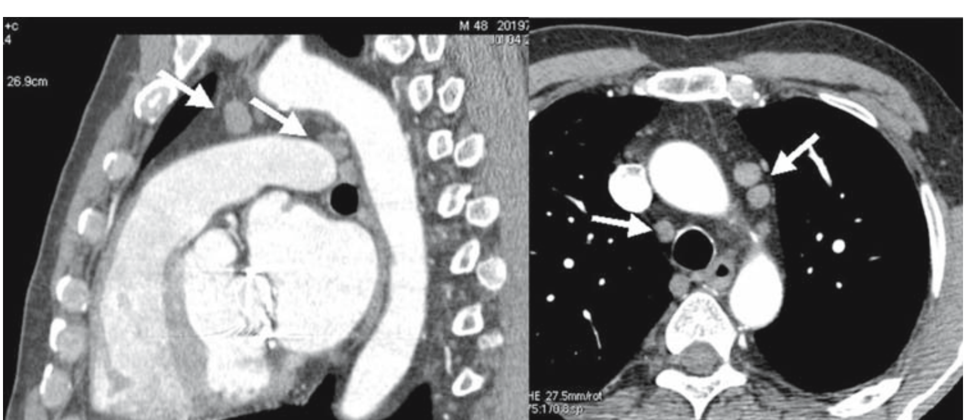


Figure 2.19 Accessory findings. Axial and sagittal images. Mediastinal adenopathy

3

The Electrophysiologic Study

3.1 Diagnostic Catheters

An electrophysiologic study requires one or more diagnostic catheters. Catheters for electrophysiology are mainly manufactured using two types of materials: Dacron or a synthetic compound such as polyurethane.[1] These materials must be stiff enough to preserve the original curve and, at the same time, flexible enough to adapt to the cardiac structures and to enable maneuvers such as looping within the atria or the ventricles. For adult patients, the diameter of the diagnostic catheters ranges between 5 and 7 Fr.

Located on the distal end of the catheters are electrodes, platinum or iridium rings, designed for electrical recording or stimulation. The number of electrodes varies from a minimum of 2 to 20 or more. Quadripolar catheters are most commonly employed but for mapping of the atrioventricular valve rings, catheters with more electrodes are preferred: usually 10 for the mitral valve and 20 for the tricuspid annulus. Interelectrode distance is also variable, ranging between 1 mm and 10 mm; 2 mm and 5 mm spacing is most commonly used.

Catheters may have a fixed (preshaped) curve or may be designed: a mechanism allows the operator to adjust the curve according to his needs. Figure 3.1 depicts the curves of some common preshaped catheters.

In standard electrophysiologic studies, the most frequent recording and pacing sites are as follows: high right atrium (HRA), His region (His), right ventricular apex (RVA), and

[1] Dacron catheters have an intermediate sheath in which interwoven Dacron fibers are employed. Considerable stiffness, reduced deformation index (curve memory) as well as a good torsional ratio (transmission from the body to the tip of the torsion carried out by operator's hand) characterize this material. At body temperature this material tends to soften (bioflexibility) within 20–30 min, making it less traumatic when it must be placed for a long time inside cardiac structures such as, for instance, the coronary sinus. Polyurethane catheters have a steel net which enables good axial (suitability to transmit axial strength along the catheter axis) and torsional control. Furthermore, these catheters are rather flexible, and their distal segments lack a metal reinforcement making the tip more flexible and reducing the risk of causing trauma with the catheter. Since polyurethane catheters have high thermal endurance, they do not tend to soften and their maneuvrability characteristics tend to remain constant. In general polyurethane catheters cost much less than dacron catheters.

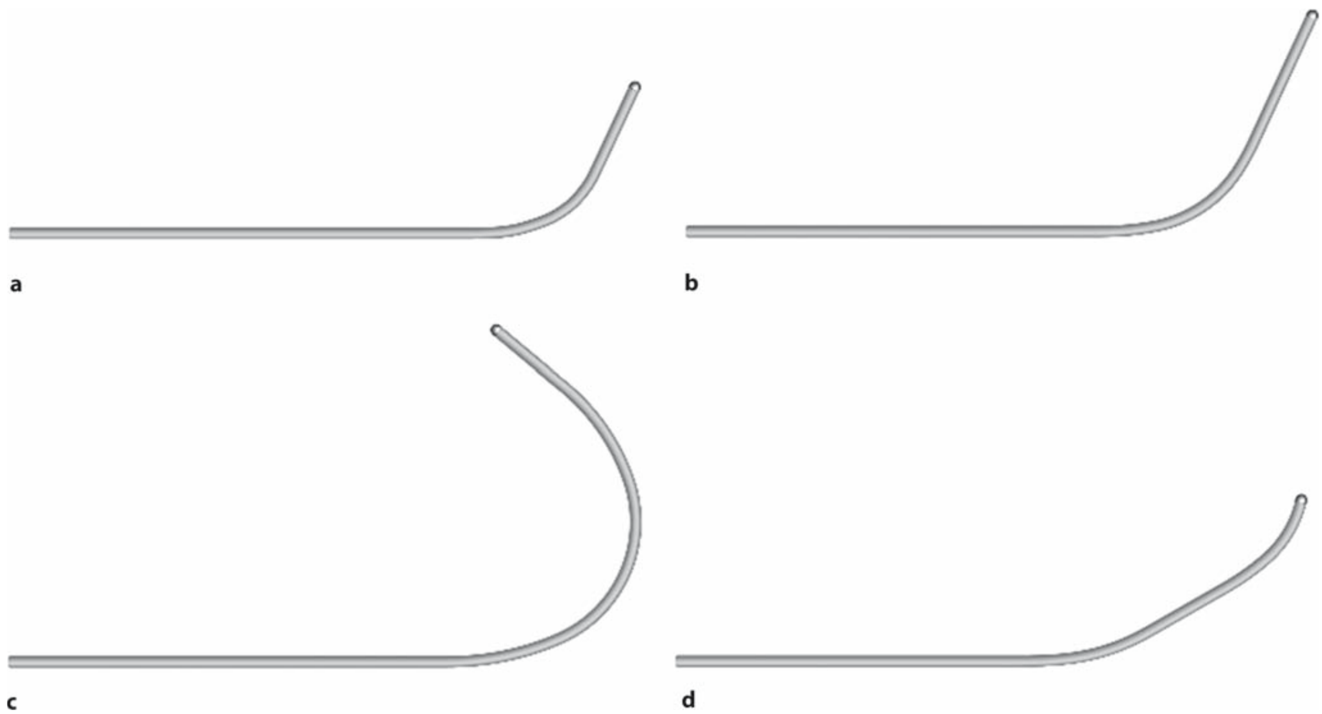


Figure 3.1 Preshaped curves most commonly used in diagnostic catheters. a Josephson curve. The most versatile and hence can be employed for the right atrium, His bundle, right ventricular apex (RVA), and also its outflow tract. In special conditions, it can be used to cannulate the CS via an inferior approach. b Cournand curve. Usually employed for His recording. Its curvature is similar to Josephson curve's one but the bent section is longer, thus allowing better setting on tricuspid valve. Cournand curve is also suitable to cannulate the CS via an inferior approach. c Damato curve. Wider curve, usually employed for RVA. d Curve for the CS via approach from the superior vena cava: curvature gradually changes to better adjust to the CS course. The angular outline of distal segment results in an easier way of adhering to the septum and hooking the ostium

right ventricular outflow tract (RVOT). By placing the catheter into the coronary sinus (CS) it is possible to record electric potentials both from left atrium and from left ventricle. The CS ostium, being on the interatrial septum's right side, can be entered through the right atrium and, consequently, via a venous approach. For each anatomic site one wants to reach, there are preshaped curvatures which can ease catheter's setting on a given place (Table 3.1). Alternatively, a deflectable catheter may be employed.

This chapter describes techniques for positioning catheters in various anatomic sites. Figures 3.2–3.4 show correct diagnostic catheter positioning in posteroanterior (PA), right anterior oblique (RAO), and left anterior oblique (LAO) views.

Table 3.1 Suitability of different preshaped curvatures for recording at various anatomic sites

	Josephson	Cournand	Damato	CS
HRA	+ + +	+ +	+	
His	+ + +	+ + +	+	
RVA	+ + +	+ +	+ + +	
CS	+ +	+ +	+	+ + +

CS coronary sinus, *HRA* high right atrium, *RVA* right ventricular apex

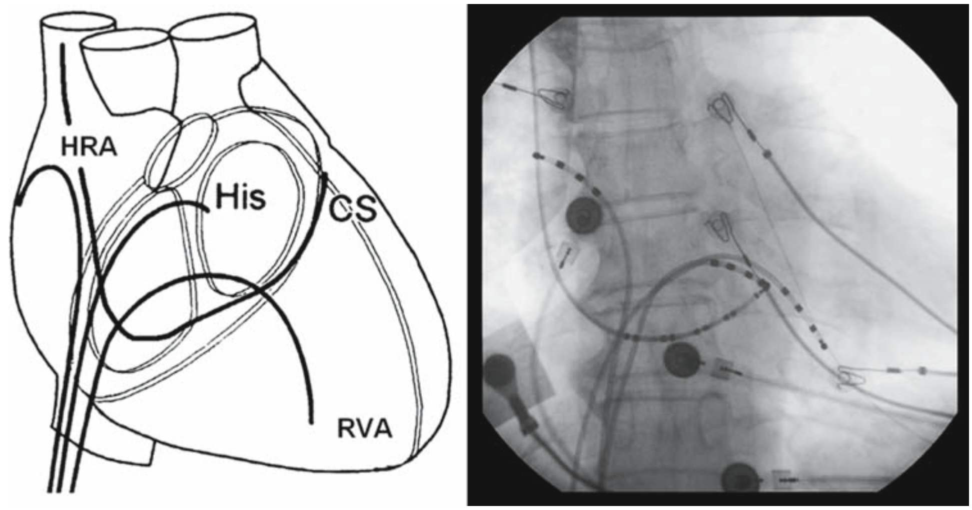


Figure 3.2 The posteroanterior (*PA*) view. The diagram shows three diagnostic catheters inserted through the inferior vena cava. High right atrium (*HRA*) is a quadripolar catheter placed in the HRA, the His catheter is at the His bundle branch site, and the right ventricular apex (*RVA*) is placed into the RVA. The coronary sinus (*CS*) catheter is positioned into the CS; it has been inserted into heart cavities via a superior approach. In the fluoroscopic image we can see catheters shown in the outline, as well as the cutaneous telemetry leads

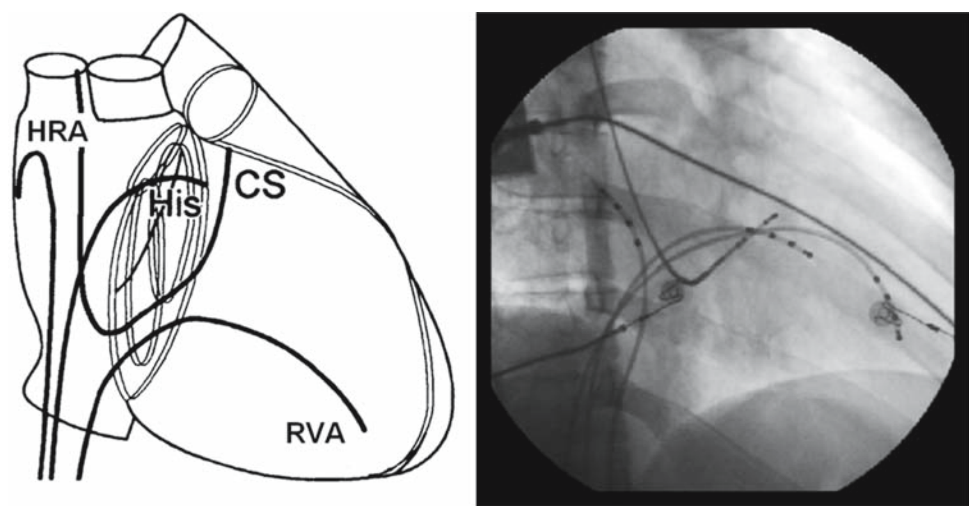


Figure 3.3 The right anterior oblique (*RAO*) view. In the diagram as well as in the fluoroscopic image one can see the four catheters in their relative settings. The catheter placed into the coronary sinus (*CS*) overlaps the valvular plane, thus clearly separating the atrial chamber from the ventricular chamber

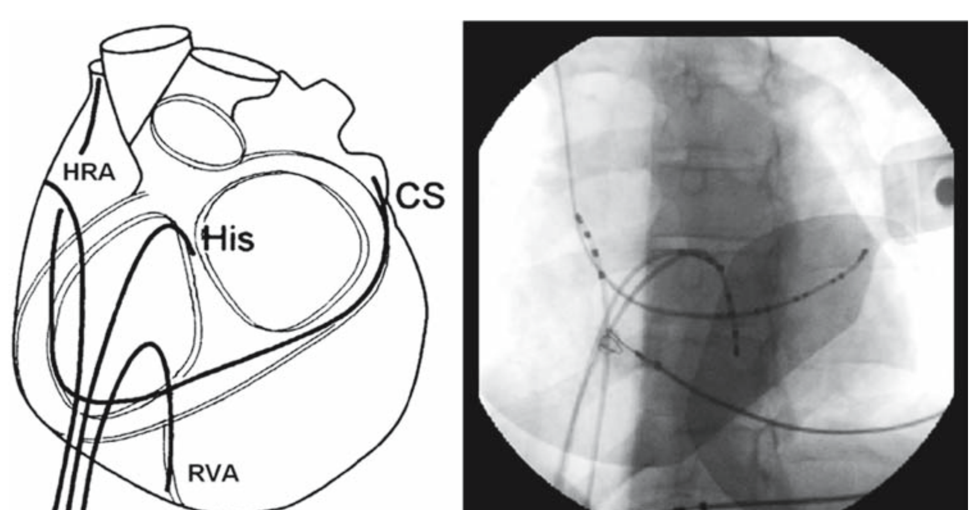


Figure 3.4 The left anterior oblique (*LAO*) view. In the diagram and the radiographic image catheters are seen from the LAO view. The His catheter and the ventricular catheter appear overlapping one another as they adhere to the septum; one can clearly see the coronary sinus (*CS*) at full length surrounding the mitral annulus

3.2 Atrial Catheter

When studying the atria, quadripolar catheters with either fixed curves (usually Josephson type) or deflectable curves are typically used. Positioning of the catheter into the right atrial appendage or into the high lateral wall, close to the sinus node, can be easily carried out using PA view and turning the catheter's tip to superior anterolateral position (Figures 3.5–3.9).

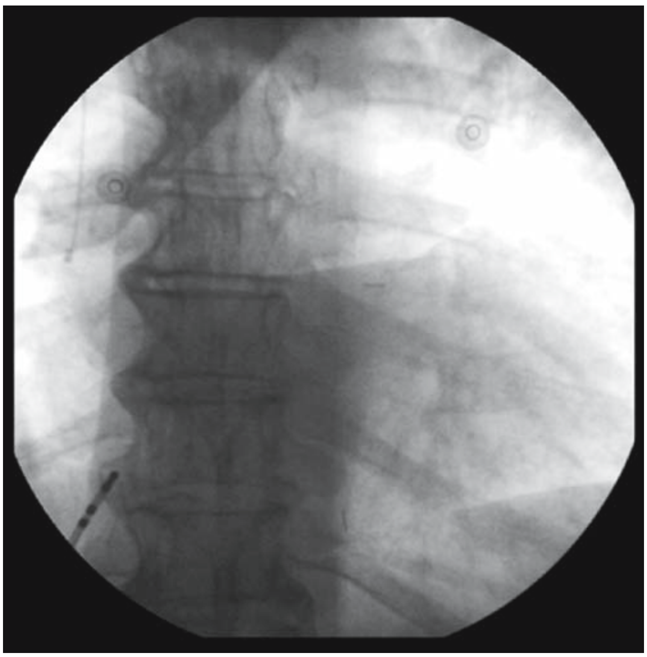


Figure 3.5 In the posteroanterior (*PA*) view, a catheter is advanced via the inferior vena cava up to the vena cava and the right atrium junction

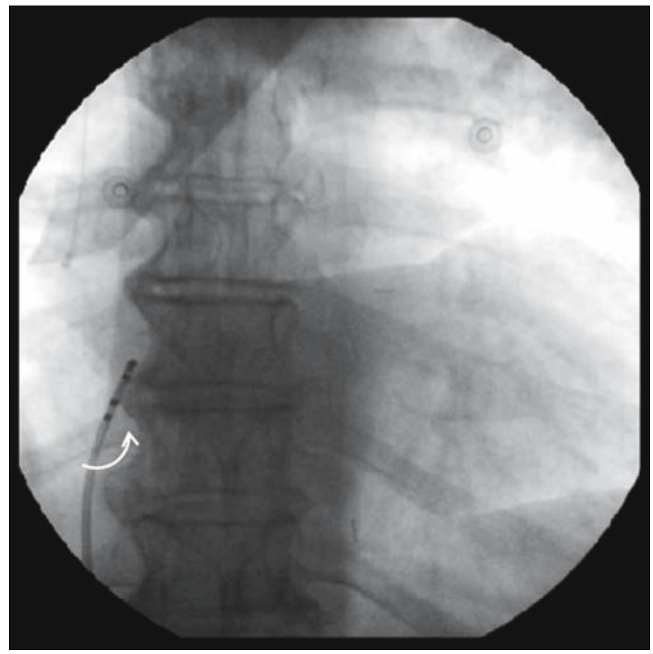


Figure 3.6 Still in the posteroanterior (*PA*) view, the catheter is further advanced so that its tip is freely floating in the right atrium. By rotating clockwise or counterclockwise, according to where movement is not hampered by the atrial wall, the catheter tip is directed toward the anterolateral wall

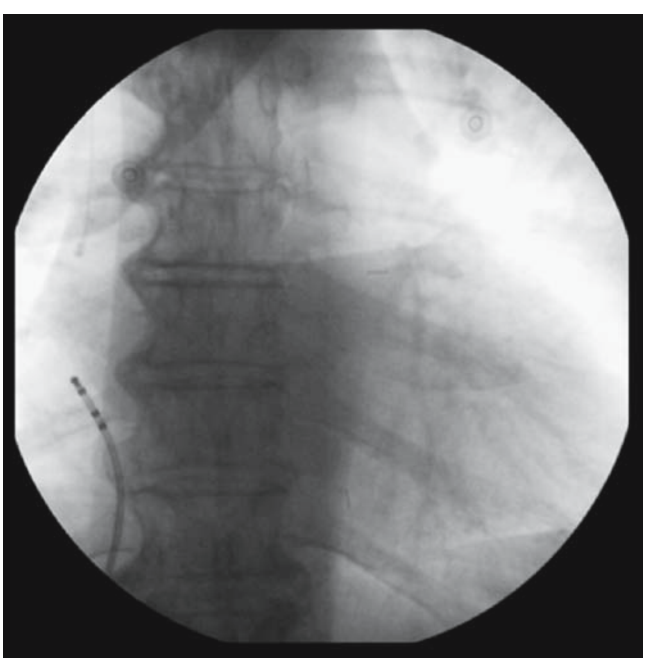


Figure 3.7 In this image the catheter tip is lying in the anterolateral direction

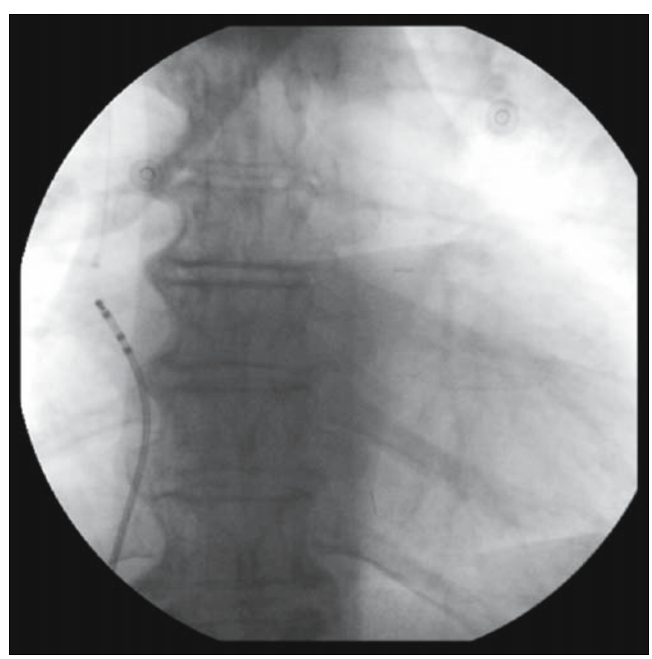


Figure 3.8 The catheter is advanced with care until it is brought into contact with the atrial wall. Contact is perceived as resistance to catheter's movement and is confirmed by endocardial recorded signal

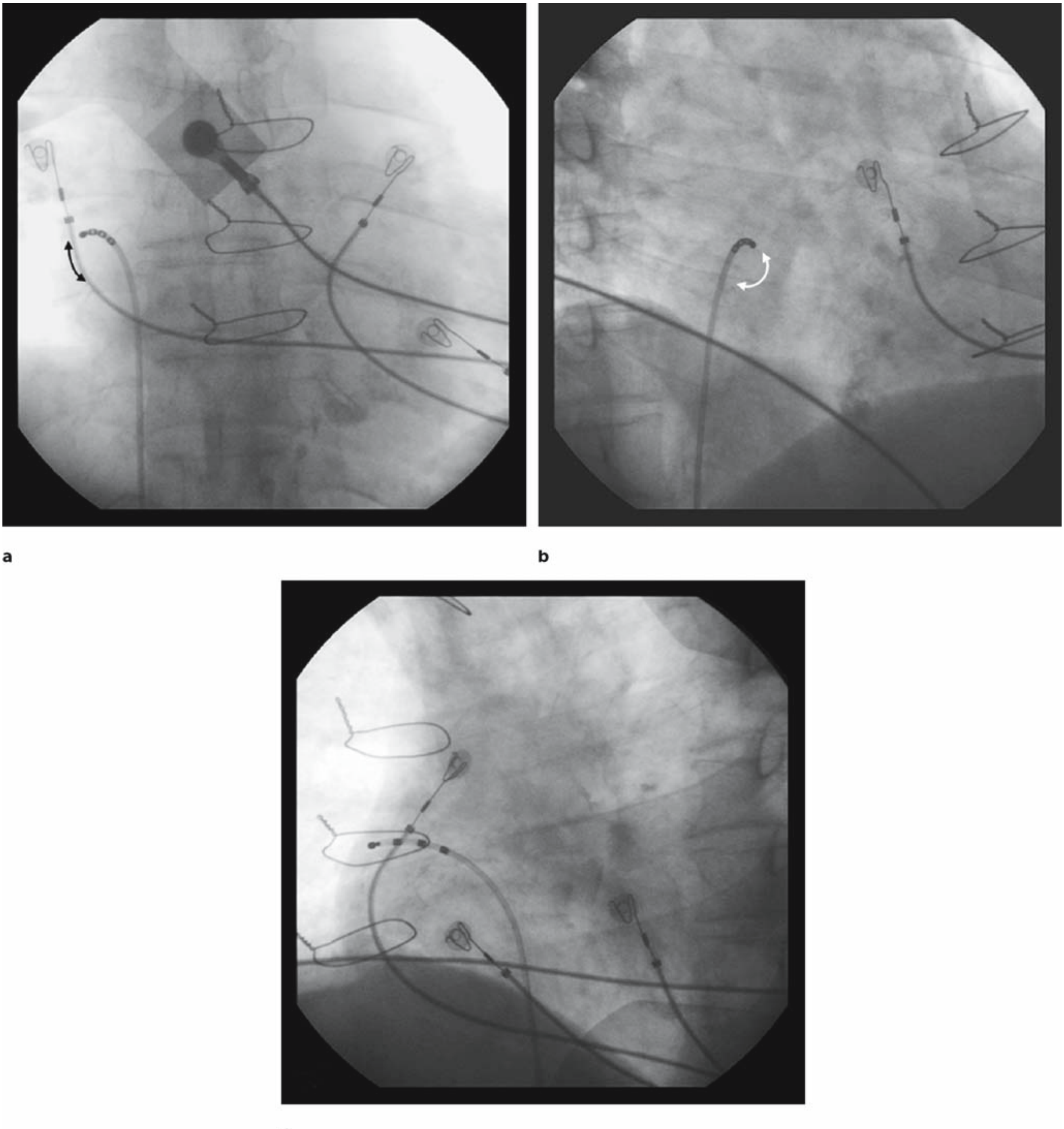


Figure 3.9 The atrial catheter position in the posteroanterior (*PA*), right anterior oblique (*RAO*), and left anterior oblique (*LAO*) projections. In the PA view three sternal wires from previous sternotomy are visible. **a** In the PA view, the catheter tip is pointed toward the lateralsuperior atrial wall. The catheter's curve will be alternatively opened and closed with the cardiac cycle. **b** In the RAO view, the catheter's curve is viewed enface. Fluoroscopy will exhibit the catheter tip's anteroposterior movement following cardiac cycle. **c** The LAO view shows the catheter's curvature in profile: compared with other views, catheter movement with the cardiac cycle will be less apparent

Correct positioning of the catheter must be confirmed by endocardial recording of a clear or sharp atrial potential. Optimal position must also be confirmed by atrial stimulation capturing atrial myocardium without stimulating the right phrenic nerve, which runs along the anterolateral surface of the superior vena cava, then follows the right atrium's posterolateral wall. Phrenic nerve stimulation manifests by diaphragmatic contractions concurrently with atrial stimulation.

3.3 His Catheter

For His bundle recording, either a fixed curve (Josephson or Cournand type) quadripolar catheter or a deflectable-tip catheter may be employed.

His catheter placement is facilitated in the RAO view. For proper placement it is necessary to advance the catheter tip into the right ventricle across the superior segment of the tricuspid annulus. The catheter is then withdrawn until an atrial potential can be recorded on the proximal electrode couple. Clockwise rotation of the catheter brings the catheter into better contact with the septum (Figures 3.10–3.14).

Correct placement of the His catheter cannot be performed without electrocardiographic guidance. Proper positioning will yield a His electrogram as well as a large ventricle and smaller atrium electrogram.

The tip of the catheter often drifts away from the septum. Constant clockwise pressure either by hand or by using towels, adhesives, or other measures to maintain this pressure may be required to prevent the tip from drifting from the His position.

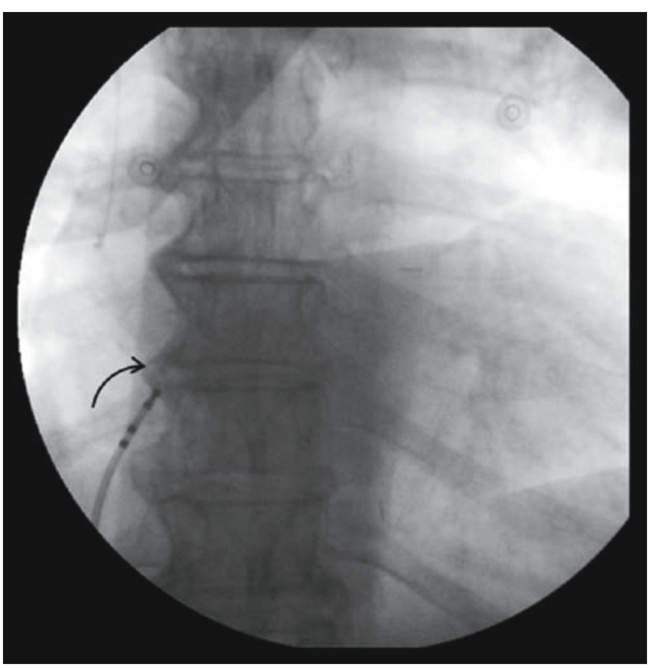


Figure 3.10 In the posteroanterior (*PA*) view the catheter is advanced into the right atrium

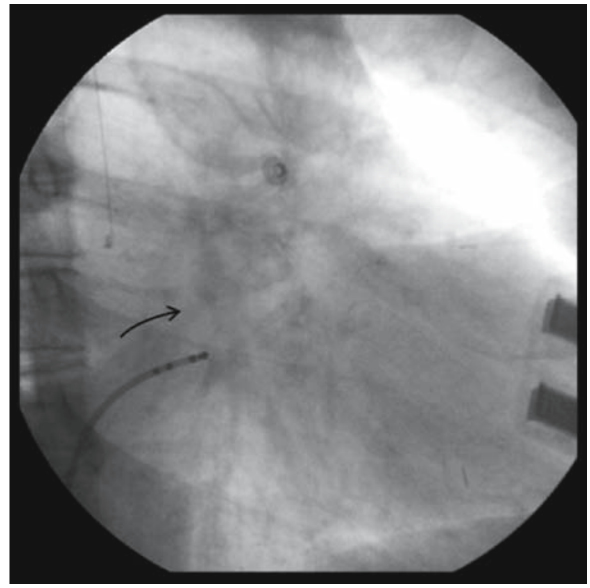


Figure 3.11 Then, in the right anterior oblique (*RAO*) view, the catheter is rotated counterclockwise directing its tip toward the right ventricle

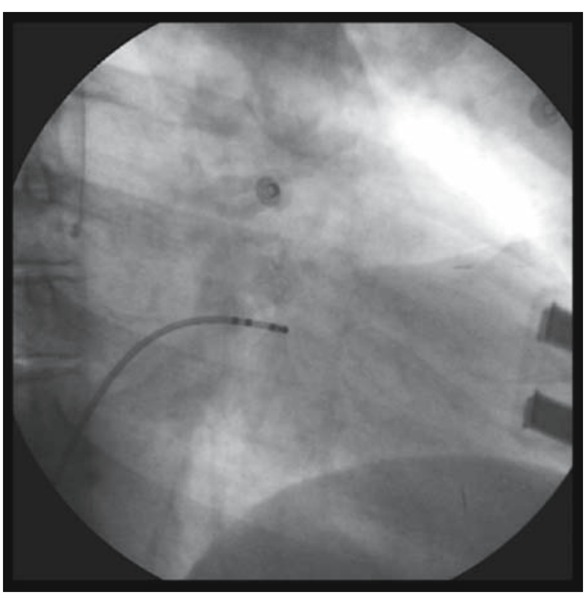


Figure 3.12 Still in the right anterior oblique (*RAO*) view, the catheter is advanced as far as the tricuspid annulus. Contact with the valve ring is perceived as a slight resistance. Using gentle clockwise or counterclockwise rotation, the catheter tip is freed and, eased by ventricular contraction, it springs into the ventricle going beyond the tricuspid valve. This image shows the catheter tip at the valve ring

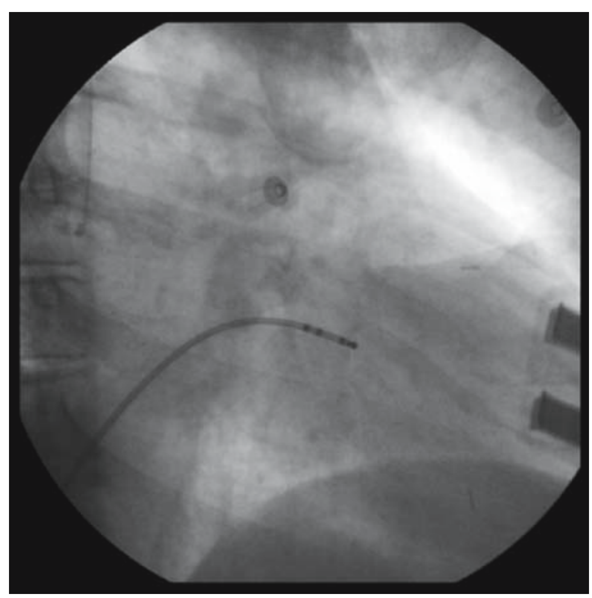


Figure 3.13 The catheter tip has been successfully advanced beyond the valve. Now, with clockwise rotation, the catheter is withdrawn until a clear His potential is recorded. Clockwise rotation is required to keep the catheter adhering to the septum. Too much clockwise rotation can rotate the catheter tip toward the right ventricular outflow tract (*RVOT*) (see Figures 3.20 and 3.21)

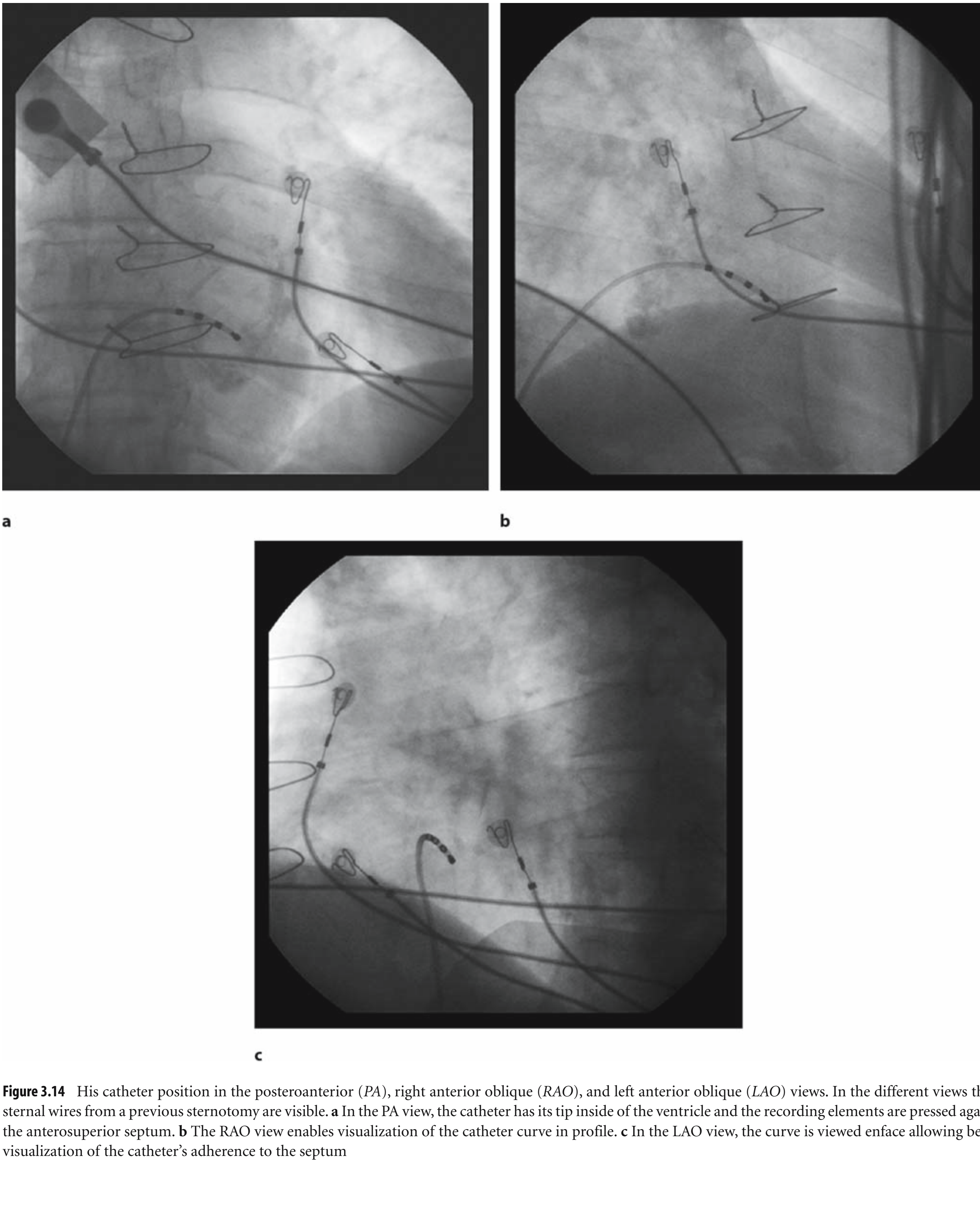


Figure 3.14 His catheter position in the posteroanterior (*PA*), right anterior oblique (*RAO*), and left anterior oblique (*LAO*) views. In the different views three sternal wires from a previous sternotomy are visible. **a** In the PA view, the catheter has its tip inside of the ventricle and the recording elements are pressed against the anterosuperior septum. **b** The RAO view enables visualization of the catheter curve in profile. **c** In the LAO view, the curve is viewed enface allowing better visualization of the catheter's adherence to the septum

3.4 Right Ventricular Catheter: Apex and Outflow Tract

The right ventricle may be studied by employing a fixed curve diagnostic catheter (Josephson or Damato type) or a deflectable-tip catheter. As with positioning of the His catheter, the most favorable view is the right antero-oblique view. The diagnostic catheter should pass through the tricuspid annulus in its midsection, so that its tip can easily move toward the ventricular apex (passing through the valve's superior section can result in the tip's imprisonment in anterior ventricular wall's trabeculae). Positioning procedures are similar to those employed to place the catheter into the His region; in this case, however, when the catheter is advanced beyond the valve ring, the catheter must be directed into the ventricular apex (Figures 3.15–3.17). It is useful to remember that, fluoroscopically, the apex of the heart shadow is formed primarily by the left ventricle, and the RVA is frequently inferior to the left one. Therefore, the diagnostic catheter is positioned at the "fluoroscopic apex." This is preferable in most cases considering the paper-thin musculature and the vulnerability to perforation at the true right ventricle apex. Reaching the true apex, with the catheter tip inferior to the level of "fluoroscopic apex," is limited to particular situations such as ventricular substrate mapping, ventricular tachycardia ablation, and pacemaker lead positioning.

Ventricular catheters must be always placed so that the tip rests securely on the ventricle's endocardial surface without embedding. If positioning is correct, fluoroscopy will show synchronous movement of the whole segment inside of the ventricle with the cardiac cycle; at the same time, endocardial recording will show a clear ventricular potential. In case of embedding, the catheter tip kneels during ventricular systole and endocardial recording

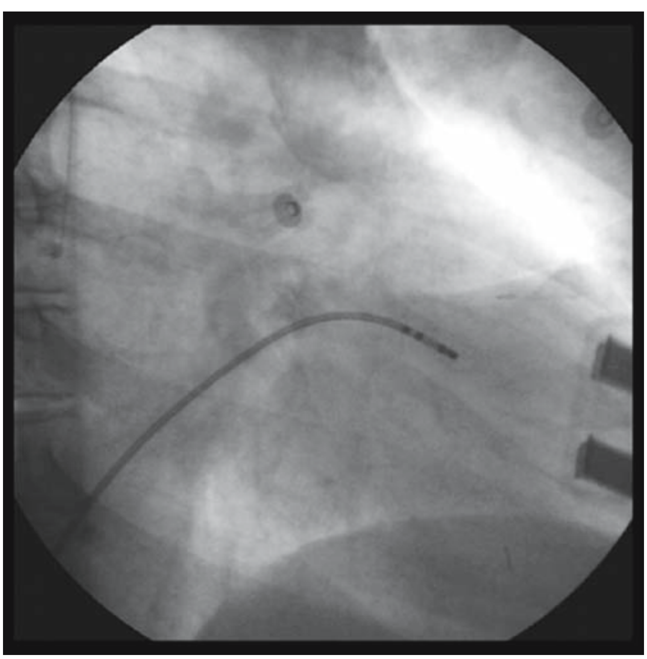


Figure 3.15 In the right anterior oblique (*RAO*) view the tip of the catheter has gone beyond the valve plane. The catheter must then be advanced toward the ventricular apex until resistance is perceived

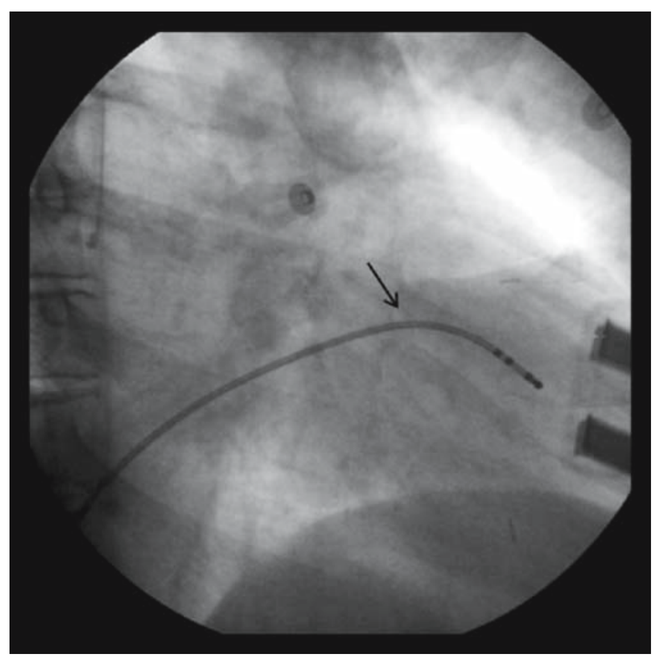


Figure 3.16 The catheter will slide correctly into the ventricular apex when the tip is turned downward (toward the apex). The portion of the catheter at the junction of its straight and curve segments is in contact with the ventricle's anterior wall (arrow)

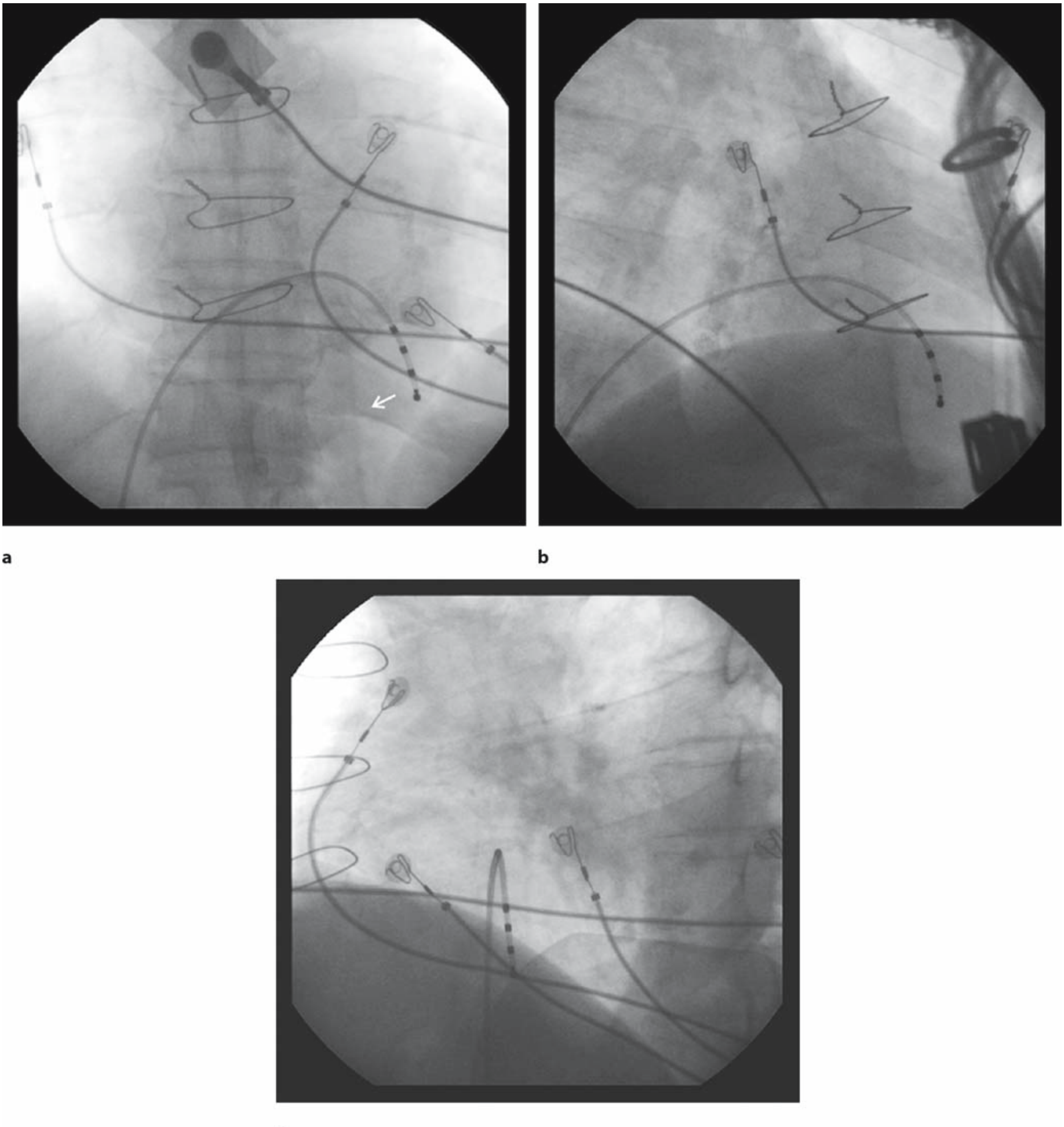


Figure 3.17 Position of the catheter into the right ventricle apex in the posteroanterior (*PA*), right anterior oblique (*RAO*), and left anterior oblique (*LAO*) views. In all views one can see three sternal wires from a previous sternotomy. **a** The PA view showing the catheter tip in the right ventricular apex (*RVA*). Fluoroscopy reveals catheter movement in an anteroposterior direction (arrow), following cardiac cycle. **b** The RAO view showing the catheter in profile. The catheter's movement is minimum in this view. **c** The LAO view allows visualization of the septal or lateral position of the catheter; in this view the catheter's movement is reduced

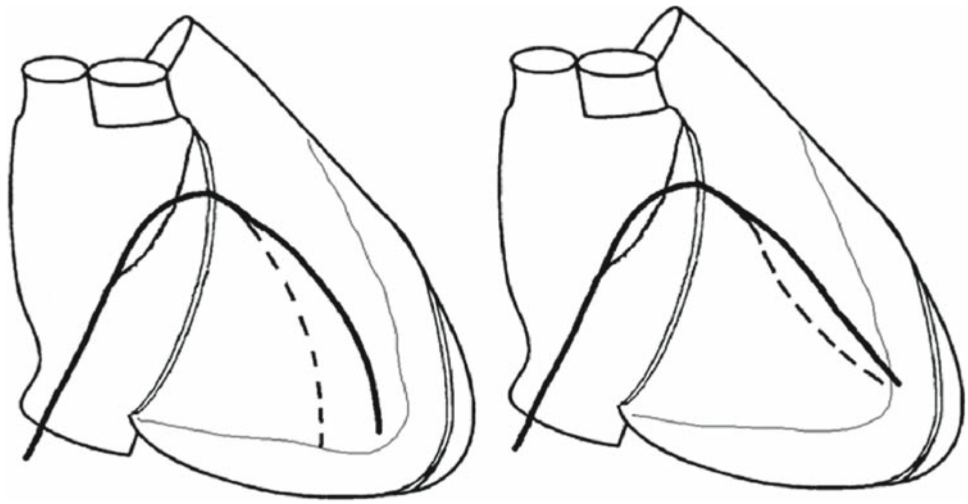


Figure 3.18 Diagram of the catheter's movement during ventricular systole with correct placement (left) and with a catheter embedded inside of the myocardium (right). The solid line shows the ventricular catheter position during diastole; the dashed line, instead, shows the catheter's position during ventricular systole

will show a ventricular potential followed by low voltage potential corresponding to T wave of surface tracing (Figures 3.18 and 3.19). Besides increasing the risk of perforation, an embedded catheter might cause mechanical extrasystoles or other arrhythmias.

The same catheter can be moved into the RVOT if needed. This is carried out in the RAO view. The tip is withdrawn from the ventricular apex along the ventricle's superior wall; when it is in the posterior section of the superior wall (a position similar to the His catheter's position but advanced more toward the ventricular side) it is necessary to simul-

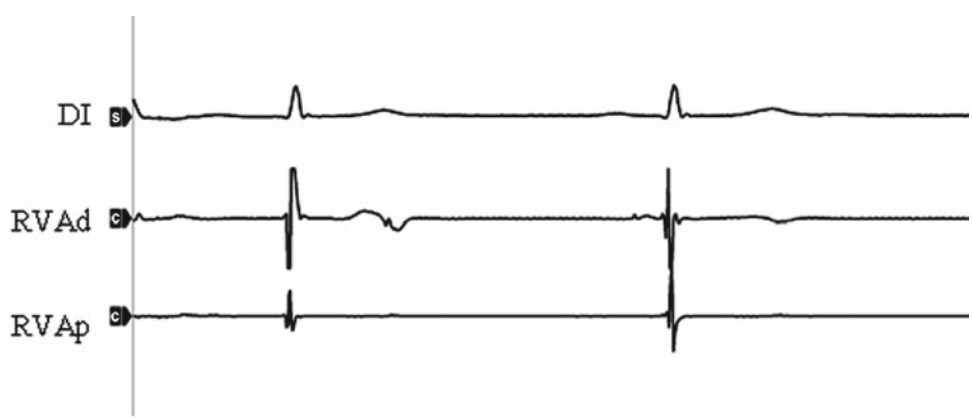


Figure 3.19 Starting from the top, the following are represented: a surface lead (*DI*), endocardial recordings of distal (*RVAd*) and proximal right ventricle (*RVAp*). From left to right, two sinus beats are recorded. In the first beat, the catheter inside the right ventricle embedded into the muscle (note that wide and low voltage wave on RVAd corresponding to the T wave on I); in the second beat, the ventricular catheter has its tip resting on the muscle and only a minimum deflection corresponding to the T wave of the surface lead can be seen on *RVAd*

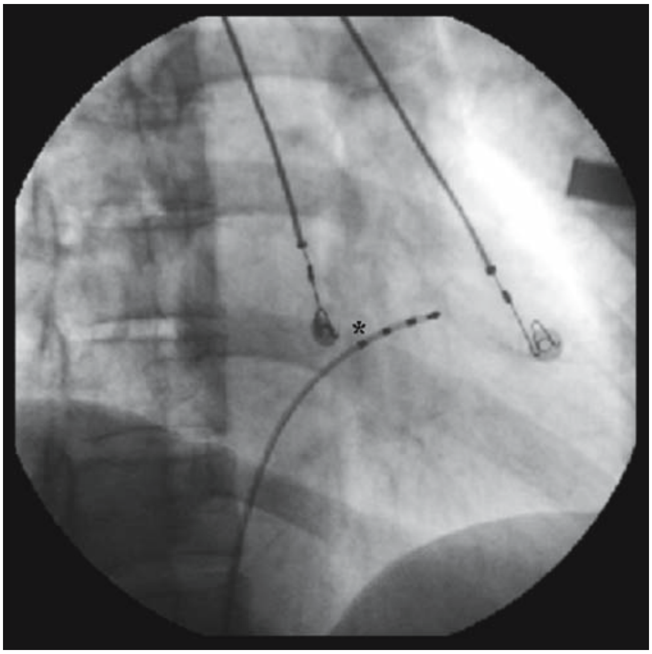


Figure 3.20 In the right anterior oblique (*RAO*) view, the ventricular catheter is withdrawn almost to the His bundle's recording site (*)

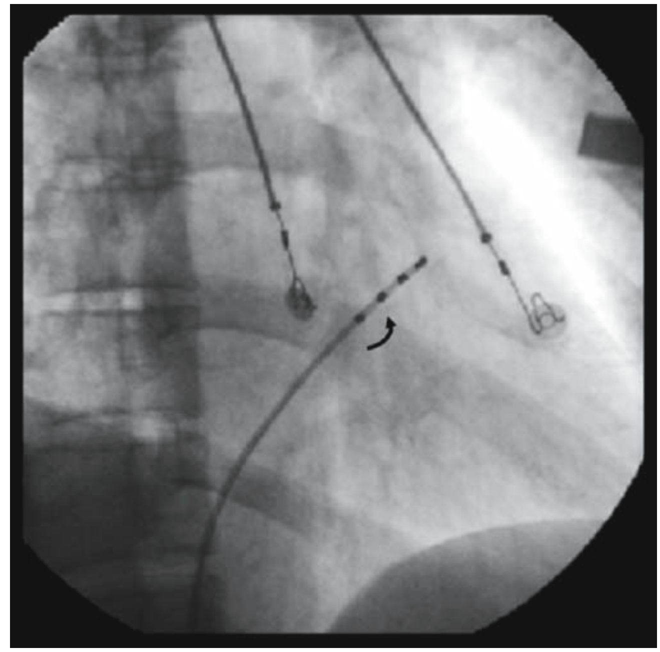


Figure 3.21 At this point, the catheter is rotated slightly clockwise so that its tip turns toward the interventricular septal area and will often spring toward the base of the outflow tract

taneously rotate the catheter clockwise while advancing the catheter so that it can slide into the outflow tract (Figures 3.20–3.24). The most secure position is often at the level of the pulmonary valve; however, recording and stimulation there are often poor. It is therefore advisable to slightly withdraw the catheter and, if necessary, hold its position by hand, so as to prevent it from sliding along the anterior wall of the ventricle.

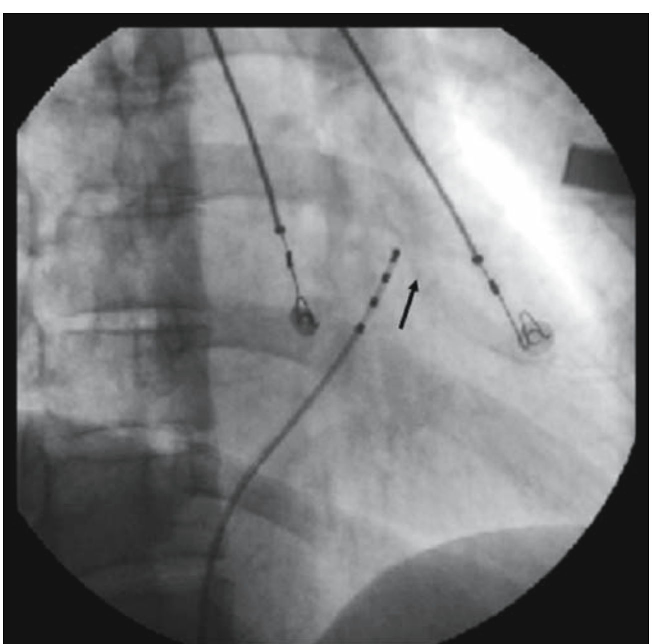


Figure 3.22 The catheter, while maintaining clockwise rotation, is advanced forward into the right ventricular outflow tract (*RVOT*)

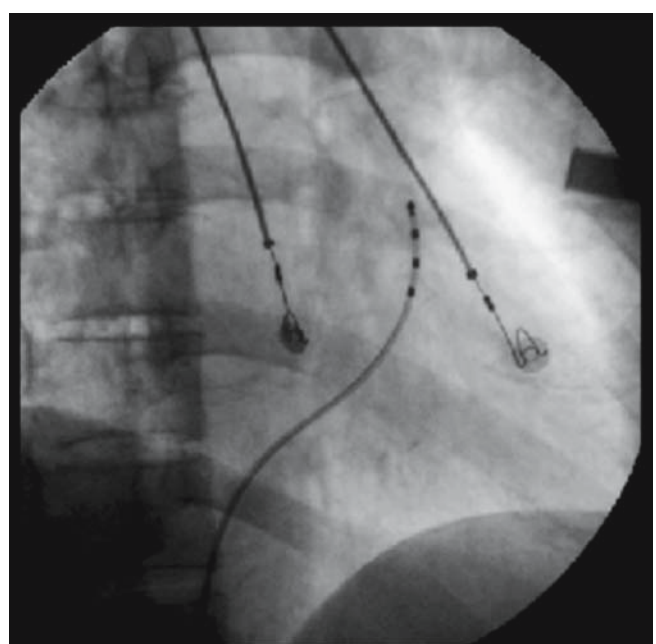


Figure 3.23 At this point, the catheter tip is inside the right ventricular outflow tract (*RVOT*), just below the pulmonary valve plane. In the right anterior oblique (*RAO*) view it is possible to assess if the catheter tip is turned toward posterior or anterior wall (as in this case) of the outflow tract

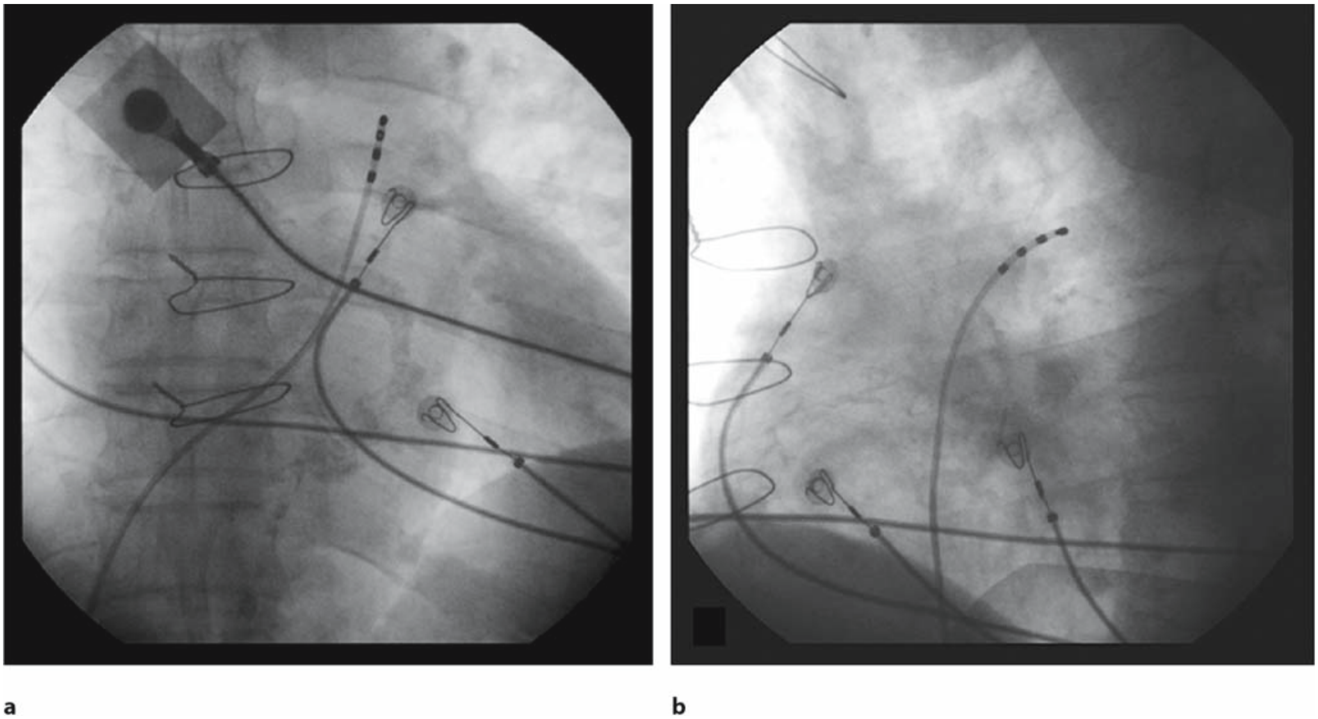


Figure 3.24 In the two images, the ventricular catheter is placed into the right ventricular outflow tract (*RVOT*) in the posteroanterior (*PA*) (panel a) and left anterior oblique (*LAO*) (panel b) views, respectively. The LAO view enables visualization of the lateral or septal (as in this case) position of the catheter in the outflow tract

In the following sequence of images, the set of catheters used for a complete baseline electrophysiological study is demonstrated. Diagnostic catheters are placed into the right atrium, the His, the RVOT, and the coronary sinus (CS), respectively (Figures 3.25–3.27).

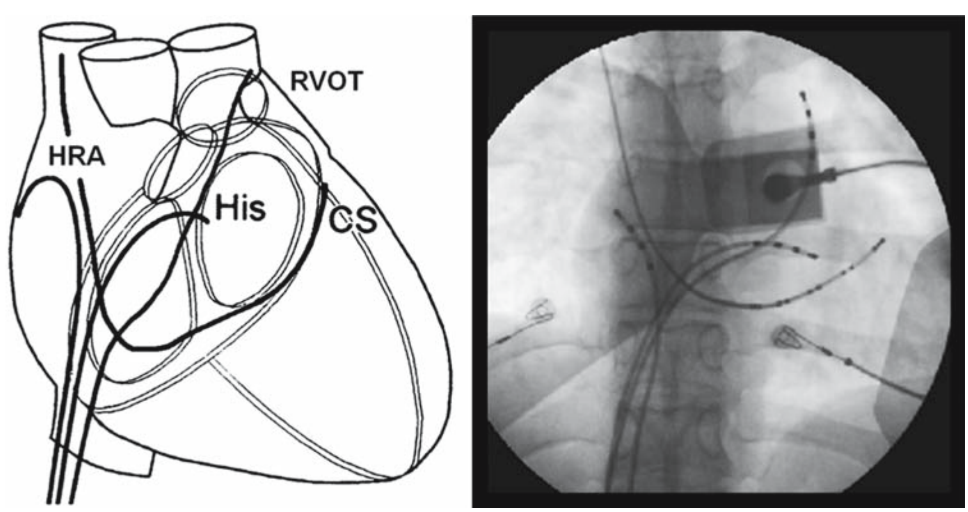


Figure 3.25 The posteroanterior (*PA*) view. In the diagram, one can see three diagnostic catheters inserted via the inferior vena cava. The high right atrium (*HRA*) is the catheter placed into the right atrium, His is the catheter in the His region (*His*), the right ventricular outflow tract (*RVOT*) is placed in the *RVOT*. The coronary sinus (*CS*) is the catheter placed into the CS, inserted via a superior approach. In the fluoroscopic image the four catheters are shown in their respective positions

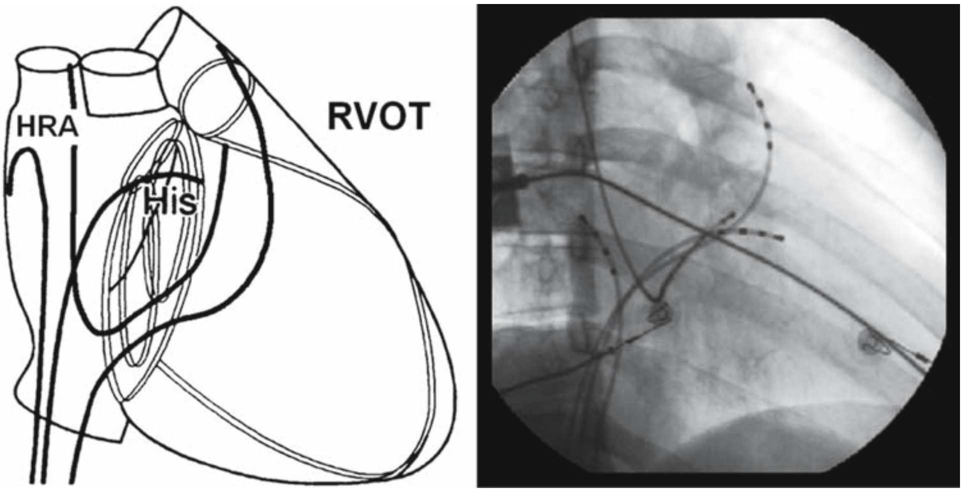


Figure 3.26 The right anterior oblique (*RAO*) view. In the diagram as well as in the fluoroscopic image, the four catheters are in their respective positions

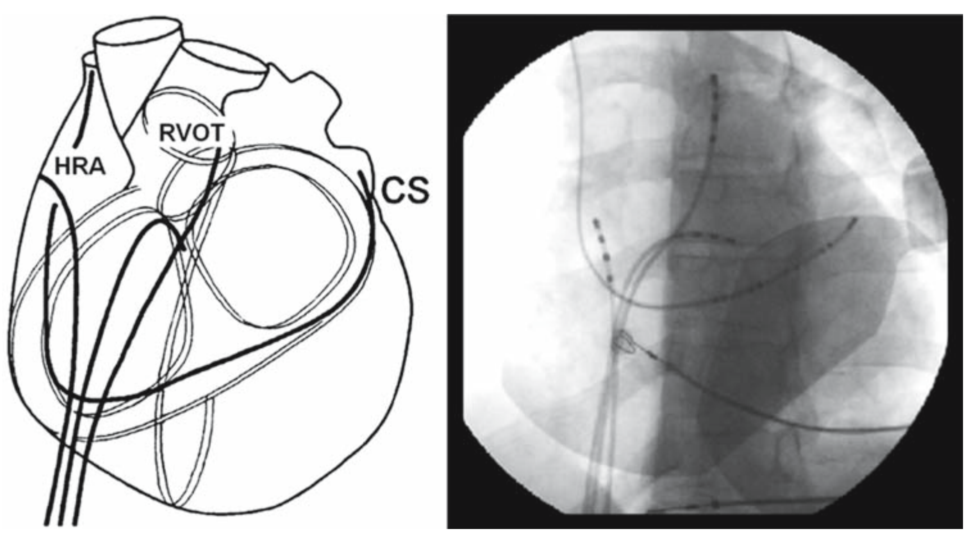


Figure 3.27 The left anterior oblique (*LAO*) view. In the diagram as well as in the fluoroscopic image, the four catheters are seen in their respective positions

3.5 The Approach to the Coronary Sinus

The catheter for the CS recording is often placed via a superior venous approach, entering the right atrium through the superior vena cava. In the superior approach, the catheter is usually inserted into the right internal jugular vein or into the subclavian vein (preferably the left one) (Figure 3.28).

The superior approach, characterized by an anterosuperior direction, is made easy by the Thebesian valve; a thin crescent valvelike fold hinged posteroinferiorly deriving from the embryonal great right venous valve, occupying a more or less wide space at the CS ostium (Figure 3.29). A catheter approaching from the inferior vena cava must pass over the valve and its ridge before turning inferiorly to engage in the CS.

By the superior approach, it is possible to use a preshaped fixed curve catheter, or a deflectable catheter. Should it be necessary to use an inferior approach, a deflectable catheter is advisable. The number of recording poles depends on the necessary information. Usually decapolar catheters are preferred as they allow mapping of the posterior and lateral mitral annulus.

It is easier to place the CS catheter with a LAO view. This view shows the mitral ring enface. Via the jugular vein or the subclavian vein, the catheter is advanced through the superior vena cava. As soon as the catheter tip reaches the right atrium, it must be rotated counterclockwise toward the septum. It is then moved downward until the catheter tip

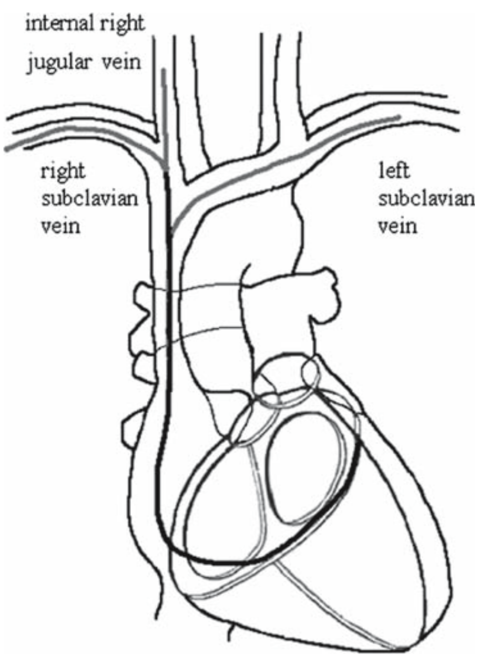


Figure 3.28 The superior venous accesses approaches: right internal jugular vein, left subclavian vein, and right subclavian vein. The first two approaches are equivalent and technically less difficult, so the operator prefers either one according to his manual skill. Approach through the right subclavian vein is less often used because it requires the catheter to form two opposite curves (subclavian vein-vena cava, right atrium- coronary sinus, *CS*, ostium), thus making its positioning more difficult

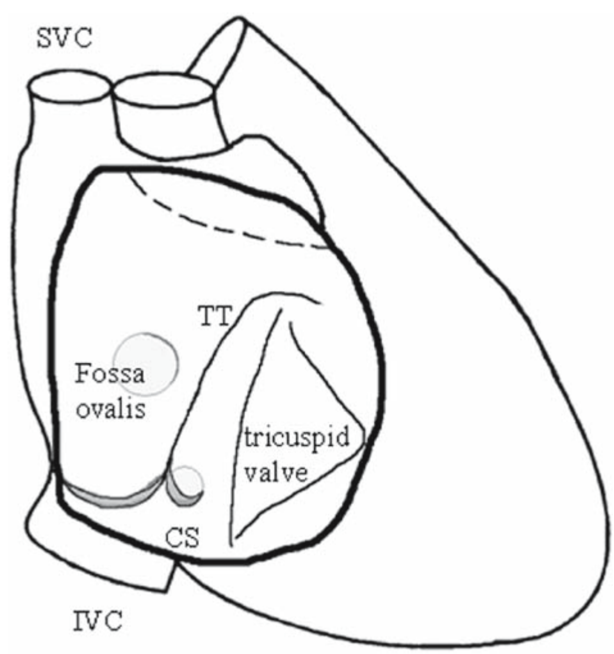


Figure 3.29 Seen from the right side, the right atrium is open. At the coronary sinus (*CS*) ostium, there is a valve with its concavity turned upward (Thebesian valve), which is continuous with the tendon of Todaro (*TT*) as far as the apex of Koch's triangle. Koch's triangle is formed, at the apex by the atrioventricular node and at the sides by the tricuspid septal edge and the TT, at the base by the CS ostium

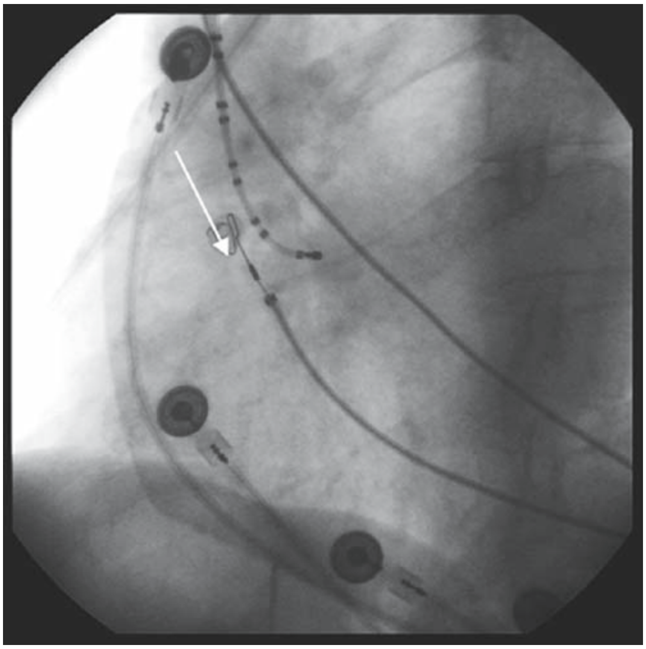


Figure 3.30 The catheter is inserted into the right atrium via the superior vena cava in the left anterior oblique (*LAO*) view

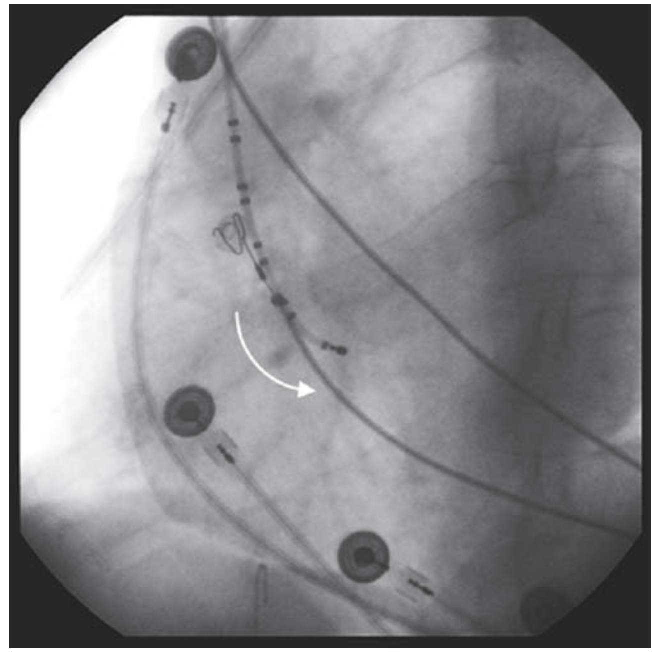


Figure 3.31 Once the catheter tip is inside of the right atrium, the catheter is rotated clockwise or counterclockwise depending on its initial position, until its tip is turned toward the interatrial septum and the catheter's curvature is perceived frontally in maximum profile

springs into the CS ostium. At this point, with light further pressure, the catheter slides along the CS to its distal portion. Should this fail to cannulate the CS on the first attempt, further attempts are possible by slightly withdrawing or advancing along the septum until a site of minor resistance is found (Figures 3.30–3.37).

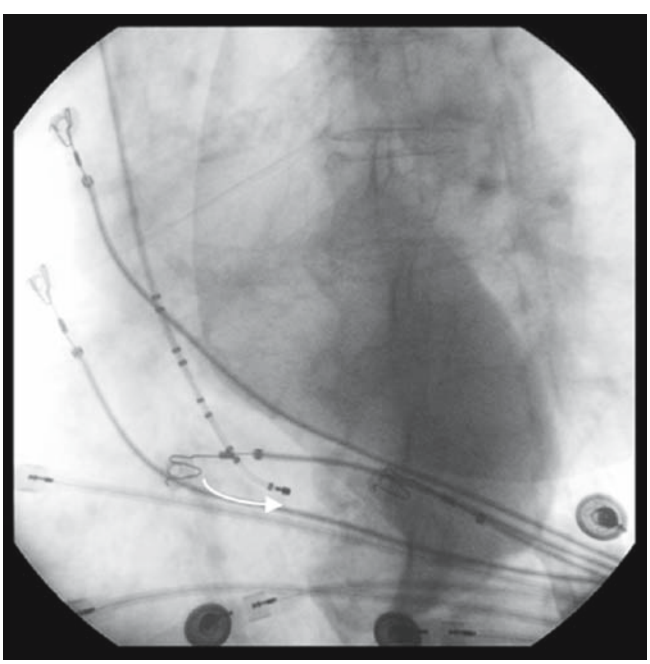


Figure 3.32 The catheter is advanced downward keeping it in touch with the septum

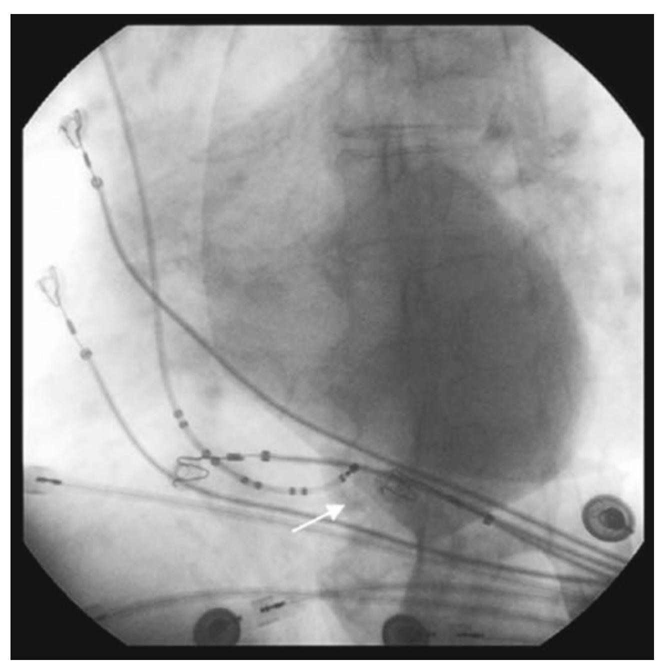


Figure 3.33 The catheter is anchored to the coronary sinus (*CS*) ostium. Hooking of the catheter tip in the *CS* ostium is confirmed by slightly pushing the catheter. Its tip gets stuck at the ostium, while in the right atrium, a wider curve of the catheter's body takes shape

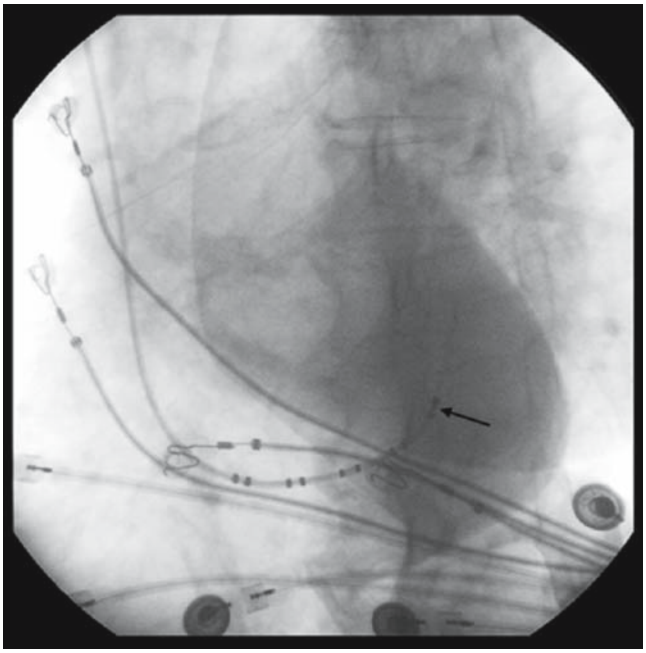


Figure 3.34 By further advancing, the catheter springs into the coronary sinus

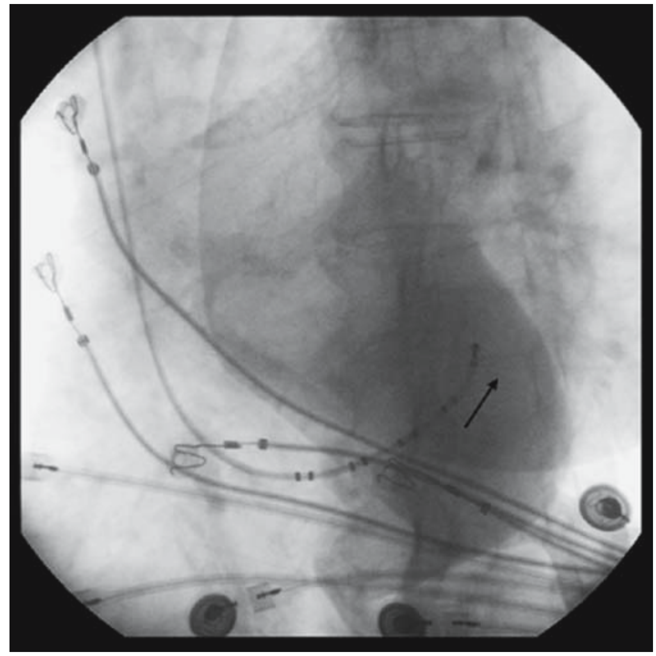


Figure 3.35 The catheter must be advanced until resistance is perceived

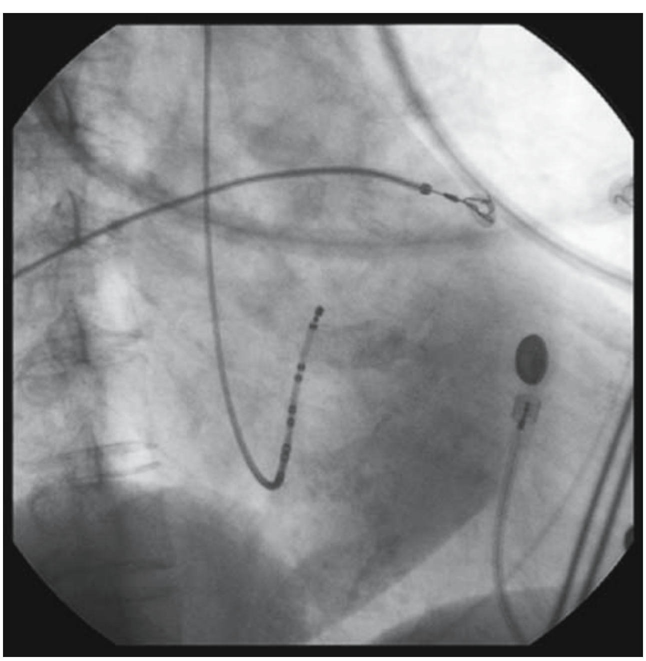


Figure 3.36 In the right anterior oblique (*RAO*) view it is possible to control whether the catheter runs in the main coronary sinus (*CS*) along the atrioventricular ring and prevent entrance into an atrial (tip being turned backward, toward the atrium) or ventricular branch (tip being turned forward, toward the ventricle)

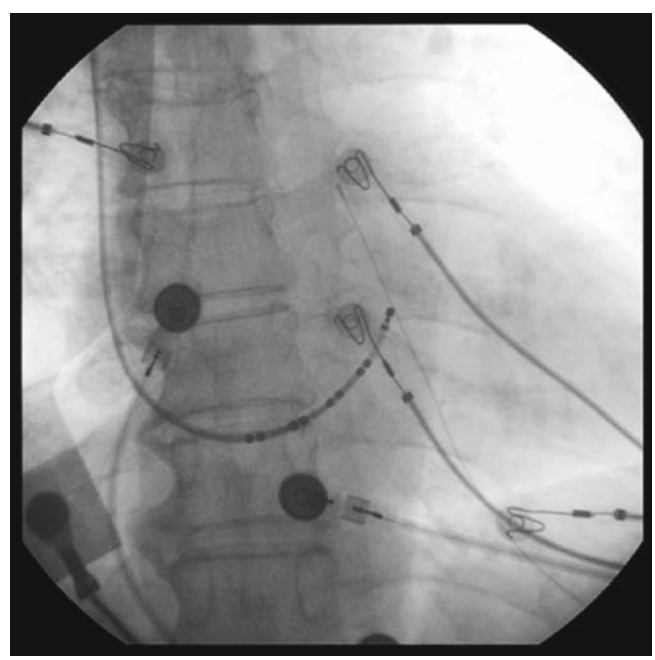


Figure 3.37 The posteroanterior (*PA*) view of the catheter in the coronary sinus (*CS*). In this view the catheter's course is similar to the one perceived in the left anterior oblique (*LAO*) view but with a tighter curvature

What determines the position of the catheter into the CS is the type of recording one wants to carry out. In the case of atrial flutter, the catheter will be placed in such a way that the proximal electrode couple rests at the level of the ostium; in mapping a left accessory pathway, the catheter is positioned proximally if the pathway is posterior, or it will be advanced forward distally in case of a lateral pathway. Finally, in atrial fibrillation, the catheter is advanced as distally as possible, so that stimulation enables one to distinguish clearly atrial potentials from those originating from the left pulmonary veins. For standard electrophysiological study, the catheter is placed so that its proximal bipole overlies the lateral border of the vertebral bodies in the PA view: this generally approximates to the location of the CS ostium and is a reproducible landmark.

In dilated right atria, a preshaped catheter may be insufficient; the catheter will tend to go down along the septum as far as the inferior vena cava without ever coming in contact with the interatrial septum. In these cases it is advisable to pull out the catheter and increase its curvature by hand. If the catheter still fails to reach the septum despite adjusting its curvature, a deflectable catheter can be employed.

If the catheter tip gets stuck at the CS ostium and cannot be advanced, the patient can be invited to breathe deeply while advancing the catheter in the inspiratory phase. This maneuver increases venous return, dilates the CS, thus easing the catheter's advancement.

If there is difficulty finding the CS ostium, one can use the RAO projection, which shows the CS ostium as a radiotransparency at the inferoposterior section of the Koch triangle (Figure 3.38). After positioning of the catheter tip at the CS ostium's level, the catheter is advanced in the LAO view.

The RAO view is also useful when the catheter tends to spring into the right ventricle, namely, into the outflow tract. This occurrence is usually accompanied by ventricular extrasystoles. In the LAO view this malposition might not be immediately evident, whereas in the RAO one can clearly see the catheter passing by the tricuspid valve. In such a case, it is necessary to withdraw the catheter into the right atrium and twist it counterclockwise so as to direct the catheter more posteriorly (Figures 3.39–3.42).

Finally, the RAO view is useful in those cases when the catheter does not succeed in advancing as far as the left atrium's lateral wall, though it has entered the CS correctly. In these cases, most often the catheter has entered an atrial or ventricular branch, which can be confirmed by endocavitary recording. In the RAO view we can clearly see diversion from

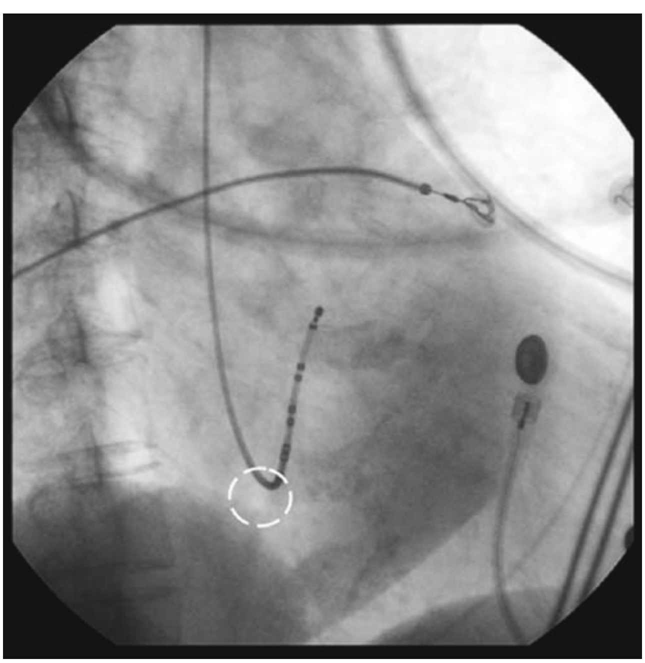


Figure 3.38 In the right anterior oblique (*RAO*) view one can perceive a radiotransparency at the base of Koch's triangle moving with the cardiac cycle (dotted circle); this coincides with the CS ostium

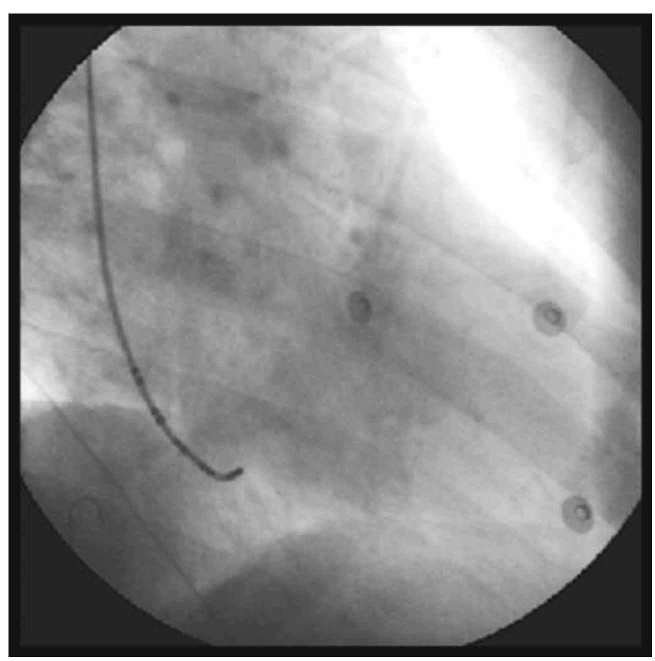


Figure 3.39 In the right anterior oblique (*RAO*) view, the decapolar catheter turns toward the coronary sinus (*CS*) ostium

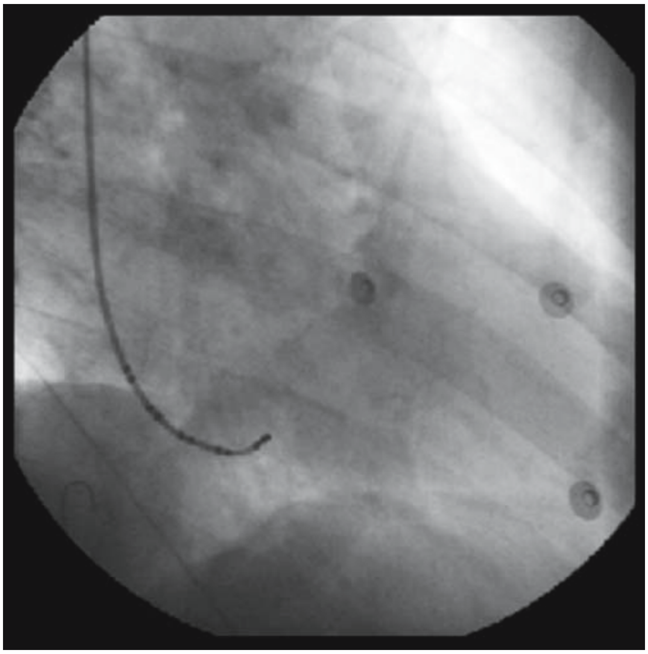


Figure 3.40 The catheter hooks the coronary sinus (*CS*) ostium, and it is possible to notice that the catheter tends to bend in its proximal curvature

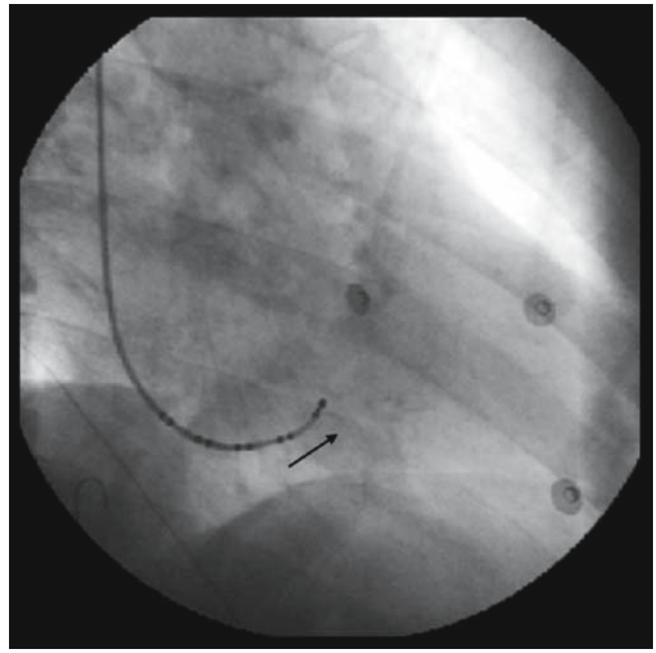


Figure 3.41 Advancing the catheter further, it springs anteriorly toward the ventricle

valve plane. At this point, it is necessary to withdraw the catheter until the tip is free and then advance it forward along the valve plane with slight clockwise rotation if the catheter tends to track into an atrial branch, or with slight counterclockwise rotation if, instead, the catheter tends to track into a ventricular branch.

The inferior approach is usually more difficult and, as a rule, does not enable to reach to the most distal sections of the CS; when it is necessary to get a distal CS recording, a superior approach is therefore preferred. One can try to directly cannulate the CS by turning the catheter tip toward the interatrial septum and probing from bottom to top in the LAO view (Figures 3.43–3.46). Otherwise, it is possible to loop the catheter body within the right

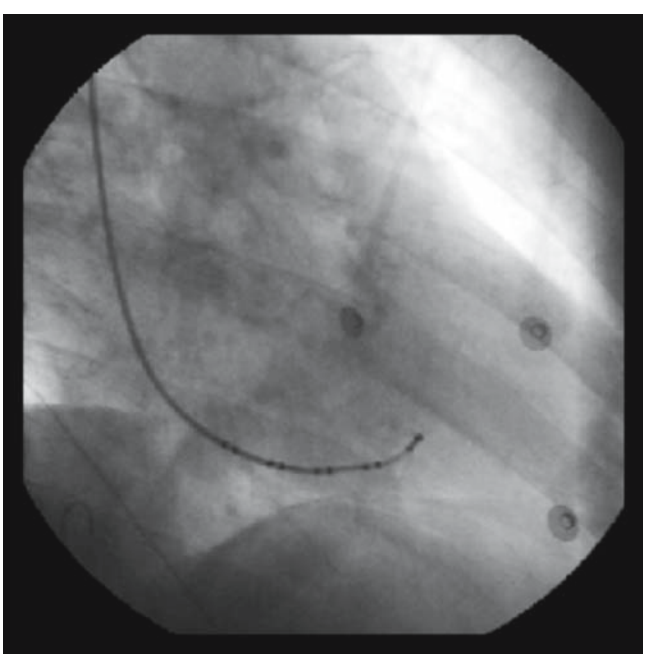


Figure 3.42 The catheter has advanced completely into the right ventricle. At this point one must withdraw the catheter into the right atrium and repeat the maneuver

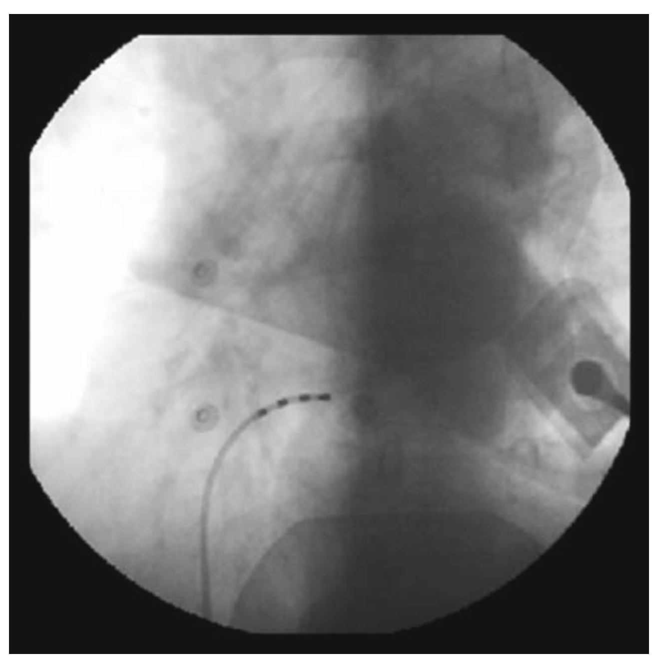


Figure 3.43 In the left anterior oblique (*LAO*) view, quadripolar catheter is placed in the posteroseptal region

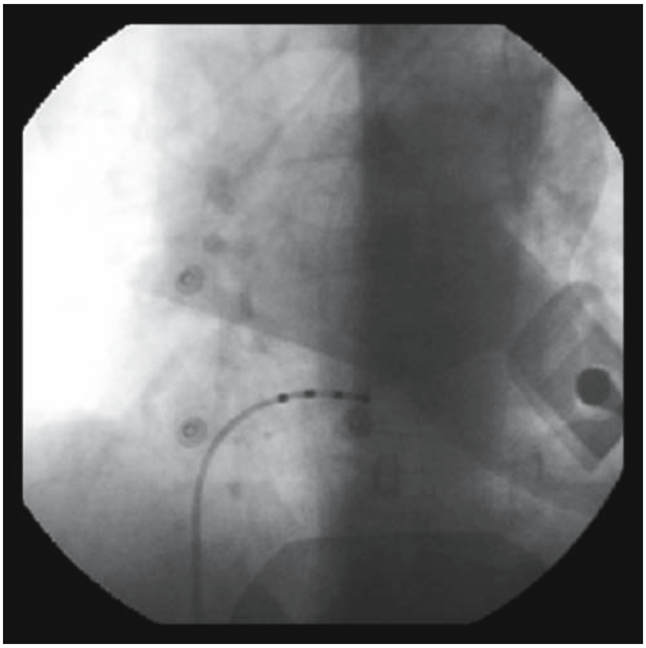


Figure 3.44 The catheter is advanced slightly toward the septum until an area of minor resistance is found corresponding to the coronary sinus (*CS*) ostium

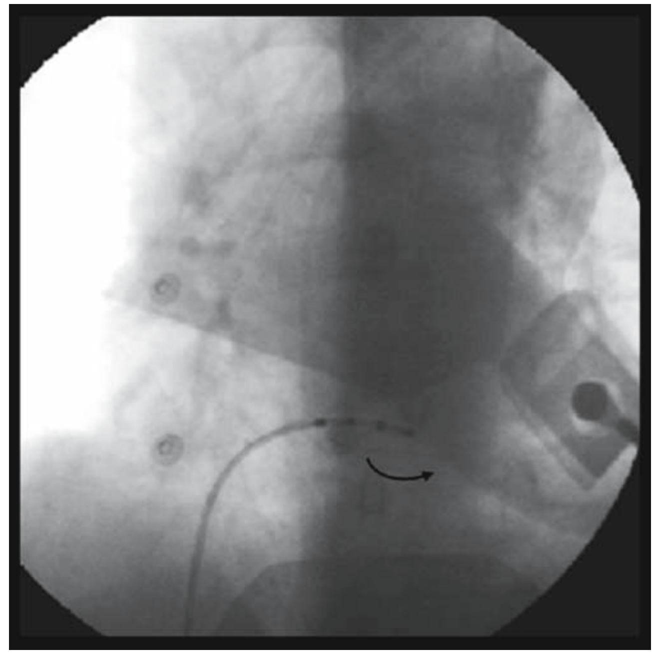


Figure 3.45 If the catheter tip is correctly oriented in the proximal coronary sinus (CS), gentle forward pressure should advance the catheter along the CS

atrium in order to get the catheter tip oriented inferiorly, thus mimicking the approach from the superior vena cava (Figures 3.47–3.53). When cannulating the CS via an inferior approach, it is possible to use a fixed curve catheter, of Josephson type, or however a deflectable catheter may make positioning easier (Figures 3.54–3.63).

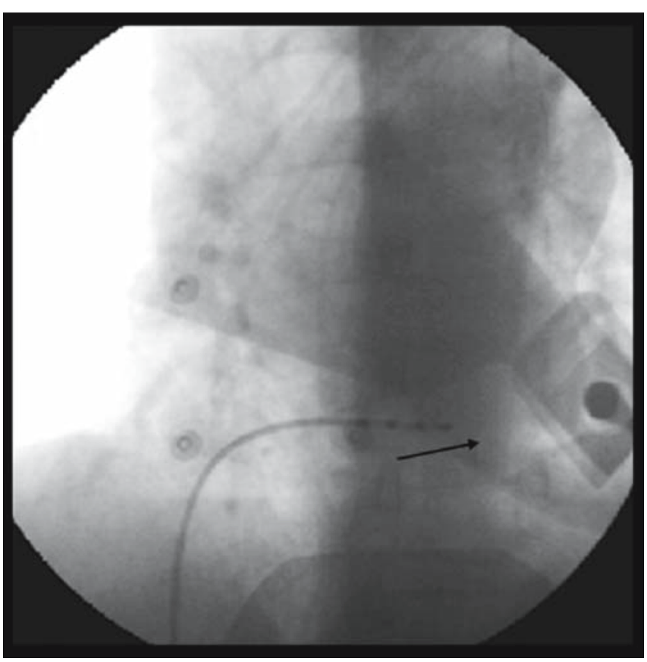


Figure 3.46 Still in the left anterior oblique (*LAO*) view, one advances the catheter forward while gently rotating clockwise so that the catheter tracks the oblique course (from back to front and from top to bottom) of the coronary sinus (*CS*). Sometimes the catheter happens not to run in the body of the CS but instead tracks into a branch so that, when pushing, tension grows in its body; thereafter, it springs into the right atrium

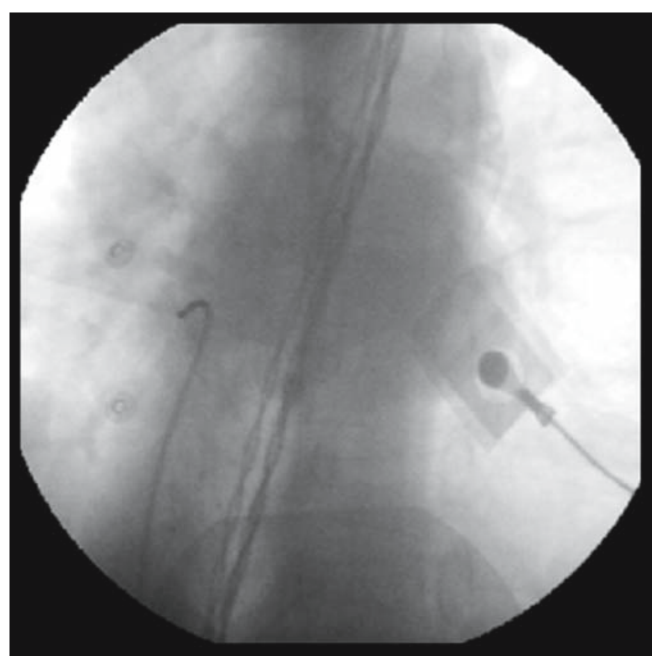


Figure 3.47 In this sequence of images, positioning of a fixed curve catheter into the coronary sinus (*CS*) via an inferior approach by looping into the right atrium is demonstrated. Once the catheter has been advanced into the right atrium, in the left anterior oblique (*LAO*) view the catheter is turned toward the atrium's free wall. As a rule one attempts not to catch the catheter tip into the atrial appendage, whose entrance can be found superiorly

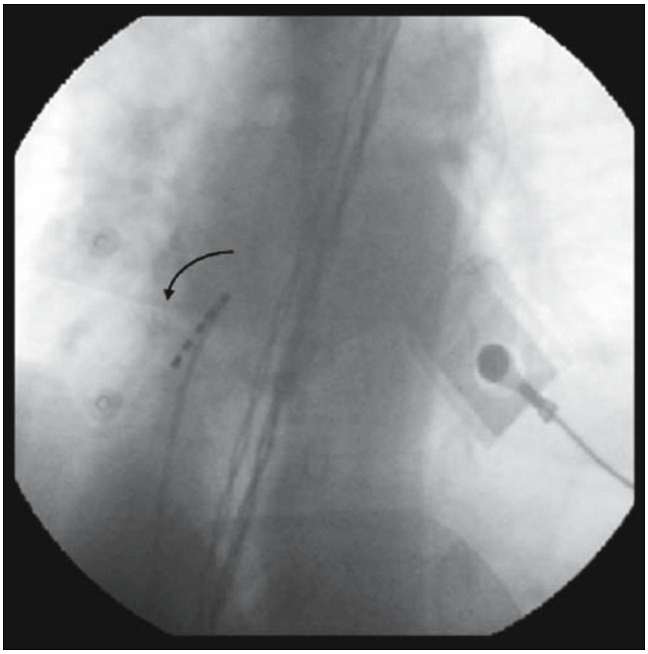


Figure 3.48 The catheter is advanced in such a way that its tip slides along the atrial wall from the top toward the bottom

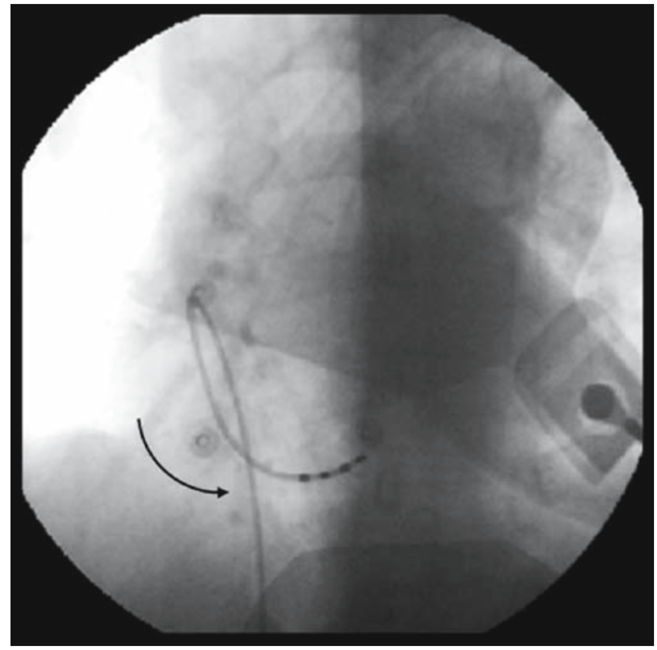


Figure 3.49 If one further advances the catheter forward, the catheter loops within the right atrium. The catheter tip moves toward the interatrial septum with a curve similar to the one employed when positioning via the superior approach. Movements applied to the catheter's body are transmitted by using the looped catheter in contact with the atrial wall as a fulcrum

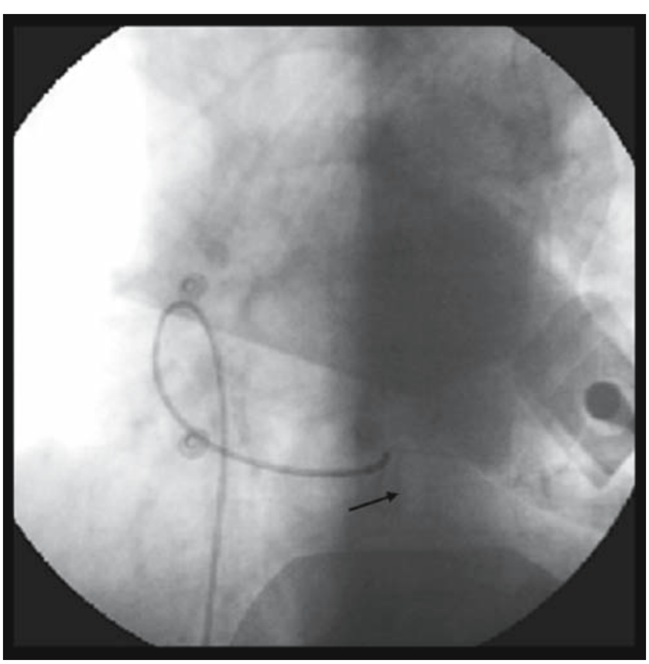


Figure 3.50 This loop directs the catheter tip toward the coronary sinus (*CS*) ostium, which is perceived as an area of minimal resistance

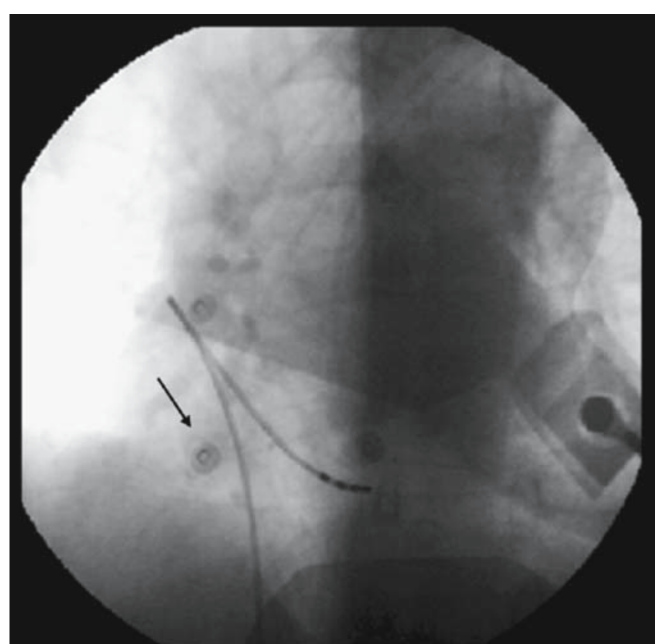


Figure 3.51 Very often, as the catheter moves forward in the coronary sinus (*CS*), the catheter will become unlooped. If this does not occur, once the catheter is advanced into the CS, the catheter's body can be withdrawn so as to unloop the catheter

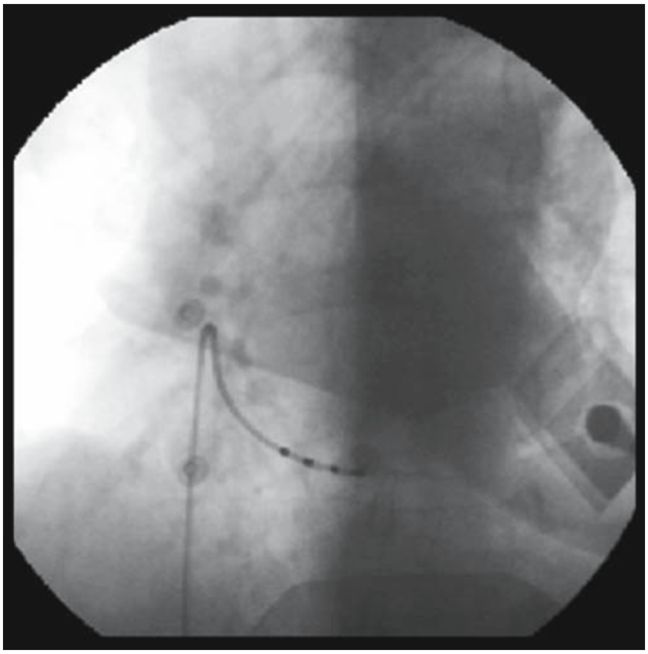


Figure 3.52 When unlooping the catheter, its tip tends to advance along the coronary sinus (*CS*) course

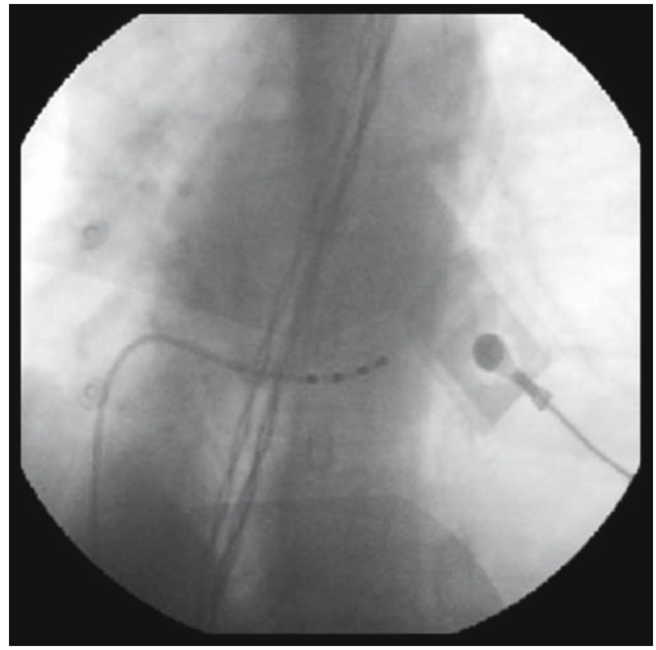


Figure 3.53 In the left anterior oblique (*LAO*) view, the quadripolar catheter is seen correctly positioned within the coronary sinus (*CS*)

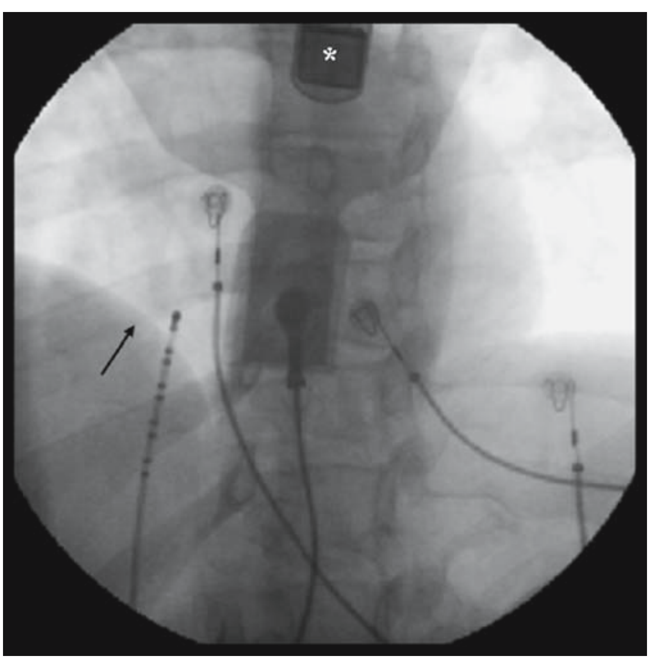


Figure 3.54 This sequence of images illustrates the positioning of a deflectable catheter into the coronary sinus (*CS*) via the inferior approach. After advancing the catheter into the right atrium, the maneuver is best carried out in the left anterior oblique (*LAO*) projection. In this patient, an implanted loop-recorder (*) can be observed in the upper section of the fluoroscopic image

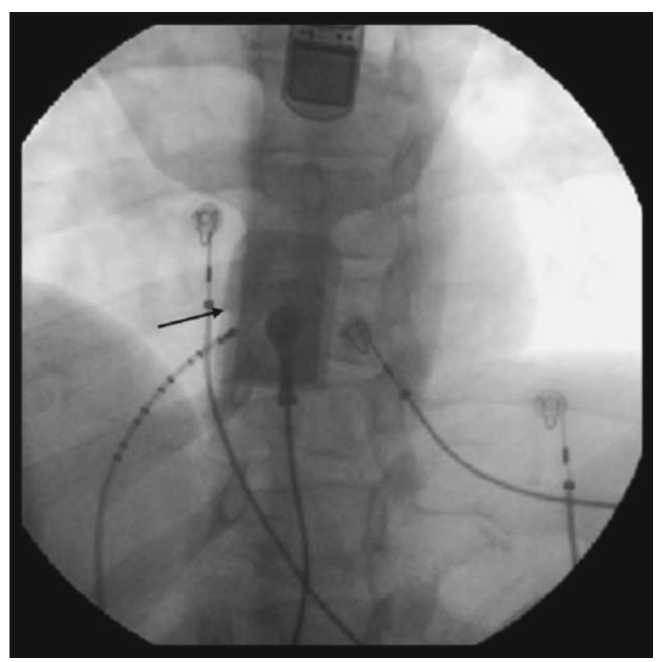


Figure 3.55 The catheter is deflected slightly while rotating it toward the interatrial septum until its tip is perceived in contact with the interatrial septum (usually a Josephson curve takes shape)

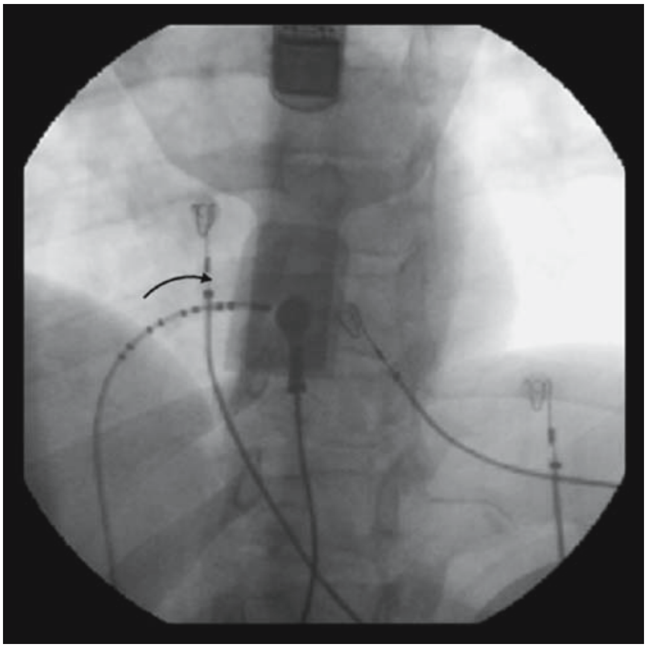


Figure 3.56 Inspecting the interatrial septum, one searches for the coronary sinus (*CS*) ostium where the catheter moves forward in a region of minimal resistance

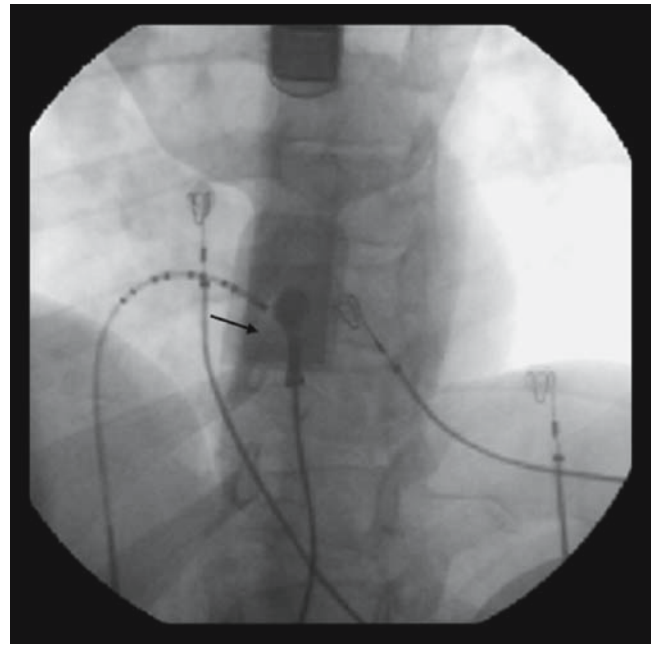


Figure 3.57 Advancing the catheter forward, the tip may simply cause the catheter body to begin to loop within the right atrium; springing thereafter, this can cause the catheter tip to push back into the right atrium. Instead, once the catheter tip is hooked into the coronary sinus (*CS*) ostium, it is useful to open the catheter curve slightly and withdraw the catheter just a bit in order to avoid looping within the right atrium

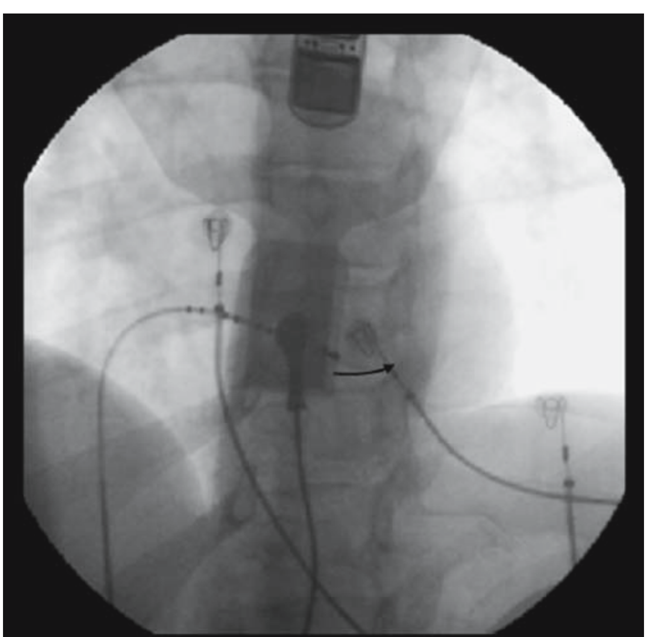


Figure 3.58 Having opened the curve slightly, the catheter is advanced while rotating it clockwise

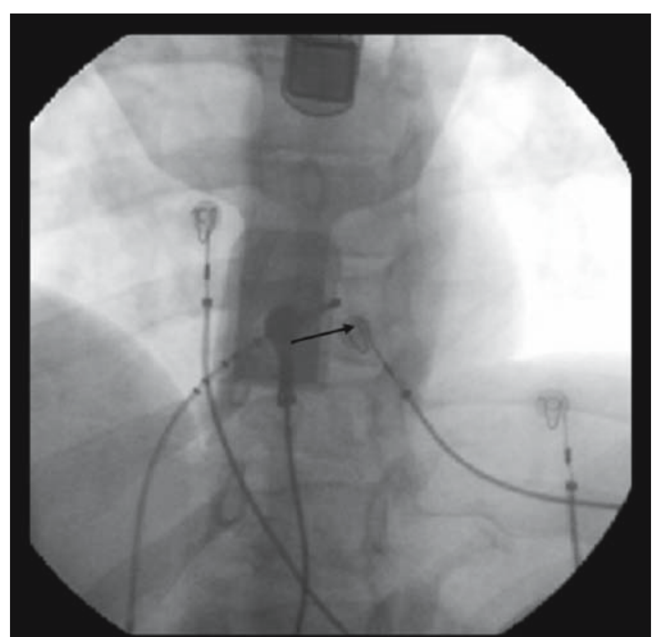


Figure 3.59 The catheter is withdrawn slightly so as to straighten its body and then gently readvanced with clockwise rotation

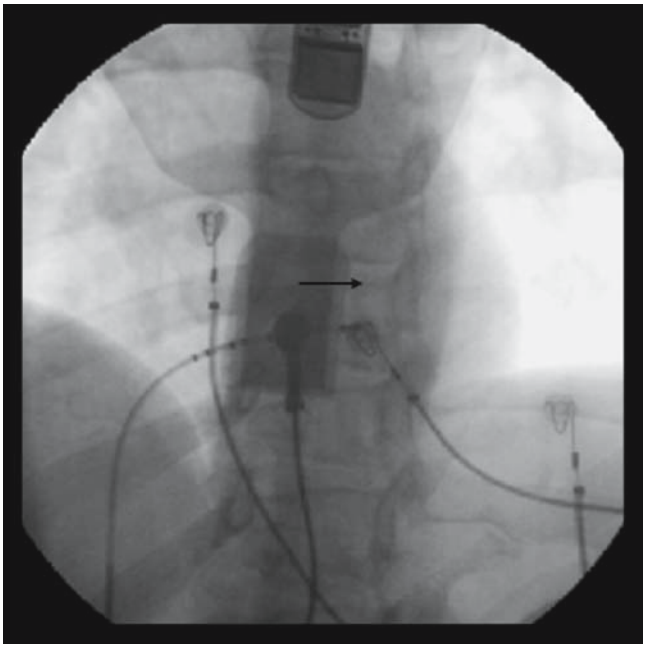


Figure 3.60 The catheter is advanced with clockwise rotation (note that excessive torque may cause the catheter to cannulate a coronary sinus, *CS*, branch), until it easily moves forward sliding into the body of the *CS*

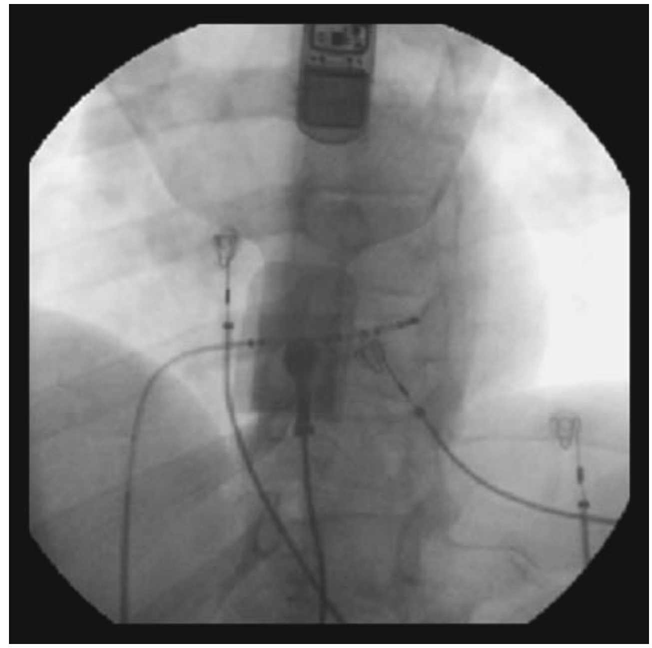


Figure 3.61 The left anterior oblique (*LAO*) view. At this point the catheter is positioned within the coronary sinus (*CS*) with the proximal electrode couple placed between the CS ostium and the right atrium

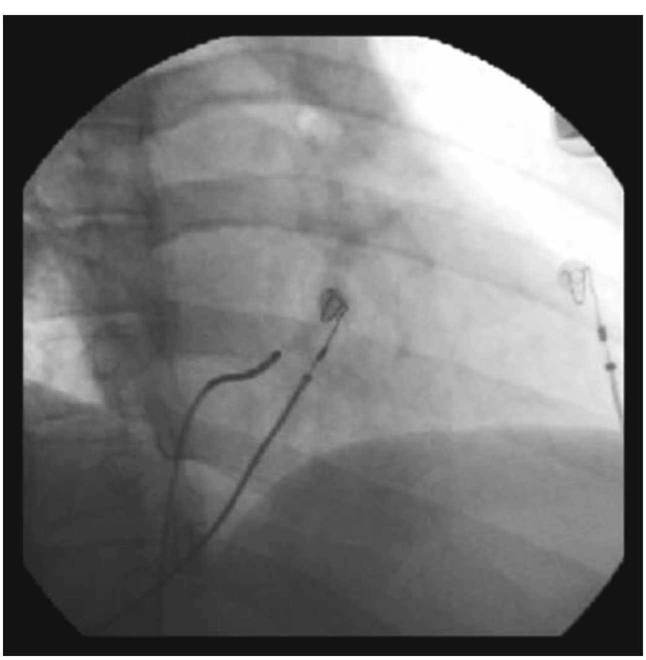


Figure 3.62 The catheter positioned within the coronary sinus (*CS*) in the right anterior oblique (*RAO*) view

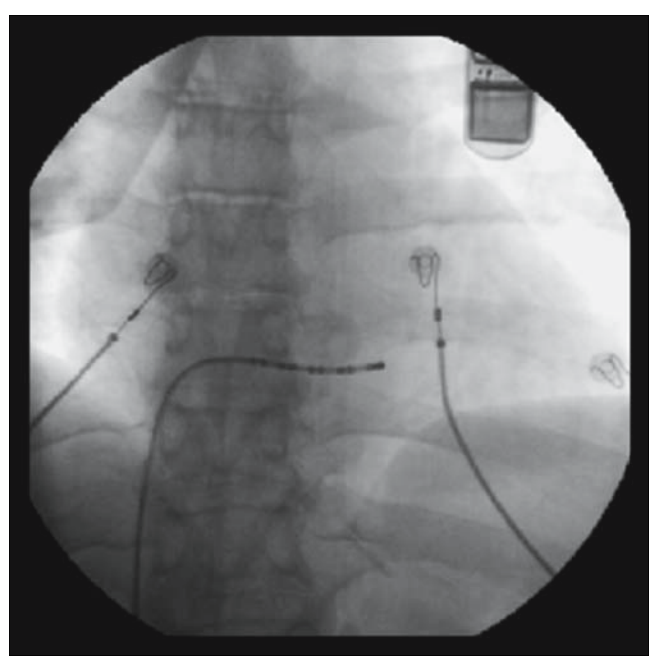


Figure 3.63 The posteroanterior (*PA*) view of the catheter positioned within the CS via an inferior approach

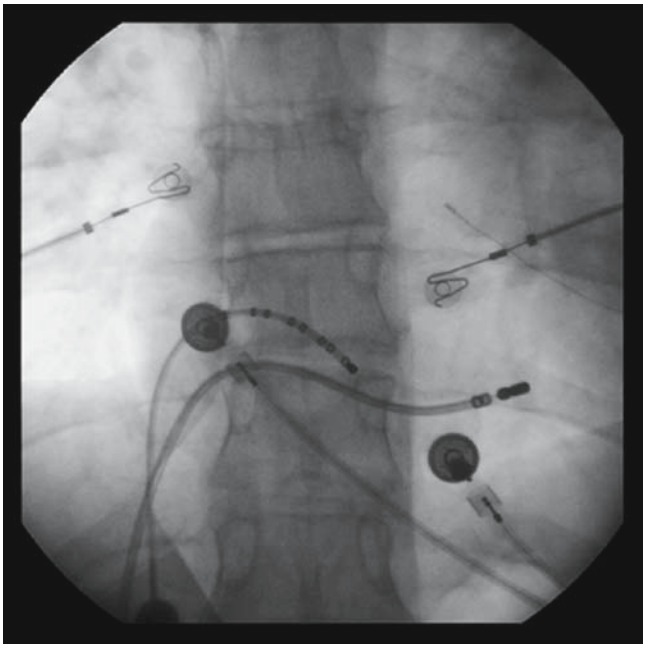


Figure 3.64 Example of a catheter positioned within the coronary sinus (*CS*) via lower approach, in the left anterior oblique (*LAO*) view. Since decapolar diagnostic catheter got stuck at the coronary sinus (*CS*) ostium, we turned to an ablation catheter in order to ease cannulation. The ablation catheter, thanks to its increased stiffness, moves with greater ease into the CS, thus providing a trick for the diagnostic catheter

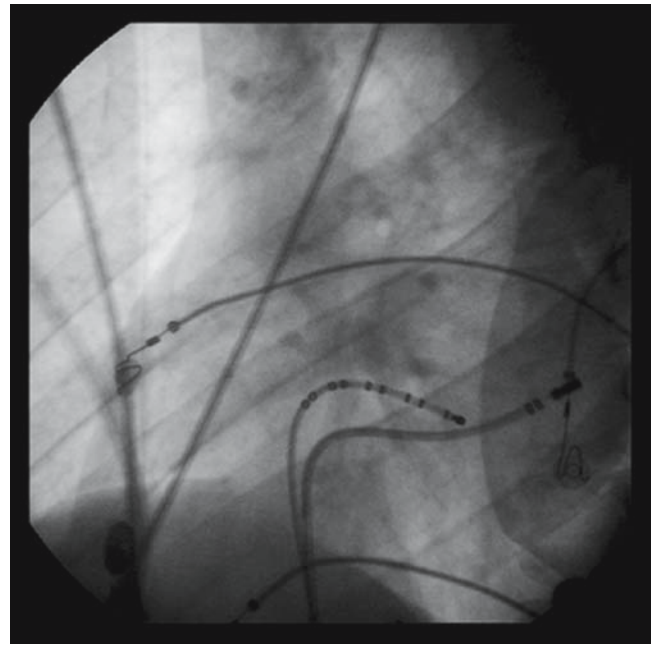


Figure 3.65 Same image in the posteroanterior (*PA*) view

If one successfully locates the CS ostium but the catheter does not move forward, one may instead employ an ablation catheter. The ablation catheter, thanks to the deflectable curve and to its increased stiffness, makes it easier to reach the distal CS. The decapolar catheter can then be inserted following the route created by the ablation catheter. As a rule, it is generally easier inserting the second catheter along the ablation catheter's track (Figures 3.64–3.66).

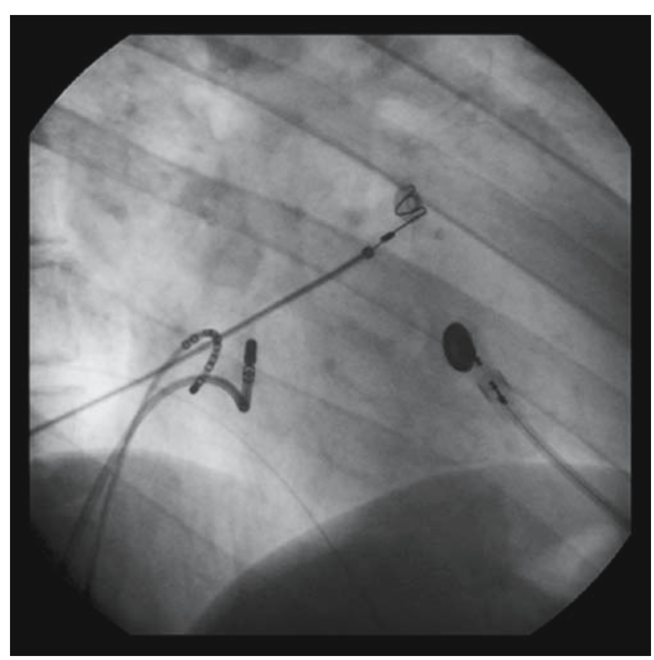


Figure 3.66 The right anterior oblique (*RAO*) view of the ablation catheter within the coronary sinus (CS) and of the decapolar diagnostic catheter stuck at the CS ostium

As previously mentioned, CS cannulation enables mapping of the posterior as well as the lateral section of the mitral ring. Cannulation of the distal CS may be necessary for ablation of an anterolateral accessory pathway or for ablation of atrial fibrillation, or in some cases of ventricular tachycardia, specifically ventricular tachycardias originating from the left ventricular outflow tract. Catheter positioning may be particularly difficult for patients with a valve of Vieussens (a valve distally located at the origin of the vein of Marshall; please see Part III, Chap. 10, Sect. 10.1 for CS anatomy), or for those patients with an acute angulation of the CS passage at the left atrial appendage base. In this case, very thin catheters or microcatheters can be employed, ranging between 1.5 Fr and 2.5 Fr, with 8 or16 electrodes at a very short interelectrode distance (Figures 3.67–3.69). Because of their reduced solidity, advancement into the CS is facilitated by a guiding catheter (Amplatz AL 1 or 2, 8 Fr). The guiding catheter is inserted within the CS, usually as far as 1–2 cm into the CS. The microcatheter is then advanced through the guide until it reaches the anterior section of the mitral ring. Should one want to map multiple CS branches, it is possible to place up to three microcatheters via the same guiding catheter. However, one must take care that the microcatheter does not push the guide out of the CS ostium as it is advanced down the CS. If the guide begins to push back while advancing the microcatheter, the microcatheter should be pulled back slightly and the guide then advanced further into the CS over the microcatheter to obtain greater support.

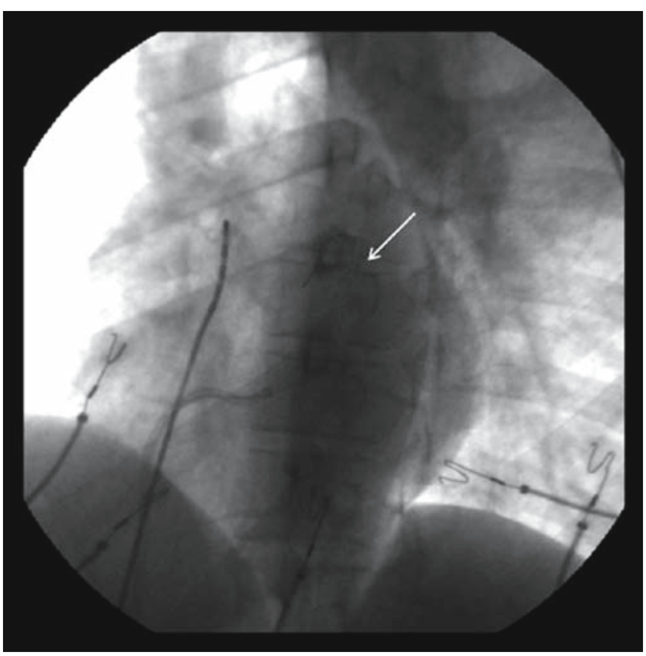


Figure 3.67 In the left anterior oblique (*LAO*) view, the guiding catheter is placed at the coronary sinus (*CS*) ostium; thereafter, it is advanced slowly into the venous sinus in order to anchor the catheter. Through the guiding catheter more than one microcatheter can then be placed to map CS branches

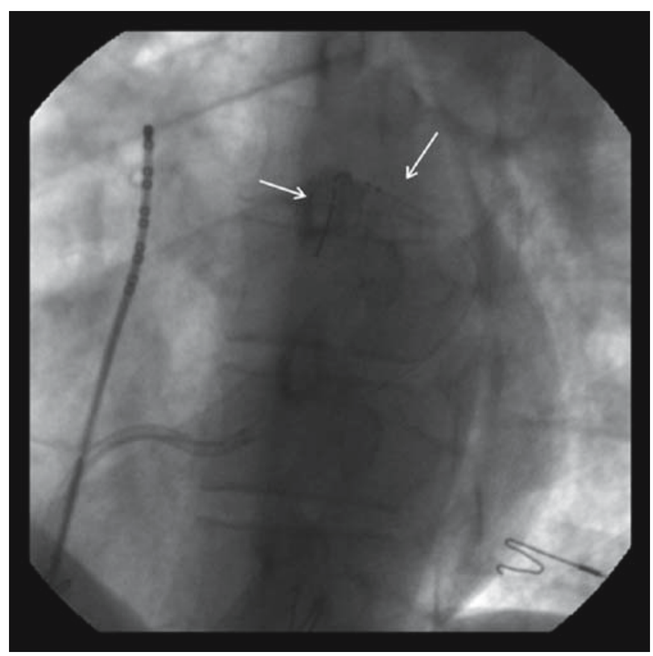


Figure 3.68 In the left anterior oblique (*LAO*) view, the microcatheter is inserted within the coronary sinus (*CS*). The catheter has reduced stiffness and slides along the CS and its branches with little resistance. An increased twist strength might push the guiding catheter out of *CS*. The guiding catheter is placed at the CS ostium, then is pushed slowly into the venous sinus in order to steadily anchor the catheter's distal hook-shaped segment

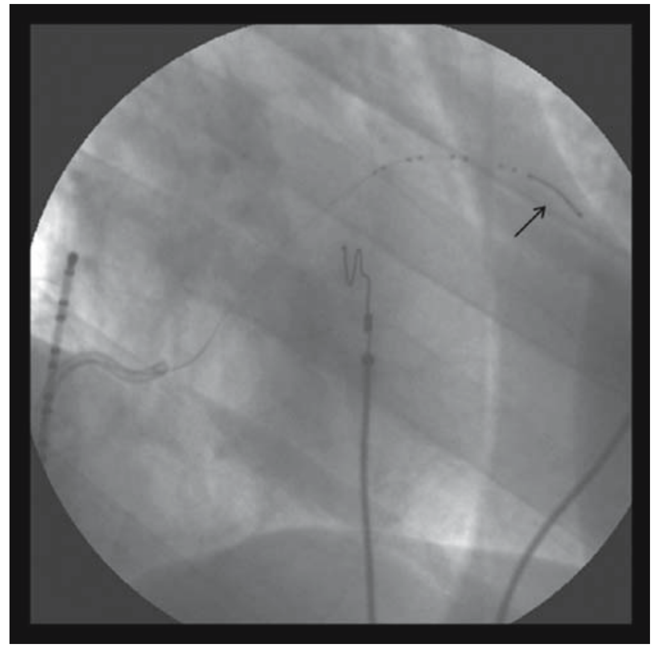


Figure 3.69 Image in the right anterior oblique (*RAO*) projection showing the guiding catheter within the first coronary sinus (*CS*) tract; inside of it runs a microcatheter which moves forward into the CS and, with its distal segment, enters a ventricular branch

4

Ablation of Supraventricular Tachycardias from the Right Atrium

4.1 Ablation Catheters

Ablation catheters are electrocatheters which can record electric potentials, stimulate the myocardium, and deliver energy. Delivery of energy is done to create a lesion within the cardiac tissue, thus preventing an electric impulse from passing through a region indispensable for producing and supporting arrhythmias. Among the different kinds of presently available energies, radiofrequency (RF) is most often used. A 300–750 Hz alternating current causes tissue burn damage by thermal injury.[1] Another kind of energy, employed in special cases, is cryoablation,[2] which, as opposed to RF, causes tissue damage by freezing. Experimental employed energies are also micro-wave, laser, and ultrasound.

Radiofrequency ablation catheters have three different tips: 4 mm, 8 mm, and a cooled tip (ranging between 3.5 mm and 5 mm) (Figure 4.1). Catheters carrying an 8 mm distal electrode have the ability to cause a larger lesion area. This sort of catheter is usually stiffer; therefore, it is slightly less maneuverable than the 4 mm tip catheter. Furthermore, the wider electrode reduces the resolution of the recorded electrogram and can result in less accurate mapping. Cooled tip catheters have an internal duct which delivers a physiological solution

---

[1] A permanent lesion with radiofrequency is created when a 45–50°C temperature is reached at the catheter-myocardium interface, and such a lesion acts on myocardium up to 3–5 mm depth. When higher temperatures are reached, above 60–70°C, clotting and endocardium's carbonization can be produced, with an increased thromboembolic risk, without creating a larger size lesion. Still higher temperatures, closer to 100°C, besides carbonization, can also produce a sudden "boiling" responsible for popping. In order to increase RF lesion volume, it is not necessary to increase temperature at the contact surface which may be done employing catheters with a larger or "irrigated" distal electrode.

[2] Cryoablation employs cooling to cause tissue damage. A refrigerant gas, usually Freon, runs through the catheter; it chills the catheter's tip creating an ice ball. Myocardial tissue first incurs hypothermia (down to –30°C) causing a temporary lesion. Continued cooling as far as –70–80°C causes intracellular ice formation, which causes permanent damage. The first hypothermal phase, also called Cryomapping, is employed to ascertain ablation at that site is effective and safe (for instance, when ablation on anteroseptal accessory pathway one can notice disappearance of preexcitation as well as absence of atrioventricular block along nodal pathways); only in the second phase a irreversible cryoablation is carried out. The catheter is held securely to the site by icing and the tissue architecture is preserved avoiding thrombogenic risk. Moreover, cryoablation is usually painless and well tolerated by patients. Cryoablation, however, is reserved at present for special kinds of ablation since the lesion volume is smaller, lesions take much more time to create and are carried out by consecutive points, making thus difficult linear lesions.

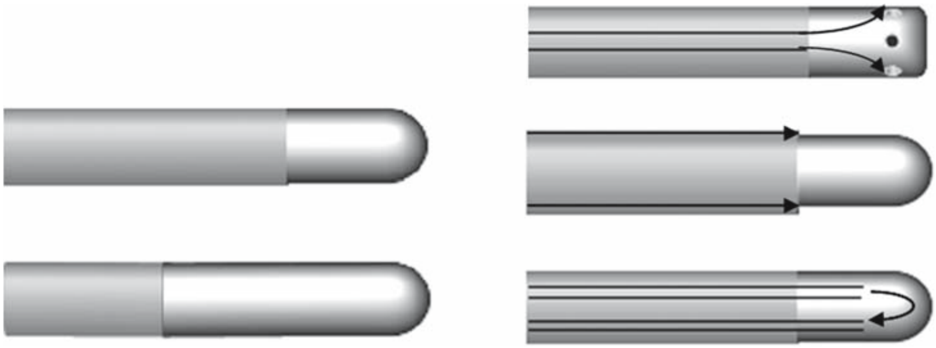


Figure 4.1 On the left, catheters with a 4 mm tip (top) and an 8 mm tip (bottom). On the right, three models for catheters with cooled tip by means of different cooling circuits. The first two catheters have an open circuit, where physiological solution is infused into the blood pool; the third catheter, instead, has a closed circuit, in which internally irrigated saline remains confined to a catheter-pump apparatus. Within open circuit catheters, physiological solution, once it has reached the catheter's tip, flows out through purposely arranged pores or can flow through a very little space between the catheter's tip and the outer sleeve

at room temperature. The physiologic solution cools the electrode–myocardium interface, thus enabling the delivery of a higher amount of energy for longer periods. As a consequence these catheters produce a deeper lesion with a larger volume. The irrigation flow is usually 2 ml/min during mapping phases and 20–35 ml/min during RF delivery. Great attention must be paid to ascertain that the extension tube connecting the infusion pump to the catheter is thoroughly devoid of air bubbles as they would be directly sent into the cardiac cavities.

Cryoablation catheters have a distal electrode which can measure 4 mm, usually used for pediatric patients, and electrodes measuring 6, 8, 10, and 15 mm for adults.

Besides the distal electrode, ablation catheters differ in their curvature. Ablation catheters are all deflectable catheters: some are bidirectional, that is to say they can make two

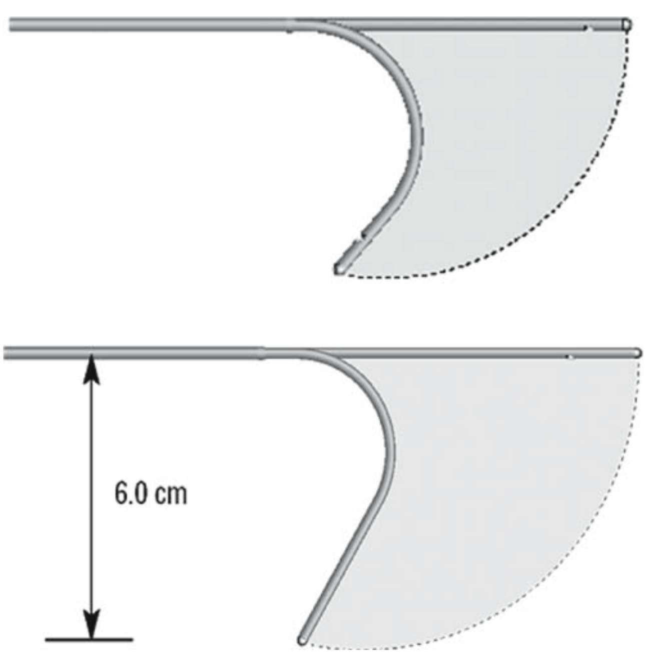


Figure 4.2 Pattern of two ablation catheters with different curves. Catheter a has a 5 cm small curve; catheter b has a 6 cm middle curve. Moderate curves are optimal for ablation of nodal reentry tachycardias, of right and left accessory pathways, and of right ventricular tachycardias. Wide curves are mainly used for atrial flutter, atrial fibrillation, and left ventricular tachycardias ablations. Small curves can be used for right accessory pathways

different types of curves, and some can also rotate their distal ends. The catheter's curve is the distance between the distal electrode and the catheter's body at an angle of 90° from its deflectable segment (Figure 4.2). Available curves are numerous; for adults curves ranging between 5 cm and 7 cm are used.

4.2 Atrioventricular Nodal Reentry Tachycardia

In atrioventricular nodal reentry tachycardia (AVNRT), the nodal slow pathway is the target of ablation. Anatomically, the slow pathway can be found at the base of Koch's triangle (Figures 4.3 and 4.4), in that area of tissue located between the coronary sinus (CS) ostium and the tricuspid annulus.

The posteroseptal position is the first to be mapped: the likelihood of the slow pathway to be located in this region is very high; and, in that area, RF applications can be carried out safely. This site is far from the compact atrioventricular node and the fast pathway. Frequently, however, it is necessary to move toward higher positions, such as the postero-midseptal region or the midseptal region (Figure 4.5).

For nodal slow pathway ablation, it is advisable to place a catheter on the His region, either as anatomic identification point, since it singles out Koch's triangle's apex, or as electrophysiological identification point of the atrioventricular (AV) conductive system. It is also useful to place a diagnostic catheter into the right atrial appendage in order to point out nodal retrograde

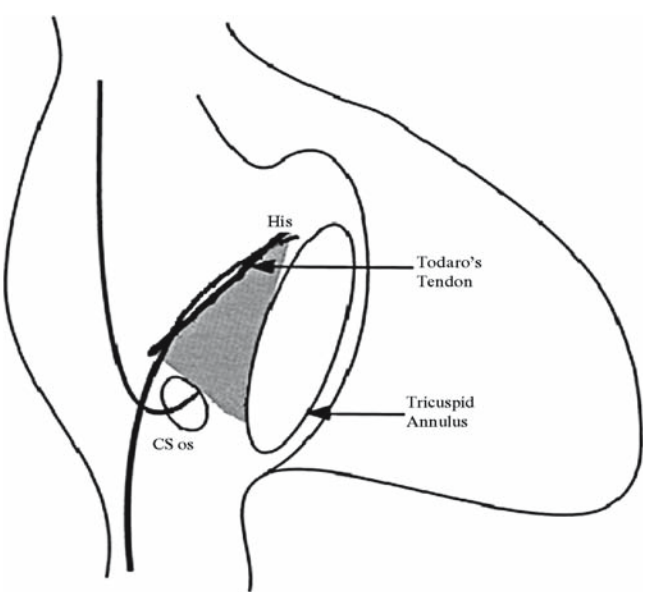


Figure 4.3 Diagram of Koch's triangle. The two sides are made, anteriorly, by the hinge of the septal leaflet of the tricuspid annulus and, posteriorly, by Todaro's tendon (*TT*) that continues from the free border of the Eustachian valve and runs in the musculature of the sinus septum. The base of the the triangle is represented by the coronary sinus (*CS*) ostium together with the vestibular portion immediately anterior to it. This vestibular portion, also known as the septal isthmus, is the area often targeted for ablation of the nodal slow pathway. At the apex of the triangle, the atrioventricular node with the penetrating bundle of Hits can be found

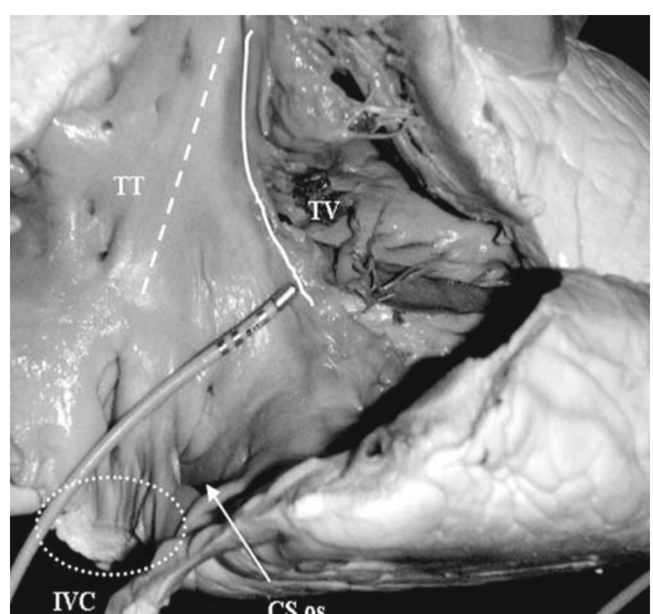


Figure 4.4 Gross specimen of the interatrial septum as seen through the right atrial lateral wall. The heart is oriented reproducing a right anterior oblique (*RAO*) view. The arrow shows the coronary sinus (*CS*) ostium, the curved line outlines the hinge of the septal leaflet of the tricuspid valve (*TV*), and the dashed line defines Todaro's tendon (*TT*). In the picture one can see an ablation catheter with 4 mm tip which, via the inferior vena cava (*IVC*), settles onto midseptal area of Koch's triangle

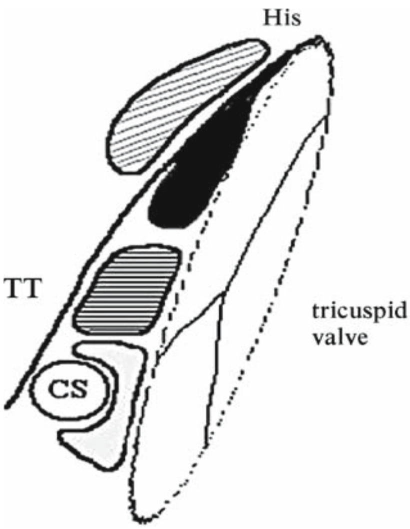
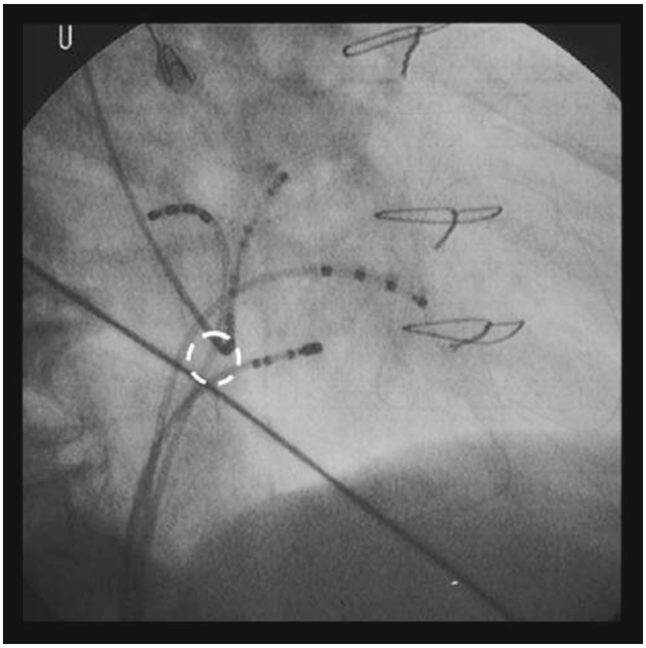


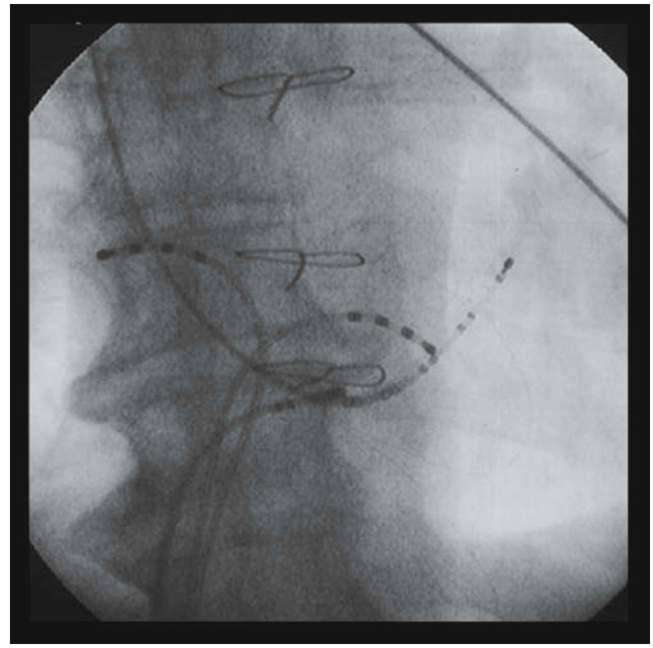
Figure 4.5 Koch's triangle outlined by the Hits, Todaro's tendon (*TT*), the coronary sinus (*CS*) ostium, and the valve ring. In the triangle, starting from top, first we meet the atrioventricular node (black area) and then the mid-septal area (horizontal dashing). Radiofrequency (*RF*) application in the midseptal area causes slow pathway block in 70% of cases and fast pathway block in 30% of cases. Finally, toward the front of the *CS* ostium, one can see the posteroseptal area (light grey) where the slow pathway is found. Above the atrioventricular node and beyond *TT*, the site of the fast pathway in the anteroseptal (oblique dashing) area can be found

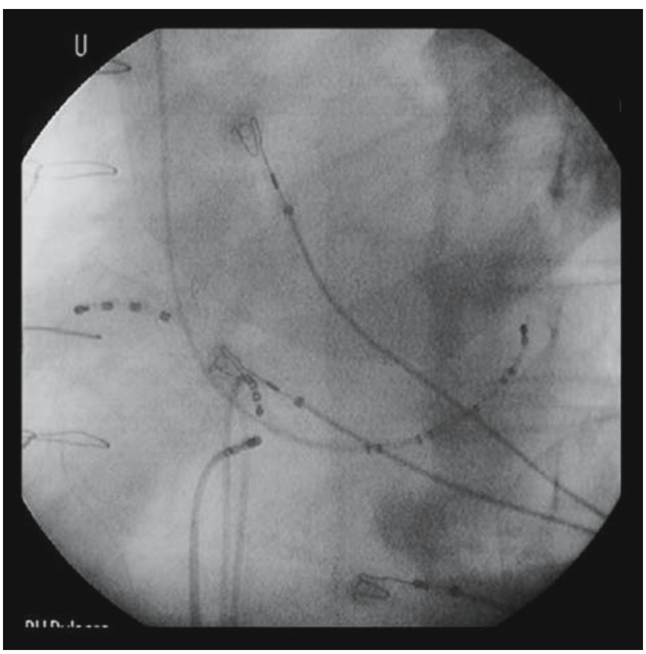
conduction during junctional beats caused by RF applications. A catheter placed within the CS can be useful in order to locate the CS ostium and, consequently, Koch's triangle's base; furthermore, the catheter's proximal recordings can easily point out an eventual slow pathway's exit on the left. The employed ablation catheter is usually a deflectable one with a 4 mm tip. Curvature is chosen depending on heart size, but moderate or small curves are most frequently used.

Approach to the slow pathway can be carried out in right anterior oblique (RAO) and left anterior oblique (LAO) projections. In the RAO view, the catheter is placed within the right ventricle, and then its body is lowered and held by applying gentle clockwise rotation so as to make it adhere to the septum. Thereafter, the catheter is pulled back along the tricuspid ring until an atrioventricular potential with 1:3 ratio or a slow pathway potential is seen. After placing the catheter, the LAO projection can help to ascertain that it is well against the septum. For this purpose it useful to remember that by rotating clockwise, the catheter moves toward the septum, whereas by rotating counterclockwise, the catheter moves laterally. Examples of slow pathway mapping with or without catheter within the CS are, respectively, shown in the series of Figures 4.6–4.10.

When delivery of RF energy within the posteroseptal area is not effective, it is necessary to map the posteromidseptal and midseptal areas (Figures 4.11 and 4.12). Starting from posteroseptal area, one makes the catheter slide upward with its whole body, slightly opening its curvature and avoiding pushing the catheter toward the ventricular side. The most stable positions are usually those with the ablation catheter parallel to the His catheter,







Figures 4.6–4.8 Ablation catheter placed in the posteroseptal area where it records a slow pathway. In the three images one can see the three views right anterior oblique (*RAO*), left anterior oblique (*LAO*), and posteroanterior (*PA*), respectively. In the *RAO* view, one can see the ablation catheter in a lower position compared to the His catheter and toward the front of the *CS* ostium (dashed circle). In the *LAO* view, the catheter tip comes into contact with the interatrial septum

but positioned more toward the atrium and more inferior. A good rule is to avoid closing the curvature too much or rotating too strongly because the catheter, this way, becomes unstable. In this case too, the LAO projection can be employed to ascertain good contact to the septum.

By placing the ablation catheter in the LAO view, one may enter the CS ostium, thus recording potentials in this area. Thereafter, the curvature should be opened slightly and, then, the catheter is gently pulled back until it comes out of the ostium and settles just above it. At this point, the catheter is advanced slightly, holding it in contact with the interatrial septum (clockwise torsion) until a slow pathway potential is recorded (Figure 4.13).

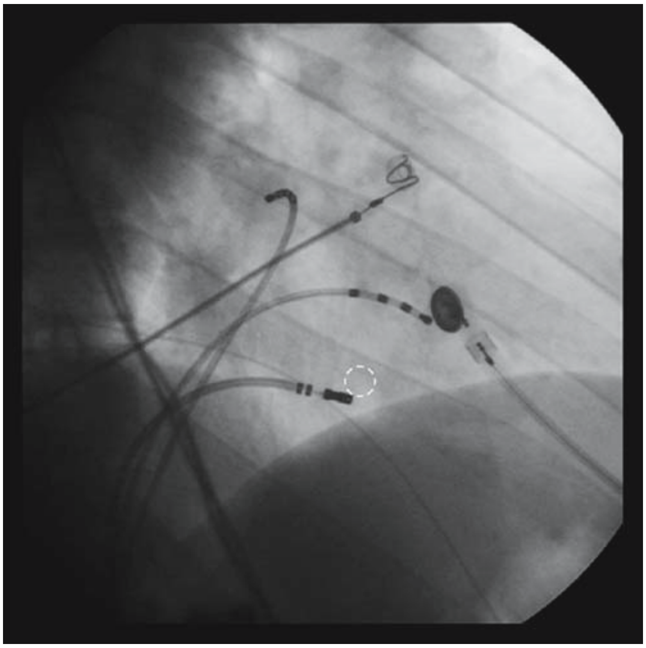


Figure 4.9 The right anterior oblique (*RAO*) view. The ablation catheter is in the posteroseptal area, next to the coronary sinus (*CS*) ostium (dashed circle). The catheter's body is parallel to the His catheter. This view enables visualization of the distance between the His area and the site where radiofrequency (*RF*) energy is to be applied

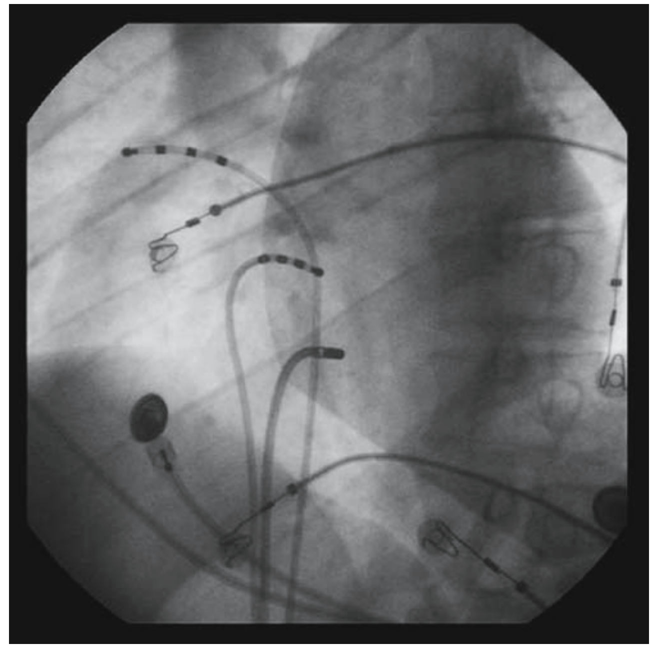


Figure 4.10 The left anterior oblique (*LAO*) view. The ablation catheter's contact with the interatrial septum is clearly demonstrated

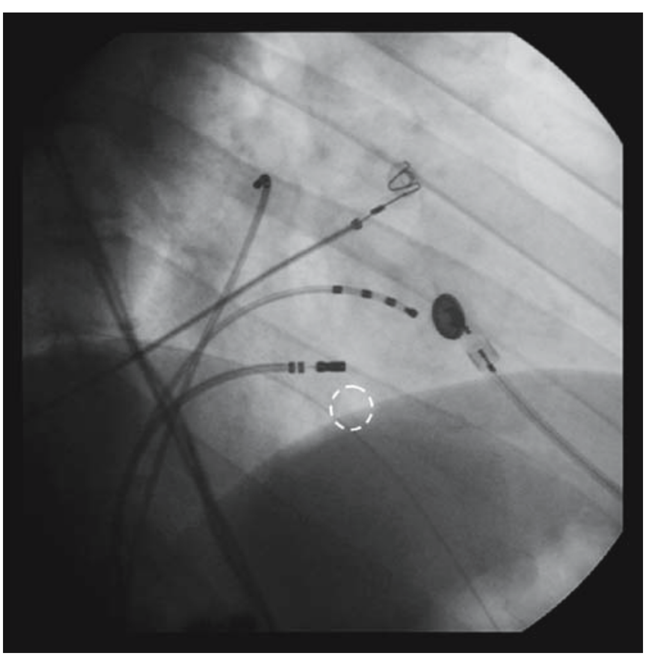


Figure 4.11 The right anterior oblique (*RAO*) view. The ablation catheter is in the midseptal area, above the coronary sinus (*CS*) ostium (dashed circle); the catheter's body is parallel to the His catheter

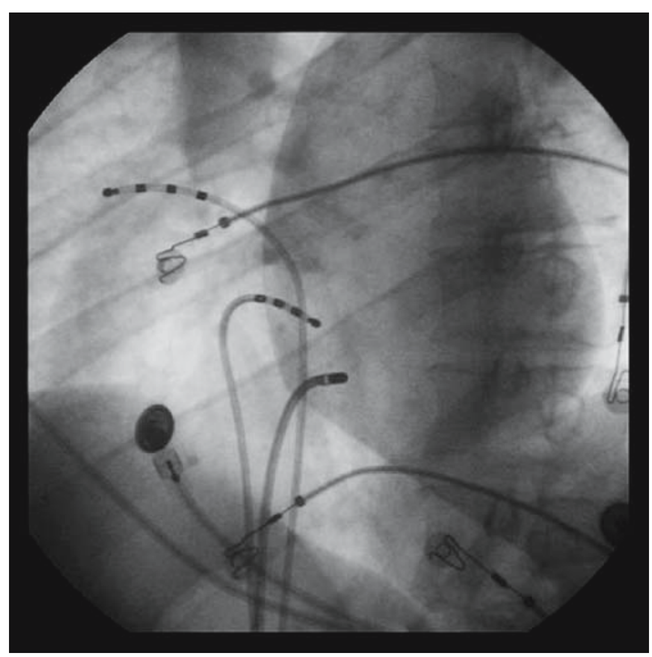


Figure 4.12 The left anterior oblique (*LAO*) view shows the ablation catheter in contact with the interatrial septum

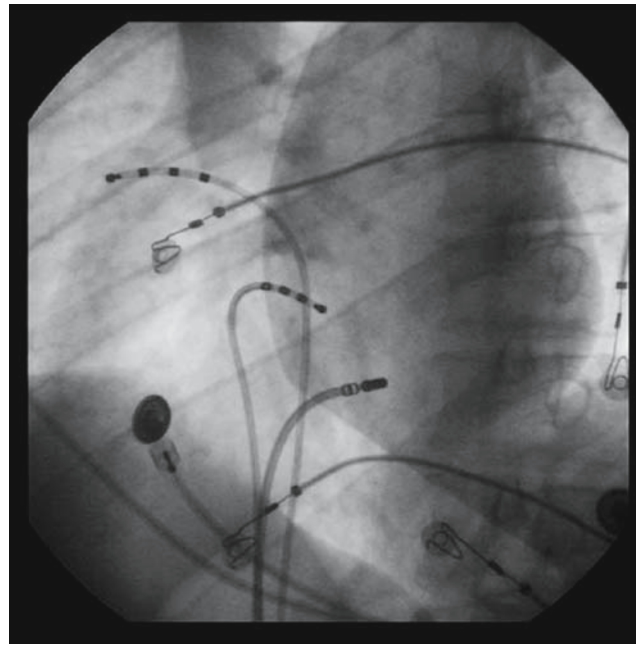


Figure 4.13 In the left anterior oblique (*LAO*) view the ablation catheter tip enters into the coronary sinus (*CS*). The anatomic position has to be confirmed by the intracardiac electrograms and by the impedance parameters

Even when the ablation catheter is placed in the LAO view, the RAO view will enable us to control the position and, during the RF application, will permit a quick verification that the ablation catheter position has not moved toward the anteroseptal region.

4.3 Atrioventricular Node's Modulation and Ablation

Ablation and modification of the atrioventricular node can be carried out in the treatment of atrial fibrillation, atrial flutter, atypical atrial flutter, or atrial tachycardia with high ventricular response in patients who are refractory to pharmacologic therapy.

In AV node modification, the target is the slow pathway and the procedure is carried out in a similar manner to the one used for ablation of AV nodal reentry tachycardia. Usually, slow pathway ablation rather than fast pathway ablation is preferable, because, though having a lower conduction rate, the slow pathway has a shorter refractory period and consequently works less efficaciously as a filter.

The target of AV node ablation is, instead, the nodal structure at the junction of the AV node and the proximal section of the His bundle. This structure is located within the interatrial septum, in the superior third of Koch's triangle, just beneath the endocardium.

As for slow nodal pathway ablation, the ablation catheter used is a middle curvature deflectable catheter, carrying a 4 mm tip; 8 mm tip or the irrigated tip is usually chosen when the 4 mm tip fails or in case of septal hypertrophy.

For this kind of ablation, in addition to the ablation catheter, it is necessary to insert a diagnostic catheter into the right ventricular apex to allow ventricular pacing, once AV block is achieved. Placing a back up pacing catheter within the right ventricular apex is also useful for patients with permanent pacemaker (PM), as, during ablation, RF can inhibit PM activity.

The ablation catheter is placed at the His region in order to record the His bundle potential. In the RAO projection, the ablation catheter is slightly pulled back while rotating clockwise so that the catheter tip is more atrial and a little lower compared to the His (Figures 4.14 and 4.15); the electrograms to record will be an atrioventricular potential with an amplitude ratio >1.

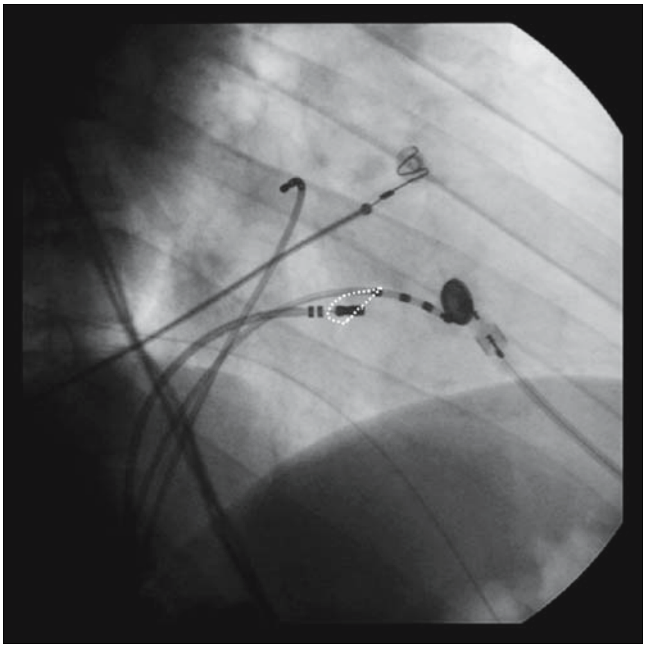


Figure 4.14 The right anterior oblique (*RAO*) view. The ablation catheter is in the anteroseptal region; the catheter body is parallel to the His catheter and only slightly pulled back. The area outlined by the dashed circle shows the zone where most often the atrioventricular node is located

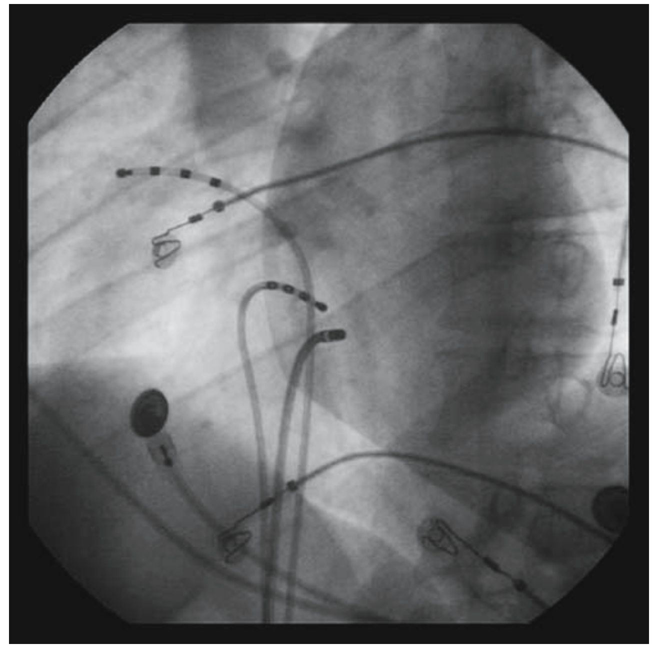


Figure 4.15 The left anterior oblique (*LAO*) view shows the ablation catheter in contact with the interatrial septum

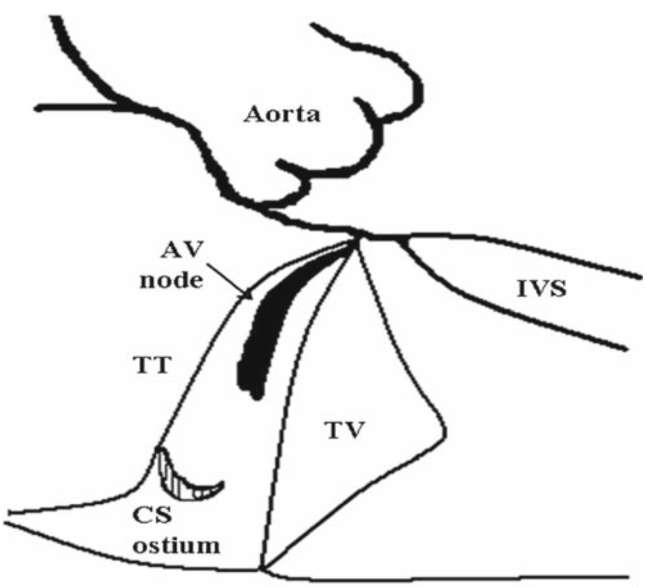


Figure 4.16 The atrioventricular (*AV*) node and the central fibrous body of the heart. The *AV* node is located at the apex of Koch's triangle. This area corresponds to the central fibrous body of the heart, a thickened area of fibrous continuity between the leaflets of the mitral and aortic valves together with the membranous component of the cardiac septum. The central fibrous body is crossed by the penetrating bundle of His. At this site, the penetrating bundle of His branches into the right and left bundle branches. The left bundle branch emergency descends directly from the *AV* node down the subendocardium of the ventricular septum, constituting the marker of the left side of the AV node. *TT* Todaro's tendon, *TV* tricuspid valve, *IVS* interventricular septum

The right side approach is usually successful; in case of this approach being unsuccessful or undesirable, an alternative approach may be the retrograde arterial approach in order to reach the subaortic interventricular septum. In rare circumstances, the AV node ablation may be performed at the region of the noncoronaric aortic cusp where His bundle potentials may be recorded. The retrograde arterial approach in fact enables to reach the left side of the AV node. (Figure 4.16).

4.4 Typical Atrial Flutter

Either in its common variant or in the uncommon one, typical atrial flutter ablation requires a lesion along the isthmus between the inferior vena cava and the tricuspid valve. This arrhythmia is caused by a macroreentry in the right atrium, and a critical isthmus is present as a zone of slow conduction in the right atrial inferior wall defined posteriorly by the Eustachian valve at the inferior vena cava entrance and anteriorly by the tricuspid ring. Anatomically, the inferior vena cava-tricuspid isthmus can be divided into three parts: the tricuspid valve vestibule, the trabeculate part or "sinus," and the Eustachian valve (Figures 4.17–4.19). The vestibular area is made of smooth musculature surrounding the valvular orifice with the musculature inserting into the leaflets; this area is rather consistent among patients. The trabeculate area, conversely, is highly variable among patients and can be made of parallel or crossed muscular bundles giving shape to recesses or veritable aneurysmatic formations. The crista terminalis' (CT) posterolateral branches form muscular bundles in this region. This area is also called sub-Thebesian as it is located below the CS ostium. The third and last part is represented by the Eustachian valve; this one too is variable among individuals. It can be a triangular flap of fibrous electrically silent tissue or it can have muscular extensions which from CT are directed toward the front and upward meeting the posterior section of the CS ostium. The presence of musculature within the Eustachian valve acts in such a way that the septal isthmic lesion, connecting the tricuspid valve with the CS ostium, does not always succeed in blocking the typical flutter circuit.

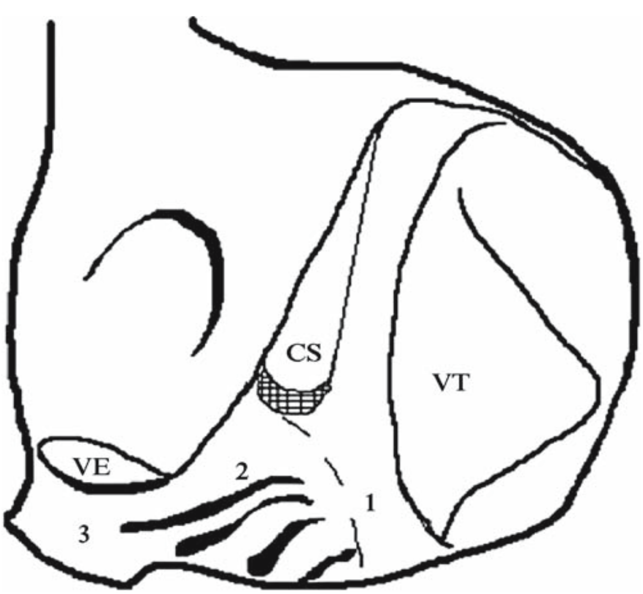


Figure 4.17 Vena cava-tricuspid isthmus is a structure of the right atrial inferior portion. Posteriorly it is defined by the Eustachian valve (*EV*), anteriorly by the tricuspid valve (*VT*), an, superiorly, by the coronary sinus (*CS*) ostium. The isthmus includes a zone of smooth tissue or the tricuspid vestibule (zone 1), a trabeculate central part, variable among individuals (zone 2), and at last the Eustachian valve (zone 3)

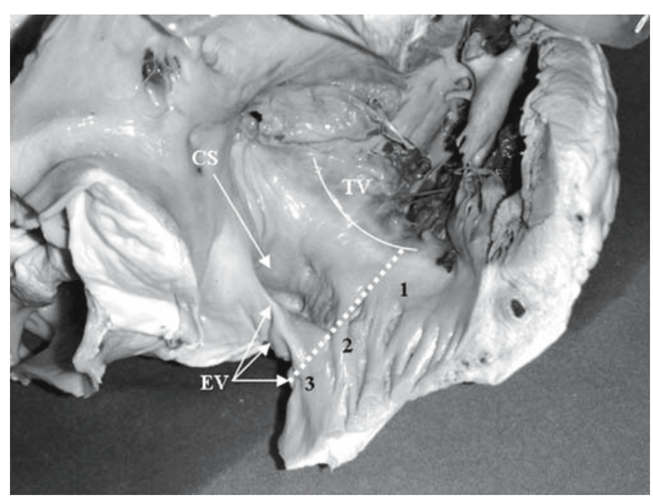


Figure 4.18 Autoptic image of the vena cava-tricuspid isthmus (dashed line). Posteriorly it is defined by the Eustachian valve (*EV*), anteriorly by the tricuspid valve (*TV*), and superiorly, by the coronary sinus (*CS*) ostium. One can clearly see how the isthmus is made of one portion of smooth tissue or tricuspid vestibule (zone 1), a trabeculate central part (zone 2), and, at last, by the Eustachian valve (zone 3). Sometimes the Eustachian valve is particularly large and perforated, forming delicate filigree called the Chiari network that may constitute an obstacle to passage of catheters from the inferior vena cava to the right atrium

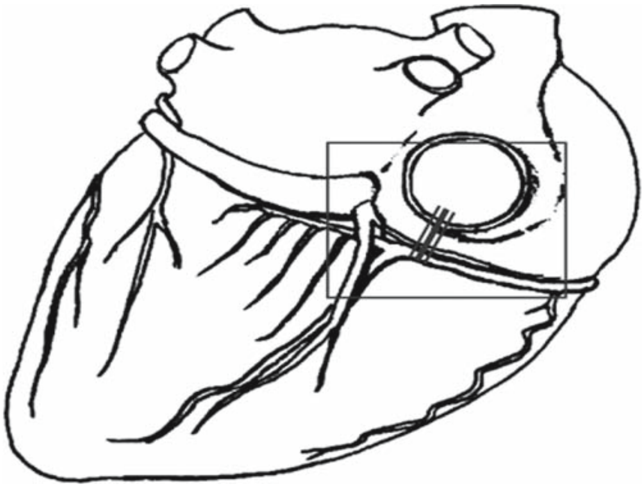


Figure 4.19 The heart viewed posteriorly. The inferior vena cava-tricuspid isthmus coincides with the triple line within the rectangle

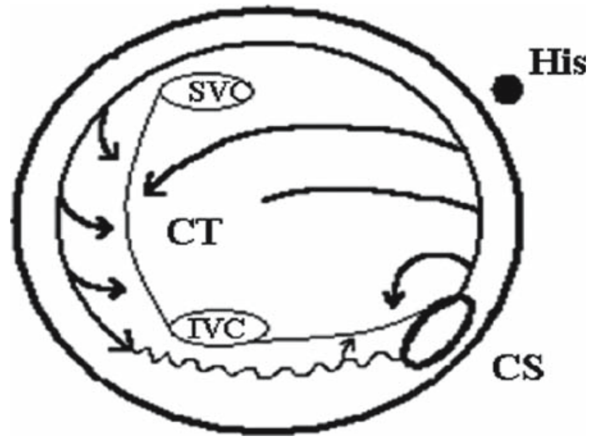


Figure 4.20 Right atrial activation pattern during typical atrial flutter. The crista terminalis (*CT*) gives shape to a line of block connecting the superior vena cava's (*SVC*) ostium with the inferior vena cava (*IVC*). The *CT* is a rather thick muscular structure connecting the superior vena cava with the inferior vena cava, dividing the right atrial posterior wall, made of smooth muscle, from the anterolateral wall, which, conversely, is made of trabeculate musculature. If the 20-polar catheter were positioned posteriorly to the *CT*, the recorded atrial potentials would not be part of the reentry circuit and so they would give wrong information about the arrhythmia circuit

Actually resistant ablation cases have been described and, usually, they are related to the inferior vena cava-tricuspid isthmus anatomy. Anatomic variations which may make successful ablation difficult include pouches, trabeculations, muscular thickness, deep recesses, and also the protective cooling effect of luminal blood flow in minor coronary vein or right coronary artery lying in the AV groove.

For the ablation of the typical flutter, it is necessary to use one diagnostic catheter within the CS and one 20-polar deflectable catheter in order to record the right atrial lateral wall activation.

20-polar catheter has to be positioned initially in the right atrium in the posteroanterior (PA) view; then it can be easily adjusted in the LAO view. The catheter tip must be bent toward the low lateral wall; thereafter one has to advance the catheter body holding its tip bent, so that the intermediate electrodes slide along the atrial wall and press firmly to the atrial roof. At this point, open the catheter curvature in such a way that its distal segment comes into contact with the lateral wall. The catheter must then be checked in the RAO view to ensure that its tip is turned anteriorly, in front of the CT. The atrial flutter activation front spreads anterior to the CT; therefore, if the 20-polar catheter tip were posterior to the crista, it might give wrong information about the arrhythmia circuit (Figure 4.20).

The sequence of images from Figures 4.21–4.28 shows how to position the 20-polar catheter.

Once the 20-polar catheter's position has been checked, the ablation catheter is inserted. For typical atrial flutter ablation, we usually choose an ample curve catheter, carrying an 8 mm tip or cooled tip. The ablation, as we have already said, consists in making a tricuspid-inferior vena cava isthmic lesion. Linear lesions can be carried out by successive points, that is to say, by successive 60-s applications of RF; at the end of each one moves the catheter slightly. This may also be carried out by dragging the catheter; in this case a long application is employed and the catheter is dragged under fluoroscopic guidance. Ablation by successive points might leave gaps along the line which one is making; on the contrary, ablation by dragging requires good catheter stability.

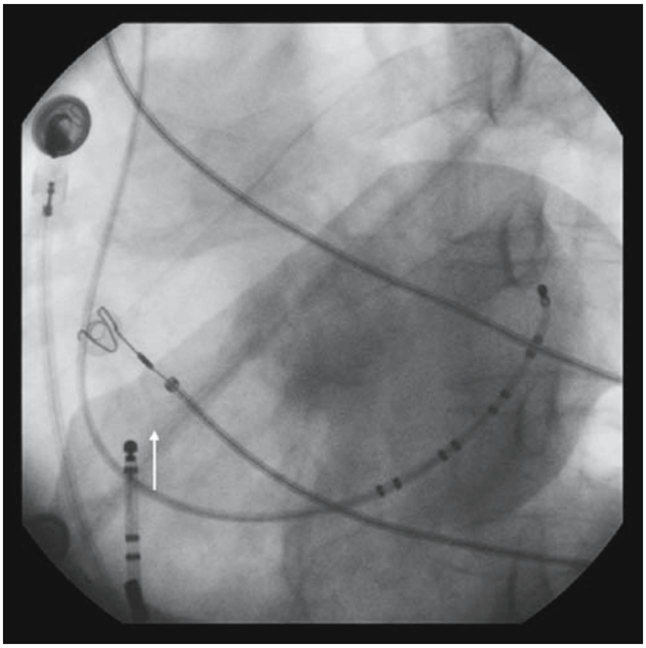


Figure 4.21 The 20-polar catheter enters the right atrium. Please notice the decapolar catheter within the coronary sinus (*CS*) inserted via the right internal jugular vein

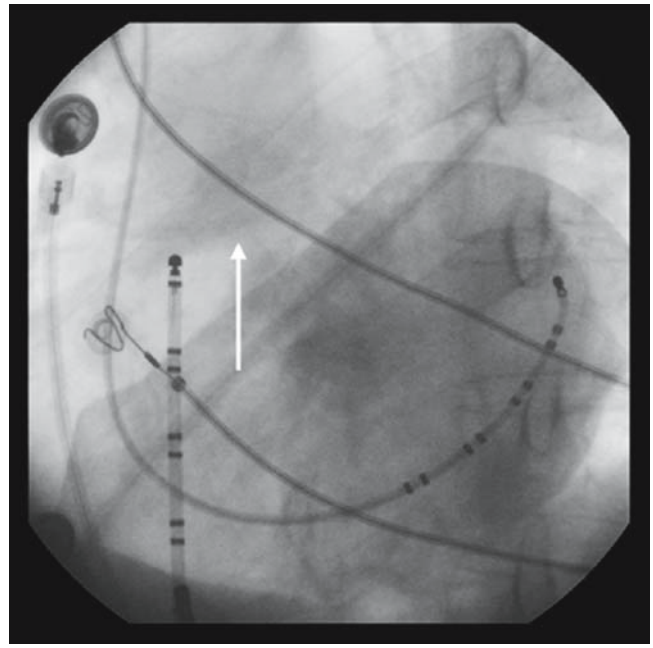


Figure 4.22 The catheter is further advanced up to the atrial cavity's superior third section

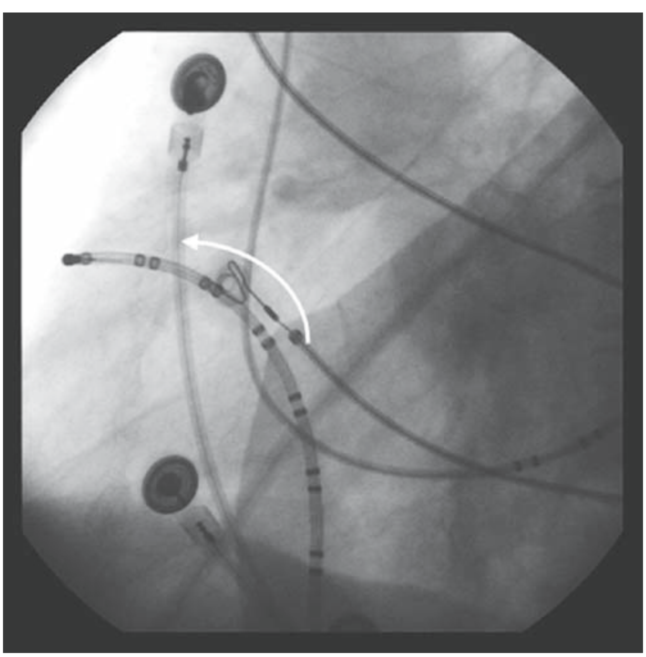


Figure 4.23 One begins to bend the catheter, turning its tip toward the free wall

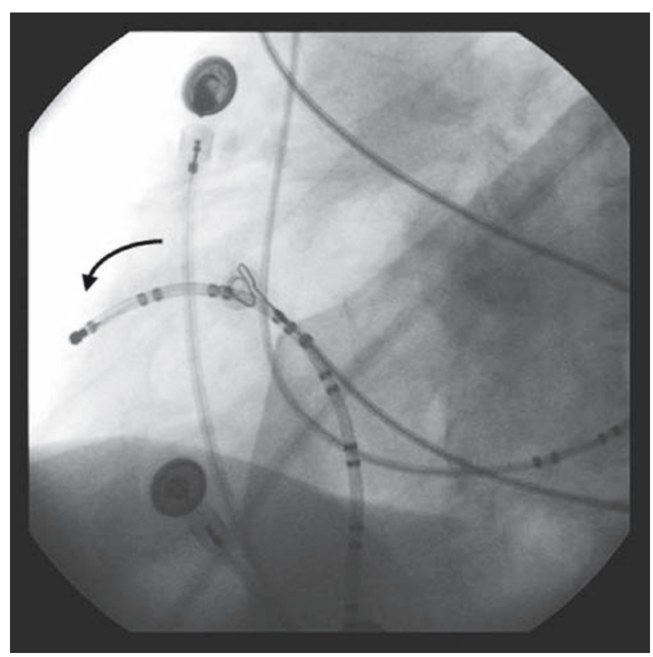


Figure 4.24 The catheter is further bent down to the lateral wall's third inferior section

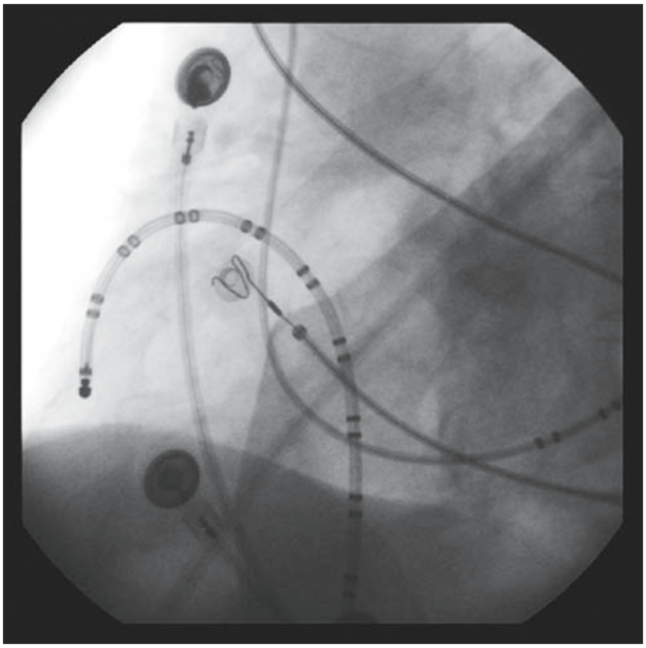


Figure 4.25 In order to make the catheter slide along the atrial wall, it is necessary to push it forward holding its maximum curvature. If the catheter tip gets stuck, most likely it is entrapped into the right atrial appendage. In this case it is necessary to straighten the catheter and pull it back, then repeat the whole positioning sequence

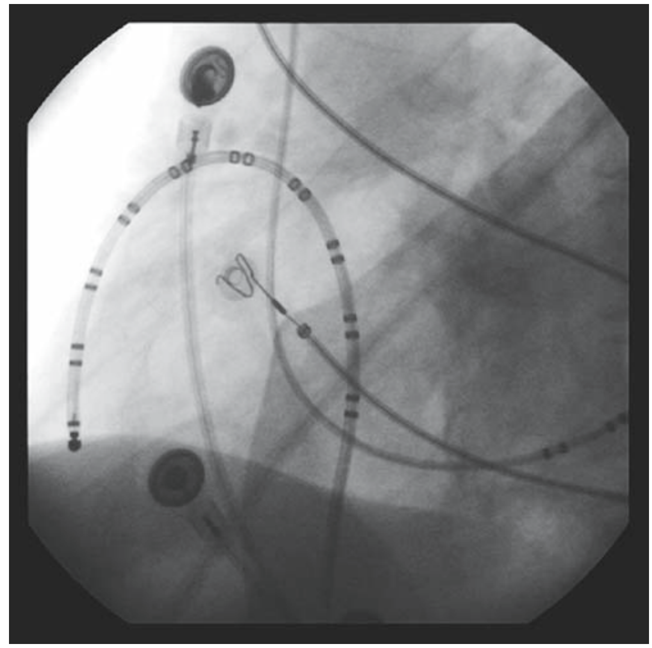


Figure 4.26 The catheter is further advanced, in such a way that its distal segment lies along the lateral wall and the intermediate electrodes come into contact with the right atrial roof

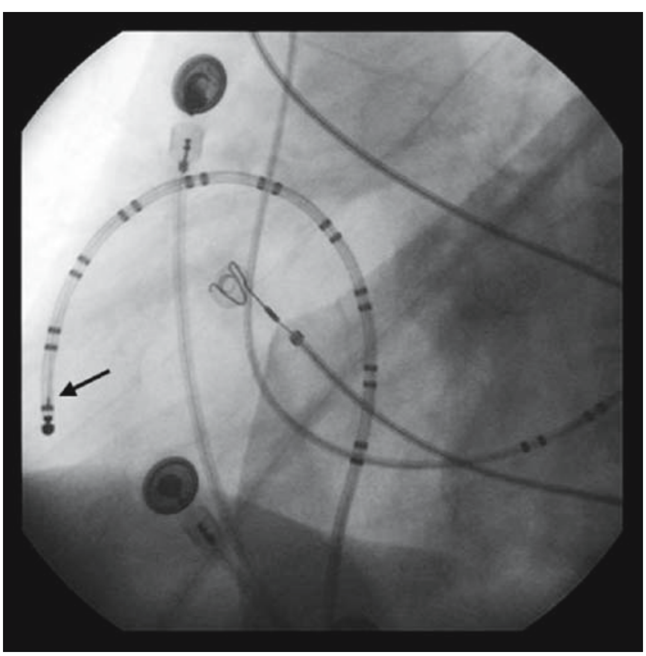


Figure 4.27 The curve is thoroughly opened (arrow) in order to make the catheter's distal segment adhere to the lateral wall

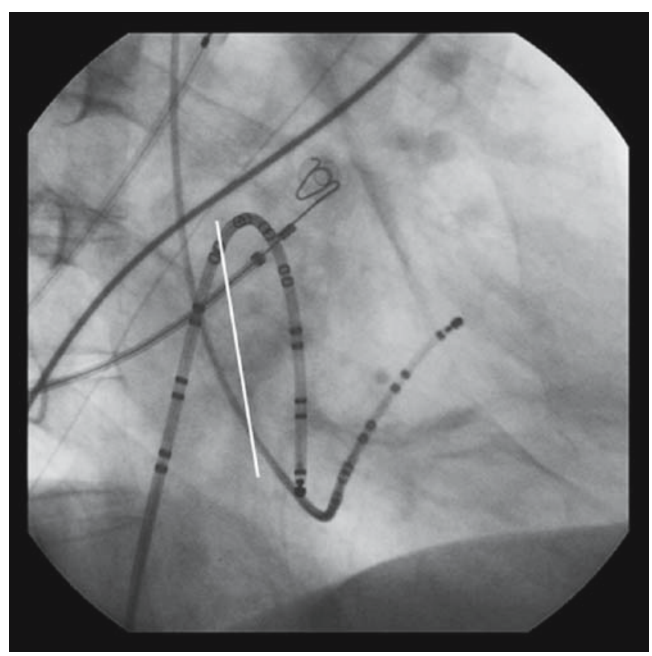


Figure 4.28 In order to be sure that the catheter lies anterior to the crista terminalis (*CT*) (line), one must check, in the right anterior oblique (*RAO*) view, if the catheter's distal segment is turned toward anteriorly, toward tricuspid ring

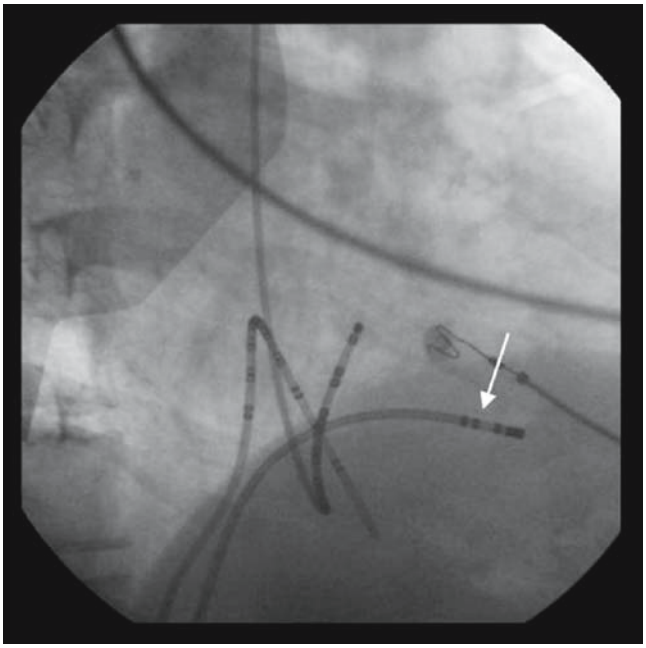


Figure 4.29 In the right anterior oblique (*RAO*) view, the ablation catheter is placed within the right ventricle passing into the intermediate portion of the tricuspid valve

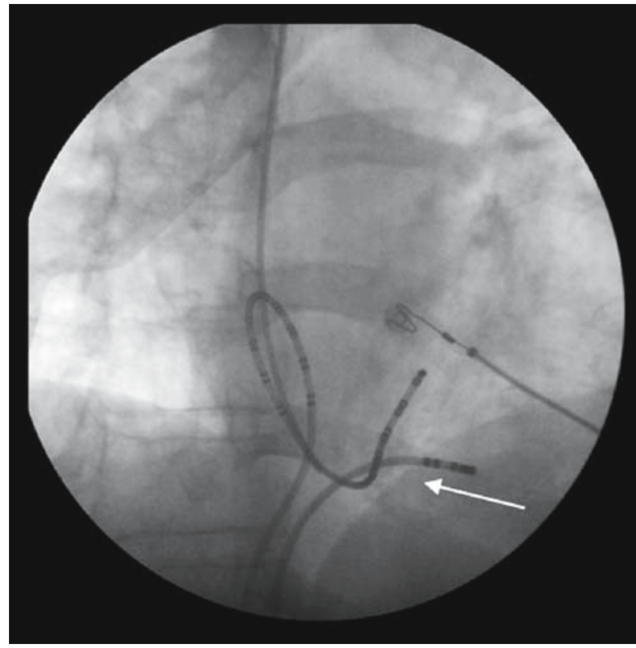


Figure 4.30 In the right anterior oblique (*RAO*) view, the whole catheter body is drawn down so that it rests on the isthmus; at the same time it is stabilized on the ventricular side by bending its tip

At the beginning, the ablation catheter is positioned within the right ventricle in the RAO view. Then it is slightly bent and pulled back in such a way that its body sticks to the inferior portion of the tricuspid ring, on the inferior vena cava-tricuspid isthmus, and its tip on the ventricular side. The sequence of images from Figures 4.29–4.35 shows how to position the ablation catheter.

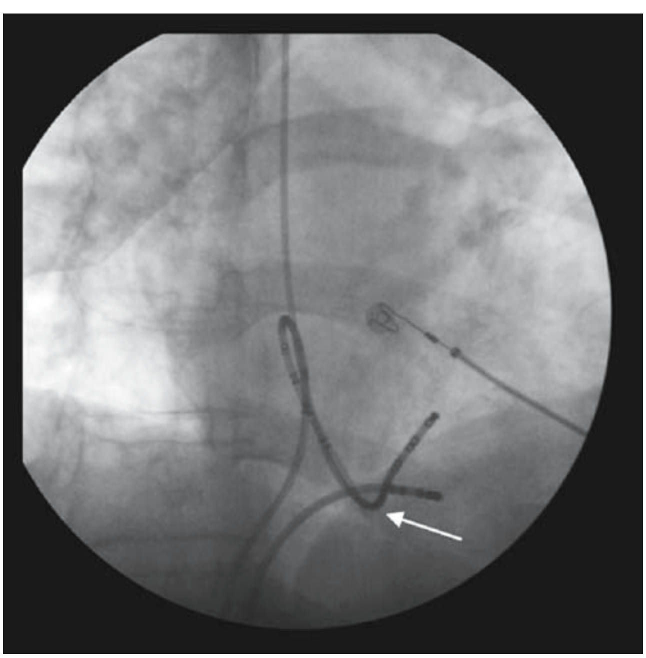


Figure 4.31 Still in the right anterior oblique (*RAO*) view, one pulls progressively back the catheter body holding it in contact with the muscular isthmus

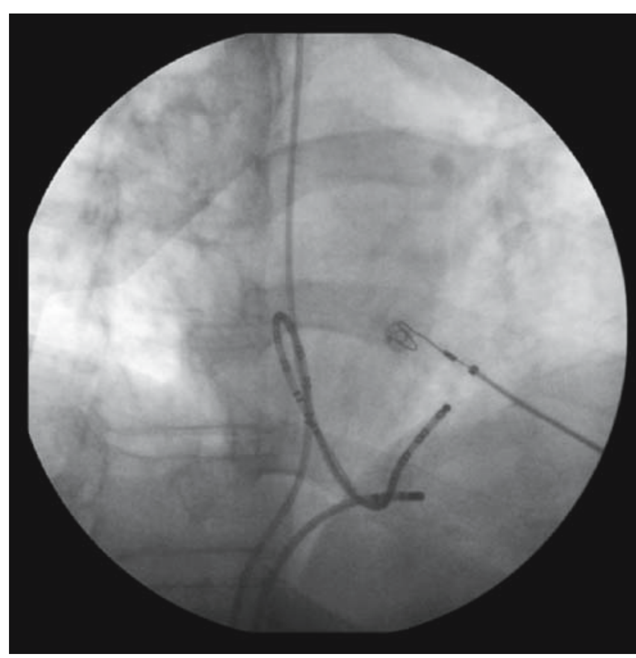


Figure 4.32 One begins to slightly open the curve in the middle portion of the isthmus, holding in contact with the muscular tissue the whole distal electrode, and not only its tip

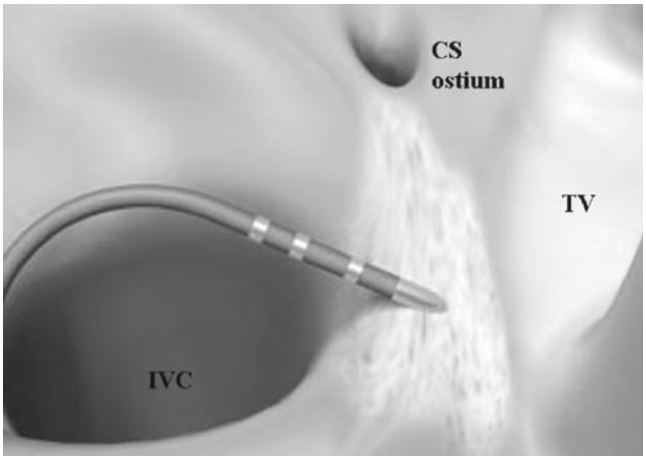


Figure 4.33 The ablation catheter with only the tip in contact with the isthmus wall. Usually, it is better to relax the catheter curve so that the distal electrode is in contact for its full length. Holding the catheter with a marked curvature can be useful, instead, when the presence of recesses along the isthmus is suspected. In this case a bent tip makes the catheter fall into recess and hook it, holding its position stable. *TV* tricuspid valve, *IVC* inferior vena cava

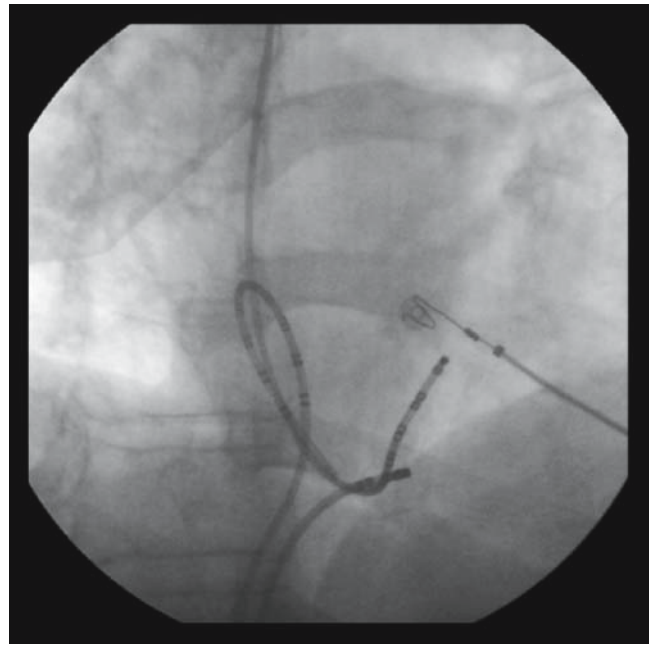


Figure 4.34 The catheter is further withdrawn, moving from the isthmic middle section toward the caval portion

At this point, in the LAO view, the catheter position is checked to see whether it is septal or lateral. Usually the ablation line is carried out within the middle portion of the isthmus, at 6:00 h on a hypothetical dial. Some operators prefer to perform the lesion more septally, where the isthmus is shorter (Figures 4.36–4.38). RF applications are carried out in the LAO view, withdrawing the catheter from the ventricular side as far as the caval side. While

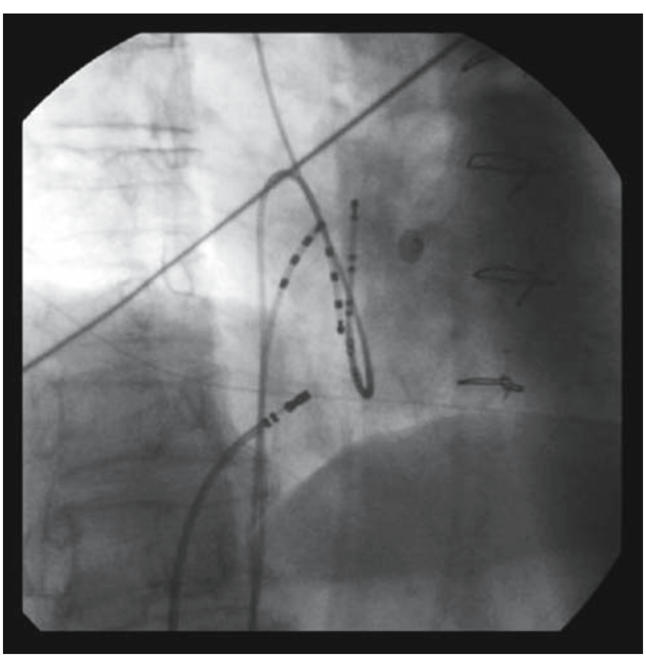


Figure 4.35 The lesion line is completed when the isthmic caval side is reached. In this position one must hold the catheter steady enough to prevent it from sliding into the inferior vena cava

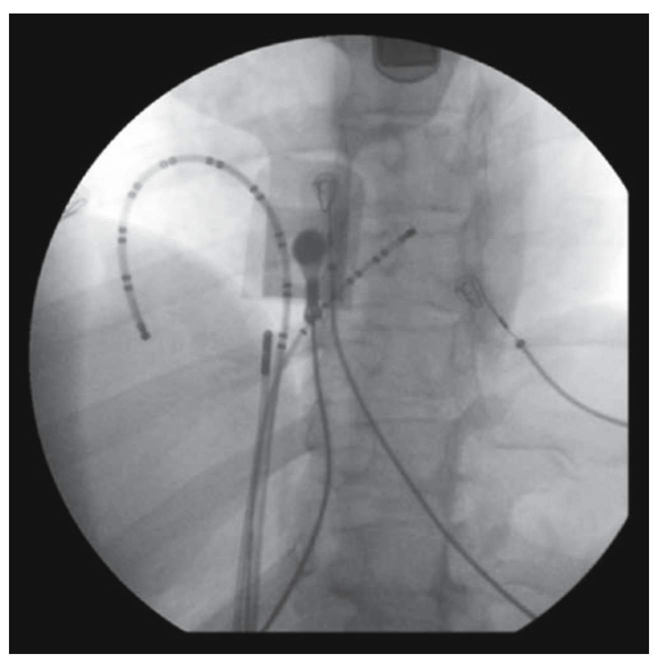


Figure 4.36 In the left anterior oblique (*LAO*) view, one ascertains that the ablation catheter is at 6:00 hrs on a hypothetical dial. It is possible to notice that, in this case, the decapolar catheter settled within the coronary sinus (*CS*) has been inserted via a femoral approach

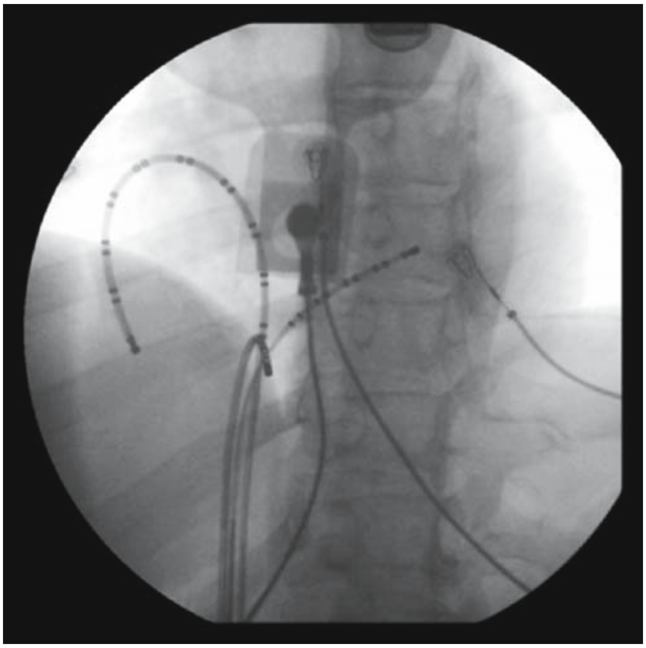


Figure 4.37 Compared to the previous image, the ablation catheter is slightly more septal

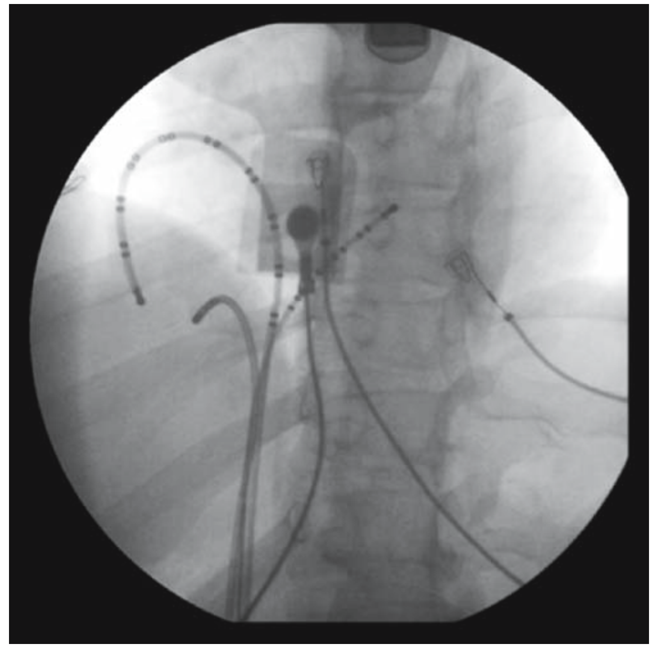


Figure 4.38 In this case, the left anterior oblique (*LAO*) view enables us to see that the position of the ablation catheter is too lateral. The decapolar catheter within the coronary sinus (*CS*) has been inserted via a femoral approach

the catheter is withdrawn from the tricuspid toward the vena cava it is necessary to relax its curvature so that the distal electrode is always in contact with the muscular isthmus for its entire length (not with its tip only) (Figures 4.39–4.41).

In cases of severely dilated atria, where the catheter's curve does not succeed in reaching the ventricular side, it is possible to employ long, purposely preshaped sheaths which steady the catheter, allowing it to reach the ventricular side (Figures 4.42–4.49).

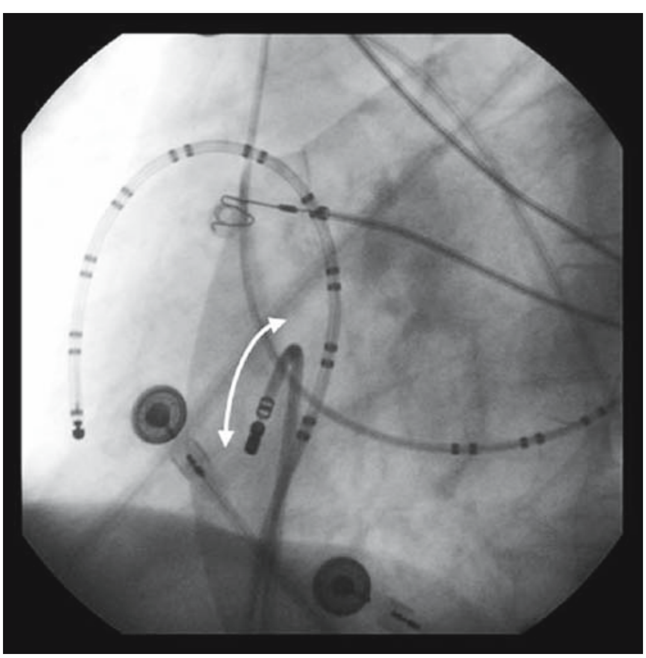


Figure 4.39 The left anterior oblique (*LAO*) view. The ablation catheter lies on the isthmus, with its tip on the ventricular side. The white arrow shows retraction movement that the catheter has to make in order to carry out isthmic lesion. The LAO view allows one to check the line continuity when holding the catheter at 6:00 hrs on a hypothetical dial on the tricuspid ring

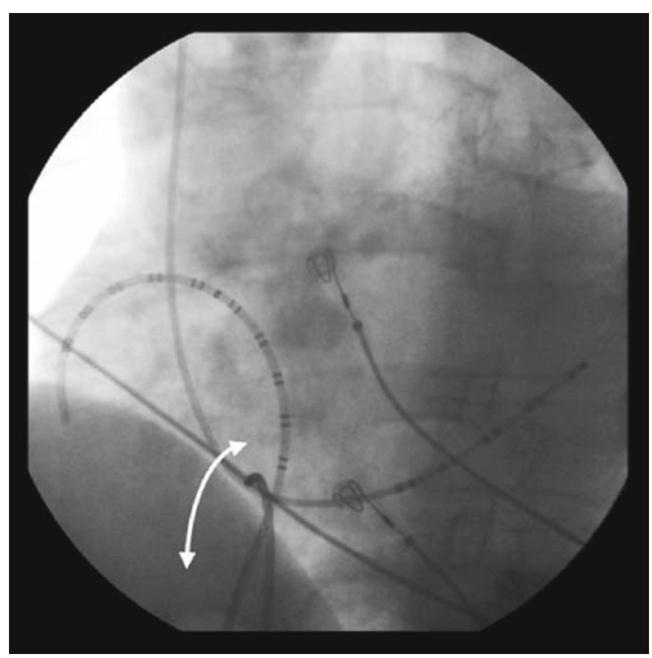


Figure 4.40 The left anterior oblique (*LAO*) view. The ablation catheter is on the middle portion of the isthmus

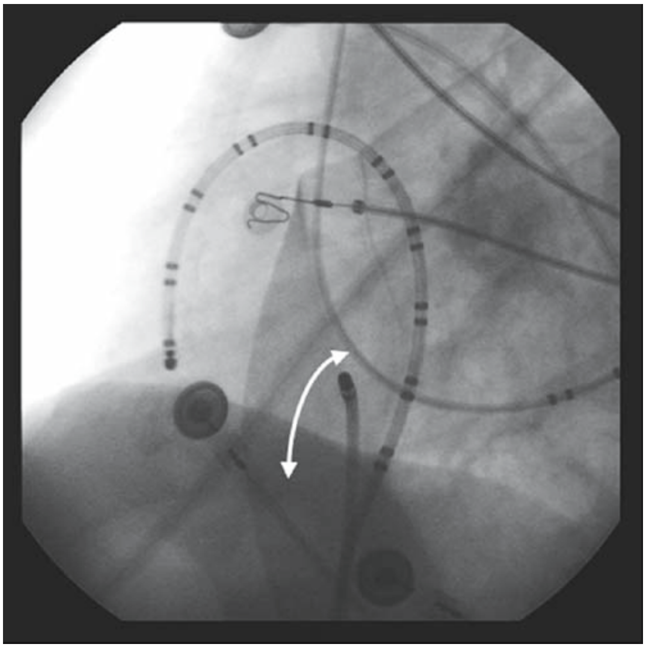


Figure 4.41 The left anterior oblique (*LAO*) view. The ablation catheter has been withdrawn as far as the caval side holding its position at 6:00 hrs

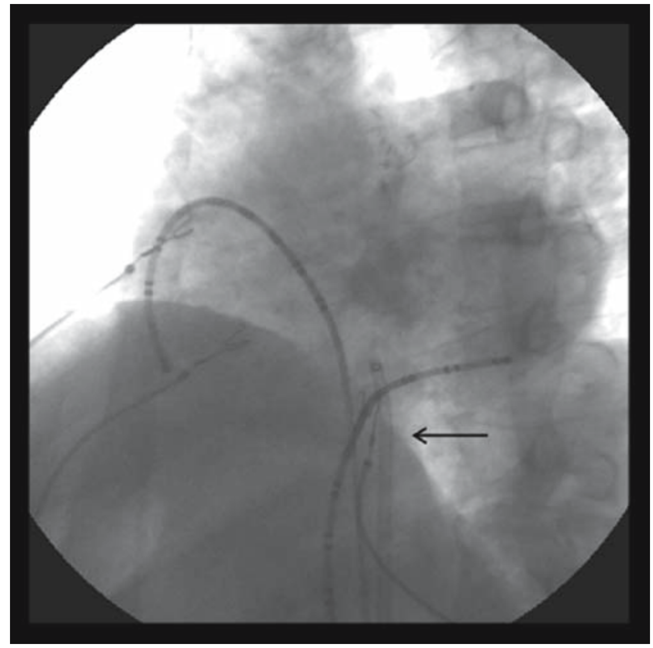


Figure 4.42 In this case one can see how a long sheath (arrow) has been inserted into the right atrium. In the left anterior oblique (*LAO*) view, one can also see the 20-polar catheter within the right atrium and the decapolar catheter within the CS, inserted via a femoral approach

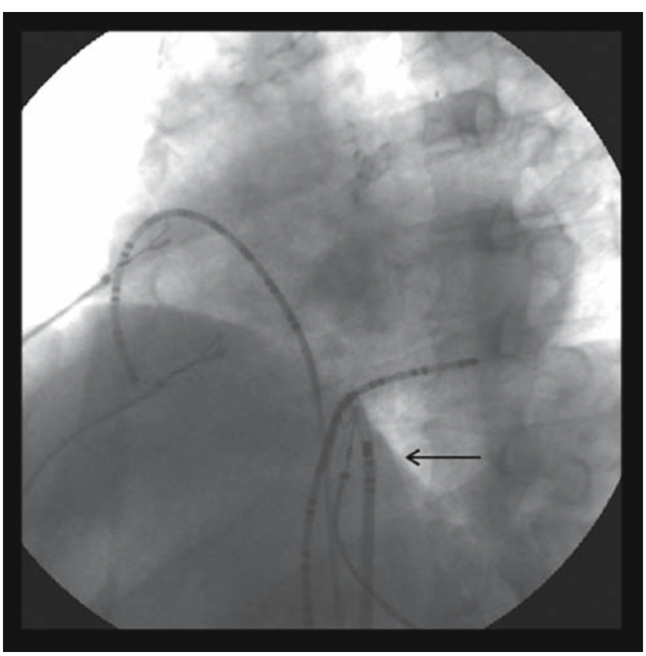


Figure 4.43 The ablation catheter (arrow) is advanced through the long sheath

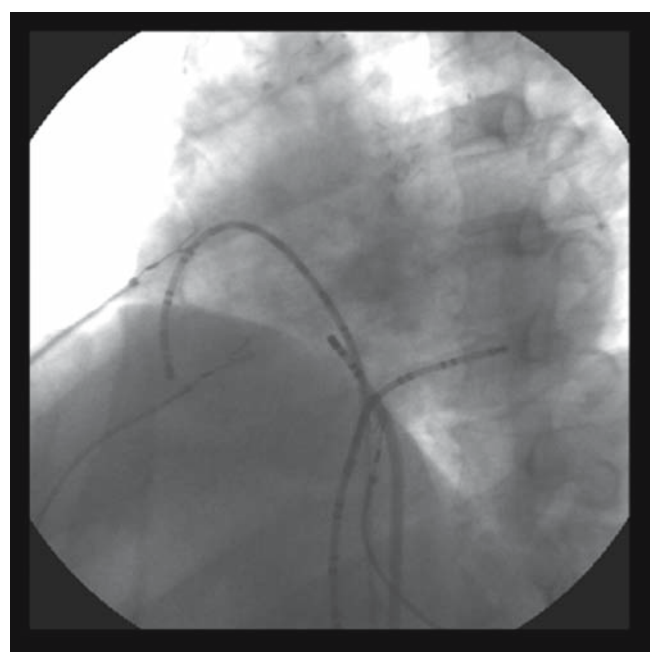


Figure 4.44 The ablation catheter is advanced into the right atrium

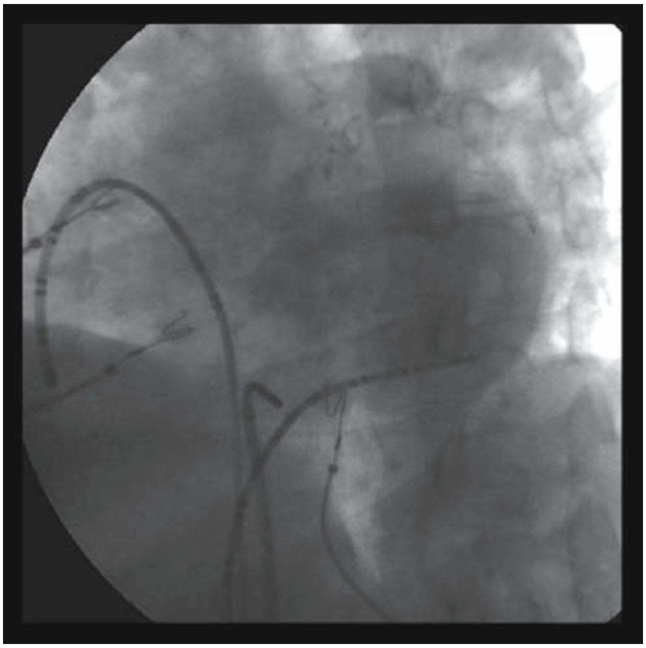


Figure 4.45 In the right anterior oblique (*RAO*) view, the ablation catheter is placed on the ventricular side of the isthmus. The long sheath enables greater stability of the catheter and allows to reach the ventricular side in an easier way

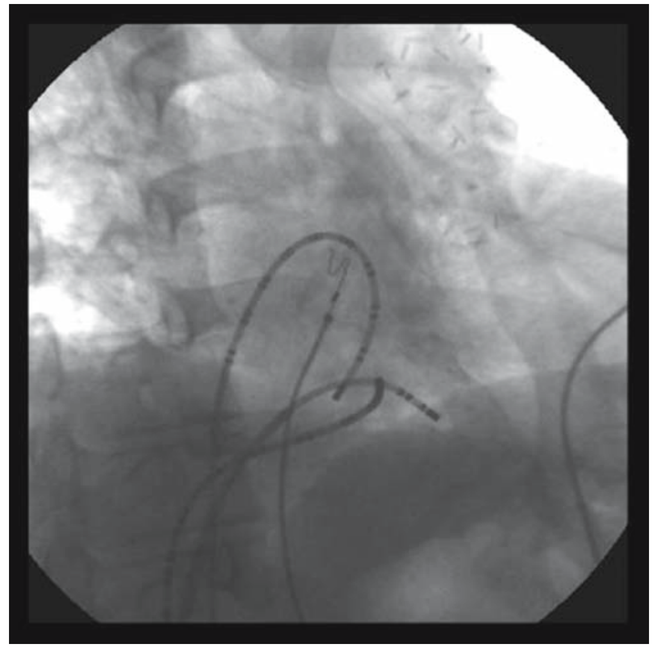


Figure 4.46 Before beginning radiofrequency (*RF*) applications, the catheter position is always checked in the left anterior oblique (*LAO*) view

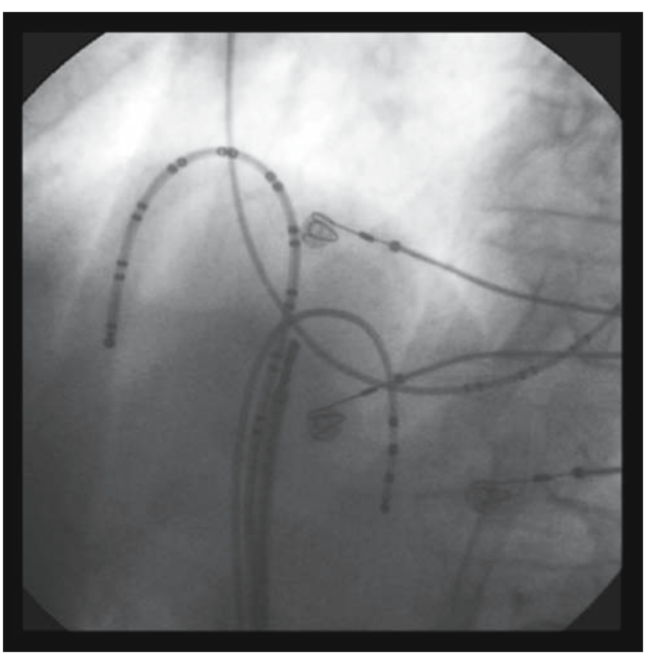


Figure 4.47 The long sheath allows reach to the ventricular side, as well as catheter stability on the caval side, as in this case, in the left anterior oblique (*LAO*) view. Very often, on the caval side, the Eustachian valve forms a sort of step that, during respiration, makes the catheter tip spring into the vena cava

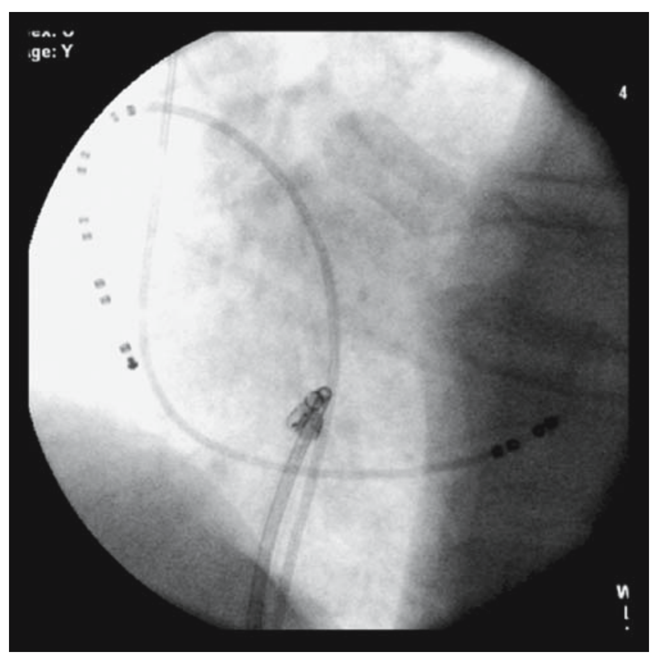


Figure 4.48 In this patient, the inferior vena cava-tricuspid isthmus' ablation is carried out by employing cryoablation. In the image, in the right anterior oblique (*RAO*) view, we see the ablation catheter, carrying a 10 mm tip, positioned by means of a long sheath, on the ventricular side of the isthmus

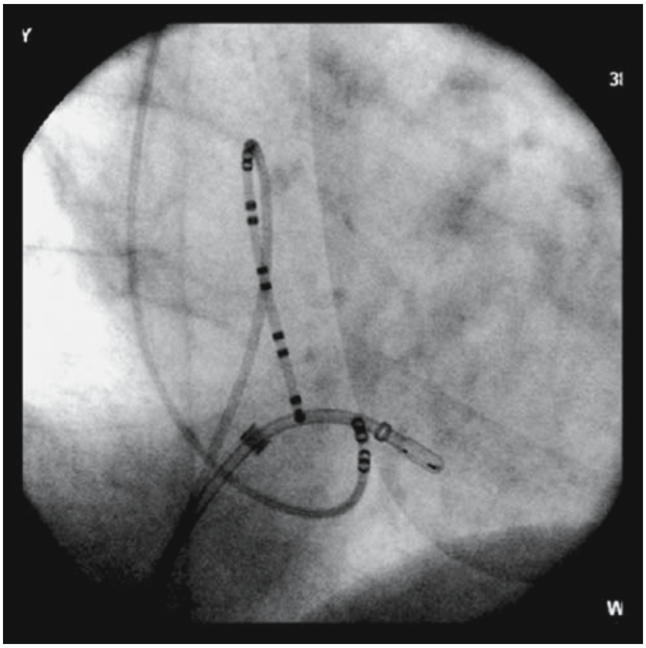


Figure 4.49 The left anterior oblique (*LAO*) view of the same sequence

5

Approach to the Left Heart Chambers

5.1 Transaortic or Retrograde Arterial Approach

In the transaortic or retrograde arterial approach, the catheter is inserted into the femoral artery and then advanced in the posteroanterior (PA) view as far as the descending portion of the arch of the aorta. After femoral artery's puncture and sheath insertion, heparin infusion is initiated in order to minimize the thromboembolic risk associated with left catheterism. It is sometimes necessary to use a braided or a long sheath in patients with femoral artery or iliac artery tortuosity; a long sheath enables passage through these tortuous zones and offers greater catheter stability.

Once the arch of the aorta is reached, within its descending or ascending section, one bends the catheter's tip with maximum curvature so as to give it a J-like loop. The looped catheter is then advanced as far as the bulb of the aorta. Passage into the left ventricle can be performed either in the right anterior oblique (RAO) view, where it is necessary to be sure the catheter's J is directed posteriorly, or in the left anterior oblique (LAO) view, where instead one must keep the catheter's tip central within the bulb of the aorta without engaging the coronary arteries. Major risks connected with this maneuver are, therefore, perforation of an aortic cusp or a coronary artery ostial lesion with possible coronary dissection. Figures 5.1 and 5.2 show a sketch of position of the catheter and its relationship to the coronary ostia in the two views.

Once the catheter has reached the aortic valve's plane, the catheter loop may find the valve closed (diastolic phase) and it may rest on a valve's cusp; in this case, resistance is perceived and catheter loop deformation is visualized by radioscopy. Therefore, it is necessary to retract the catheter back and try to pass again by slightly rotating clockwise or counterclockwise so as to cross the valve between the cusps during valve opening (systolic phase). Once the catheter passes through the aortic valve, the catheter tip opens, relaxing the previously formed curvature, as it is no longer constrained by the ascending aorta's cylindrical structure.

If one cannot bend the catheter within the arch of the aorta, it is possible, in the PA view, to advance the catheter as far as the bulb of the aorta and then try again to bend the catheter's tip. Should this maneuver also be unsuccessful, one can try to directly enter the left ventricle with the catheter's tip, by employing one of the two oblique views and paying close attention to avoiding the coronary ostia. Straight catheter insertion into the left ventricle across the aortic valve should be tried only after repeated unsuccessful attempts of looping the catheter within the descending aorta or the bulb.

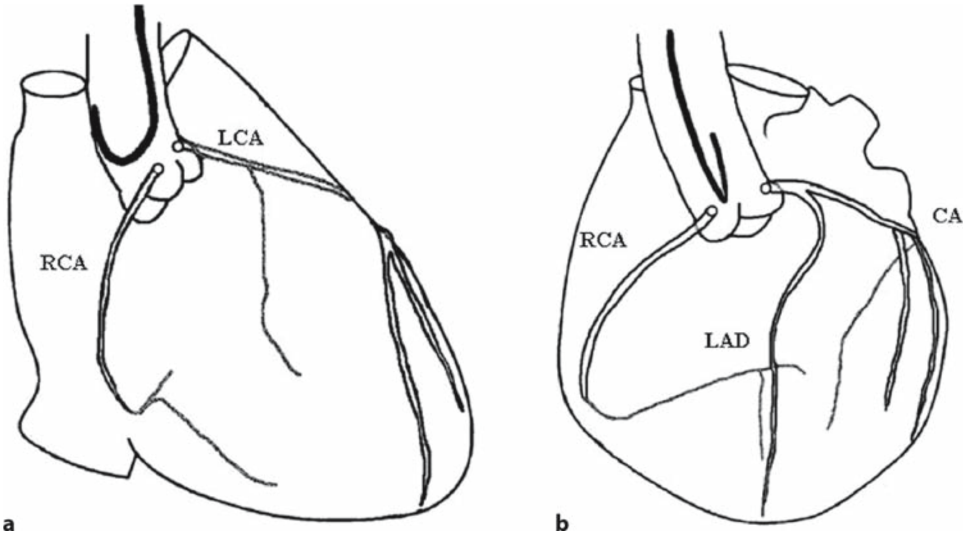


Figure 5.1 Sketch of coronary ostia and main coronary branches: right coronary artery (*RCA*), main left coronary artery (*LCA*), left anterior descending artery (*LAD*), circumflex artery (*LCA*). a The right anterior oblique (*RAO*) view. Coronary ostia are located within the two anterior aortic sinuses; in this view, the ablation catheter must pass with posteriorly opened J and its tip turned toward the noncoronary sinus of Valsalva. b The left anterior oblique (*LAO*) view. In this view, coronary ostia are seen on both sides of the aortic valve; the ablation catheter loop must remain in the same axis as the shaft of the catheter without deflecting laterally

Sometimes special long sheaths, the braided sheaths, can be useful. These sheaths reach the thoracic aorta and stabilize the catheter, giving support and allowing the bending of the catheter, especially in the case of a dilated aortic arch.

In the series of Figures 5.3–5.19, two sequences of retrograde aortic approach are shown.

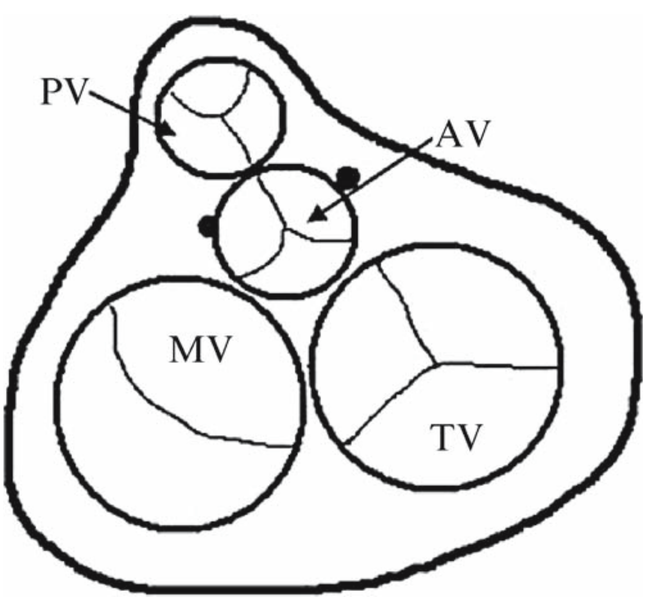


Figure 5.2 Sketch of valve rings seen from above. Anteriorly, the pulmonary valve (*PV*) sits just in front of the aortic valve (*AV*). Note the three sinuses of Valsalva along and the origin of the two coronaries (solid circles); posteriorly, the tricuspid valve (*TV*) on the right and the mitral valve (*MV*) on the left

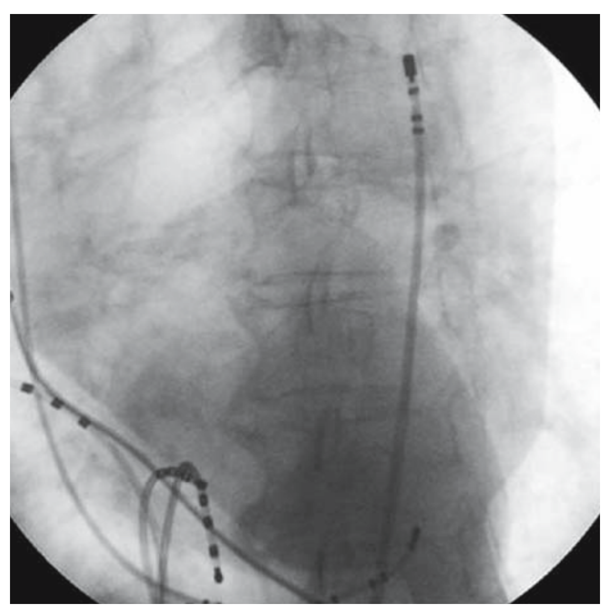


Figure 5.3 The ablation catheter lies within the thoracic aorta with its tip at the level of the arch of the aorta in the descending portion. Three quadripolar diagnostic catheters can also be seen within the right atrium, His and right ventricular apex, respectively; a decapolar catheter is inserted into the coronary sinus (*CS*). The left anterior oblique (*LAO*) view

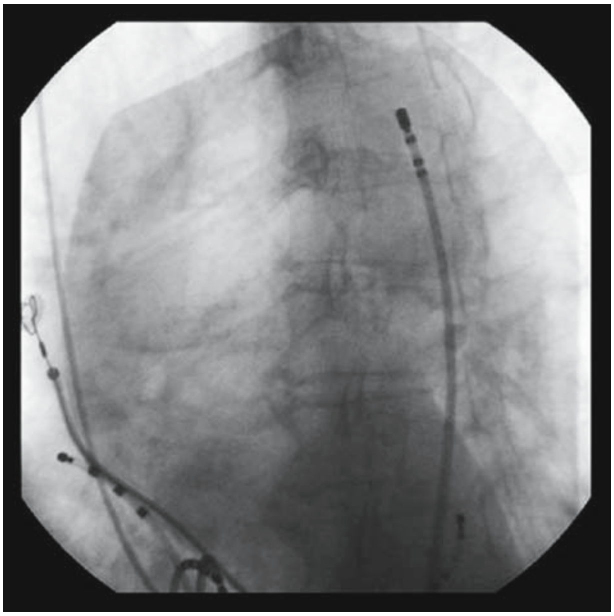


Figure 5.4 Still in the left anterior oblique (*LAO*) view, the ablation catheter is slightly bent by rotating its tip medially

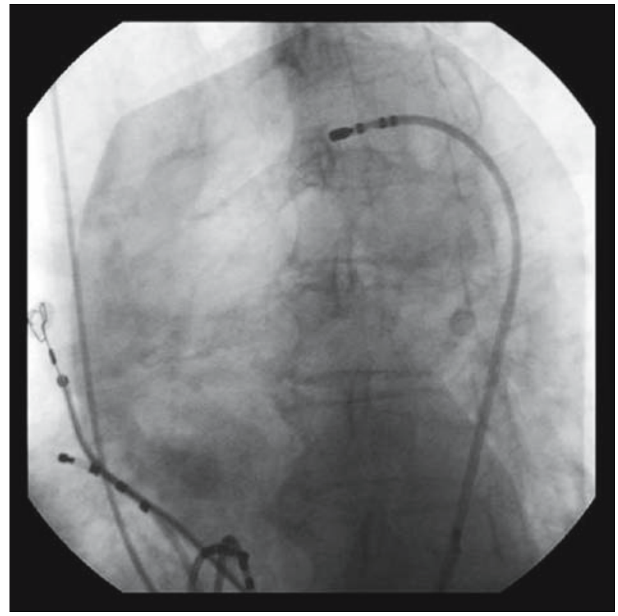


Figure 5.5 The ablation catheter's tip is emphasized

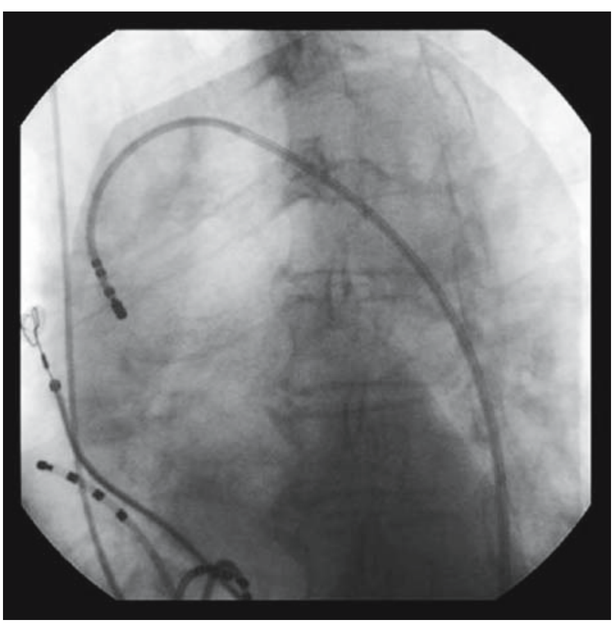


Figure 5.6 The catheter is advanced over the aortic arch into the ascending aorta

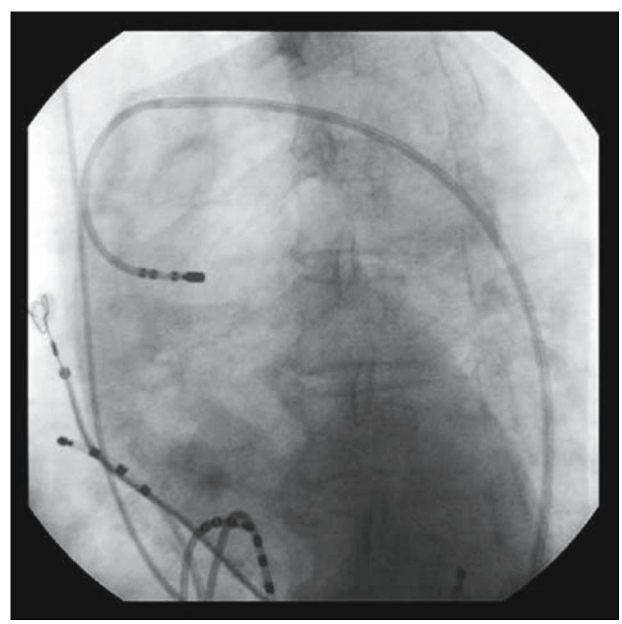


Figure 5.7 The ablation catheter is further curved to form a loop

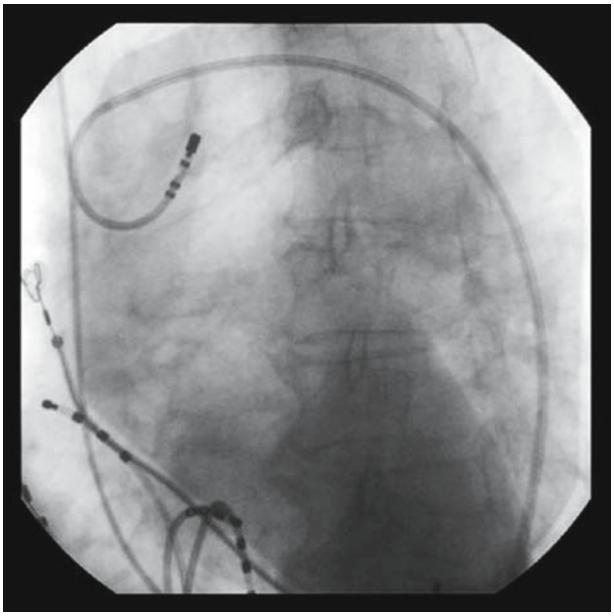


Figure 5.8 The ablation catheter is looped within the aorta's ascending portion

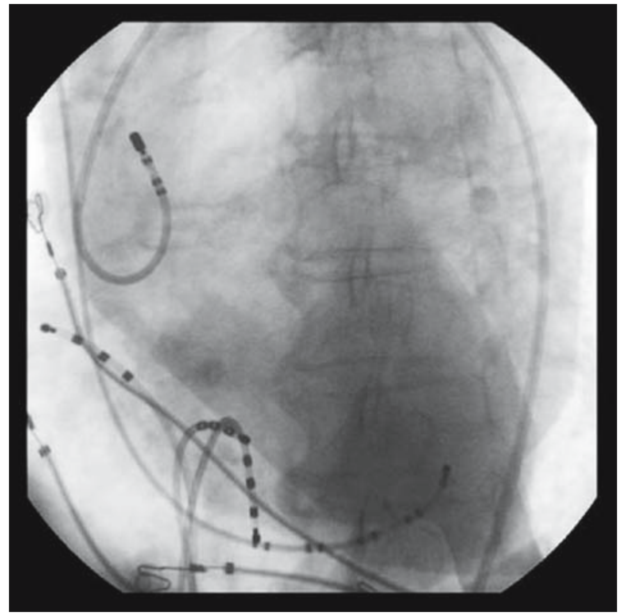


Figure 5.9 The loop is closed and advances toward the valve

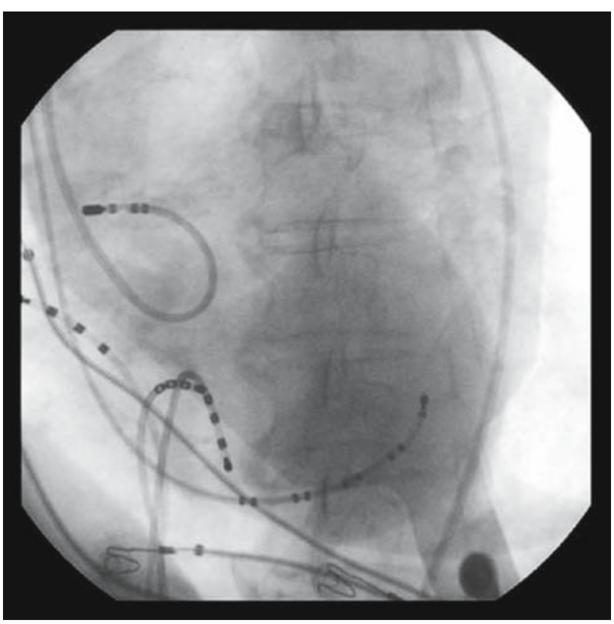


Figure 5.10 The loop is advanced into the bulb of the aorta until resistance is perceived, corresponding to the plane of the aortic valve

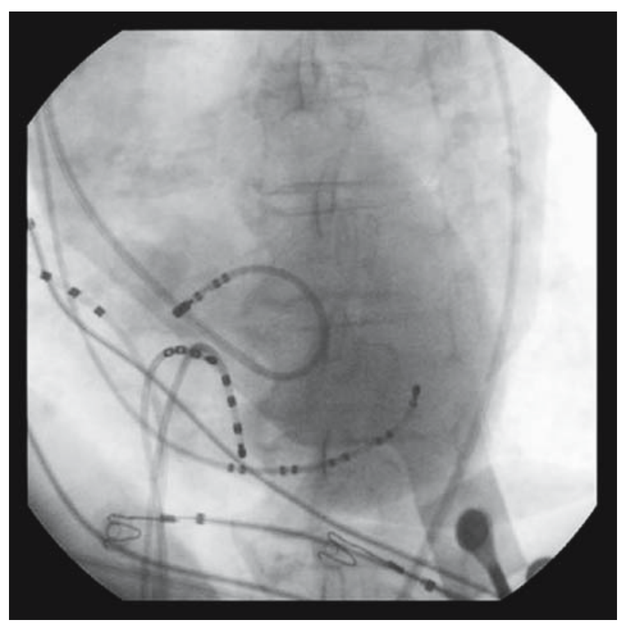


Figure 5.11 Still in the left anterior oblique (*LAO*) view, the loop is advanced through the aortic valve

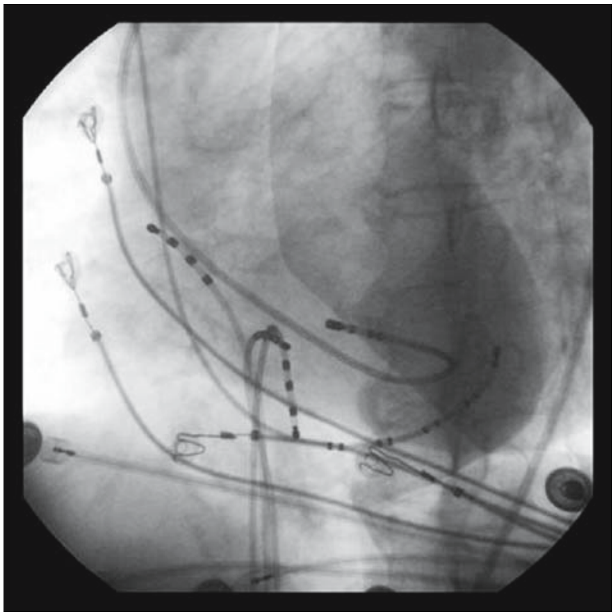


Figure 5.12 The loop has traversed the aortic valve and lies within the left ventricular outflow tract

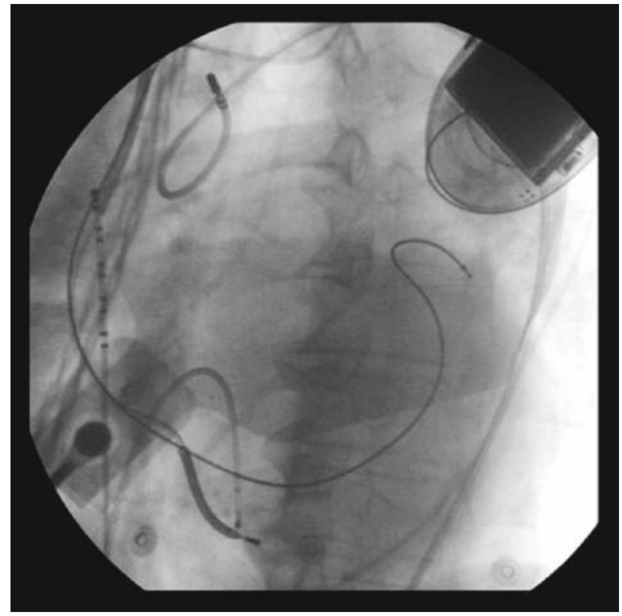


Figure 5.13 Retroaortic passing sequence of the ablation catheter in a patient with a biventricular implantable cardioverter-defibrillator (*ICD*). In the left anterior oblique (*LAO*) view, the ablation catheter, already looped, lies within the ascending aorta

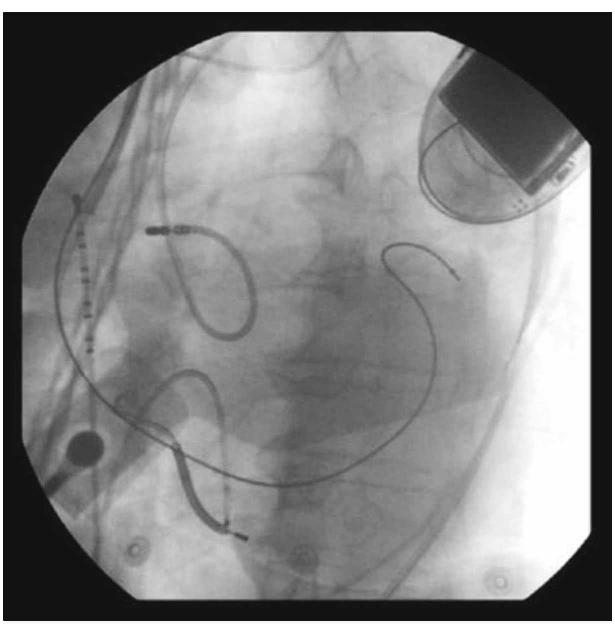


Figure 5.14 The catheter is advanced to the aortic valve plane

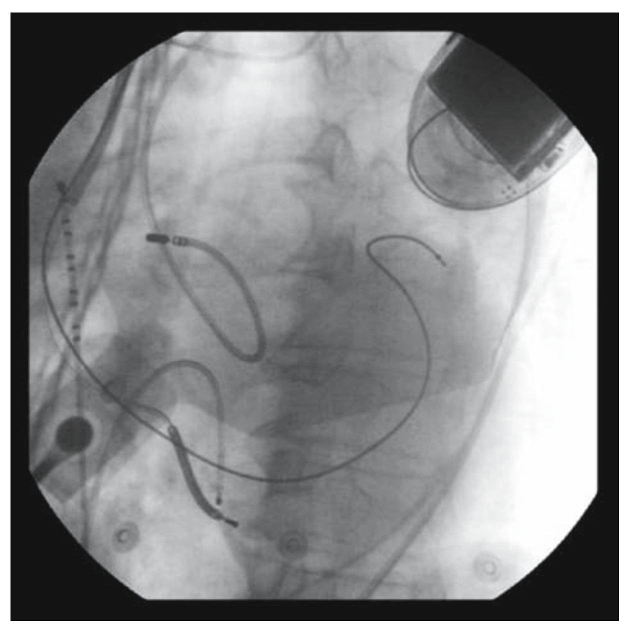


Figure 5.15 Once the catheter has reached the aortic valve plane, slight resistance is perceived, seen, on radioscopy, as catheter loop deformation. As a rule, it is sufficient to apply slight pressure to the catheter to advance it through the valve. If one is unsuccessful in advancing, across the valve, the catheter, the catheter loop is likely resting on a valve cusp. In this case, it is necessary to slightly retract the catheter and try to advance it again by twisting it clockwise or counterclockwise

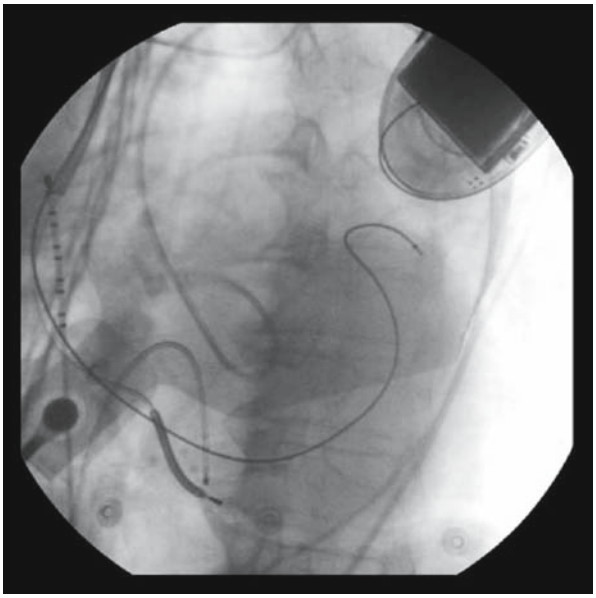


Figure 5.16 In this image the catheter is passing through the aortic valve. Quick movement is required in order to take advantage of the valve's physiological opening during ventricular systole

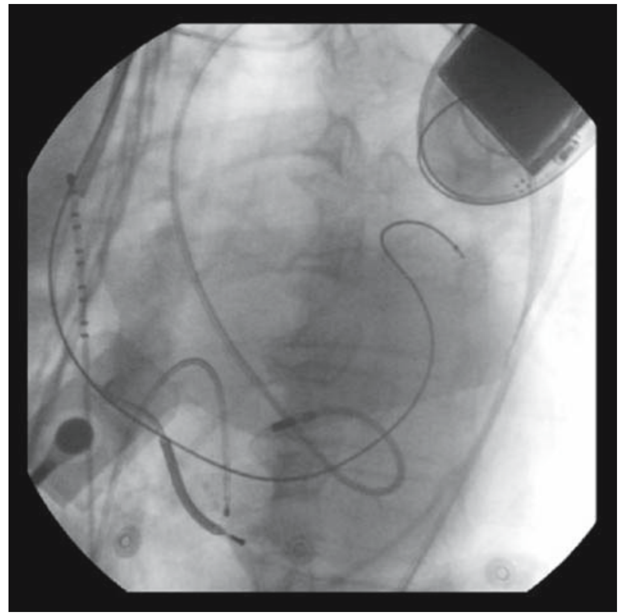


Figure 5.17 The catheter is within the left ventricular chamber

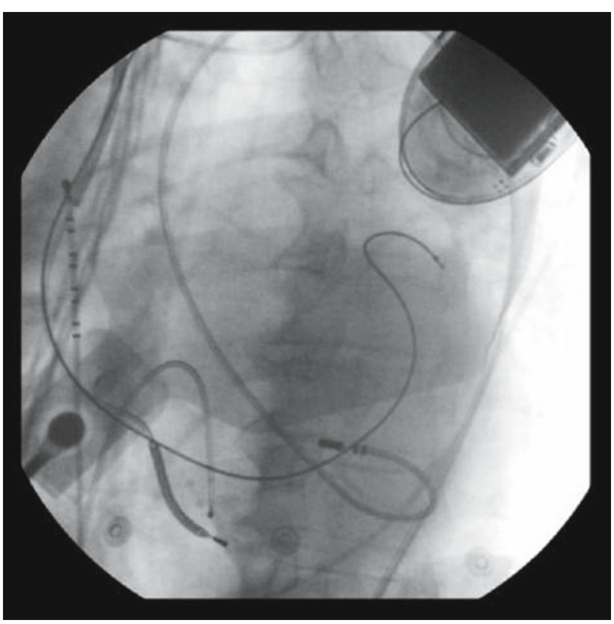


Figure 5.18 Once the catheter enters the chamber, its loop tends to open somewhat

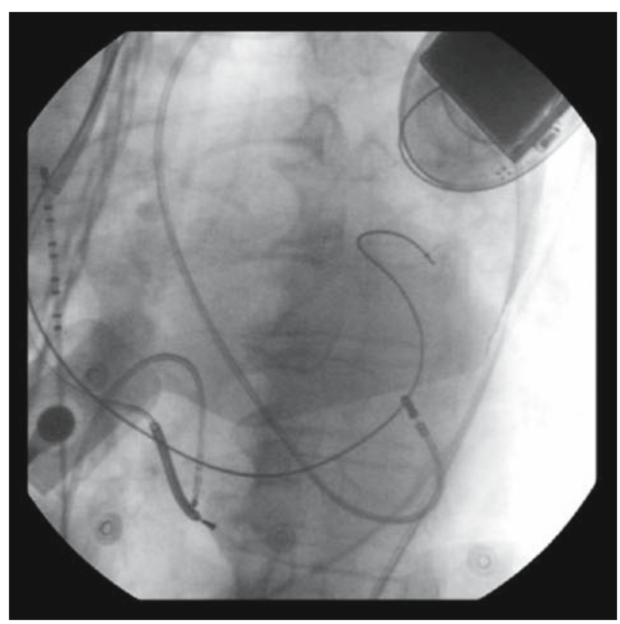


Figure 5.19 The catheter opens further until it comes into contact with the ventricular myocardium

5.2 Transseptal Approach

The transseptal approach enables one to reach the left atrium via a puncture through the interatrial septum. In the center of the interatrial septum, which is a muscular structure, there exists a region of thin fibroelastic membrane, the fossa ovalis. This is derived from the embryonal primary and secondary septum. Anatomically, only the valve of the fossa ovalis with its immediate inferior muscular ring constitutes the true septal wall. The extensive anterior septal wall lies adjacent to the aorta, and the superior rim of the fossa ovalis is the infolded wall between the superior vena cava and the right pulmonary veins (Figures 5.20 and 5.21).

The transseptal puncture is performed at the site of less resistance, the true septal wall or fossa ovalis. The fossa ovalis can be located fluoroscopically. The mitral valve plane and, consequently, the left atrium are identified by the catheter within the coronary sinus (CS). The aortic valve position is visualized thanks to a catheter positioned in the His region corresponding, on the left side of the heart, to the aortic valve position. Alternatively, a "pig-tail" catheter can be positioned in the bulb of the aorta. In summary, this fluoroscopic method of transseptal puncture requires the following: one catheter in the CS through access from above, one pig-tail catheter via the right femoral artery or one diagnostic catheter at the His position via the right femoral vein, and one long sheath via the right femoral vein. Within this last one, the Brockenbrough needle is finally inserted (Figure 5.22).

Initially, the diagnostic catheter is positioned within the CS, and then a long guidewire is inserted as far as the superior vena cava passing through the right atrium; subsequently, the pig-tail catheter is positioned. Positioning the pig-tail catheter takes place in the PA projection. The pig-tail is inserted through a femoral artery, goes up along the aorta, follows the arch of the aorta, and arrives at the ascending aorta. The aortic valve can be found when the catheter meets resistance. If the catheter is pushed further, one can see a kink on the valve plane. The pig-tail catheter is used only for anatomic target; therefore, after performing the transseptal puncture, it is a good rule to remove it, in order to reduce the thromboembolic risk.

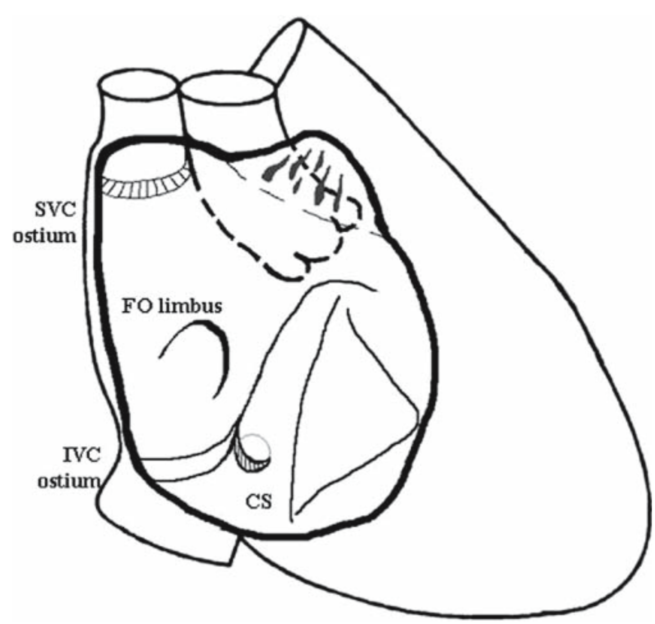


Figure 5.20 The heart as seen in the posteroanterior (*PA*) view with the right atrial lateral wall opened in order to visualize the interatrial septum. Above, the interatrial septum is defined by the superior vena cava transitioning to atrial musculature. This transition can be perceived as a step as the long sheath is withdrawn from the superior vena cava into the atrium. In the septum's central part is the fossa ovalis, which is defined on the superior and anterior sides by a muscular crest called limbus fossa ovalis. Here also, a step is perceived as the long sheath is withdrawn from the muscular septum to the fossa. Finally, the bulb of the aorta is drawn with dashed lines. *SVC* superior vena cava, *IVC* inferior vena cava, *CS* coronary sinus, *FO* fossa ovalis

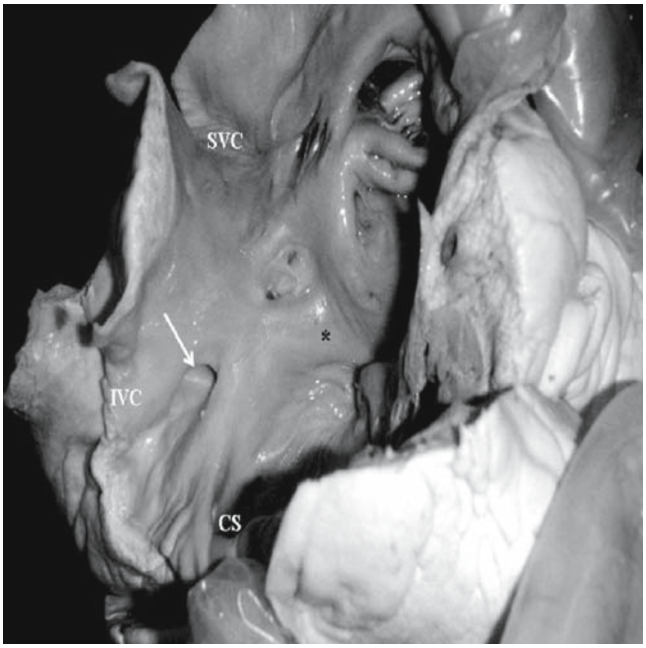


Figure 5.21 Anatomic image of the right interatrial septum as seen from the right atrium. In the central part of septum we find the true septal wall or the fossa ovalis (arrow) delimited by a well-represented muscular crest, responsible for a step being perceived during long sheath's descent. Furthermore in the image we can also visualize the superior vena cava (*SVC*), the inferior vena cava (*IVC*), the coronary sinus ostium (*CS*), and the apex of Koch's triangle (*) corresponding to the aortic bulb

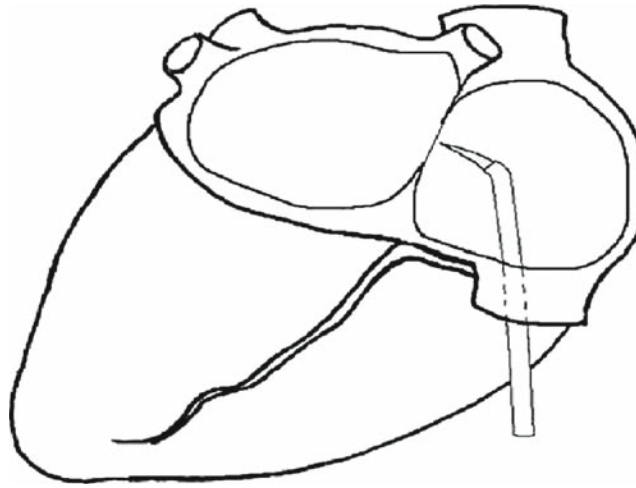


Figure 5.22 Diagram of the interatrial septum as seen from behind and cut at the level of the fossa ovalis. In the sketch we notice the long sheath arriving within the right atrium via the inferior vena cava. The tip is positioned at the level of the fossa ovalis

In the following series of figures (Figures 5.23–5.28), the sequence of pig-tail catheter positioning is shown. All images are in the PA view.

Once anatomic reference catheters have been positioned, in the PA view, the sheath–dilator complex is advanced along the guidewire until the dilator's tip gets into proximity of the carena. (Figure 5.29 is a diagram of the long sheath, dilator, guidewire, and needle complex.)

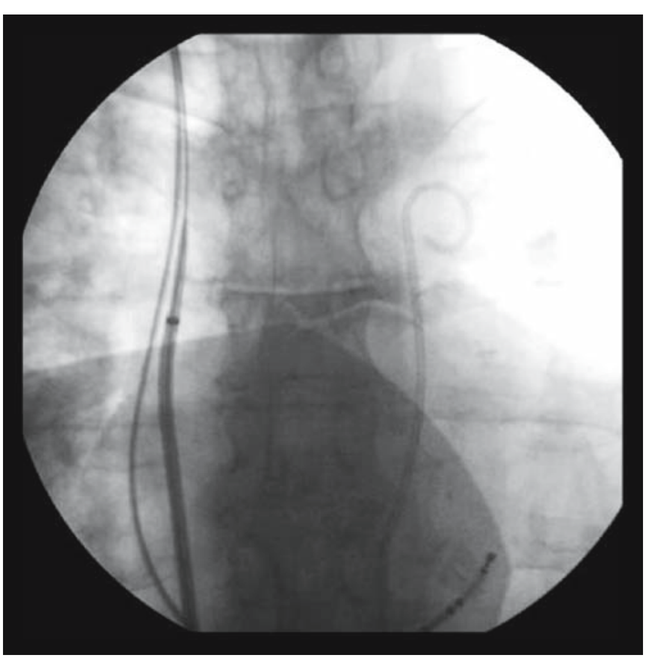


Figure 5.23 The pig-tail catheter has been advanced along the aorta as far as the descending aortic arch in the posteroanterior (*PA*) view

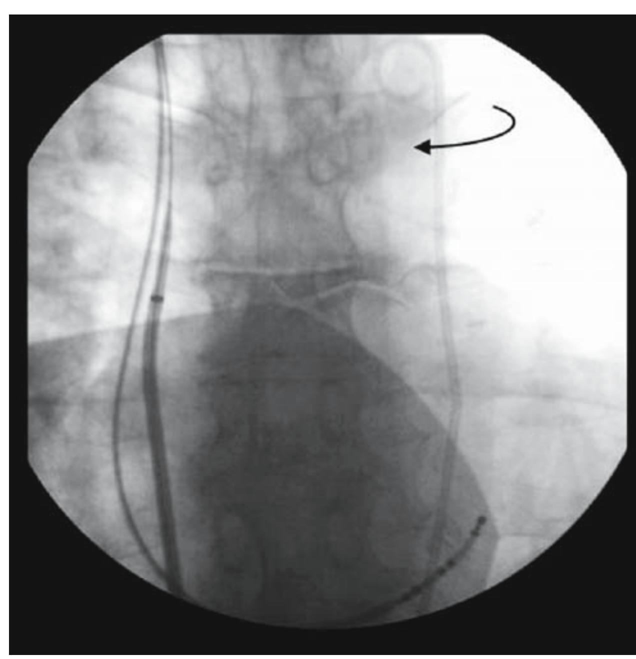


Figure 5.24 The pig-tail catheter is advanced as far as the distal arch and then it is rotated so that its curl is turned medially

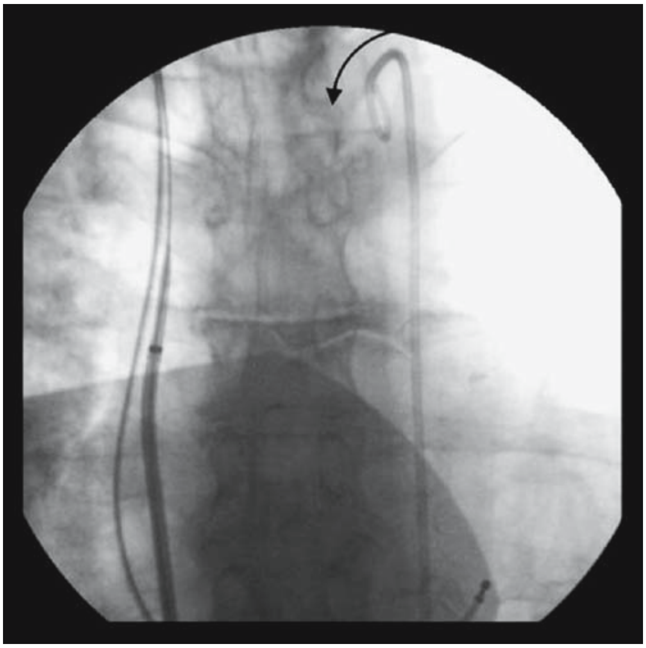


Figure 5.25 The pig-tail catheter is further advanced paying attention that it tracks along the arch of the aorta without swerving toward carotid or subclavian

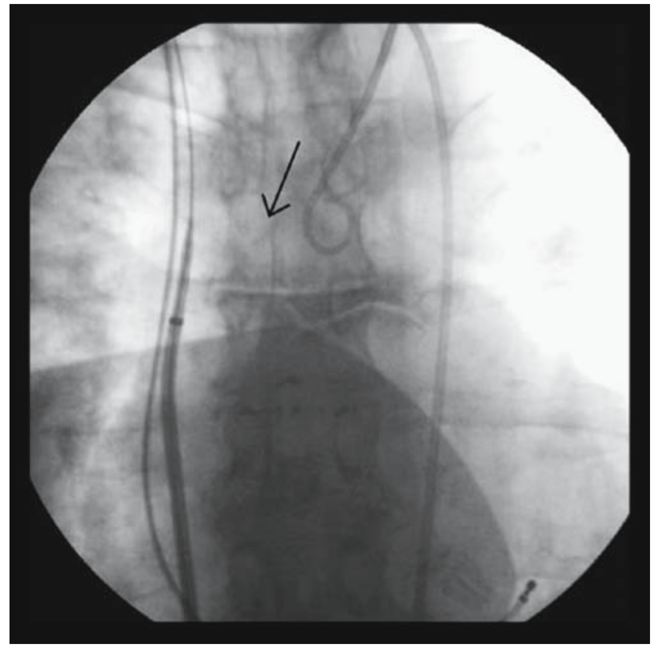


Figure 5.26 The pig-tail catheter is advanced into the ascending aorta

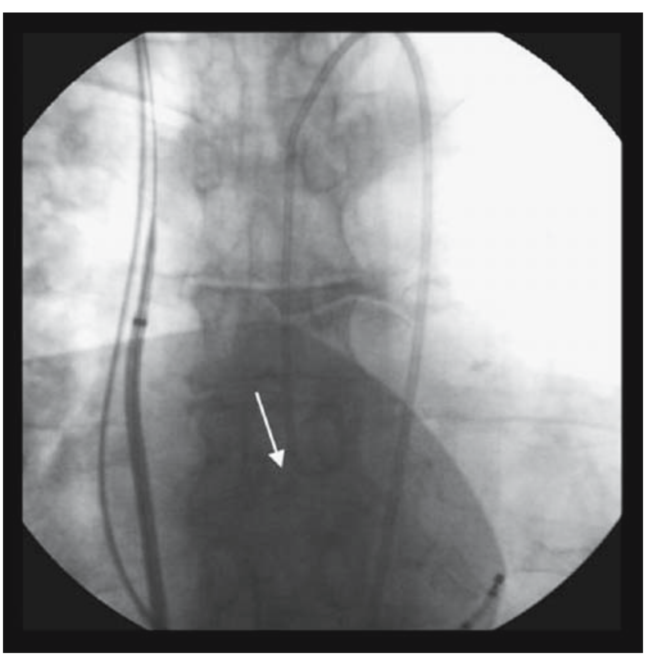


Figure 5.27 The catheter is advanced until a little resistance is felt, corresponding to reaching the aortic valve

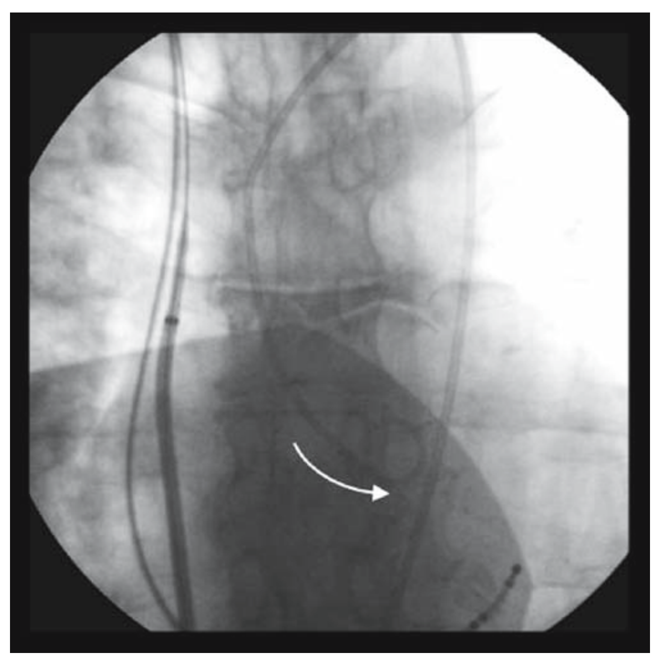


Figure 5.28 In order to ascertain the correct position, one can carefully push the pig-tail forward and visualize it kink inside the aortic bulb

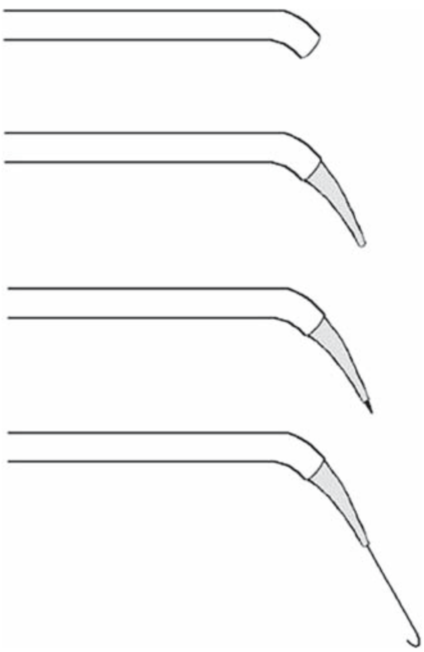


Figure 5.29 Starting from the top, the long sheath's distal portion, the sheath–dilator complex, the sheath–dilator–needle complex, and the sheath–dilator–long guidewire complex. The long sheath has an 8 Fr body with a cut off pipe distal end and is potentially traumatic. Every time one wishes to insert the transseptal needle or the long guidewire, it is also necessary to insert the dilator. The dilator, actually, makes the sheath's distal end less traumatic and stabilizes the needle or long guidewire which have less body

The guidewire is pulled out and the transseptal needle is inserted into the sheath–dilator complex; the needle is advanced as far as the dilator's distal end, paying attention, however, to the needle so that its tip does not pop out. The transseptal needle is rotated, in order to rotate the whole sheath–dilator–needle complex with curve medially opened. Still in the PA view, with continuous fluoroscopy, one begins to slowly withdraw the sheath–dilator–needle complex. When crossing from the superior vena cava to the right atrium, the tip may be felt and seen to drop. Still withdrawing the complex, a second drop is seen when passing from the muscular interatrial septum to the fossa ovalis. In this view, the fossa ovalis usually corresponds to the inferior half or third portion of the vertebral body on which the pig-tail catheter's distal section is placed. At this point, the position is checked in the RAO view. The distal portion of the sheath–dilator–needle complex should be perfectly parallel to the imaginary line running from the CS ostium to the pig-tail catheter's curl within the bulb of the aorta or the catheter's distal end on the His. If the sheath–dilator–needle complex is not perfectly lined up, its position must be adjusted by small rotations of the whole complex, rotating clockwise to go backwards or counterclockwise to go anteriorly. Too anterior a position risks a puncture at the level of the bulb of the aorta, while too posterior a position risks puncture of the right atrium's posterior wall.

When the complex has been rotated in an optimal way, the position is checked in the LAO view and the puncture of the fossa ovalis is carried out in this projection. At the beginning the needle is slightly advanced and a small quantity of dye is injected. If we are at the level of the fossa ovalis, the contrast material slides along the fossa either superiorly or inferiorly outlining a curtain-like shape, indicating the correct position. If instead tissue is impregnated with the contrast material, this indicates a position at the level of the muscular septum. In such case, it is therefore advisable to repeat the maneuver of searching for the fossa ovalis, pulling the needle out, and inserting the wire again within the sheath–dilator complex, in order to go back to the previous position, at tracheal bifurcation.

When a curtain-like shape shadow is seen with contrast injection, the needle can be advanced against the fossa ovalis until one feels a light spring corresponding to crossing the fibroelastic membrane; again one injects contrast material to confirm passing into the left atrium. The contrast can be visualized spreading within the left atrial cavity and thereafter running downward into the left ventricle. If the contrast material injected runs upward, it is necessary to exclude a puncture of the bulb of the aorta. Further confirmation that the needle is in the left atrium can be obtained by connecting the needle with a pressure line. One then covers the needle pushing the sheath-dilator forward over the needle. The needle must be thoroughly covered by the dilator but it is advisable not to pull it back too much as the needle gives body to the dilator which, otherwise, would tend to bend or to withdraw. Once the needle tip has been covered, the sheath has to be advanced, keeping the dilator–needle complex stationary until the sheath reaches the left atrium. When pushing the sheath through the fossa, a little resistance can be perceived, and sometimes it is helpful to advance the sheath slightly rotating clockwise and counterclockwise in order to ease its progression. At this point the dilator–needle complex can be pulled out. Once the access into the left atrium has been carried out, it is necessary to immediately start heparinizing the patient. Then the pig-tail catheter is removed from the aortic bulb in order to minimize thromboembolic risk.

Sometimes, while beginning to push the needle forward against the fossa ovalis, the needle, instead of moving toward the left atrium, tends to go up along the interatrial septum. This typically indicates that the curve of the needle is not sufficient. In these cases it might be useful to pull out the needle and increase the curvature by hand, and then repeat the procedure.

In some cases, the fossa ovalis can be very elastic so that when advancing the sheath–needle complex, one risks that, once fossa has been punctured, the needle jumps as far as the left atrial lateral wall. In those cases, after the sheath–dilator–needle complex is positioned properly at the level of the fossa ovalis, it is possible to keep the fossa ovalis tightened without applying any strain. Heartbeat, through its relative contraction, enables the fibroelastic septum's perforation; in addition, the long sheath, having not built up tension, stays in place without springing toward the left atrium's lateral wall.

In other cases the fossa ovalis can be very fibrotic and resistant. In this case a longer Brockenbrough needle can be chosen. In the presence of a very resistant fossa ovalis, the transseptal puncture can be carried out just by the needle but it could look impossible to cross the fossa with the dilator and the sheath. In these rather exceptional cases, it is suggested to insert an angiographic guidewire into the sheath–dilator–needle complex until the guidewire's tip reaches a left pulmonary vein (superior or inferior). Then the complex can be advanced with more force over the guidewire avoiding puncture of the left atrial wall.

At times a search for the fossa ovalis can be complicated because of anatomic variations. In this case, a transesophageal or intracardiac echo enables direct visualization of the fossa ovalis, thus guiding the transseptal puncture with greater safety.

Some examples of transseptal punctures are shown in Figures 5.30–5.72.

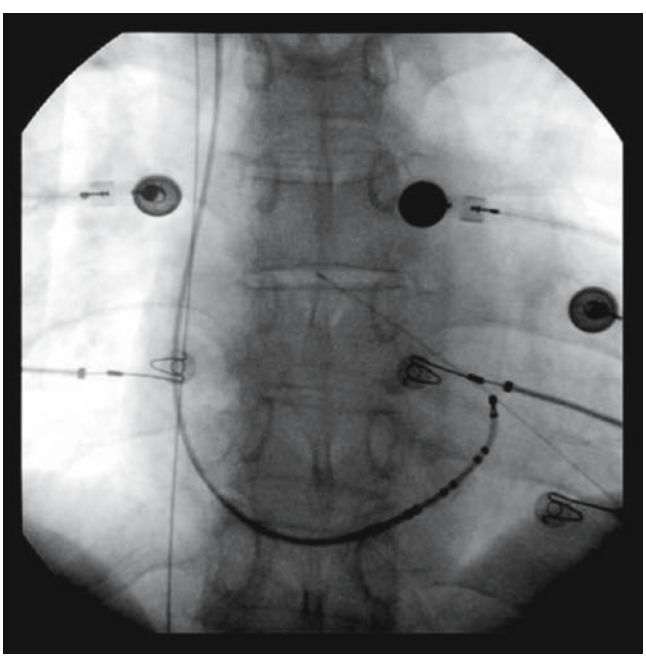


Figure 5.30 In the radiographic image, performed in the posteroanterior (*PA*) view, one can see the catheter in the coronary sinus (*CS*) and a long guidewire passing from the inferior vena cava into the right atrium and then continuing into the superior vena cava. This is the starting condition for transseptal puncture

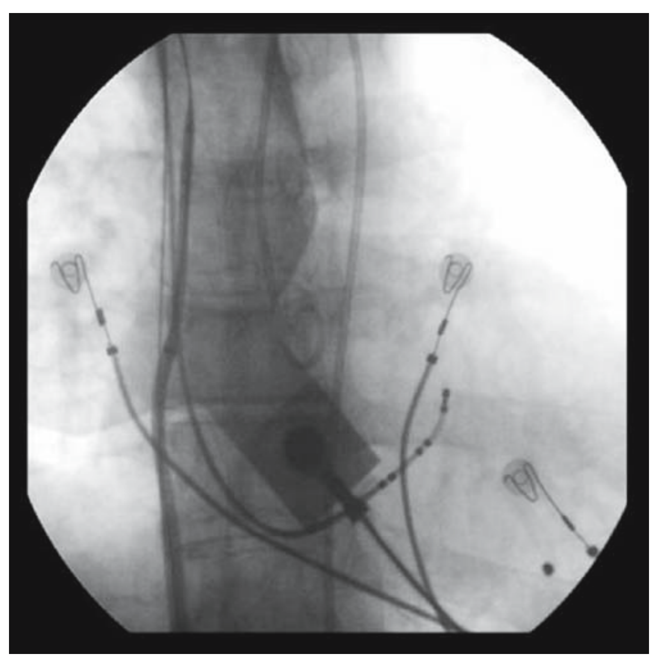


Figure 5.31 Advancing the sheath–dilator along the wire as far as the tracheal bifurcation

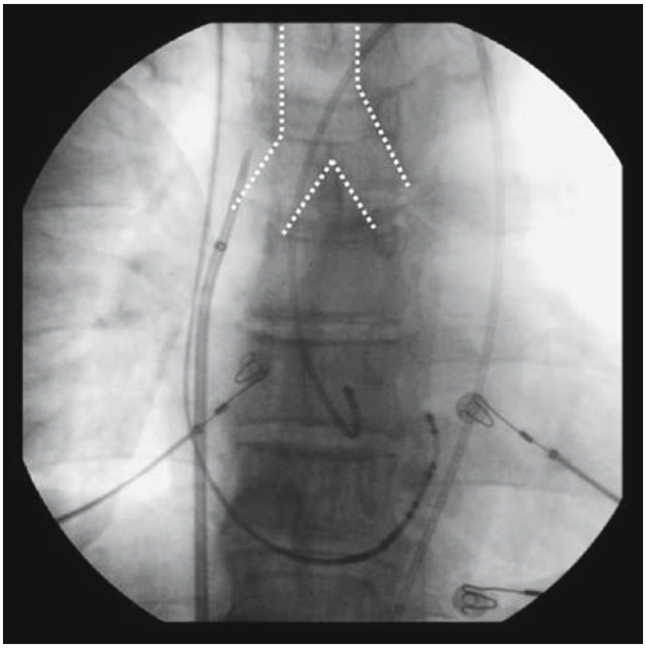


Figure 5.32 The long guidewire is removed leaving the sheath–dilator complex in place. The tracheal bifurcation is highlighted in this image with dashed lines

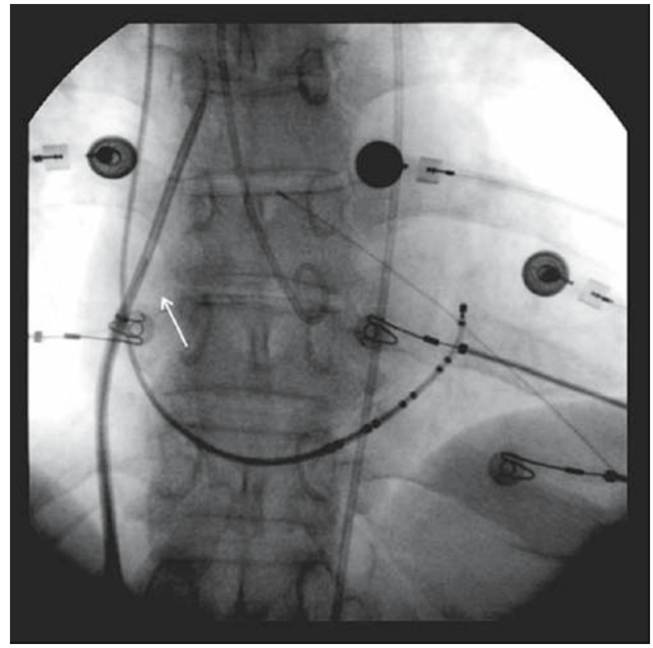


Figure 5.33 Advancing the Brockenbrough needle (white arrow) forward in the posteroanterior (*PA*) view. The needle, with its increase body, will tend to warp the sheath–dilator complex

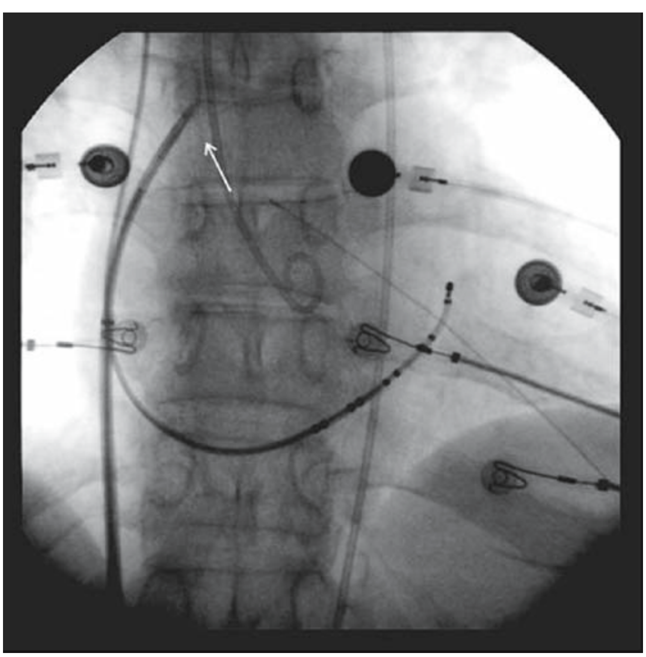


Figure 5.34 The needle (white arrow) is advanced as far as the distal end of the long dilator

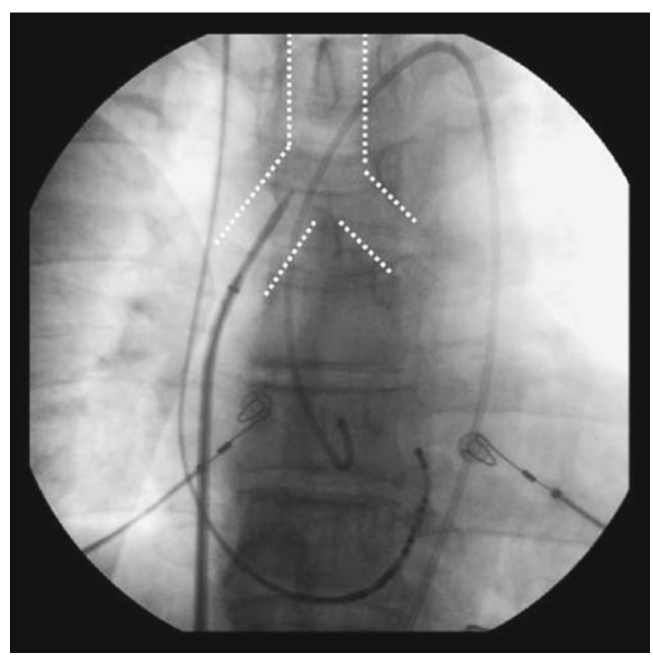


Figure 5.35 When the transseptal needle has arrived at the dilator tip, the whole system is rotated so that the tip turns, still using the posteroanterior (*PA*) view. Dotting highlights the trachea

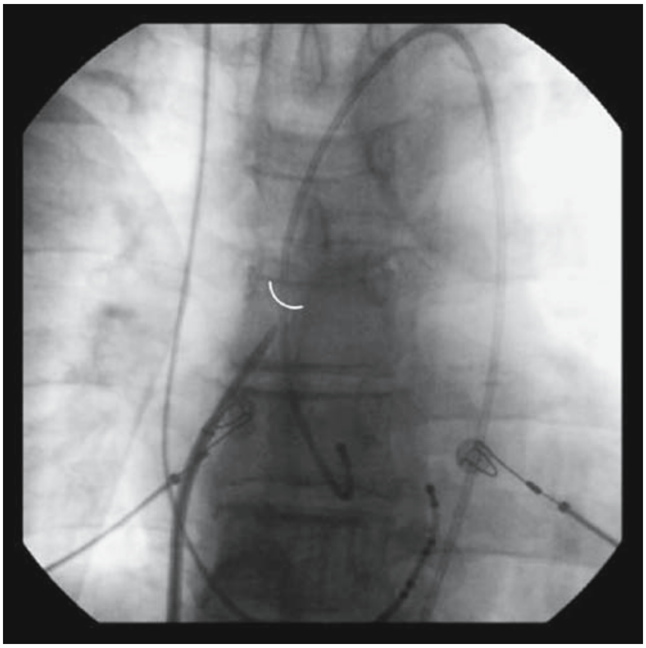


Figure 5.36 At this point one begins to withdraw the entire system, sliding along the interatrial septum in the posteroanterior (*PA*) view. At the junction of the superior vena cava with the right atrium, a drop will be perceived by touch (white line), which can also be visualized by fluoroscopy

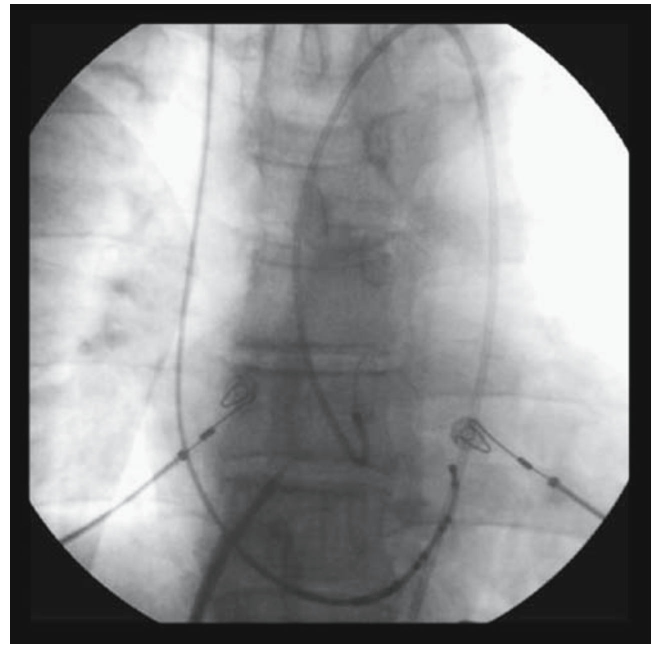


Figure 5.37 The sheath–dilator–needle complex is further pulled back until a second drop is felt, corresponding to passing from the interatrial septum to the fossa ovalis. In the posteroanterior (*PA*) view, the fossa ovalis corresponds, usually, to the inferior half or third portion of the vertebral body on which the pig-tail catheter's distal section is cast

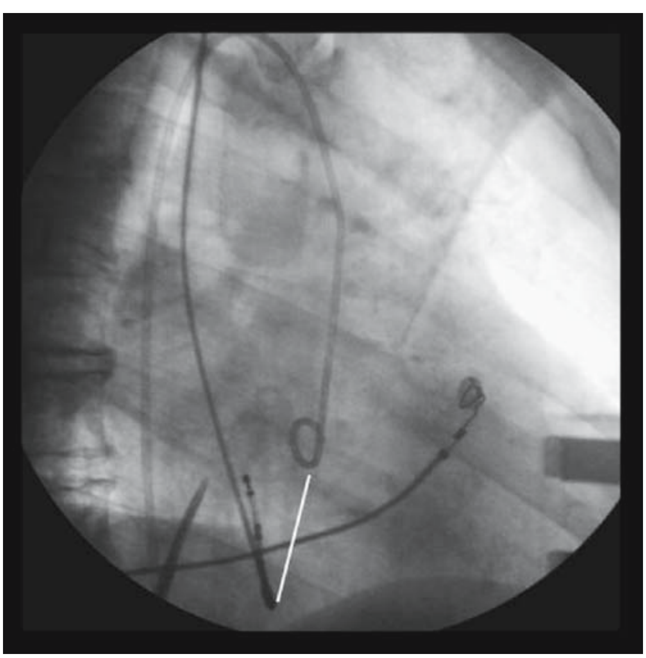


Figure 5.38 Without moving the sheath, the right anterior oblique (*RAO*) view allows to see if the needle is parallel to the axis between the coronary sinus (*CS*) ostium and the bulb of the aorta (dotted line)

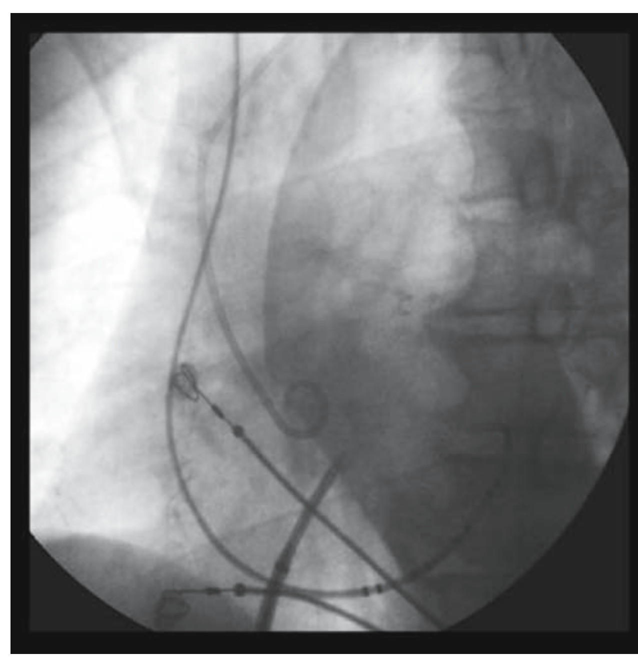


Figure 5.39 In the left anterior oblique (*LAO*) view one checks the correct orientation of the sheath–dilator–catheter complex toward the interatrial septum and the heart's left portion

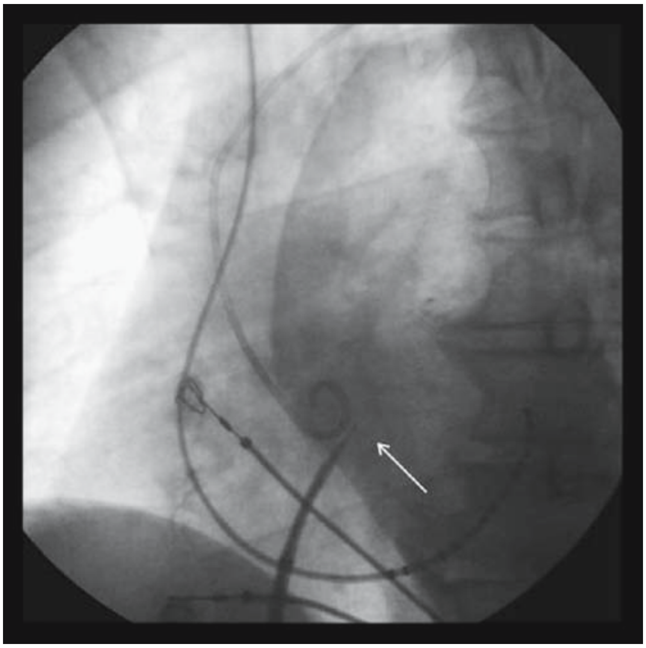


Figure 5.40 The needle (arrow) is slightly advanced so that the tip pops out of the dilator

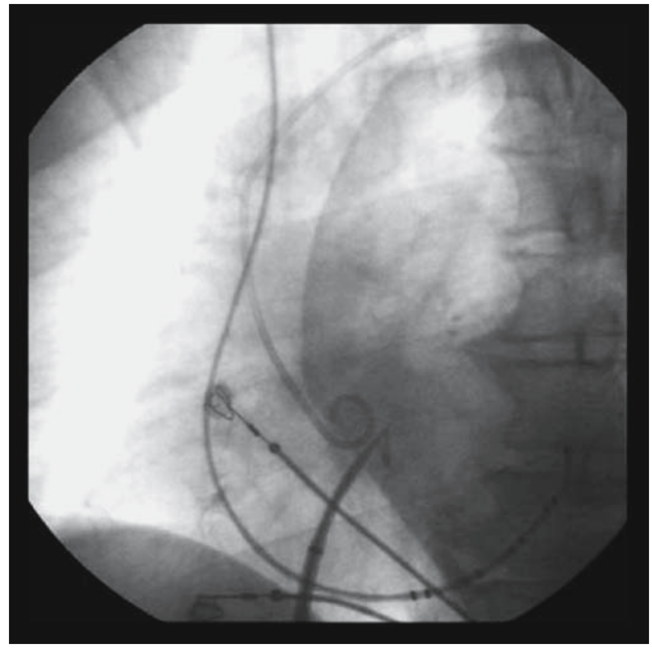


Figure 5.41 Still in the left anterior oblique (*LAO*) view, contrast material is injected to confirm position. This should make a curtain-like shape, well visible in this instance

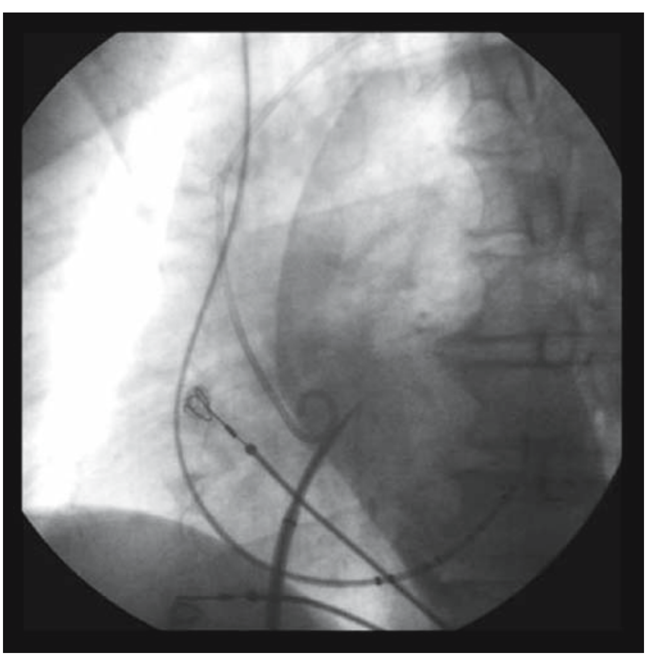


Figure 5.42 The needle is further pushed forward trying to pierce the fossa ovalis. In case of a very elastic fossa ovalis, the needle will tent the fossa ovalis pushing it leftward relative to the interatrial septum

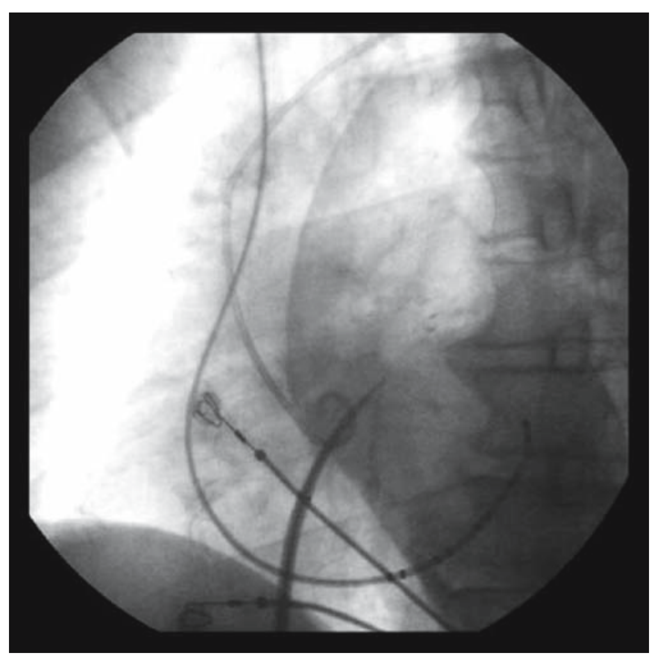


Figure 5.43 One keeps on pushing the needle, infusing dye in order to continuously visualize displacement of the fossa ovalis and preservation of the correct position, confirmed by the curtain-like image

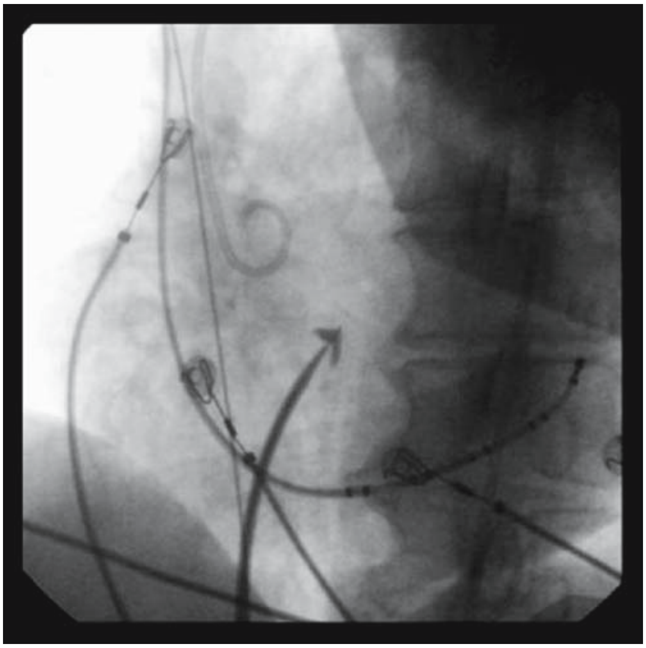


Figure 5.44 In case of a more fibrous fossa ovalis, the interatrial septum's displacement leftward is much less pronounced

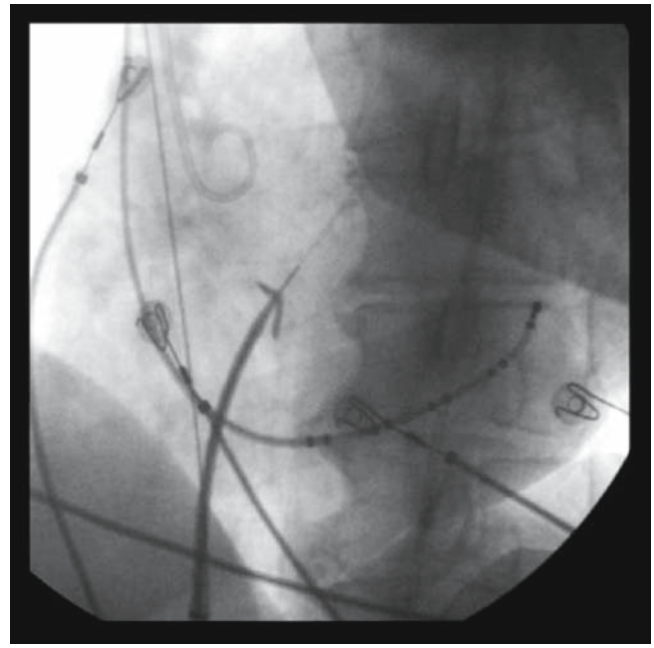


Figure 5.45 The needle is further pushed forward and, after having perceived a spring, dye is injected in order to ensure having crossed fossa ovalis

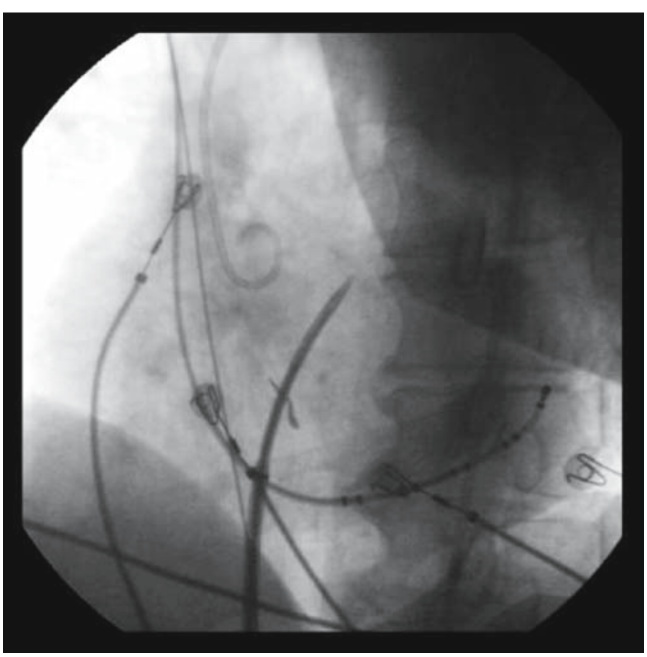


Figure 5.46 Holding the needle firmly, one advances the sheath–dilator complex over the needle until the dilator completely covers the needle's tip

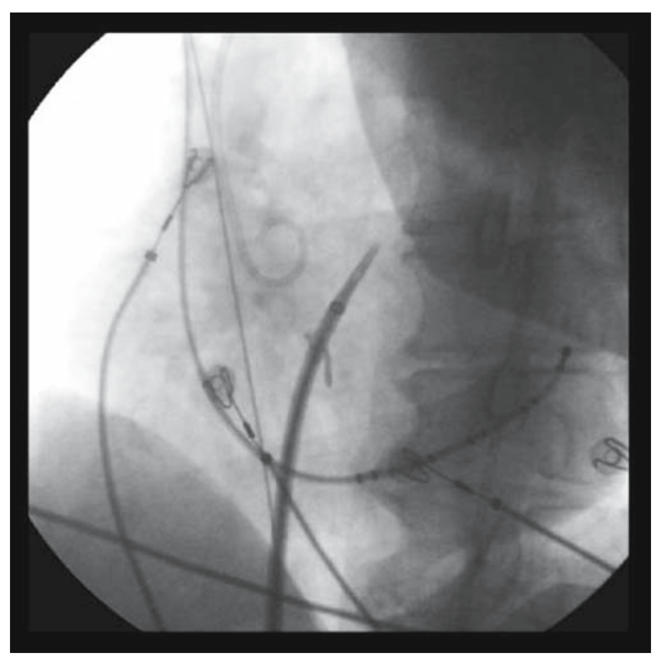


Figure 5.47 At this point one fixes the dilator–needle complex and advances the sheath only. The needle must be thoroughly covered by the dilator but it is advisable not to pull it back too much as it is up to the needle to give body to the dilator which, otherwise, would tend to bend or to withdraw. While advancing the sheath forward, when it is at the level of the fossa ovalis, where the puncture has been carried out, a little resistance can be perceived. Sometimes gentle clockwise and counterclockwise rotations facilitate its progression

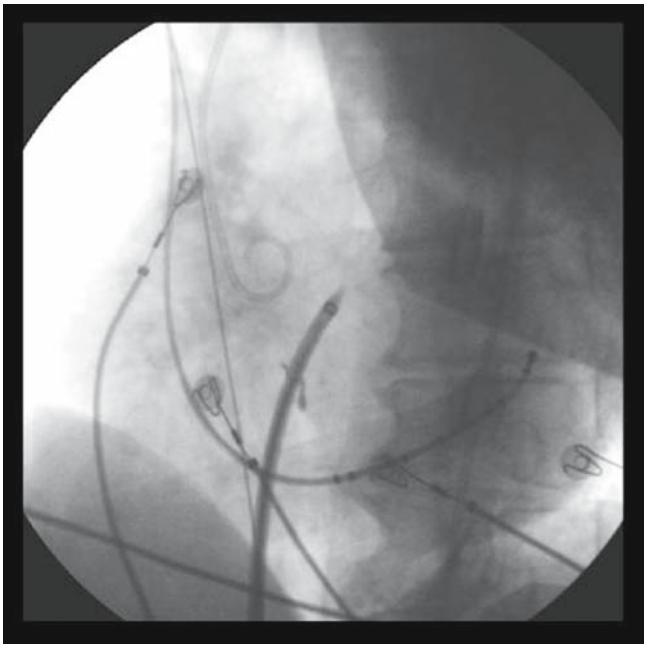


Figure 5.48 Now the sheath lies within the left atrium and thoroughly covers the dilator–needle complex

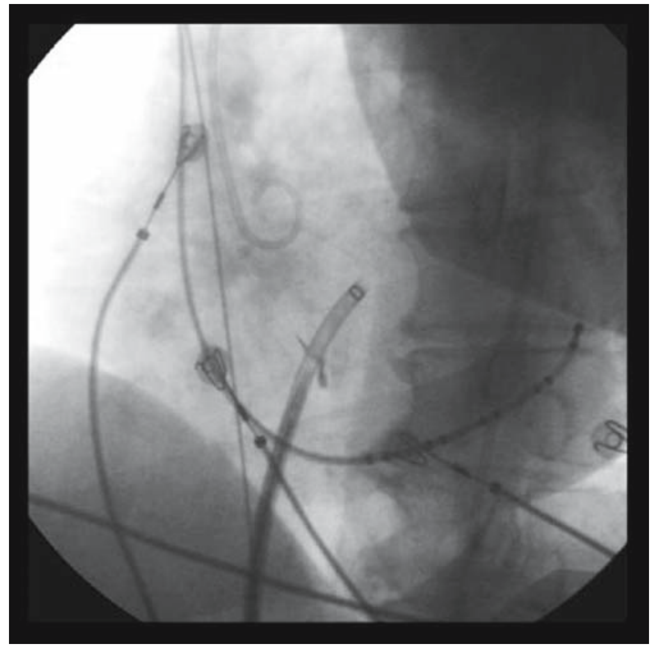


Figure 5.49 The dilator–needle complex is pulled out

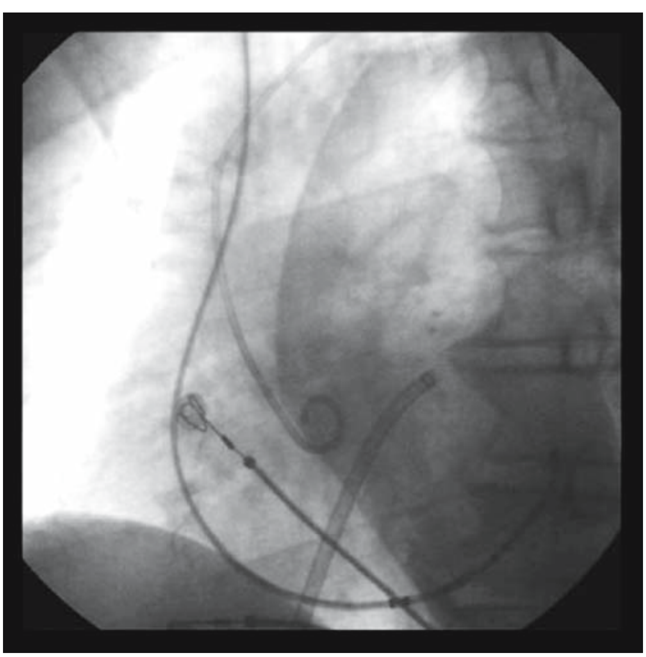


Figure 5.50 Only the long sheath is left in the left atrium. Once the long sheath's position within the left atrium is confirmed, it is advisable to remove the pig-tail catheter from the bulb of the aorta in order to reduce thromboembolic risk

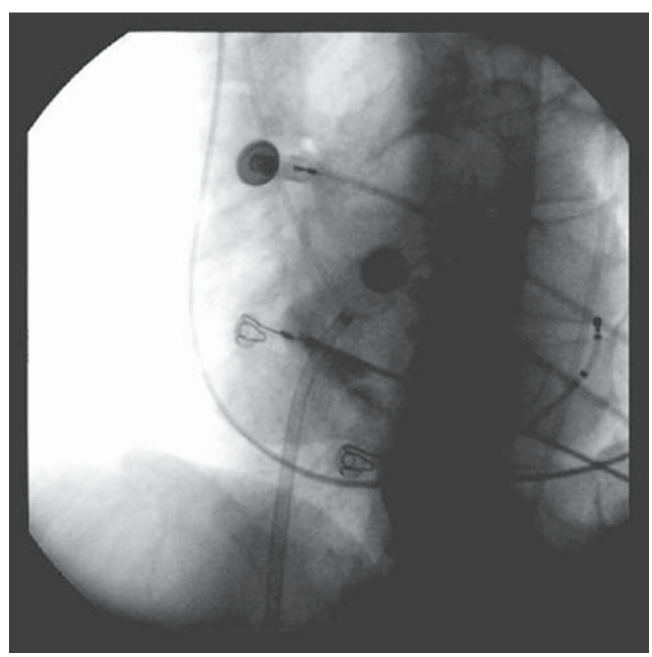


Figure 5.51 The long sheath within the left atrium in the posteroanterior (*PA*) view

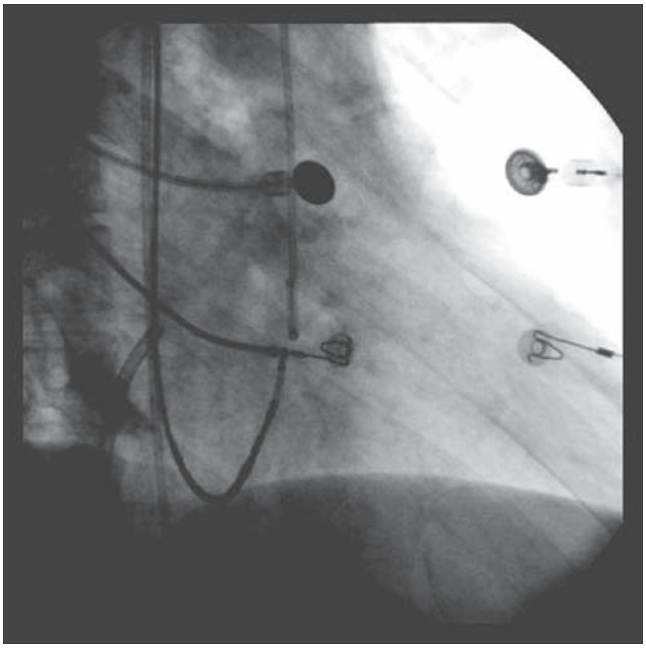


Figure 5.52 The long sheath within the left atrium in the right anterior oblique (*RAO*) view

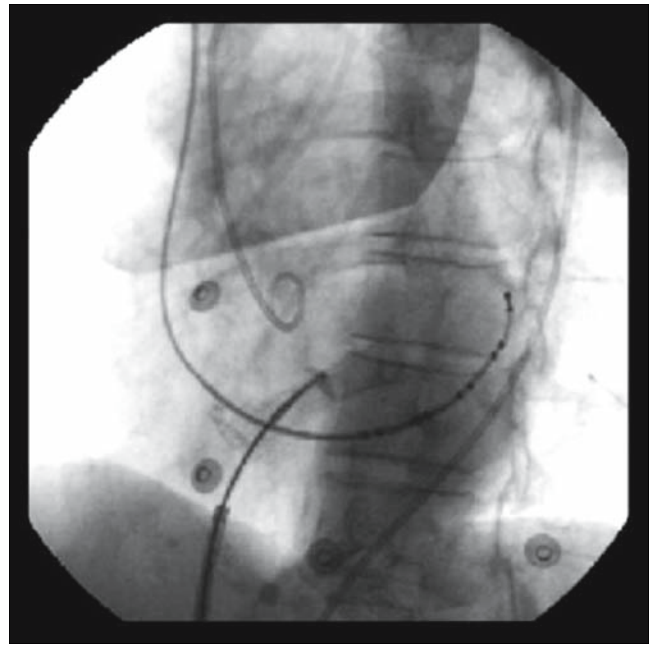


Figure 5.53 In this image, in the left anterior oblique (*LAO*) view, one can see how the needle is positioned on the interatrial septum. By injecting dye one sees that the latter tends to impregnate the septum

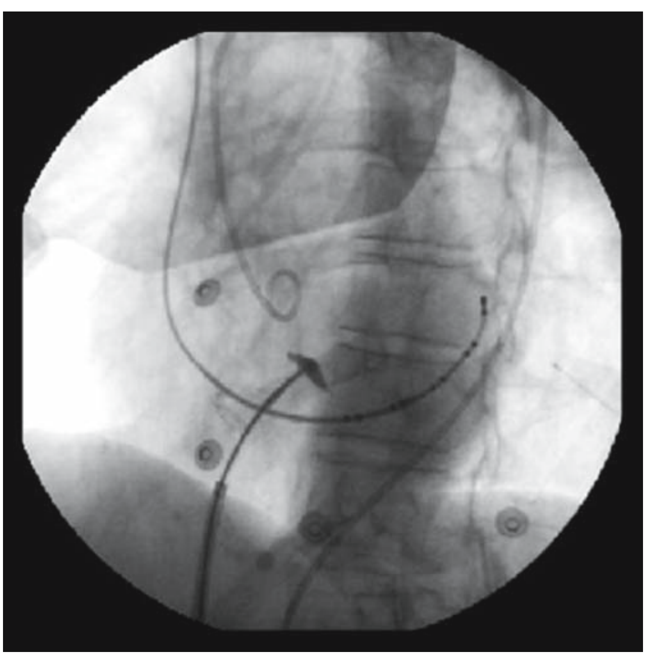


Figure 5.54 With further injection of contrast material, one can see that the position is not correct. Here dye impregnates the interatrial septum's muscular portion

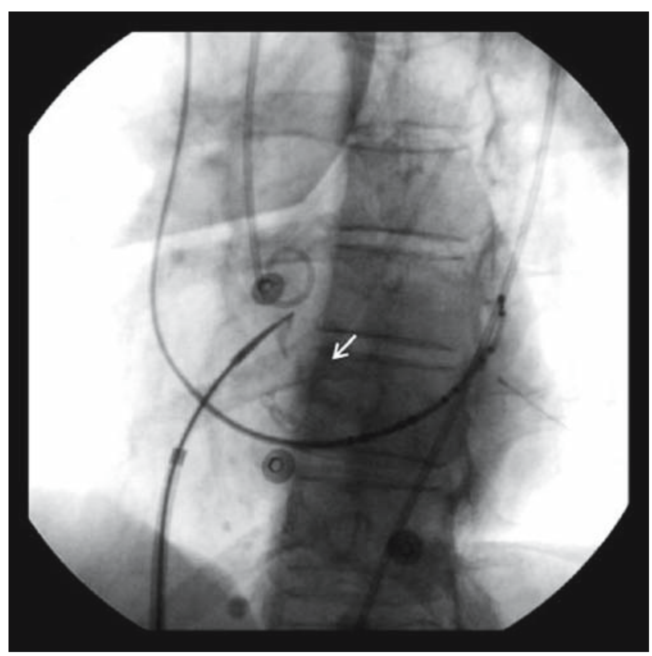


Figure 5.55 In the same patient one sees the correct position, ascertained by a curtain-like image. In this case, the correct position rests on a higher level compared to the previous site, still visible because of dye remaining within the septum (arrow)

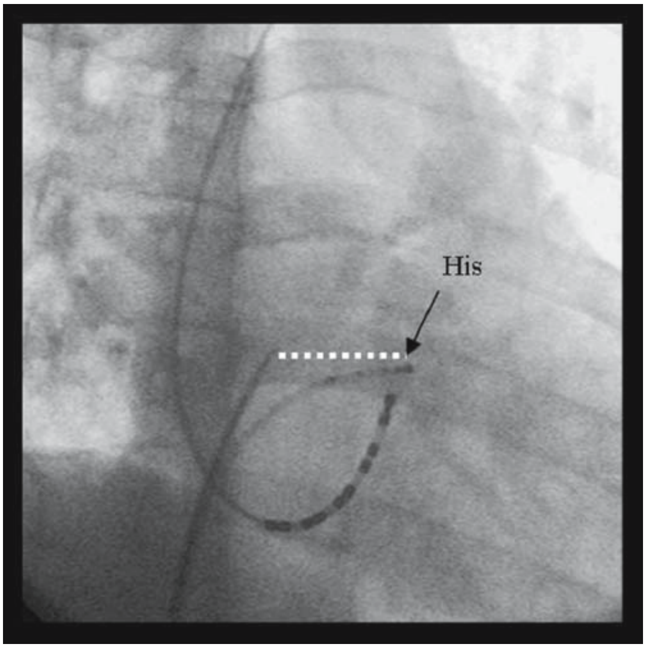


Figure 5.56 In this image, the aortic valve plane is visualized not only by the pig-tail catheter positioned within the bulb of the aorta but also, instead, by a quadripolar catheter positioned at the His position. Please notice how in the right anterior oblique (*RAO*) view, the fossa ovalis' plane, where transseptal needle is positioned, rests on the same level as the His bundle, where the quadripolar catheter is placed

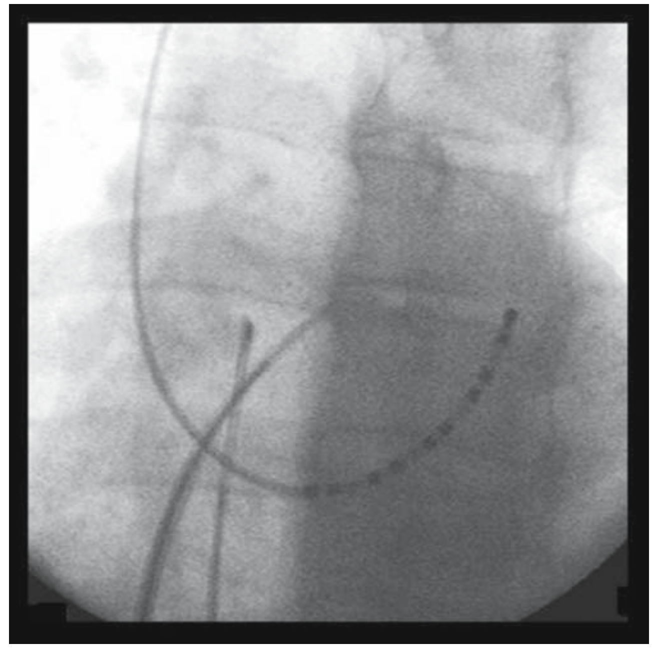


Figure 5.57 The left anterior oblique (*LAO*) view of the same patient demonstrates that the curve of the sheath–dilator–needle complex is turned leftward. The His catheter makes us see the interatrial septum at an anteroseptal level, corresponding to the aortic valve plane

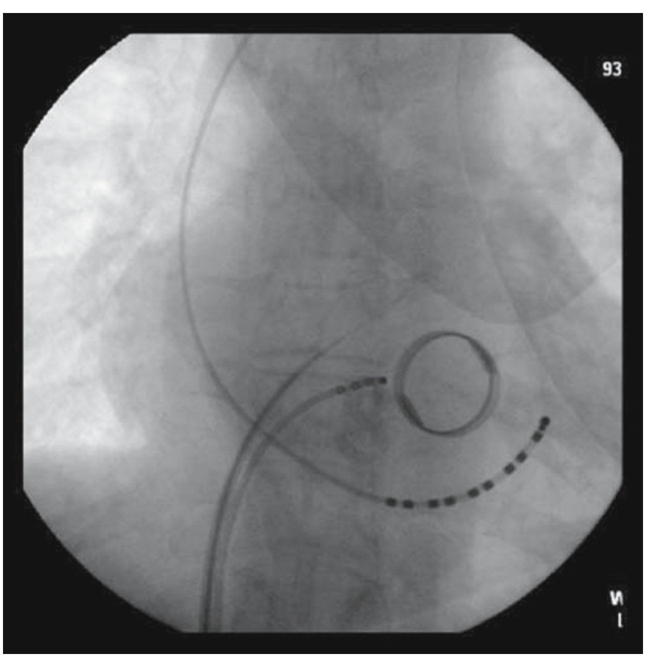


Figure 5.58 The posteroanterior (*PA*) view of a transseptal puncture in a patient with a mitral valve prosthesis. In this case the aortic valve plane has been made evident by a diagnostic catheter positioned at the His position. The transseptal puncture has just been carried out and it is possible to see the dye being injected into the left atrium

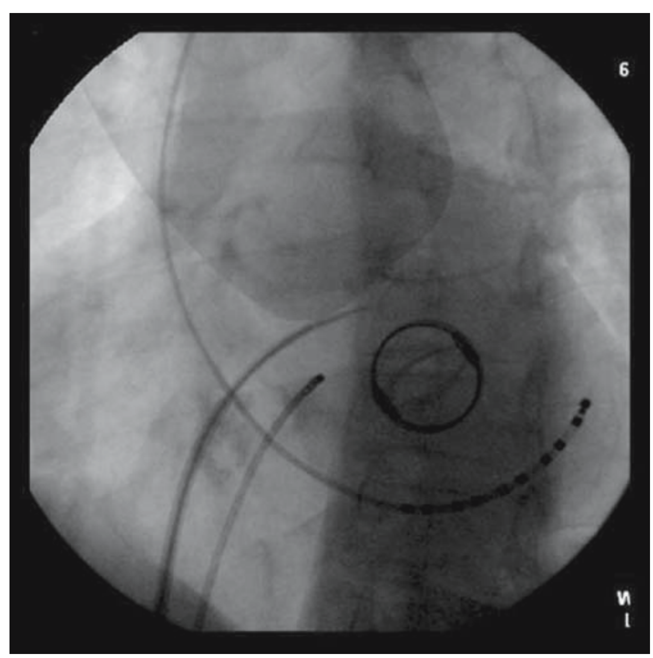


Figure 5.59 The left anterior oblique (*LAO*) view of the same patient. In this view one can clearly see how the needle is within the left atrium

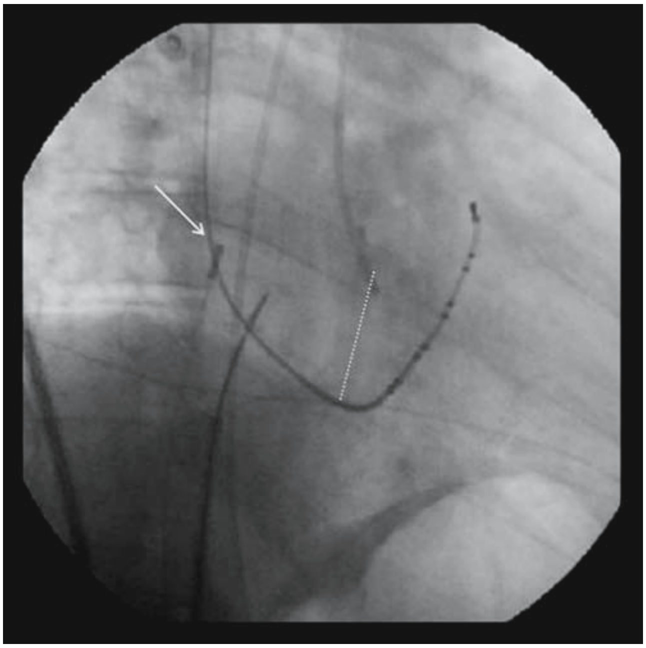


Figure 5.60 In this sequence of images we show a transseptal puncture carried out with the aid of intracardiac echocardiography (arrow). In the right anterior oblique (*RAO*) view, one sees positioning of the sheath–dilator catheter complex parallel to the axis of the coronary sinus (*CS*) ostium and the bulb of the aorta (dotted line)

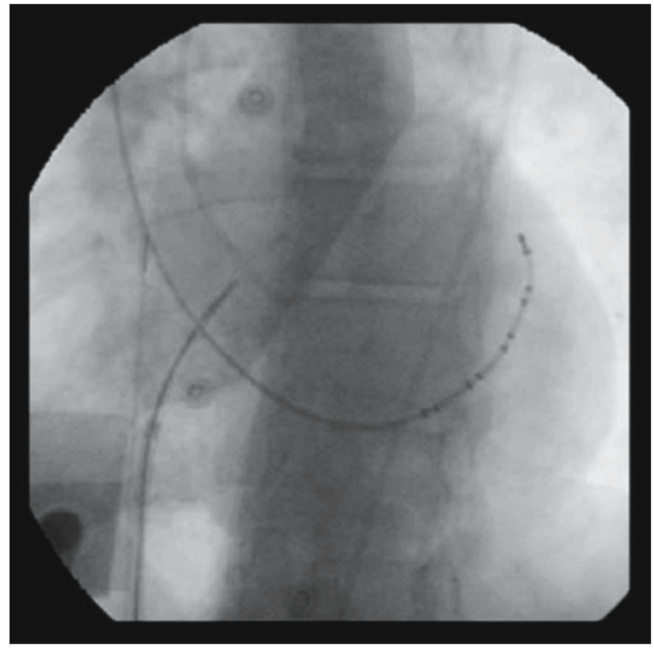


Figure 5.61 In the left anterior oblique (*LAO*) view it is ascertained that the sheath–dilator complex is oriented toward the interatrial septum. Within the right atrium one can see the intracardiac echo probe turned toward the interatrial septum

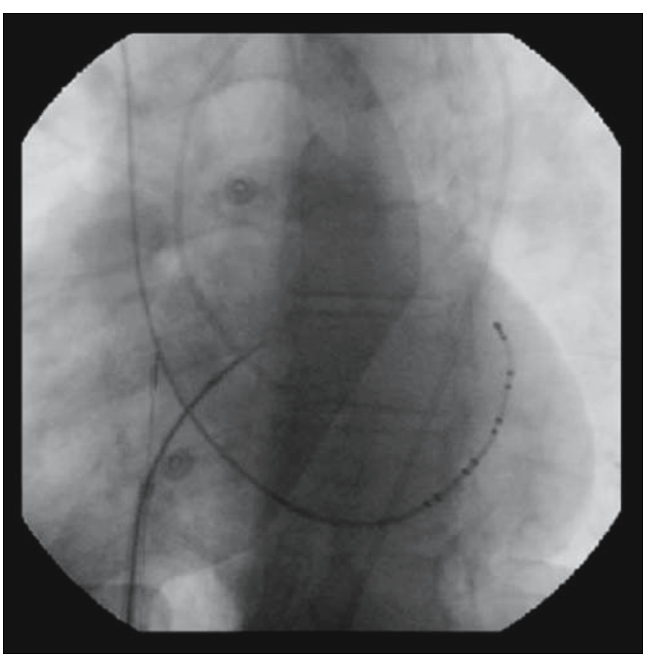


Figure 5.62 The needle tip is outside of the dilator pressing on the fossa ovalis. Contrast infusion enables visualization of a curtain-like image

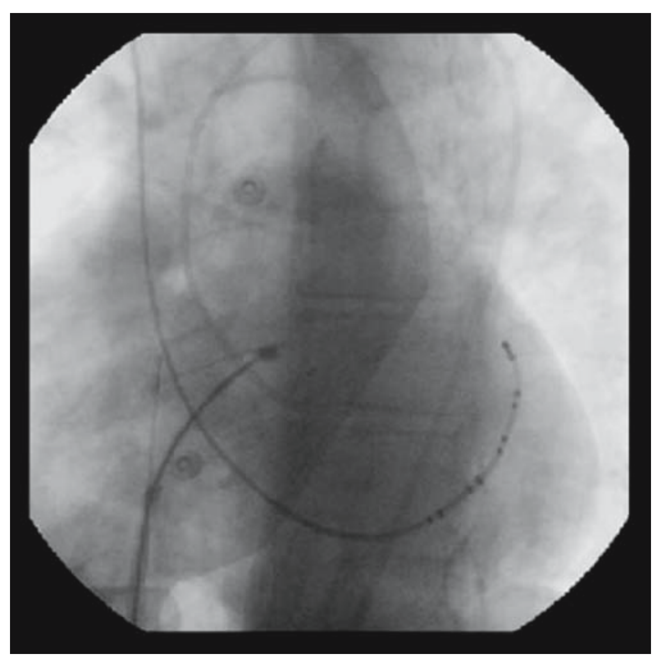


Figure 5.63 By further pushing the needle forward, the fossa ovalis tents further leftward, now made more evident by dye

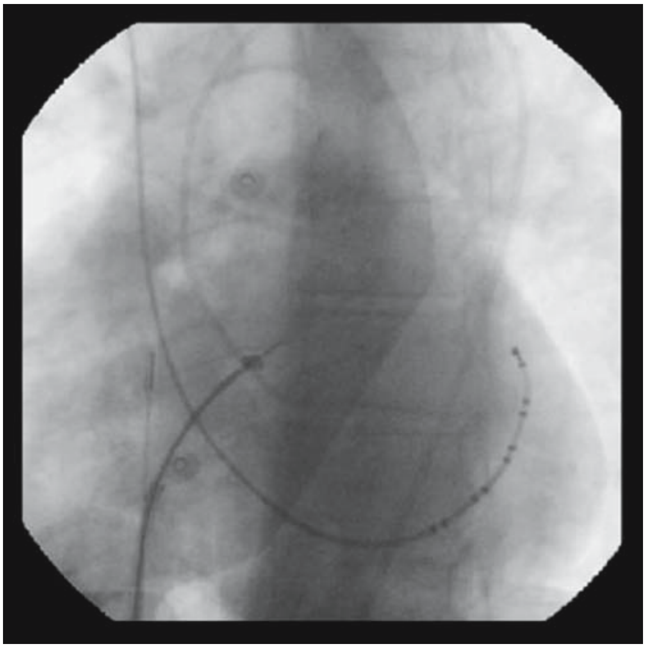


Figure 5.64 The needle has been successful in going through the fossa ovalis, which, no more under strain, tends to withdraw as one can clearly see by the contrast material location relative to the pig-tail catheter

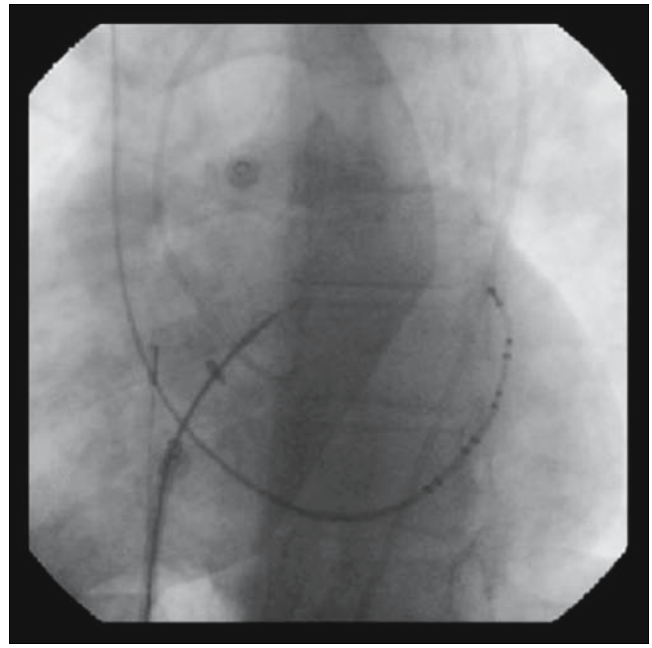


Figure 5.65 After having infused dye within the left atrium, the sheath-dilator is advanced into the left atrium sliding over the transseptal needle

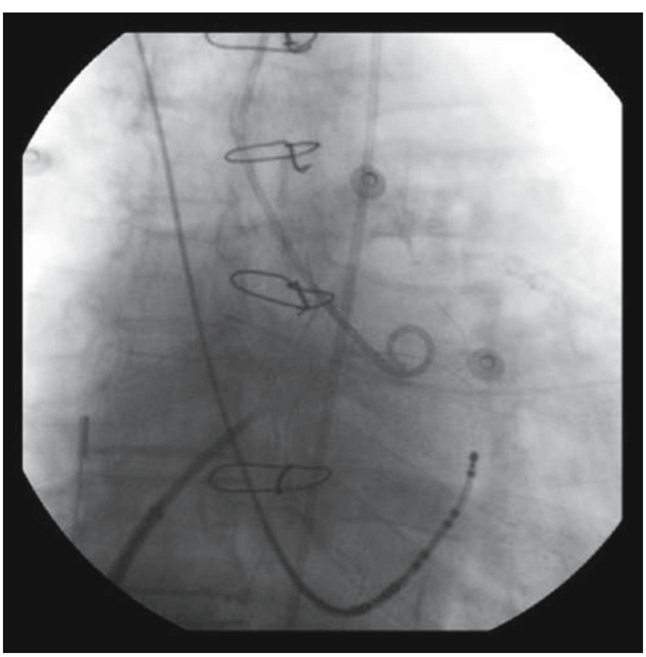


Figure 5.66 The posteroanterior (*PA*) view of another patient where the sheath–dilator complex is resting on the fossa ovalis as it is confirmed by images recorded by intracardiac echo

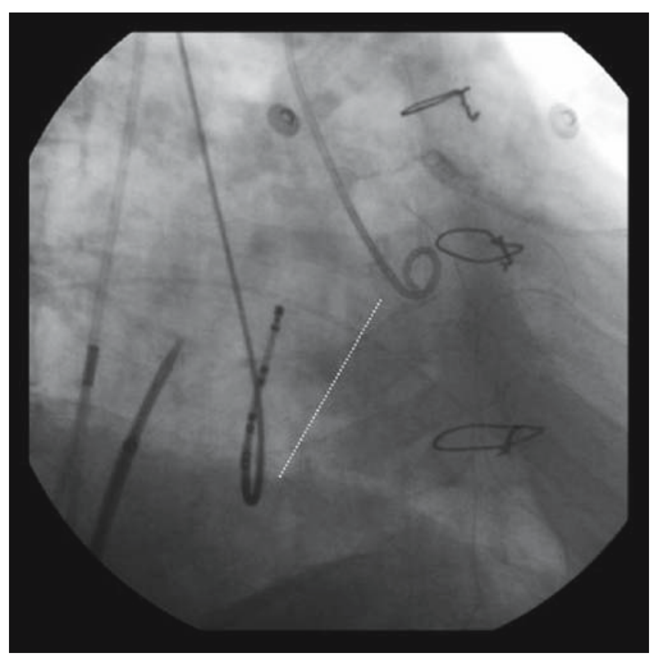


Figure 5.67 The right anterior oblique (*RAO*) view of the same patient

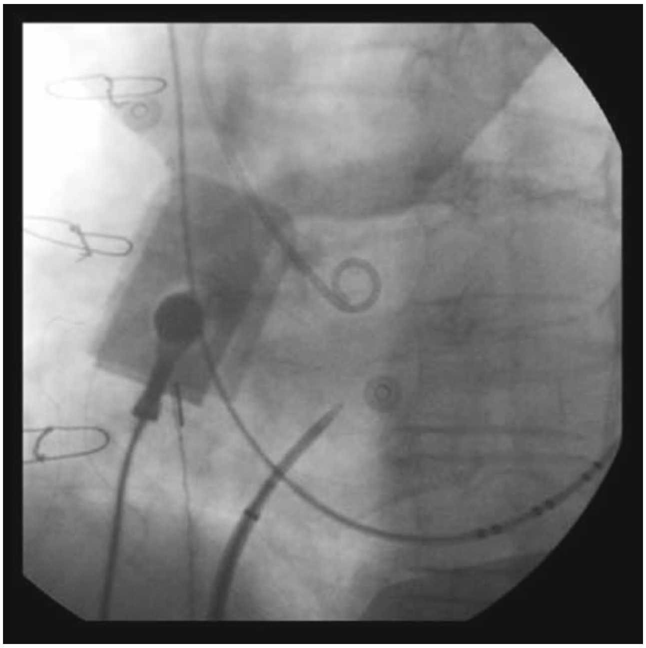


Figure 5.68 The left anterior oblique (*LAO*) view of the same patient

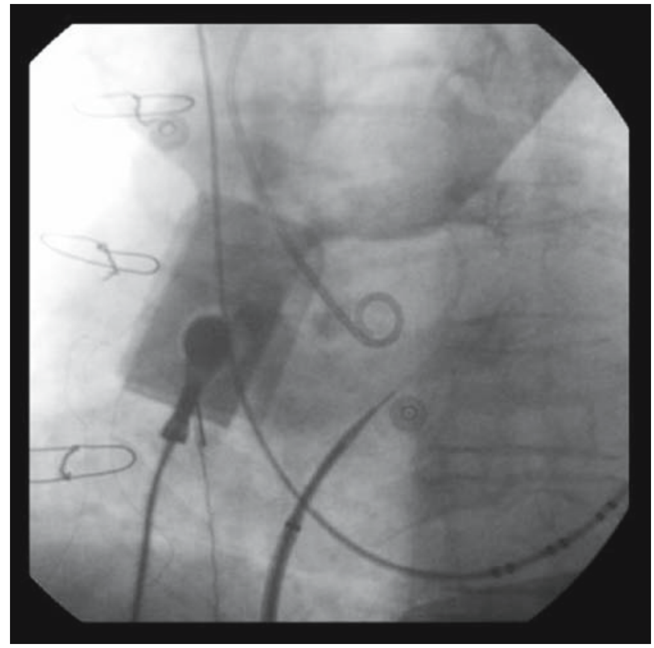


Figure 5.69 In the left anterior oblique (*LAO*) view, by slightly pushing the needle forward, it is immediately perceived to cross the fossa ovalis, and it is confirmed by injection of dye into the left atrium. Please notice how the needle lies within the left atrium, even if the fluoroscopic image might make one think that it still rests within the right atrium

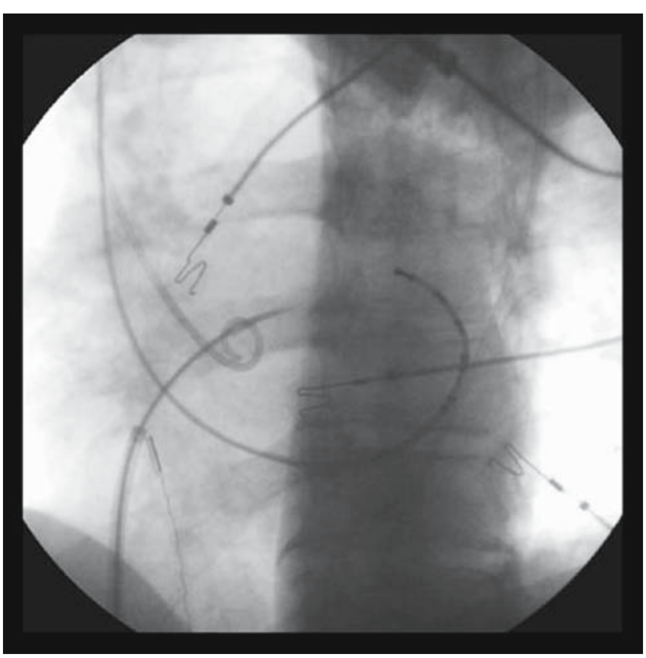


Figure 5.70 This as well as the two following images in the left anterior oblique (*LAO*) view demonstrate, instead, one patient in which we did not succeed in carrying out the transseptal puncture. Images of intracardiac echo assess correct transseptal needle positioning at the level of the fossa ovalis. Compared to the previous case, please notice how the needle is moved leftward

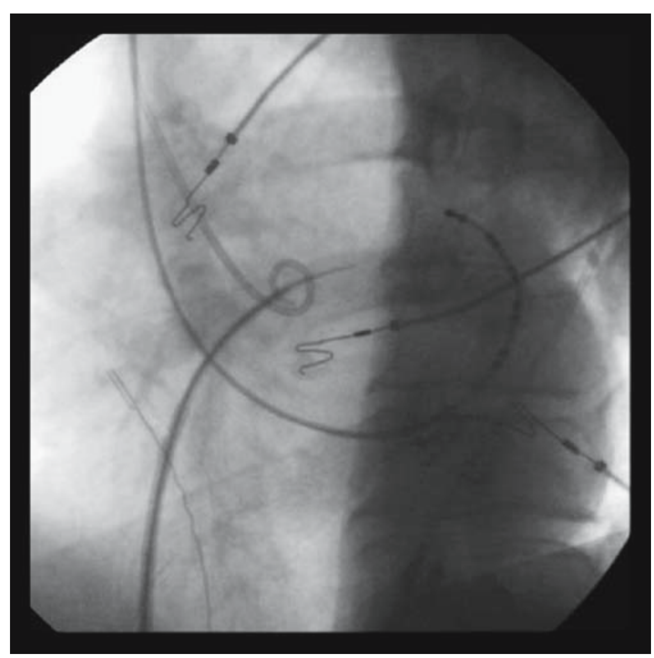


Figure 5.71 By further pushing, the needle drags the fossa ovalis still more leftward

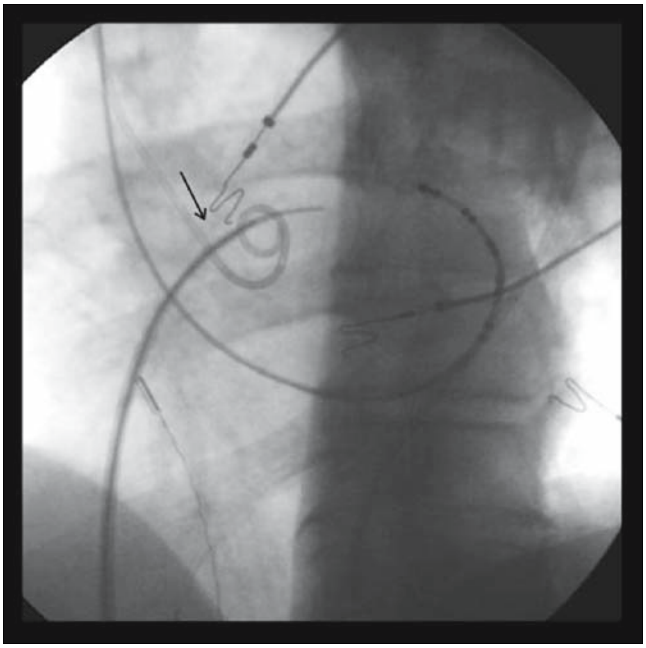


Figure 5.72 By further pushing the needle, one does not succeed in going through the fossa ovalis. Extreme strain applied to the needle makes it slightly bend emphasizing its curvature (arrow)

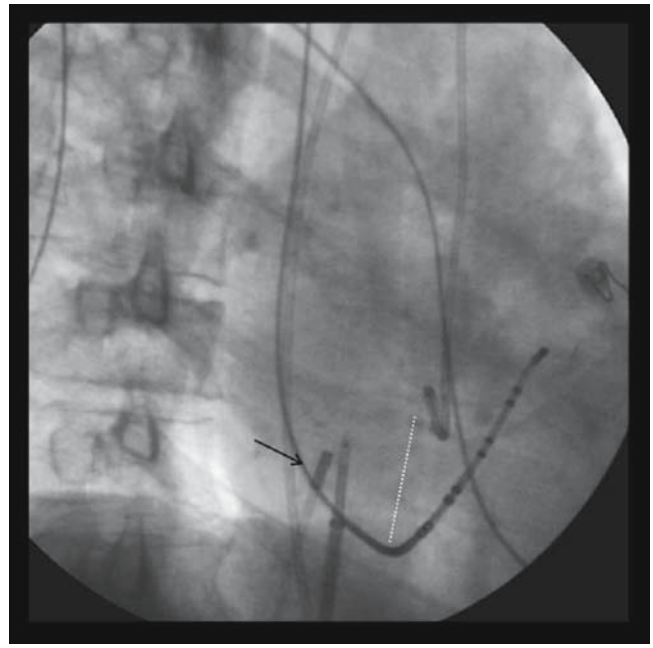


Figure 5.73 The right anterior oblique (*RAO*) view showing the sheath–dilator–probe complex position at the height of the fossa ovalis. The complex is parallel to the axis (dotted line) connecting the coronary sinus (*CS*) ostium with the bulb of the aorta. Within the right atrium intracardiac echo is positioned

In cases of particularly difficult transseptal puncture due to resistance of the fossa ovalis, a transseptal probe has been recently marketed, which drives a hole through the fossa ovalis employing short (2–5 s) issues of low voltage (5 W) radiofrequency (RF). This system employs one dedicated sheath as well as one dedicated dilator with a preshaped curvature. Positioning of the sheath–dilator system, with the RF probe inserted within the dilator, is

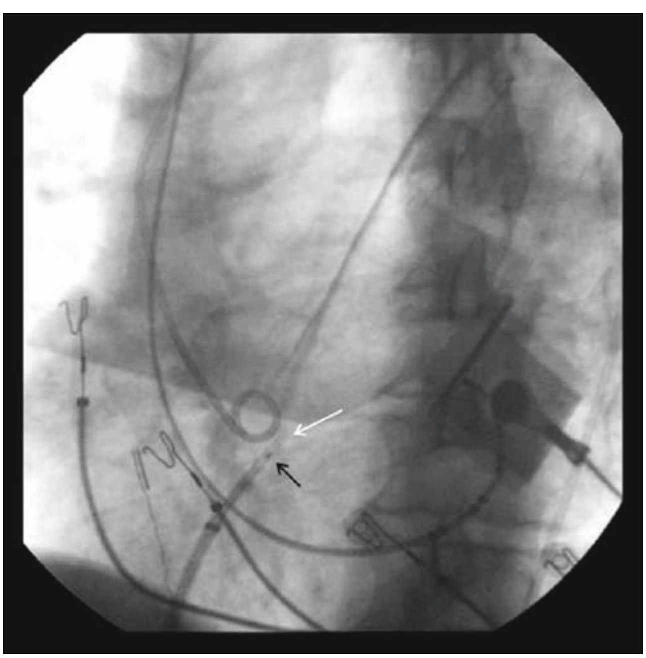


Figure 5.74 Same image in the left anterior oblique (*LAO*) view. Please notice how the transseptal probe (black arrow) lies within the dilator, whose tip is made evident by a white arrow

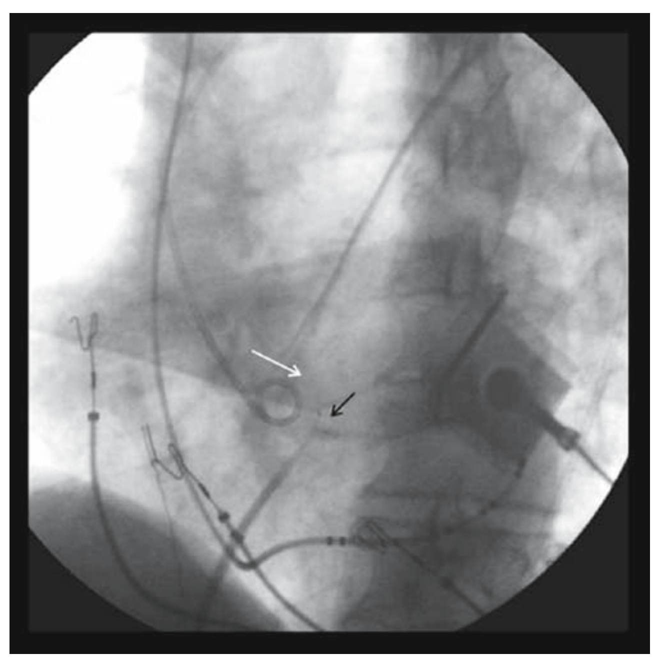


Figure 5.75 The transseptal has been carried out as it is confirmed by a puff of dye (black arrow) within the left atrium. Note how contrast material is injected by the transseptal probe's body, which has little holes in its distal portion (white arrow), and not by the probe's tip

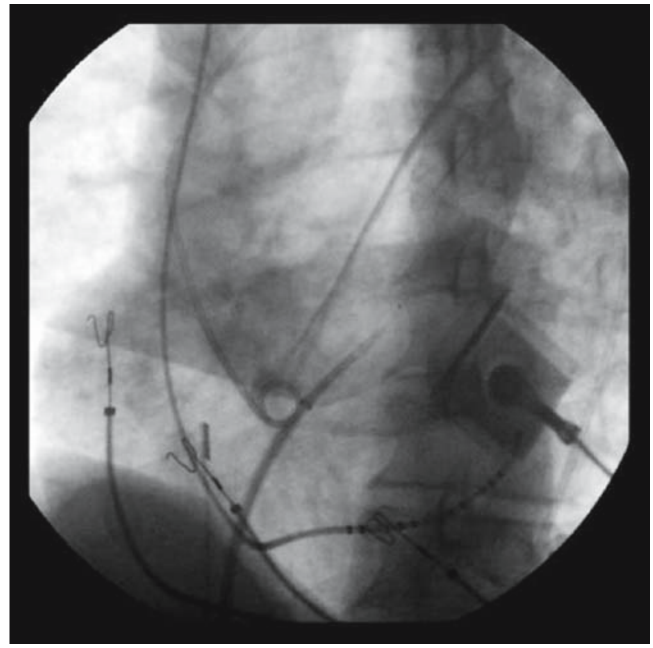


Figure 5.76 Over the transseptal probe, the long sheath is advanced into the left atrium

carried out according to the traditional system. When the dilator tip is in the correct position to carry out the transseptal puncture, the probe is pushed forward a few millimeters while issuing RF, thus creating passage into the left atrium. In the following sequence of images (Figures 5.73–5.76), we show one example of transseptal puncture carried out with this system in the patient where puncture carried out by the standard transseptal needle was not successful (see Figures 5.70–5.72).

5.3 Utility of Intracardiac Echocardiographic Imaging

Transseptal catheterization can be aided by direct visualization of the fossa ovalis, by means of transoesophageal or intracardiac echocardiography. In this latter case, a catheter-based ultrasound transducer is inserted via the venous approach into the right atrium and positioned so as to visualize the fossa ovalis as well as the corresponding transseptal needle's position. On the market, at present, there exist two types of ultrasound catheters for intracardiac echography (Figure 5.77). The first one, with a diameter of 8 or 10 Fr, has a four-way steerable tip (160° anteroposterior and right-left lateral deflections). This catheter carries at its distal end a forward facing 64-element vector phased-array acquiring images on the longitudinal plane as far as 16 cm depth; this catheter can also acquire color flow and pulsed-/continuous-wave Doppler images. The second one, a 9 Fr fixed curve catheter, has the ultrasound element placed at the tip. Thanks to an internal rotation system, the transducer acquires, on a horizontal plane, circular images over 360° with the catheter's tip located centrally and with an image depth up to 8 cm. Limitations of this ultrasound system are catheter nondeflectability, which can be overcome by using preshaped angled sheaths, and lack of Doppler capability. Color Doppler imaging can be useful in many situations regarding transseptal catheterization. For example, it may easily detect a patent fossa ovalis or guide the reinsertion of a catheter from the right atrium back to the left atrium, avoiding an unnecessary transseptal puncture.

The catheter for intracardiac echo is, usually, inserted via the left femoral vein, in order not to interfere with the long sheath–dilator complex utilized for transseptal puncture and which is, instead, positioned in the right femoral vein. Afterwards, one advances the catheter

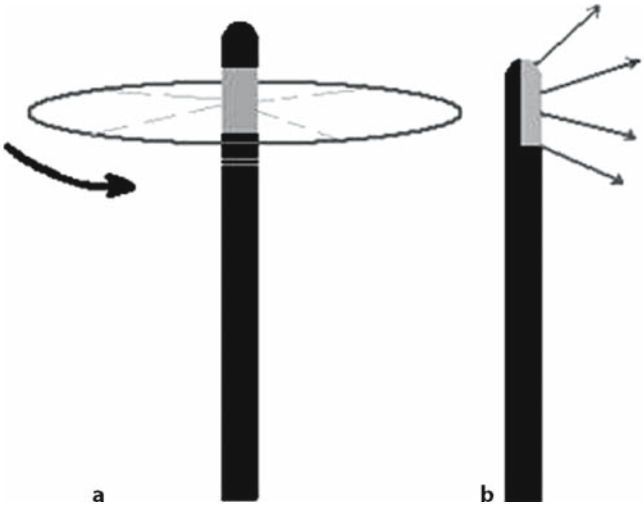


Figure 5.77 Catheters' distal ends for intracardiac echo. a 9 Fr catheter, fixed curve, acquiring an image over 360° where the catheter's tip indicates the acquisition circle's center. b 8 or 10 Fr catheter, deflectable over four planes (anterior, posterior, right, left) acquiring a triangular image where the apex, of 90°, is represented by the catheter's tip

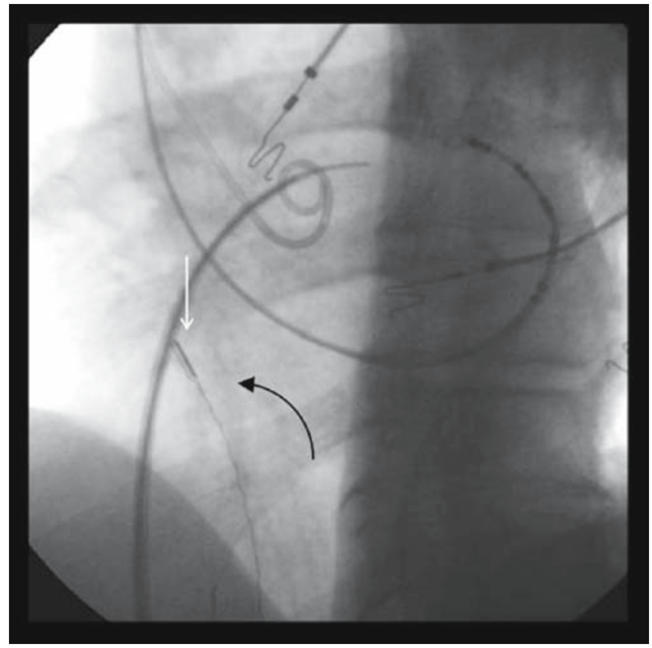


Figure 5.78 Details of Figure 5.72 where, with a white arrow, the sector ultrasound catheter active face is shown. With the black arrow, instead, we want to show how it is possible to bend the catheter, in this case into posterior direction, in order to position the sector scanning facing the interatrial septum and the left atrium

up along the venous course, being extremely careful, especially at the iliac vein passage into the inferior vena cava and at the inferior vena cava passage into the right atrium, as it is a much stiffer catheter compared to electrophysiologic catheters. Deflectability of one of these probes can make its positioning easier.

Once within the right atrium, the catheter is positioned at the height of the fossa ovalis that can be clearly seen as a thin and fibrous lamina in the interatrial muscular septum. An optimal view for guiding transseptal puncture must visualize the interatrial septum with a large and well-evident fossa ovalis and demonstrate adequate space behind the interatrial septum on the left atrial side. This view should not include the aortic root structure. In case of the fixed curve catheter, adjustment movements are just those of pushing forward or withdrawing the catheter so as to optimize the acoustic window. Deflectable catheters are easier to position, by taking advantage of the four deflection movements (anterior, posterior, right lateral, left lateral) and then the catheter can be locked in position. Moreover, as acquisition takes place on the catheter's longitudinal plane, rotation movements allow one to change the acquired window. For example, from the fossa ovalis, a counterclockwise rotation movement enables one to see the aortic bulb, placed more anteriorly, whereas a clockwise rotation allows one to see first the left atrial appendage and then the left atrium's posterolateral wall along with the left pulmonary veins' ostium. When using this catheter, one must remember that the active face, with the corresponding image directory, can be clearly recognized by fluoroscopy as it is more radio-opaque (Figure 5.78).

In the following images some examples of transseptal puncture are shown under intracardiac echocardiography guidance (Figures 5.79–5.95).

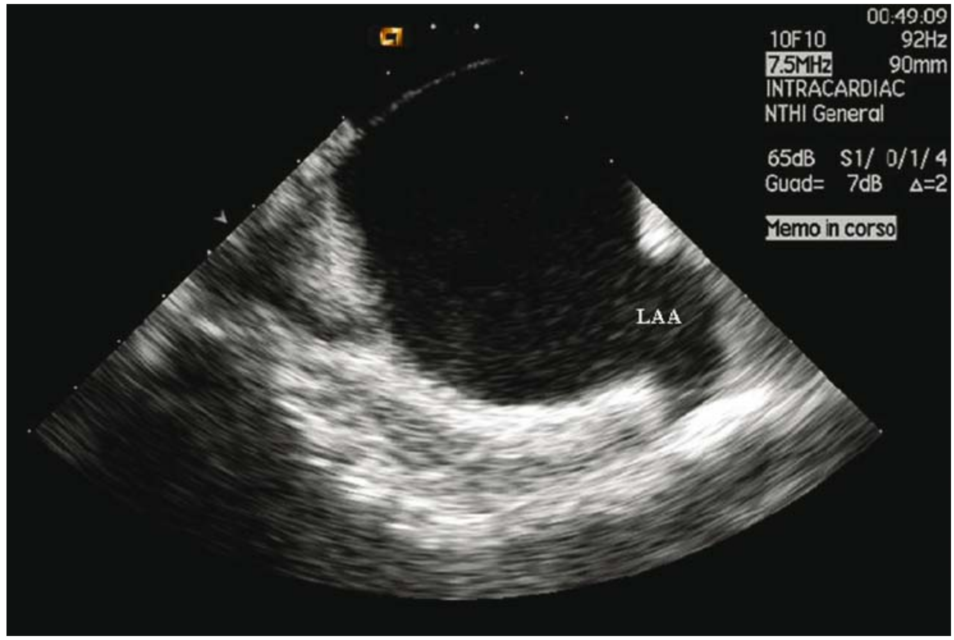


Figure 5.79 Intracardiac echo showing, looking from the right side, the fossa ovalis and the left atrium. Please notice how the left atrial appendage (*LAA*) can be clearly visualized

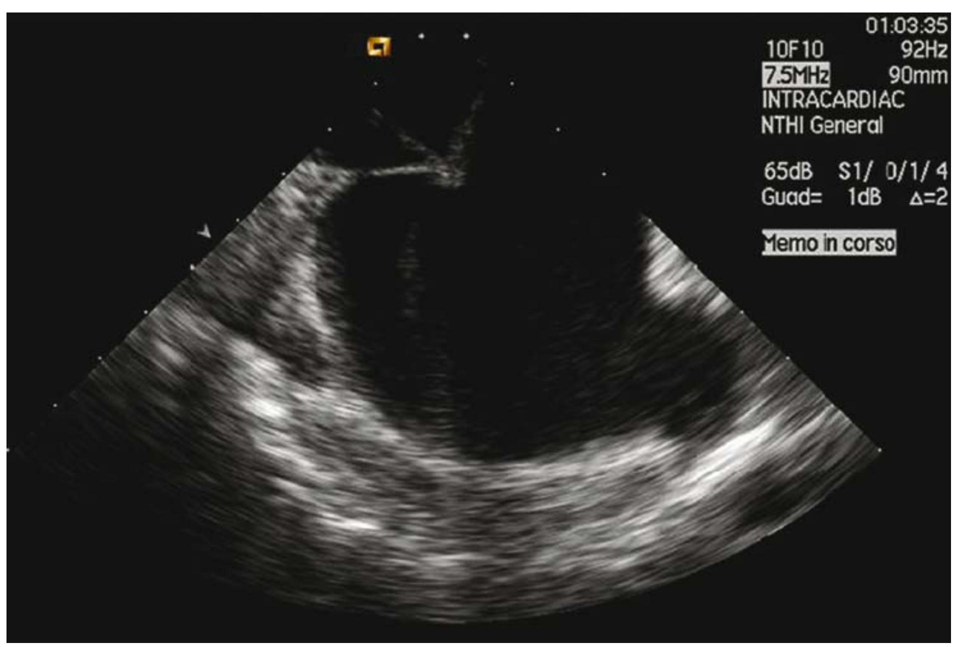


Figure 5.80 In the same acoustic window one can see the transseptal needle tenting the fossa ovalis

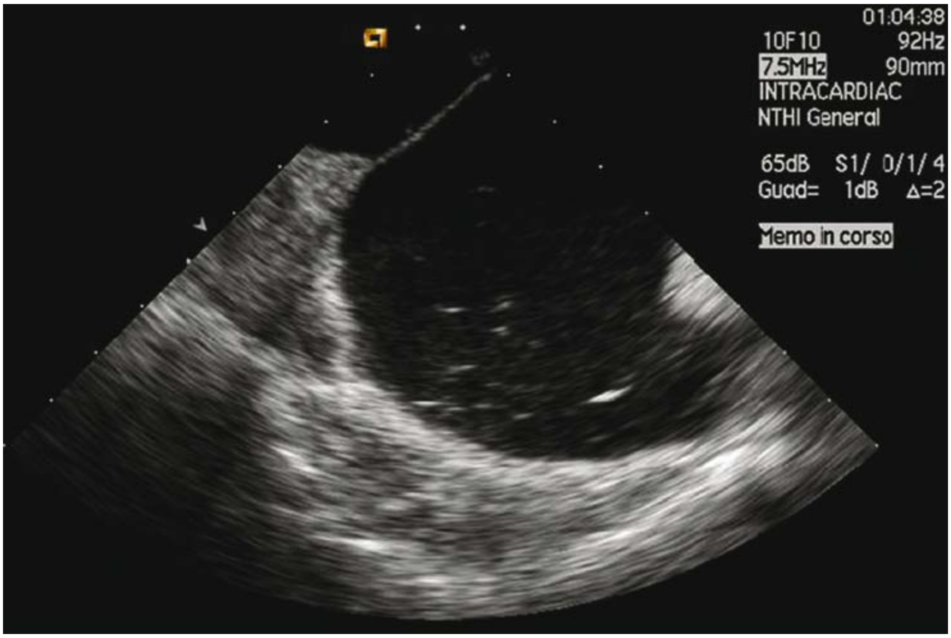


Figure 5.81 Soon after the needle crossed the fossa ovalis it distends, and one can see contrast material being infused to be confirmed as echo contrast within the left atrium

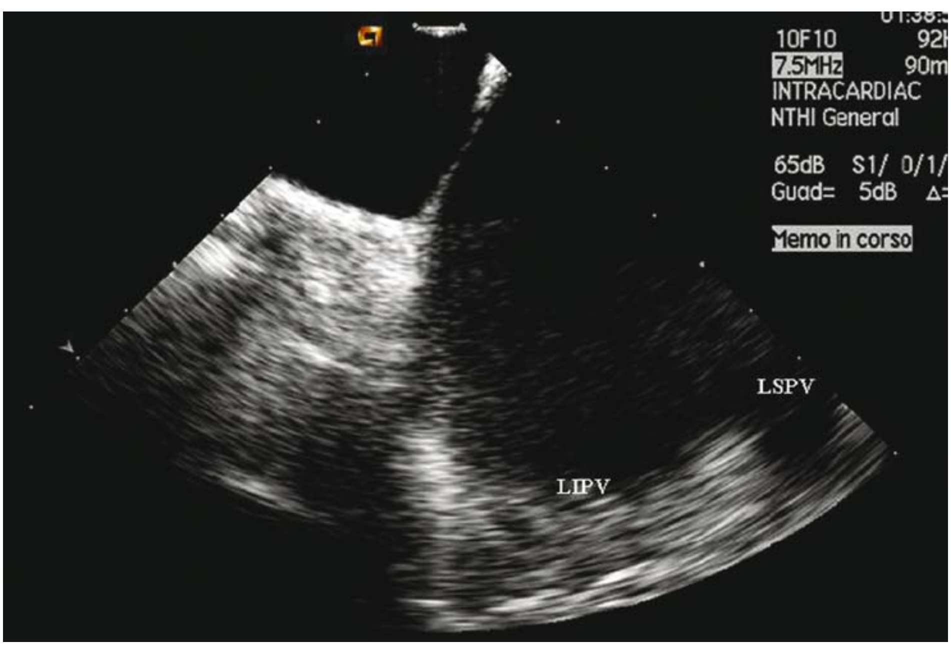


Figure 5.82 In this image, one can see a fossa ovalis that is thin but of minor size compared to the previous case. Moreover, the echographic probe is turned more toward the back as it is ascertained by visualization of ostia of the left superior pulmonary vein (*LSPV*) and of the left inferior pulmonary vein (*LIPV*)

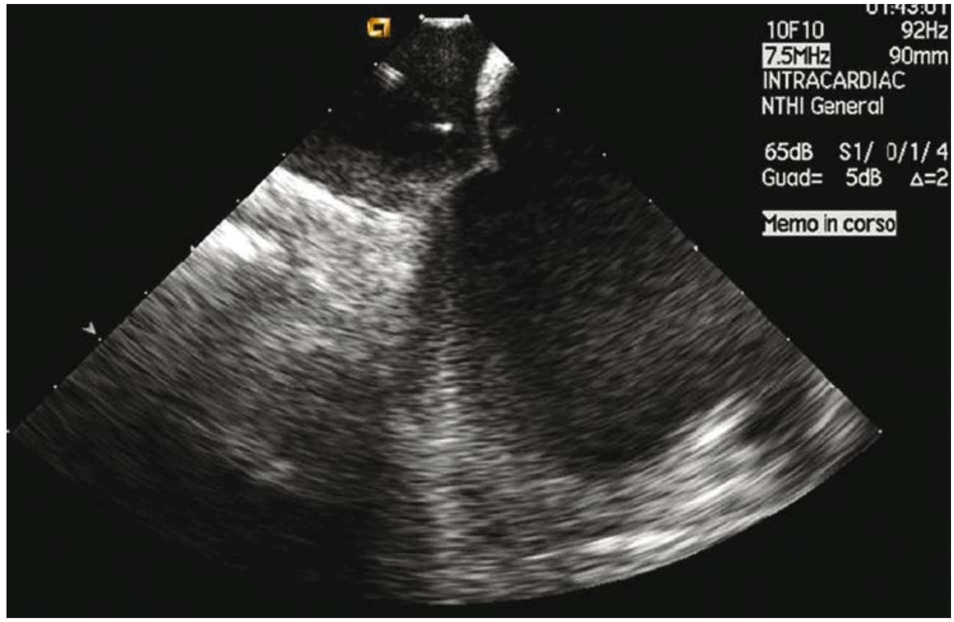


Figure 5.83 The transseptal needle tents the fossa ovalis

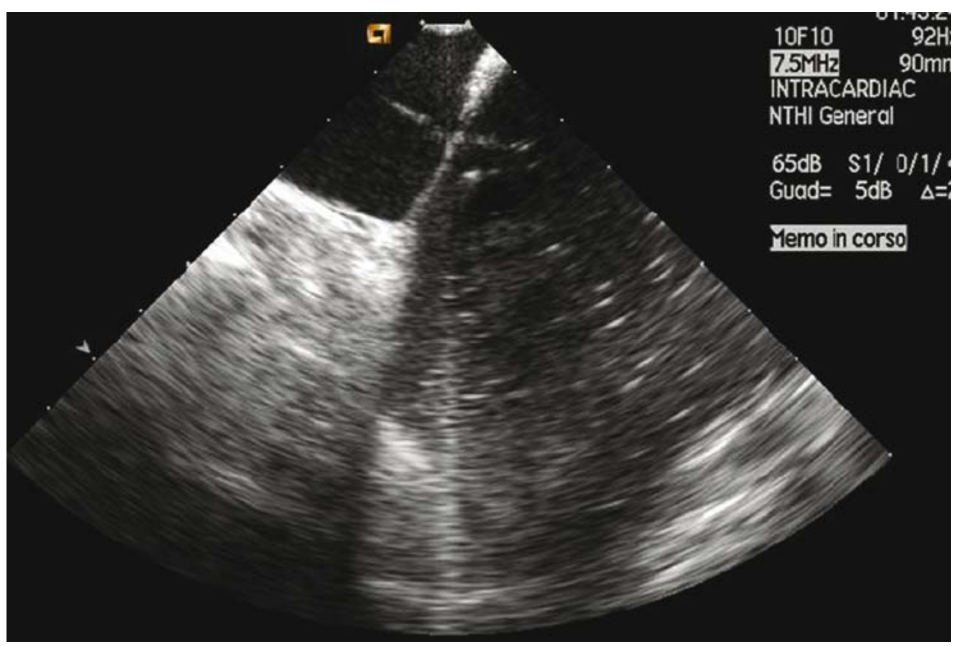


Figure 5.84 The transseptal sheath location in the left atrium is confirmed by an injection with saline forming echo microbubbles in the left atrium

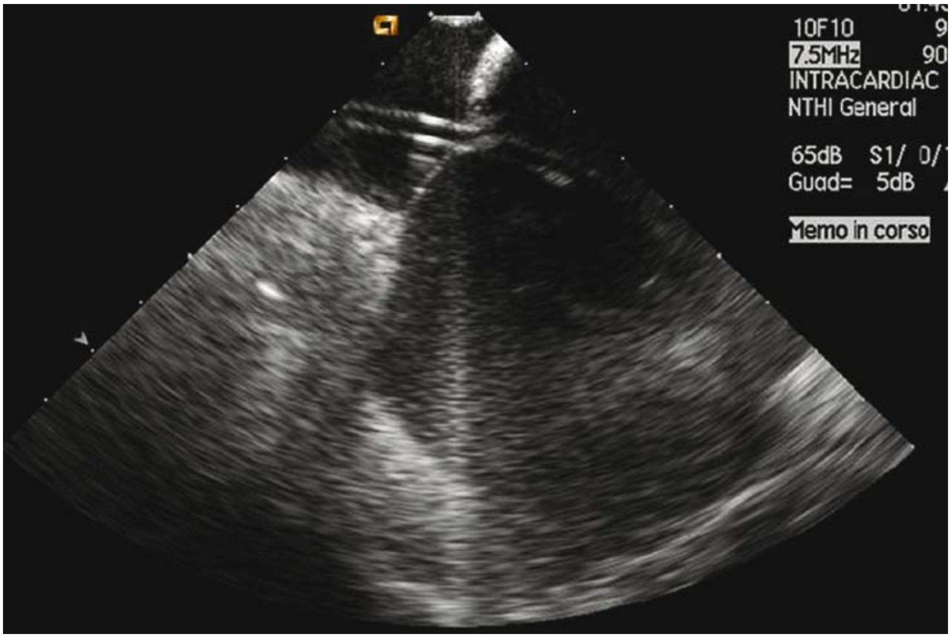


Figure 5.85 Within the left atrium the long sheath is positioned and it is clearly seen as a track-like image crossing the interatrial septum

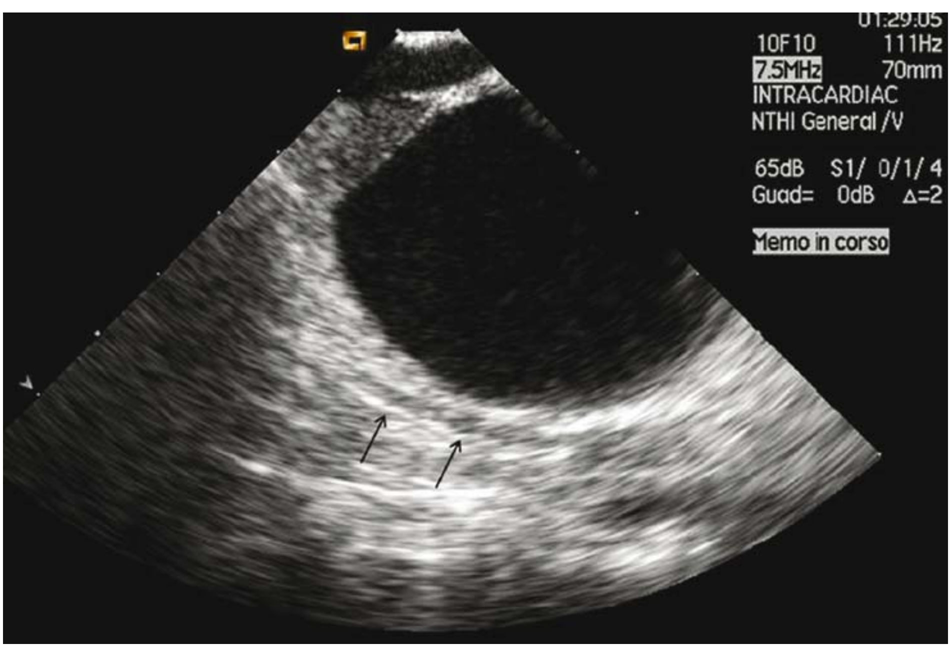


Figure 5.86 In this image one can see a thick and lipomatous interatrial septum with a small and thick fossa ovalis. Please also notice, posteriorly to the left atrium, a track-like image (arrow) corresponding to the oesophagus in its portion contiguous with atrium

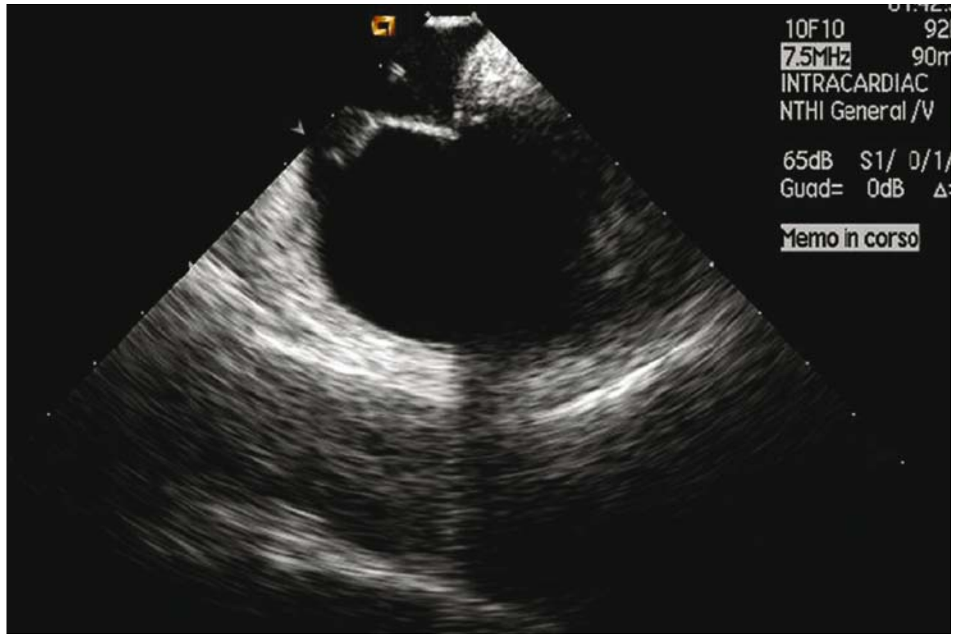


Figure 5.87 The transseptal needle tents the fossa ovalis

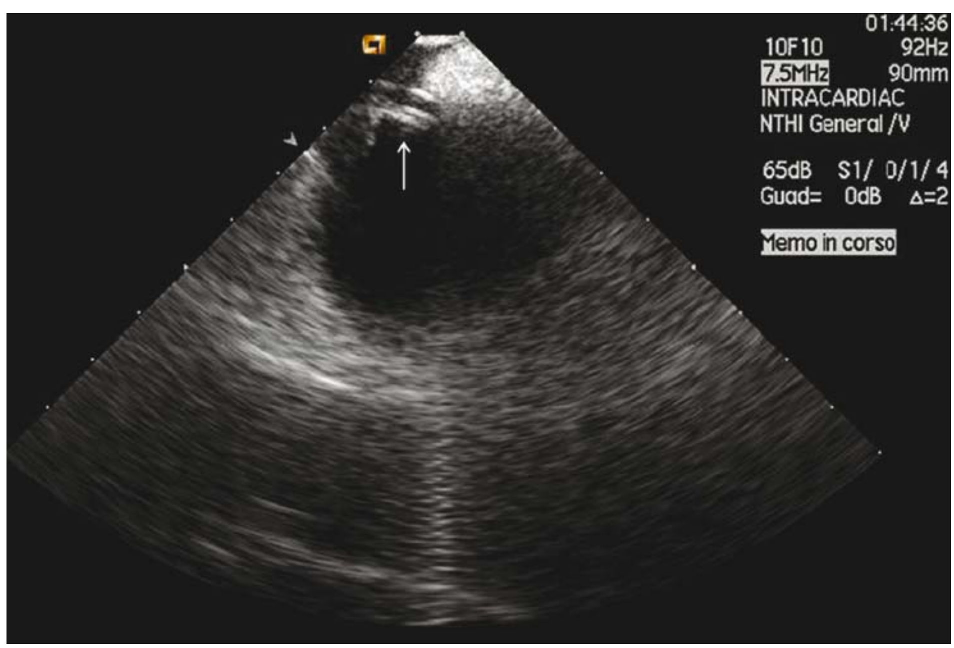


Figure 5.88 The long sheath (arrow) crosses the interatrial septum

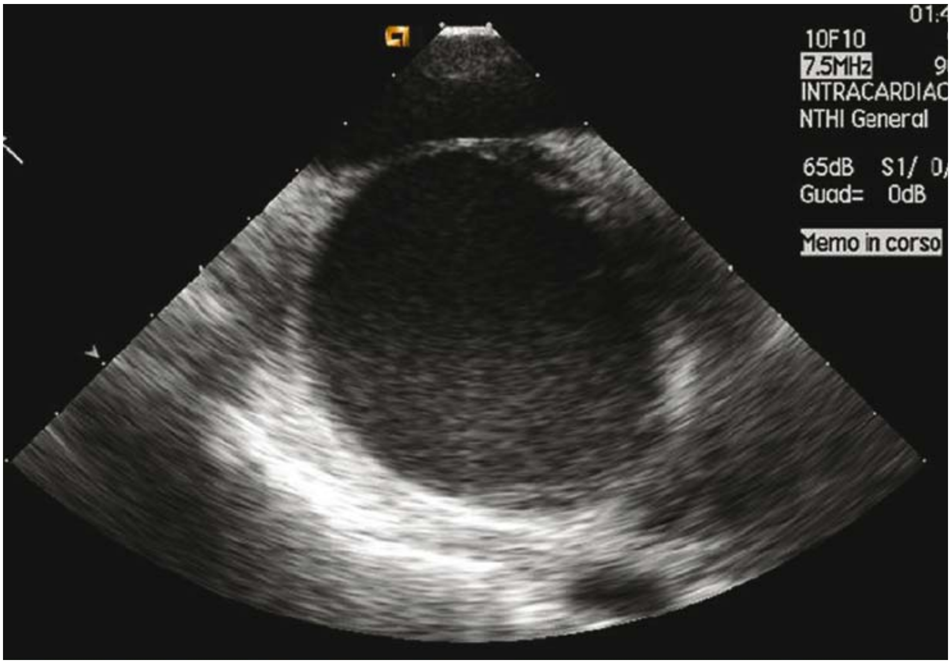


Figure 5.89 This sequence of echocardiographic images illustrates a patient in whom it was not possible to perform a transseptal puncture via standard approach but it was necessary to use the transseptal radiofrequency (*RF*) probe (see Figures 5.69–5.75). Please notice how the fossa ovalis is apparently normal as to size and thickness

Figure 5.90 The transseptal needle is positioned at the height of the fossa ovalis and one can see the tenting

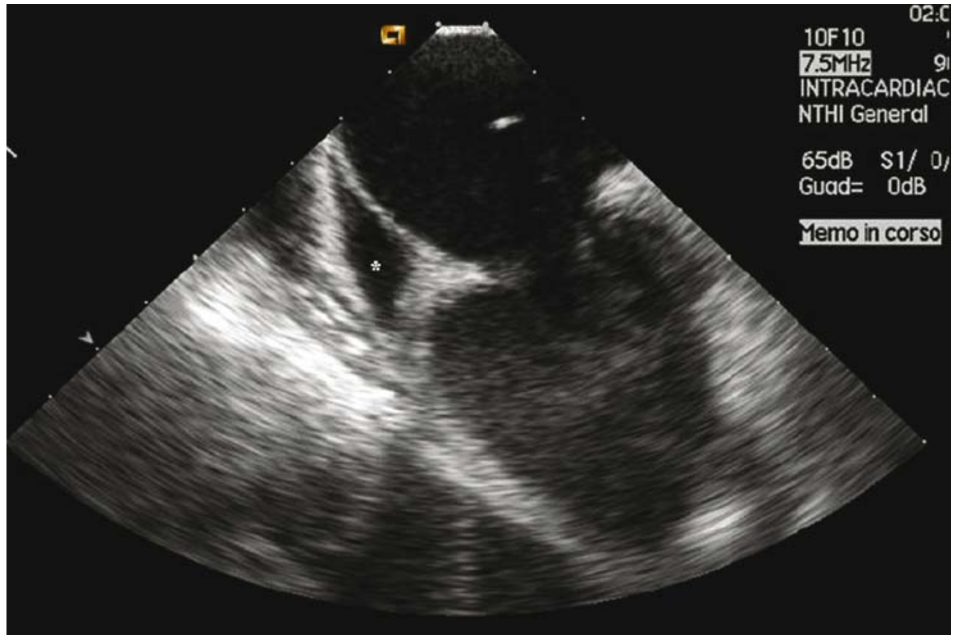


Figure 5.91 If one further pushes the needle toward the left atrium's lateral wall, the interatrial septum moves toward the left, dragging along also the right atrium. In fact, one can notice how the right atrium's posterior wall is pulled and comes unstuck from the pericardium (*)

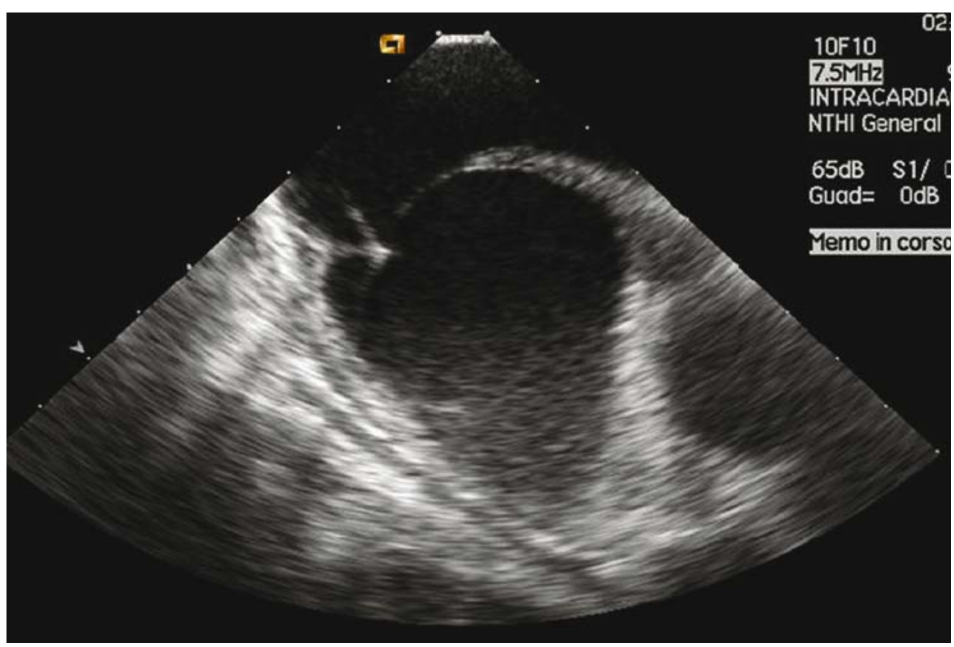


Figure 5.92 The transseptal needle has been replaced by the transseptal radiofrequency (*RF*) probe. The sheath–dilator complex has been positioned on the fossa ovalis, in a slightly lower position compared to the previous images

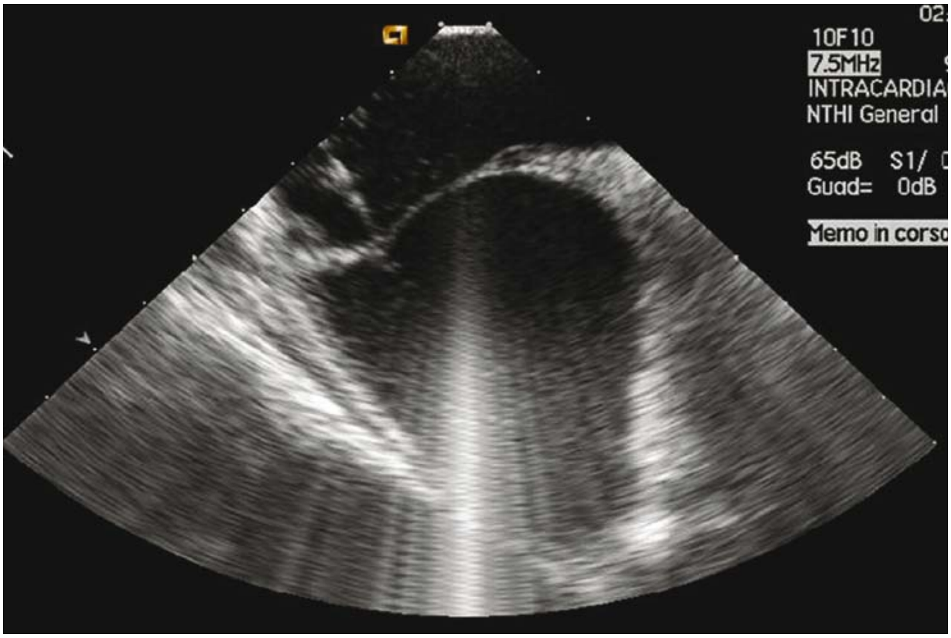


Figure 5.93 By applying radiofrequency (*RF*), which can be seen as a cone of artifacts, the transseptal *RF* probe's tip is successful in piercing the fossa ovalis

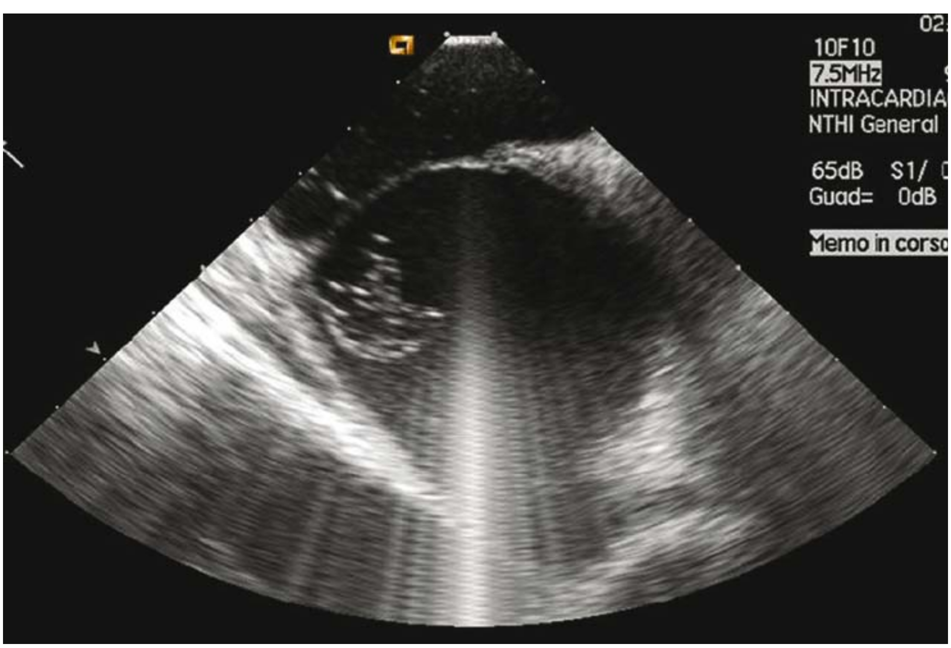


Figure 5.94 During radiofrequency (*RF*) application, one pushes forward the probe's tip and, simultaneously, injects the contrast material, which can be visualized within the left atrium

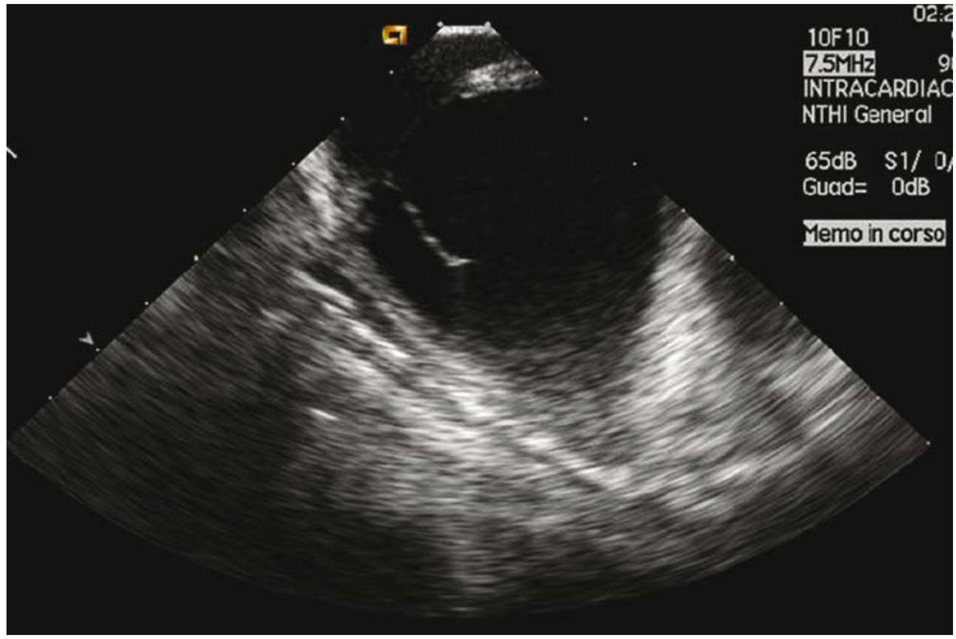


Figure 5.95 Once the radiofrequency (*RF*) application is over, the probe's tip is positioned within the left atrium. At this point one makes the sheath-dilator run over the probe in order to carry the long sheath into the left atrium

5.4 Double Transseptal Puncture

There are circumstances, as for instance atrial fibrillation ablation, requiring two catheters to be positioned within the left atrium. Insertion of two catheters via the transseptal approach can be performed in three ways: double transseptal puncture and two long sheaths in the left atrium, one single puncture and two long sheaths in the left atrium, and one single puncture and one long sheath in the left atrium.

In order to have two long sheaths within the left atrium, one can perform a second transseptal puncture that will be carried out just like the first one; however, it will be eased as the sheath already inserted into the left atrium will tell us about the crossing point through the fossa ovalis (Figures 5.96–5.99). Alternatively, after having positioned the first long sheath within the left atrium, one advances through this the dilator with the guidewire as far as the left atrium, then one inserts the wire into a pulmonary vein, usually the left superior pulmonary vein, and then pulls back the sheath–dilator complex into the right atrium, leaving within the left atrium just the guidewire crossing the passage created by the transseptal puncture. At this point the second transseptal puncture can be performed in the standard way with the help of the long wire passing through the fossa ovalis. The double transseptal puncture is usually performed in two separate sites, even if very close, of the fossa ovalis. The two different holes allow a good maneuverability of catheters and long sheaths in the left atrium without creating a friction against each other; this is the reason such approach is preferred by many operators.

In order to avoid a second transseptal puncture, one can leave in the left atrium the first guidewire and repeat the maneuver of searching for the fossa ovalis, withdrawing a second long sheath–dilator complex from the superior caval vein into the right atrium down to the fossa ovalis, using the PA projection. In this case, a second long guidewire, and not the Brockenbrough needle, is inserted in the sheath–dilator complex. The RAO view allows one to check that the dilator tip is in the correct axis, which corresponds to the crossing of the first wire passing through the transseptal hole. The guidewire is withdrawn inside the dilator and a LAO view is selected. After checking the dilator tip's correct position in this view, the sheath–dilator complex is delicately advanced so that the dilator tip slightly forces the fossa. Pushing

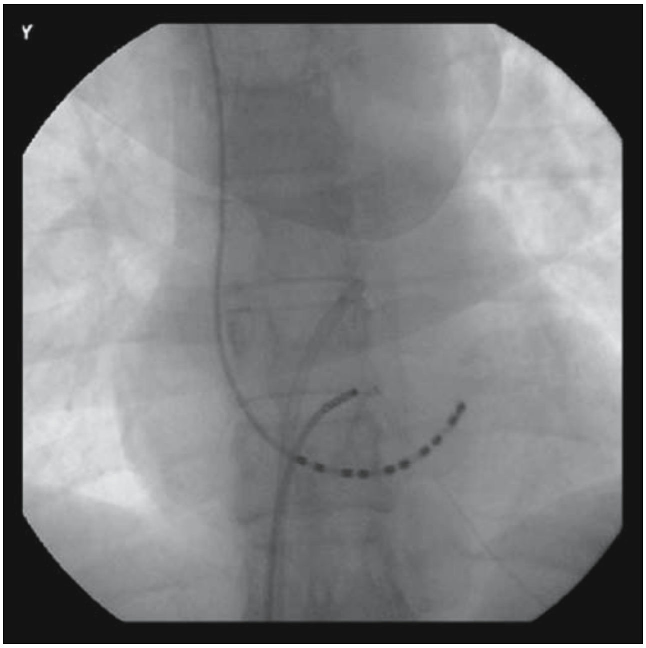


Figure 5.96 Transseptal puncture enabled the long guidewire to be inserted into the left atrium. In the anteroposterior (*AP*) view we can also see a quadripolar catheter in the His position and a decapolar catheter inserted into the coronary sinus (*CS*)

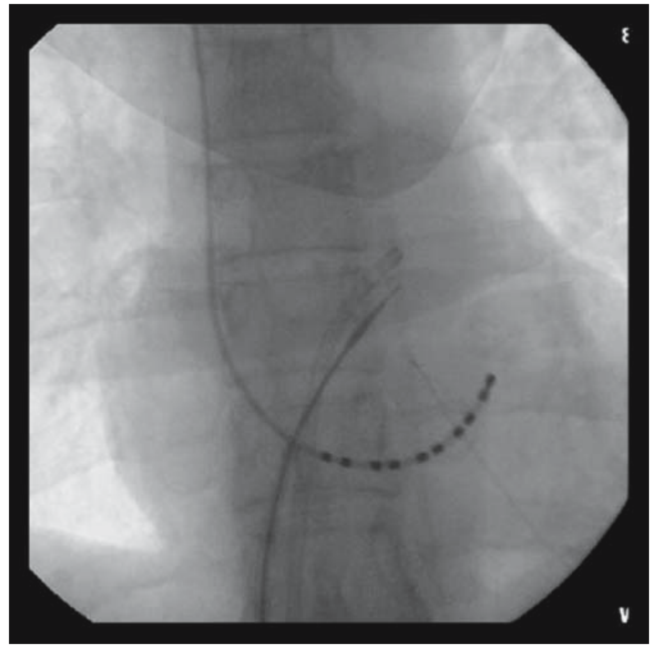


Figure 5.97 A second sheath–dilator–needle complex is advanced into the right atrium. Then one begins to position the needle at the level of fossa ovalis and carries out puncture by the aid of the point represented by the previously positioned long guidewire

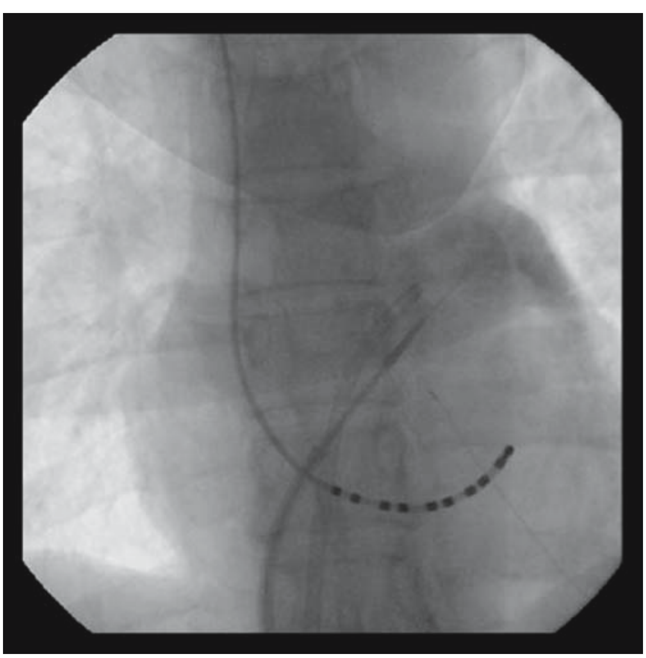


Figure 5.98 Injection of dye confirms the second transseptal passing into the left atrium

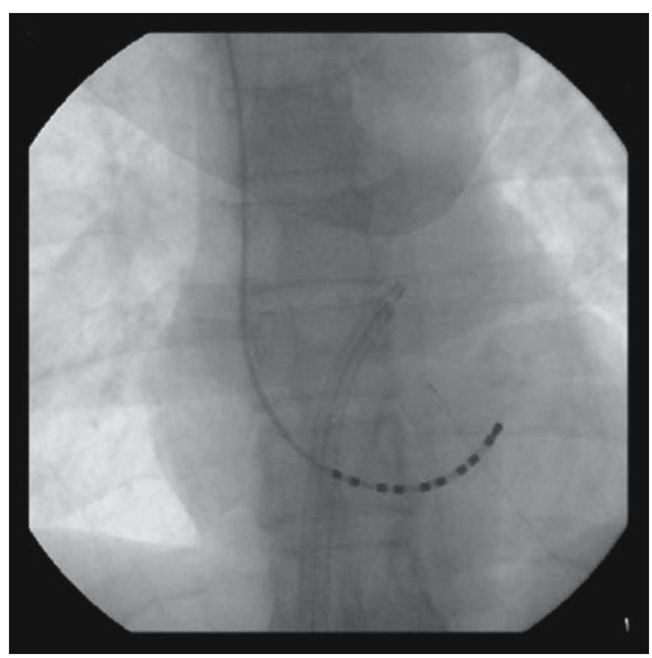


Figure 5.99 The second long sheath is then advanced into the left atrium

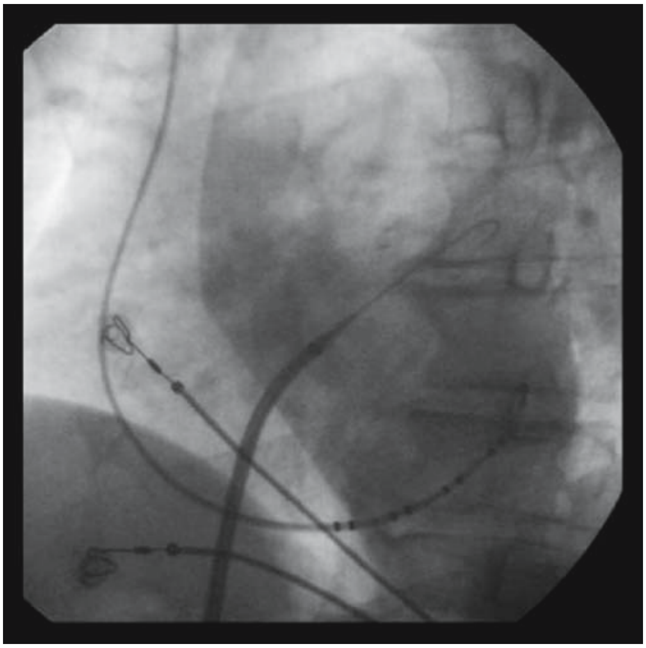


Figure 5.100 In the left anterior oblique (*LAO*) view, one carries the sheath–dilator complex into the left atrium by pushing it along the long guidewire

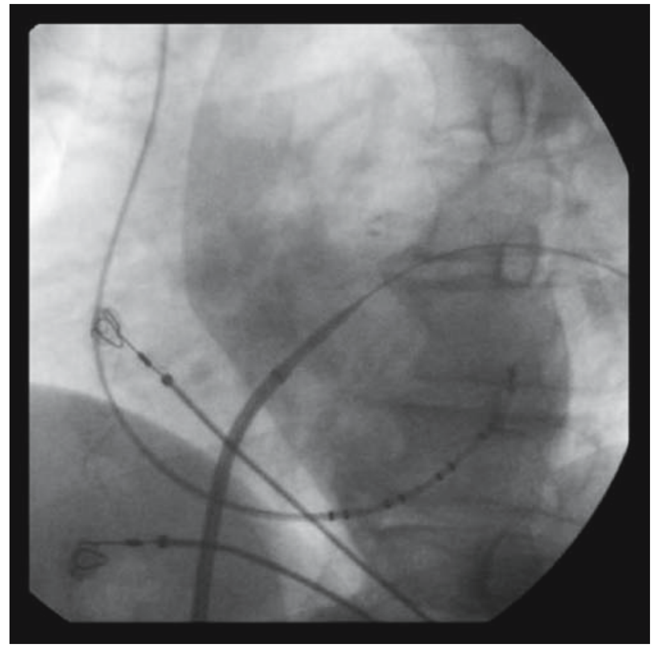


Figure 5.101 The long guidewire is positioned within a pulmonary vein, usually the left superior pulmonary vein, so that it remains steady during the following maneuvres. The sheath–dilator complex is pulled away within the right atrium, leaving the long guidewire in place

forward the guidewire, this directly passes into the left atrium through the same hole made by the previous transseptal puncture. Once both guidewires are within the left atrium, it will be possible to push forward the two sheath–dilator complexes into the left atrium and then pull away the two dilators along with the respective guidewires (Figures 5.100–5.106).

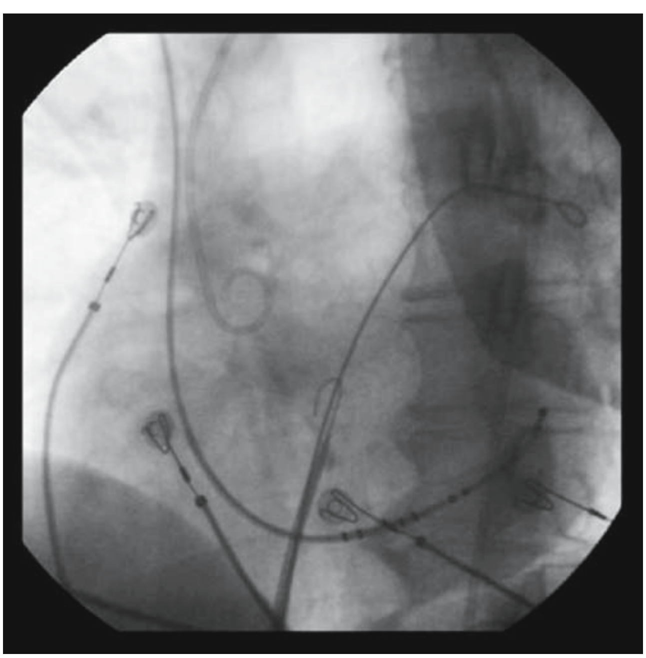


Figure 5.102 The sheath–dilator complex is pulled out to the right atrium, leaving the long guidewire in place. Meanwhile, the second sheath–dilator complex is carried into proximity of the fossa ovalis (passage is made evident by the long guidewire passing into the left atrium through the first puncture). When the dilator's tip is in the appropriate place, ascertained both by left anterior oblique (*LAO*) and right anterior oblique (*RAO*) views, the guidewire is pulled until it becomes thoroughly covered by the dilator

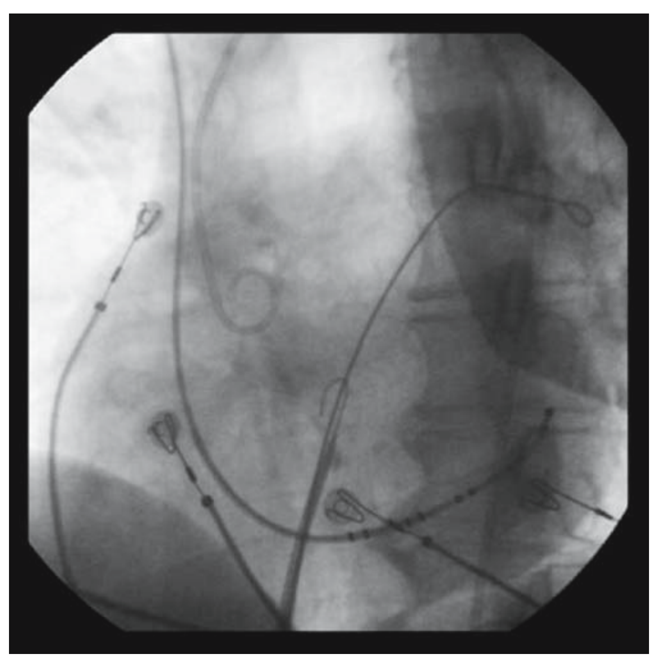


Figure 5.103 The sheath–dilator complex is delicately pushed so that the dilator's tip slightly forces the fossa, then one begins to push the guidewire forward. If position was correct, the guidewire directly passes into the left atrium through the hole made by the previous transseptal puncture

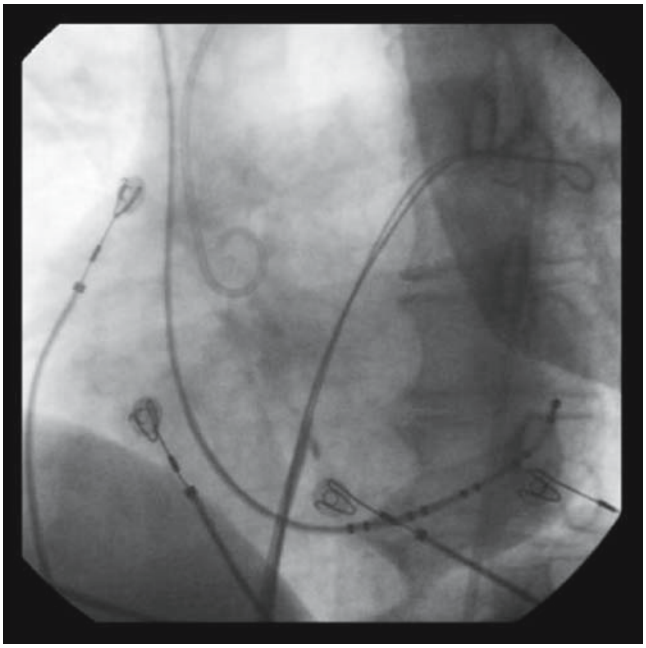


Figure 5.104 The second guidewire is pushed forward into the left atrium

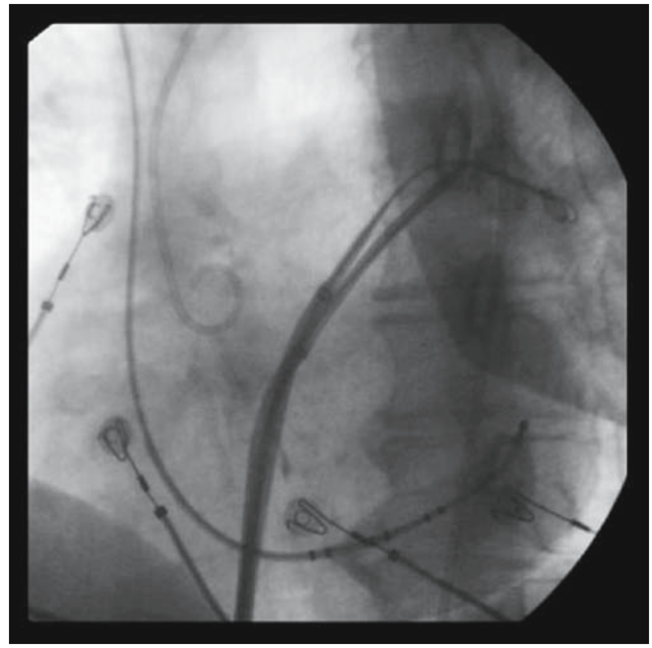


Figure 5.105 The two sheath–dilator complexes are pushed into the left atrium

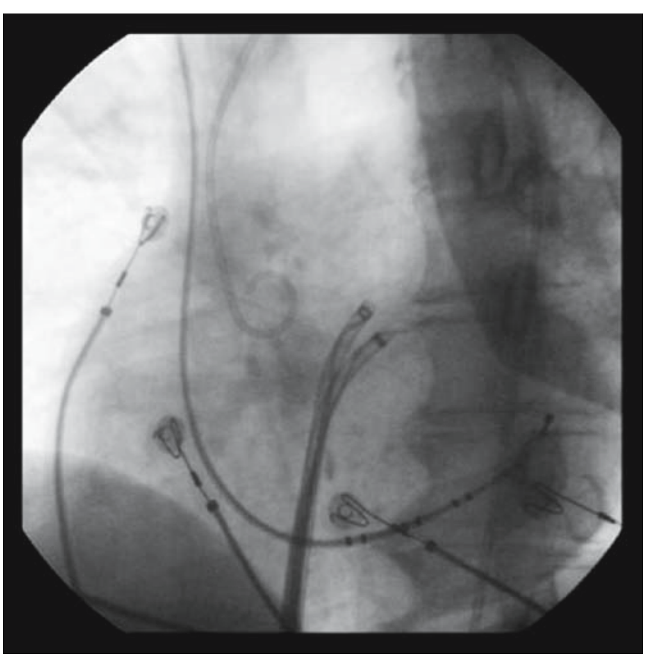


Figure 5.106 The two dilators as well as their relative guidewires are pulled away, leaving within the left atrium the two long sheaths. Then, in this patient, we positioned two long sheaths within the left atrium, by carrying out one transseptal puncture only

At this point we have the two sheaths within the left atrium. The two catheters, the ablation and the mapping catheter, will be inserted within the two respective long sheathes. With this maneuver, the two long sheaths reach the left atrium through the same hole; this may create a friction against each other, making their movement difficult, with a higher chance to lose the position. To avoid it, during the procedure, it is suggested to withdraw the sheaths back in the right atrium and to leave in the left atrium just the two catheters.

In case one prefers to carry out one transseptal puncture only and keep within the left atrium one single long sheath, it is necessary to leave the long guidewire in one of the left pulmonary veins, to withdraw the sheath–dilator complex in the right atrium, and to push the ablator forward into the right atrium. In the LAO view, the ablation catheter is bent so that it runs parallel and inferior to the guidewire on the septal side and then one pushes it forward so that it sticks to the septum. One checks in the RAO view that the catheter and the guidewire are on the same plane and, afterwards, again in the LAO view one pushes the catheter so that it passes through the hole made by the previous puncture; the catheter's tip usually crosses the septum passing under the guidewire because the wire keeps the hole open (Figures 5.107–5.116). With this maneuver too, the catheter and the sheath use the same access to the left atrium, so it is better to withdrawn the sheaths back in the right atrium whenever is possible and to leave in the left atrium just the two catheter shafts.

Manipulation of the mapping ablation catheter occasionally results in an unexpected withdrawal from the left atrium back to the right atrium. To avoid the need for additional transseptal puncture, once the patient has been heparinized, reinsertion of the catheter may be considered as the first preferred choice. In this case, the maneuver to perform is the same as explained above. In difficult cases, the catheter reinsertion site can be performed under intracardiac echo guidance; in fact Doppler color flow imaging may easily detect the tiny shunt flow toward the right atrium across the residual septal defect at the previous transseptal puncture. The residual defect after transseptal catheterization typically resolves completely during follow-up.

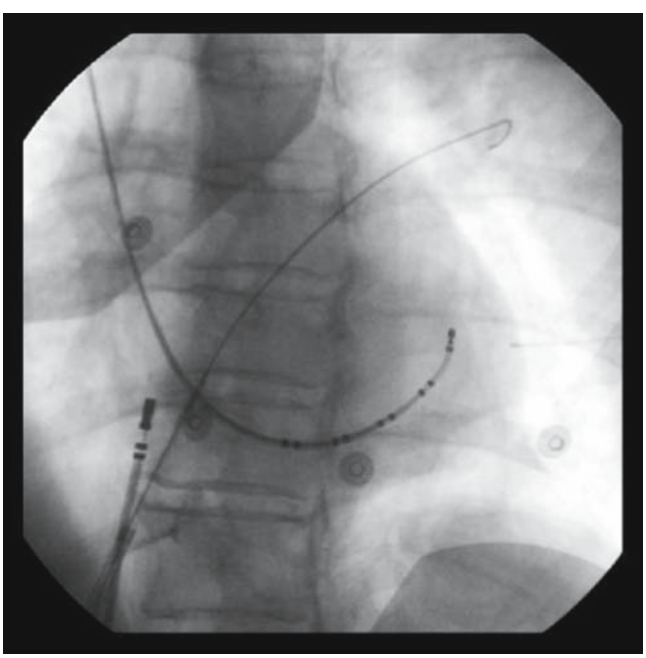


Figure 5.107 The left anterior oblique (*LAO*) view. The ablation catheter is carried into the right atrium. Within the left atrium lies the long guidewire inserted in the left superior pulmonary vein, while the sheath–dilator complex has been withdrawn into the right atrium

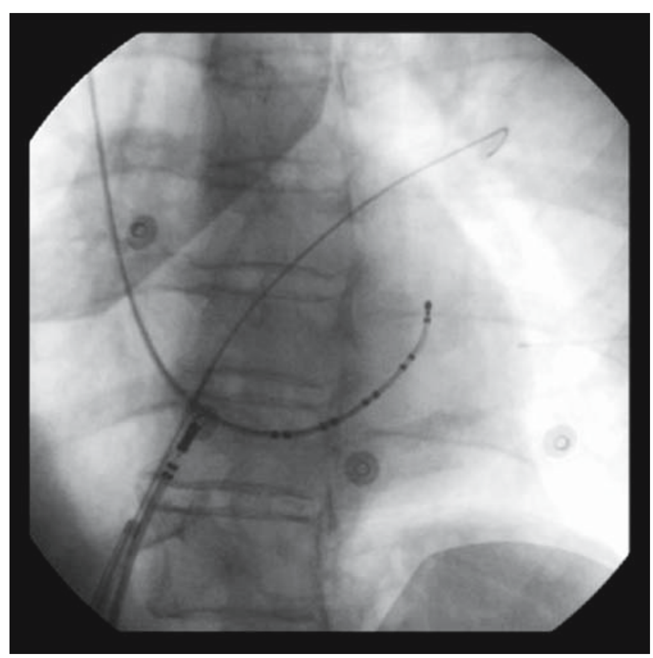


Figure 5.108 In the same view, one bends the ablation catheter until its tip gets the same angulation, with regard to the interatrial septum, as the long guidewire

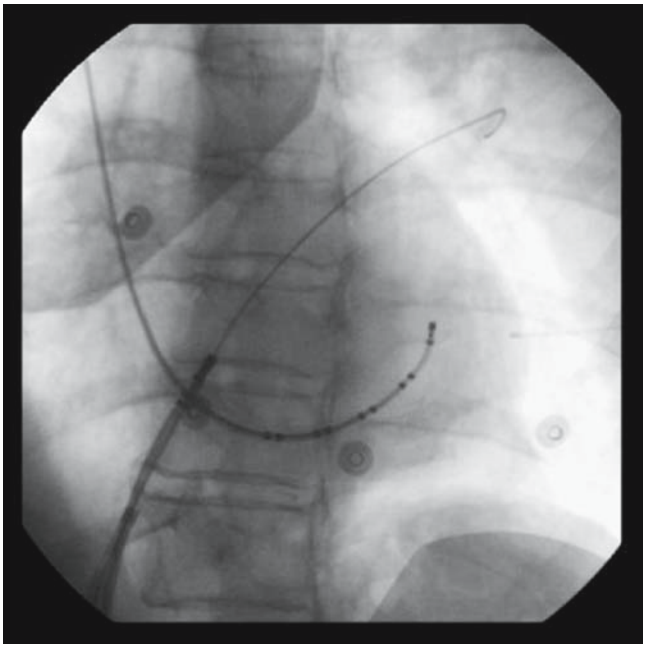


Figure 5.109 Then, the ablation catheter is pushed until its tip comes into contact with the interatrial septum, where the previous transseptal puncture had been carried out

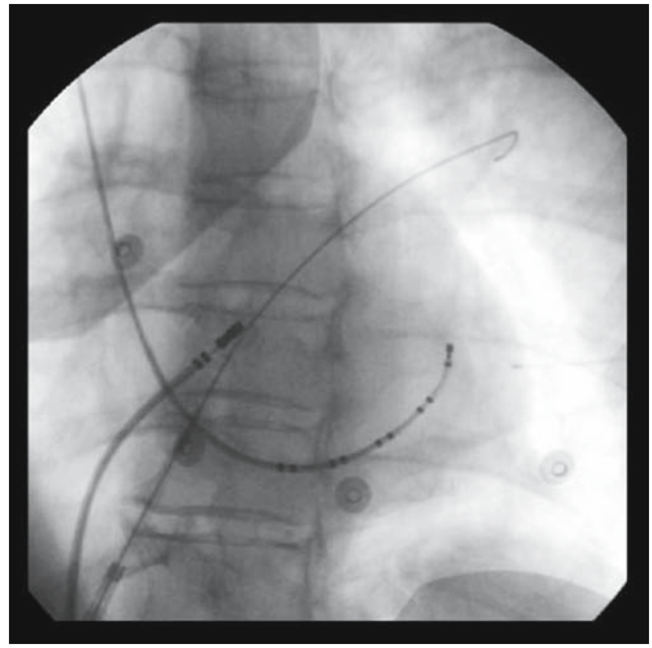


Figure 5.110 Through the hole made by the transseptal puncture, the ablation catheter is pushed forward into the left atrium. The fossa ovalis, as usual, puts up minimum resistance and the catheter tends to bend. By slight clockwise and counterclockwise twists one tries to pass through the fossa ovalis

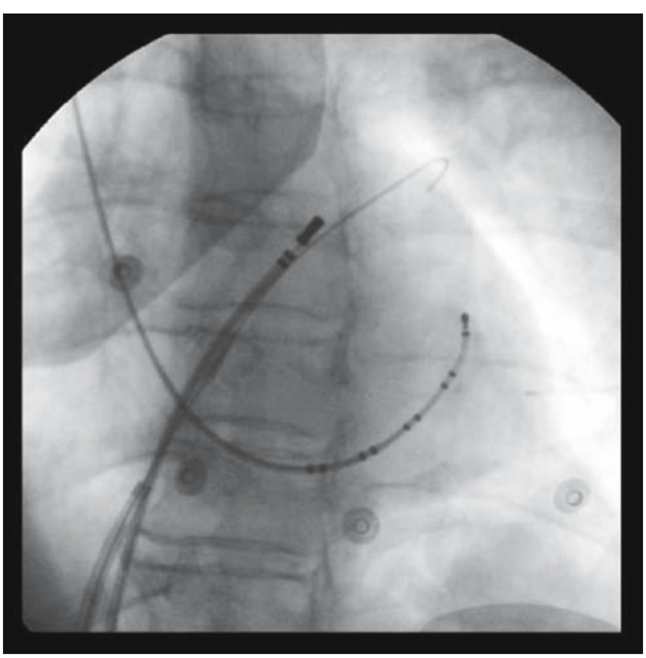


Figure 5.111 At this point the catheter has sprung into the left atrium

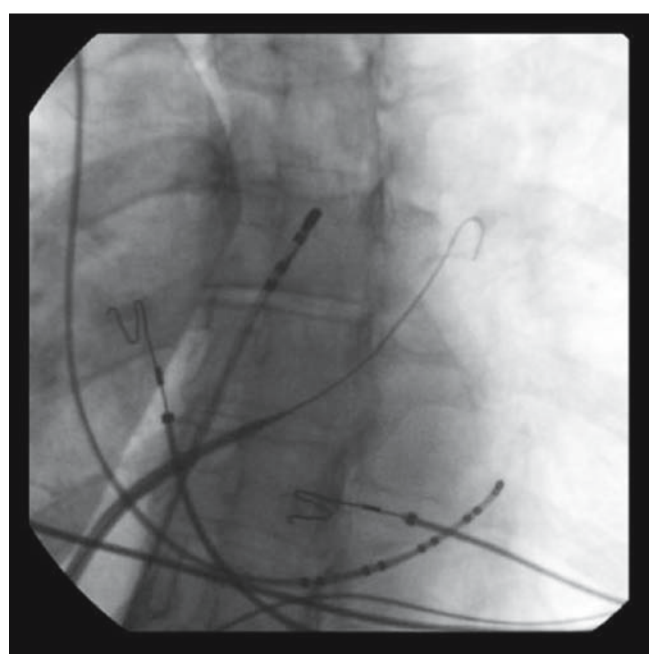


Figure 5.112 One pushes the sheath–dilator complex into the left atrium by making it go up along the guidewire

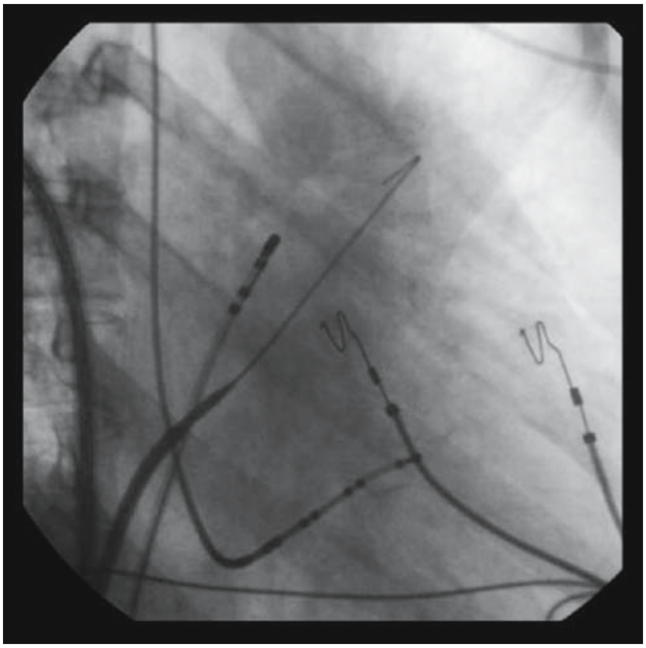


Figure 5.113 Since the passage made by the transseptal puncture is already engaged with the ablation catheter, the fossa ovalis can put up resistance to the sheath–dilator complex trying to pass through the guidewire. In this case it is convenient to position in the right anterior oblique (*RAO*) view and carry out minimum clockwise and counterclockwise twists till one is successful in forcing the fossa ovalis

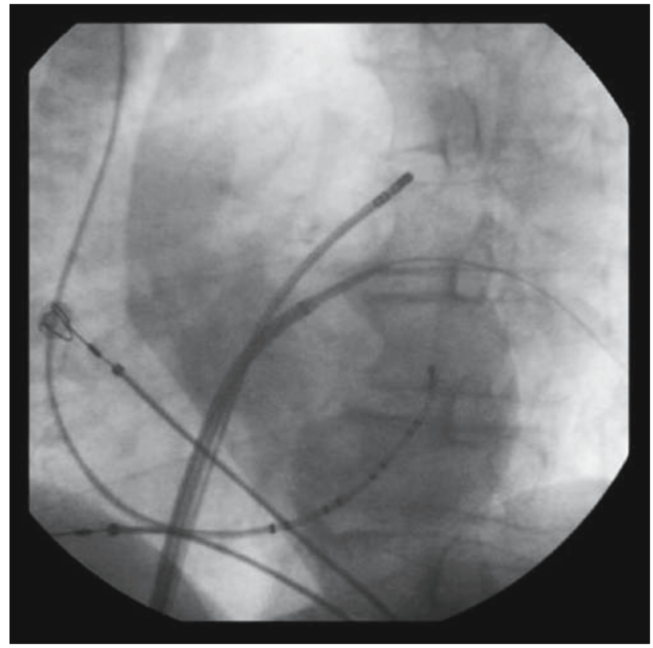


Figure 5.114 In the left anterior oblique (*LAO*) view, one verifies that the sheath–dilator complex has reached the left atrium

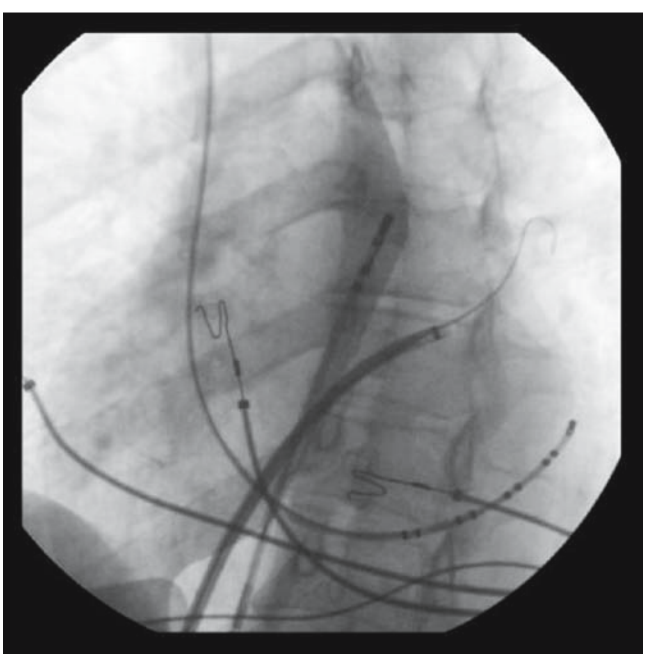


Figure 5.115 The dilator–wire complex is pulled away, leaving the sheath within the left atrium

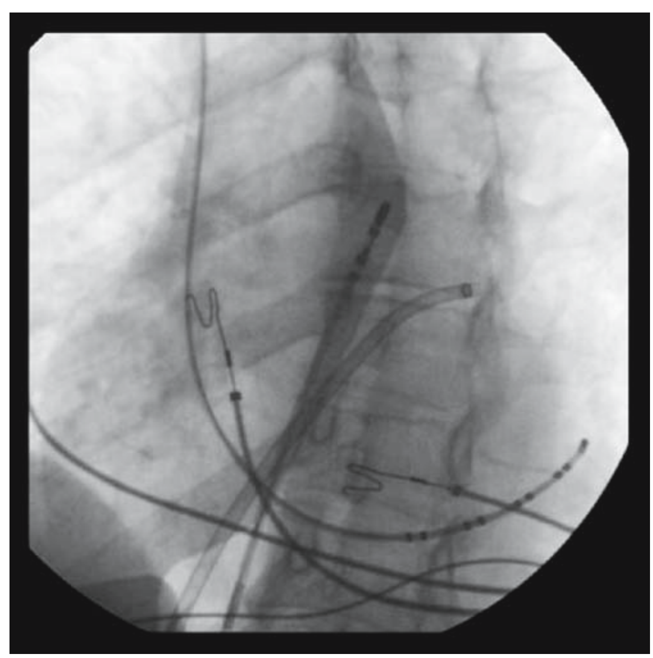


Figure 5.116 At this point we have the ablation catheter as well as the long sheath within the left atrium

6

Accessory Pathways Ablation

Accessory pathways (APs) are muscular fibers that connect the atria to the ventricles without passing through the specific conduction tissue of the atrioventricular (AV) node. These muscular connections course through the fibrofatty AV groove on the epicardial aspect of the attachments of the valvar leaflets of either tricuspid or mitral valves.

Anatomically, there are some differences between the structure of the tricuspid and mitral annuli. First of all, the two valvular annuli lie on different planes. The AV planes are quite parallel, but the right is inferior to the left one. Furthermore, they are slightly tilted (about 25°); the maximum distance, up to 5 mm, is reached at the posterior border while the minimum distance is at the anterior border. Also the interatrial and interventricular sulci are parallel, but the latter is to the right of the former (Figure 6.1; see also Chap. 8, Figure 8.28).

Moreover, the tricuspid ring is larger in circumference than the mitral one. Theoretically, APs can be localized in whatsoever spot of tricuspid valve annulus while the mitral ring has an area of fibrous continuity with the posterior and left leaflets of the aortic valve where APs do not occur.

Differences are present also in the valve attachment to fibrous annulus between mitral and tricuspid valves. The attachment of mitral valve is at right angle while the attachment of tricuspid valve is more of an acute angle oriented toward the right ventricle. Furthermore, the mitral ring has a well-formed fibrous annulus while the tricuspid ring may have some area of discontinuity where the atrium folds over the ventricle (Figure 6.2).

The traditional nomenclature of atrioventricular APs divides locations into right parietal, septal, and left parietal pathways (Figure 6.3).

Depending on their localization, right parietal APs are divided into anterior, anterolateral, lateral, posterolateral, and posterior APs. Particular types of right parietal APs are muscular connections between the underside of the right atrial appendage and the muscular supraventricular crest of the right ventricle; the Mahaim fibers or rate-dependent specialized conduction tissue pathways originating from the anterosuperior quadrant of the tricuspid valve.

Septal APs are usually divided, by position, into posteroseptal, midseptal, and anteroseptal APs. Actually the only true septal connections are ones crossing the AV component of the membranous septum or the midseptal pathways. All the other "septal" APs cross the AV grooves and, hence, part of the epicardial tissue. Thus these junctions are better called "paraseptal."

Left parietal APs can be localized all around the mitral valve ring except the area of fibrous continuity between the leaflets of the aortic and mitral valves; thus left-sided pathways are divided, by localization, into posterior, posterolateral, lateral, and anterolateral APs.

Although the overwhelming majority of APs connect directly the atrium to the ventricle, a number of unusual variants exist: atriofascicular pathways, the most frequent; atrio-His pathways; nodoventricular pathways; and fasciculoventricular pathways.

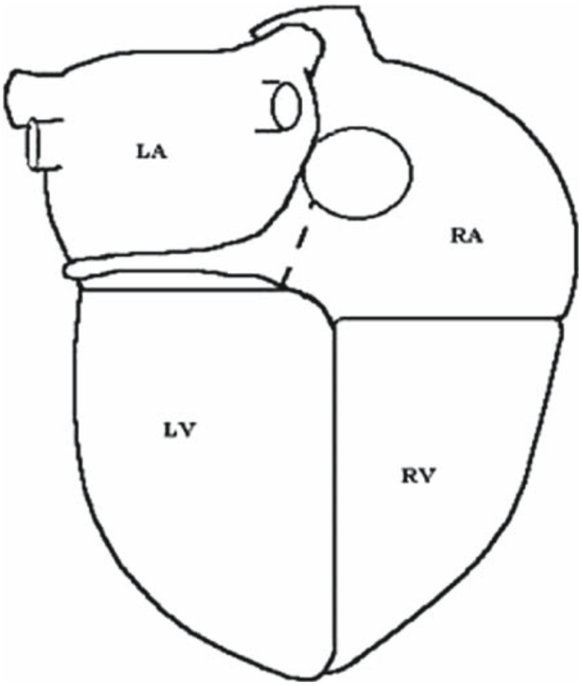


Figure 6.1 The "crux" of the heart where the atrioventricular and the septal planes cross each others at right angles. Actually, the right chambers are shifted downward in regard to left chambers in such a way that the infero medial right atrium is in contact with the posterosuperior process of the left ventricle (*LV*). Also the interatrial septum is shifted leftward and the right atrium (*RA*) wraps around the left atrium (*LA*) in such a way that the first portion of the coronary sinus lies on the superior margin of the RA–LV sulcus. The anatomy explains the reason why some posteroseptal APs are RA–LV fibers or LA–LV fibers and a left ventricle or a left atrium approach is needed for their successful ablation. *RV* right ventricle

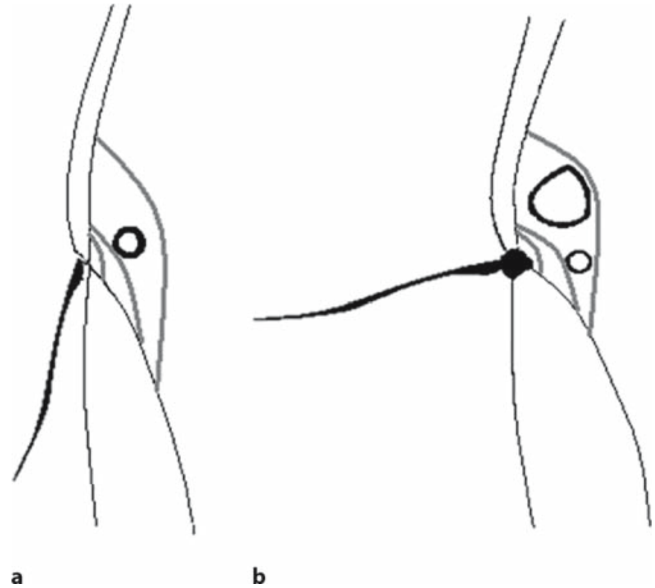


Figure 6.2 The atrioventricular junctions of tricuspid (**a**) and mitral (**b**) valves. The tricuspid valvular apparatus shows atrial and ventricular myocardiums on the same plane. Sometimes, a discontinuity of the fibrous ring allows the overlap of the two myocardial structures. The valve leaflet is angled downward, toward the right ventricle. At the mitral ring, atrial and ventricular myocardiums lie on different planes. The mitral leaflet attaches to its fibrous annulus at a right angle, making it easier to wedge an ablation catheter underneath the valve. By grey lines some possible accessory pathway (*AP*) locations are represented. The APs may bridge the fat pad close to the endocardium; may have an oblique course with an endocardial insertion, usually at the atrium, and an epicardial one, usually at the ventricle; or may run along the epicardial AV groove margin. In the mitral AV groove, epicardial APs course in close proximity to the coronary sinus, and they may be ablated from within the coronary sinus

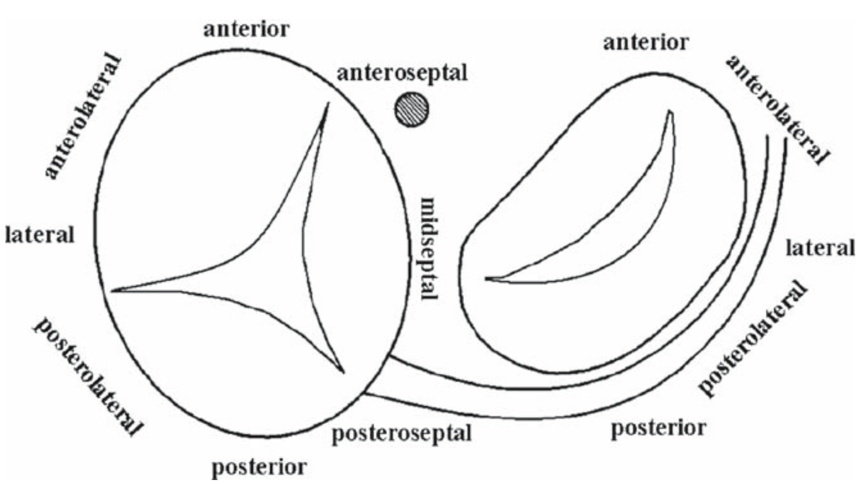


Figure 6.3 Tricuspid and mitral valves plane in the left anterior oblique (*LAO*) view. The most frequent localizations of the accessory bundles are shown. Right-sided accessory pathways (*APs*): anterior, anterolateral, lateral, posterolateral, and posterior. Septal APs: anteroseptal, midseptal, and posteroseptal (midseptal as well as posteroseptal pathways may be mapped from both right and left approaches). Left-sided APs: posterior, posterolateral, lateral, and anterolateral. APs cannot be localized around the mitral ring at anterior and anteroseptal portions when the anterior leaflet of the mitral valve extends to the right and superiorly joining the membranous septum and coming in direct continuity to the anterior half of the posterior sinus and the posterior half of the anterior sinus of the aortic valve

The ablation of APs is performed when the AP can stand up to an AV reentry arrhythmia or when an electrophysiological study certifies an AP with conduction property of high arrhythmic risk. The ablation target is represented by the accessory bundle itself. Mapping should be performed to detect both atrial and ventricular aspects of the AP, defining as more as possible the exact anatomy of the AP inserctions (Figure 6.2). Most APs are fine strands of myocardial tissue bridging the AV valve annulus near the endocardium; some are intimately related to the vessels in the AV groove; epicardial band of tissue are occasionally seen. In addition, APs may have atrial and ventricular inserction sites displaced a few millimeters above or below the AV groove. Furthermore, they may cross the annulus obliquely. The APs inserctions, especially the ventricular one, tend to ramify over a region of tissue.

6.1 Septal Accessory Pathways

To map septal pathways, a diagnostic catheter is usually positioned at the His position so as to identify the apex of the Koch's triangle. Another diagnostic catheter is inserted within the coronary sinus (CS) to mainly record the ostial portion of the vessel, corresponding to the left septal side. Finally, a quadripolar diagnostic catheter is positioned at the right ventricular apex for electrical stimulation and recording purposes.

Usually the ablation catheter is a deflectable medium curve 4-mm-tip catheter; for recidivisms, more powerful catheters can be used, 8-mm or cooled tip catheters. The ablation catheter is inserted via the femoral venous approach and is positioned at the level of the tricuspid ring in the right anterior oblique (RAO) view. The correct position is confirmed by recording of balanced AV potentials using both bipolar and unipolar configurations. The septum is usually mapped from the atrial aspect with stable catheter positions. Still in the RAO view, the mapping of the interatrial septum is carried out by slightly rotating the catheter clockwise to make it firmly fasten upon the septal side. As to the posteroseptal region, we will operate by withdrawing and bending the catheter. For the anteroseptal region, instead, we will have to advance the catheter and to open its curvature. Intermediate positions and curvatures allow one to map the midseptal regions.

As to posteroseptal APs, we shall turn to the left anterior oblique (LAO) view, and, starting from the base of the Koch's triangle, continue mapping toward the inferior vena cava-tricuspid isthmic portion by making the catheter slightly rotate counterclockwise, and toward the CS ostium with a clockwise rotation (Figures 6.4 and 6.5).

The mapping of the posteroseptal pathways also has to include the initial portion of the CS with its venous branches. In some cases, an ECGraphic aspect, suggesting a posteroseptal localization, can result from an AP running along the middle cardiac vein (for CS anatomy, please see Part III, Chap. 10, Paragraph 10.1). In this case, in the LAO view, starting from the ostium of the CS, with the catheter having an intermediate curvature, we will perform a clockwise rotation so as to insert the catheter within the CS. By slightly loosening the curvature, we will try to make the catheter slide inside of the CS proximal portion; now, when the catheter is stable within the venous sinus, without trying to come out, we shall again make a slight curvature and, sticking to a clockwise rotation, we will sound the lower wall of the CS to see if the catheter penetrates a venous branch. The RAO view might be useful to direct the catheter tip toward the lower portion of the CS. In this view, we can, then, see the catheter entering the middle cardiac vein as the catheter swerves from the valve ring and moves toward the ventricular posterior wall (Figures 6.6–6.8). Suspecting an AP running along a cardiac vein, a CS venography can clearly delineate the venous sinus and its branches guiding the mapping and the ablation procedure. It is preferable to perform the ablations inside of the CS branches employing an irrigated tip catheter or a cryoablation catheter.

If the posteroseptal mapping, performed both from the right atrium aspect and from the epicardial aspect of the CS, fails to detect the AP inserctions, the left posteroseptal region must be mapped with the use of a transaortic or a transseptal approach.

From the posteroseptal position, the mapping/ablation catheter curvature is opened along the septum to map midseptal APs in the RAO view. The APs is usually positioned, in this projection, midway between the tip of His catheter and the ostium of the CS. The contact to the septum, by clockwise rotation, can be checked using the LAO view. The optimal

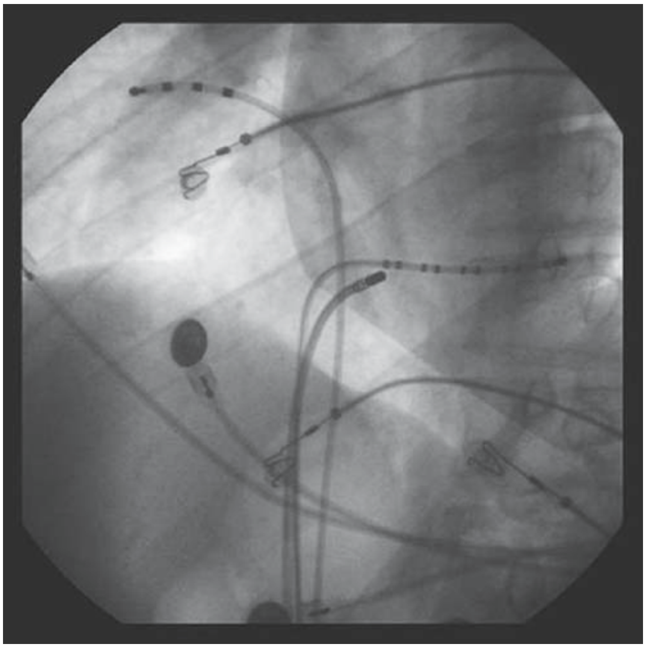


Figure 6.4 The left anterior oblique (*LAO*) view of a posteroseptal accessory pathway (*AP*) ablation. On the fluoroscopic image, a fixed curve quadripolar catheter is placed within the right atrium close to the sinus node and a decapolar catheter is inserted within the coronary sinus via an inferior approach. The ablation catheter is positioned at the level of the posteroseptal region

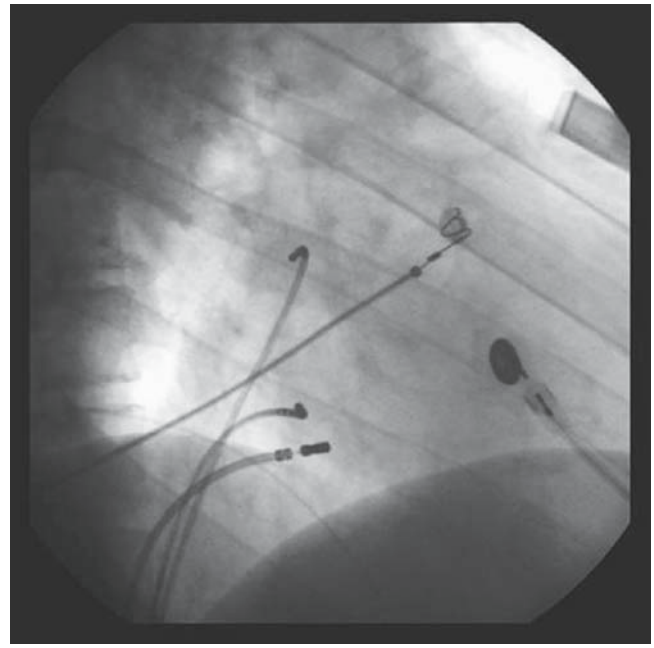


Figure 6.5 The right anterior oblique (*RAO*) view of the same sequence

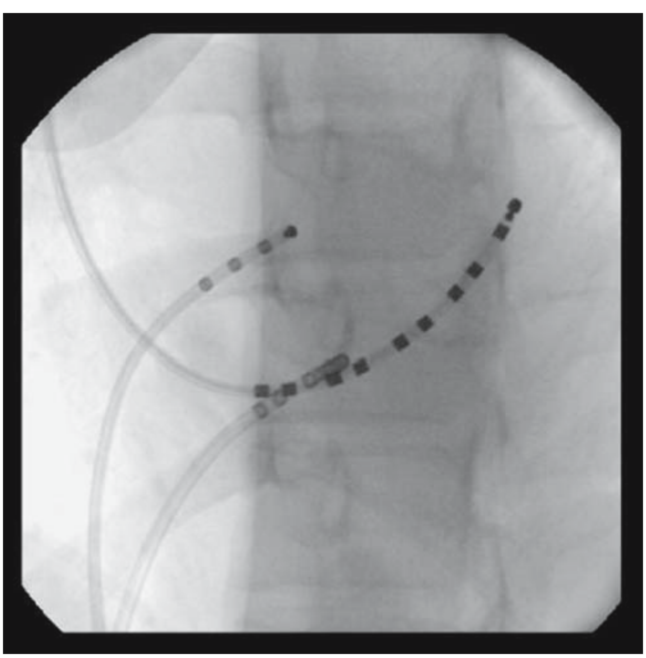


Figure 6.6 The left anterior oblique (*LAO*) view showing the ablation catheter within the first portion of the coronary sinus. In this view, it is not possible to distinguish anterior or posterior orientation of the catheter tip

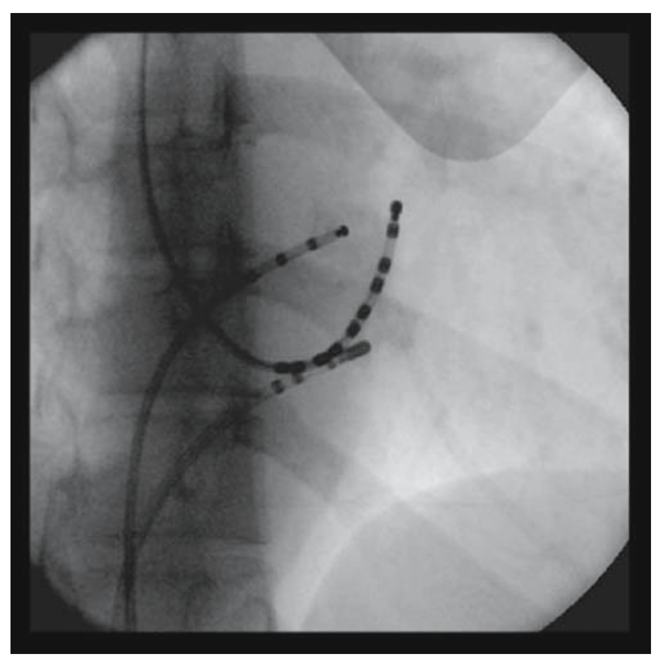


Figure 6.7 In the right anterior oblique (*RAO*) view, one can easily appreciate how the ablation catheter is oriented anteriorly, toward the ventricle

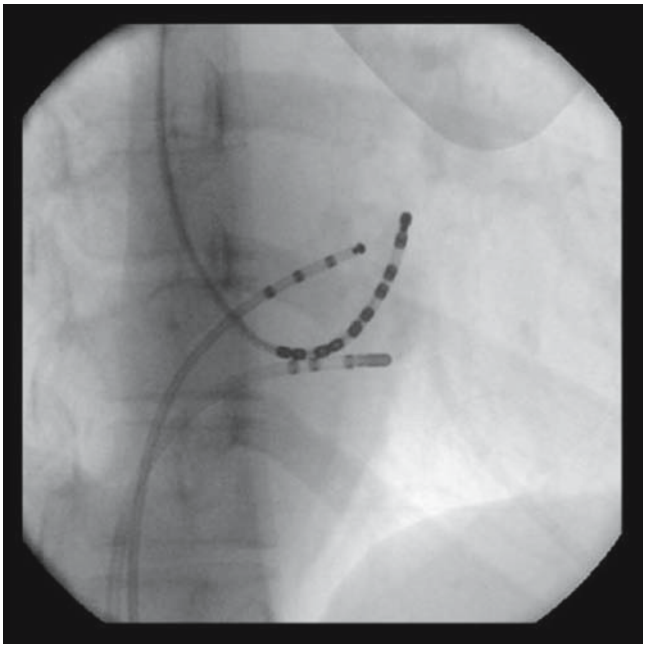


Figure 6.8 Still in the right anterior oblique (*RAO*) view, the ablation catheter is pushed forward within the middle cardiac vein where one suspects the accessory pathway is localized

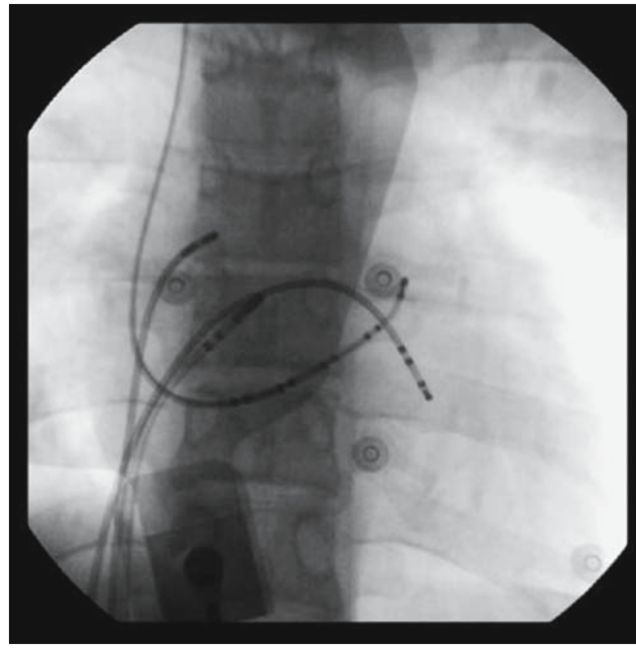


Figure 6.9 Image made in the posteroanterior (*PA*) view during the ablation of an anteroseptal accessory pathway. The patient has been instrumented with three diagnostic catheters, respectively: right atrium appendage, right ventricle's apex, coronary sinus with proximal electrode couple positioned at ostium. Ablation catheter, a cryoablation catheter with a 6-mm tip, is positioned at the anteroseptal region

site for RF applications usually lies in close proximity to the AV node; thus a more ventricular catheter position should be preferred. Midseptal APs may be mapped also from the left; in this case, the mapping/ablation catheter is advanced retrogradely into the left ventricle and positioned at the mitral ring beneath the leaflet. RAO and LAO views must confirm the mapping/ablation catheter position midway between the His position and the ostium of the CS, as for right midseptal pathways.

From the midseptal position, the mapping/ablation catheter curvature is opened along the septum to map anteroseptal APs in the RAO view. For anteroseptal APs, it is advisable to extend mapping, besides septum, to the anterior portion of the annulus also. This position is reached in the LAO view by opening the catheter curvature and slightly rotating it counterclockwise to move it away from the septum. In case of an AP localized next to the His bundle, cryoablation is advisable. This form of energy, causing lesion due to cooling, enables us to carry out test issues which produce a reversible damage. If cooling causes conduction block along the AP and does not interfere with normal conduction pathways, the temperature will be further lowered to get a permanent lesion (Figures 6.9–6.11).

Very often the ablation of anteroseptal APs is not only difficult because of the position particularly close to critical structures but also because of difficulty in making the catheter steady. Some operators remedy this problem by inserting the mapping/ablation catheter through the superior vena cava via the right internal jugular vein. Thus, the catheter, slightly bent, can be hooked onto the valve ring, this way granting good stability (Figure 6.12).

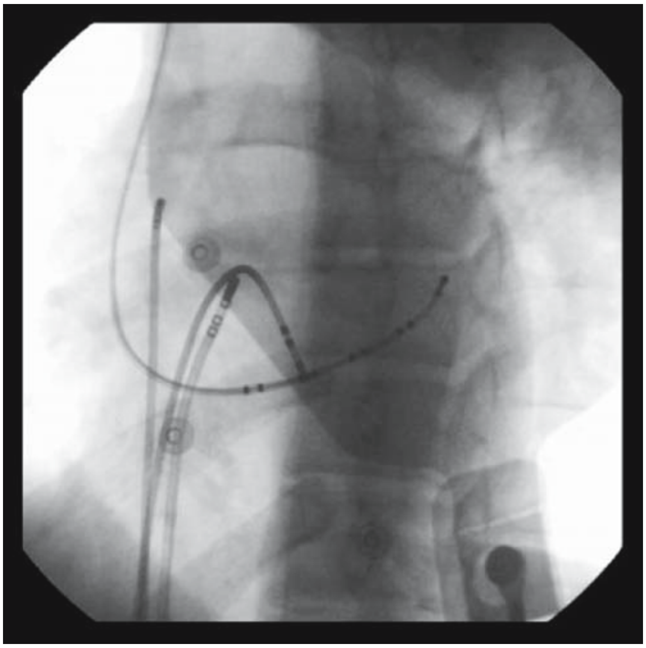


Figure 6.10 Image of the same case in the left anterior oblique (*LAO*) view

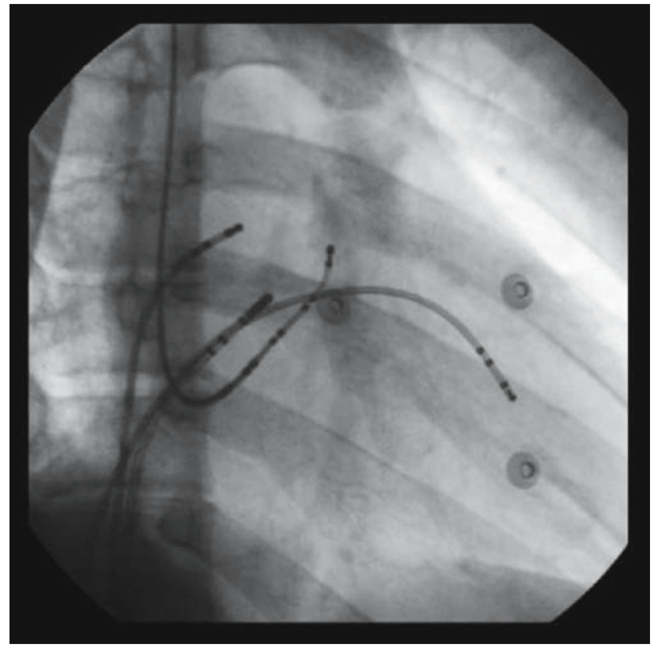


Figure 6.11 Image of the same case in the right anterior oblique (*RAO*) view. The ablation catheter is in the anteroseptal region, slightly moved toward the atrial side

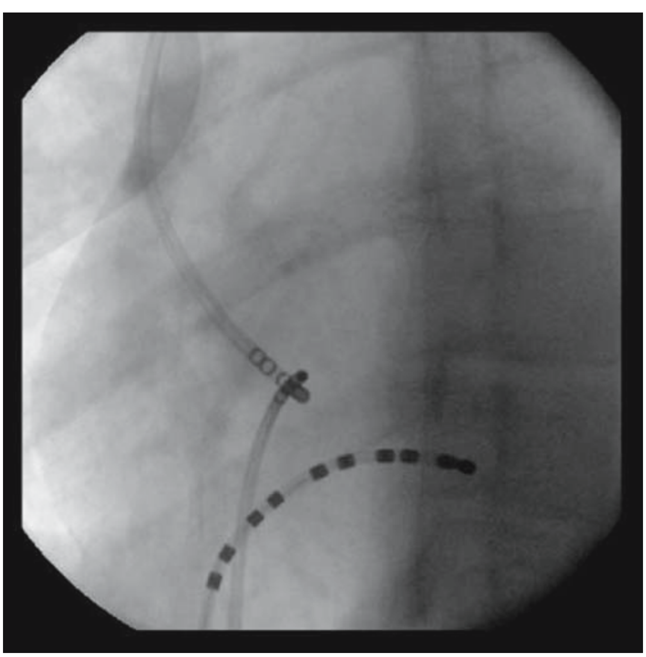


Figure 6.12 Image made in the left anterior oblique (*LAO*) view during the ablation of an anteroseptal accessory pathway. The ablation catheter, even in this case a cryoablation catheter with a 6-mm tip, is positioned at the anteroseptal region; however, it has been inserted via a superior approach to make the tip steady upon interatrial septum. In this patient, a quadripolar diagnostic catheter has been positioned at the His region as well as a decapolar catheter with its first two electrode couples within the coronary sinus, while couple 5–6 is positioned at the ostium

6.2 Right-Sided Accessory Pathways

For mapping APs of the right free wall, one can position standard diagnostic catheters to record the height of the right atrium, His and CS potentials; a catheter must be positioned at the right ventricular apex for electrical stimulation and recording purposes. Frequently, mapping is performed with a 20-polar catheter around the tricuspid ring. In rare cases it may be useful to introduce a tiny catheter into the right coronary artery to perform an epicardial mapping all along the tricuspid annulus similarly to mapping using the CS on the left. Otherwise, one can directly map the tricuspid valve by employing the ablation catheter. Usually, the ablation catheter is a deflectable medium curve 4-mm-tip catheter; for recidivisms, more powerful catheters can be used, 8-mm or cooled-tip catheters. Ablation may be performed on the atrial or on the ventricular insertions of the AP according to localization, catheter stability, and operator skill.

The mapping/ablation catheter is inserted via the femoral venous approach and is guided at the tricuspid ring in the posteroanterior (PA) view or the RAO view. The correct position is confirmed by recording of balanced AV potentials using both bipolar and unipolar configurations. The most accurate mapping, at the superior–inferior and septal–lateral directions, is carried out, instead, in the LAO view and allows one to obtain recordings from any location around the tricuspid ring (Figures 6.13–6.21). On this subject, it is necessary to remind that by twisting clockwise, the catheter rotates medially, while by twisting counterclockwise, it gets closer to the lateral wall.

Usually, because of anatomic reasons, ablation is carried out on the atrial side of the AP as it is technically easier to position the ablation catheter, coming from the inferior vena cava, upon the atrial side of the tricuspid annulus; just occasionally, a right-sided AP may be better approached by placing the catheter underneath the valvar apparatus. Several catheters with different degrees of stiffness, radius of curvature, or deflectability may be tried to achieve adequate contact and stability. When the catheter is not stable enough, as it mainly occurs to the anterolateral or anterior pathways, one can insert the catheter through

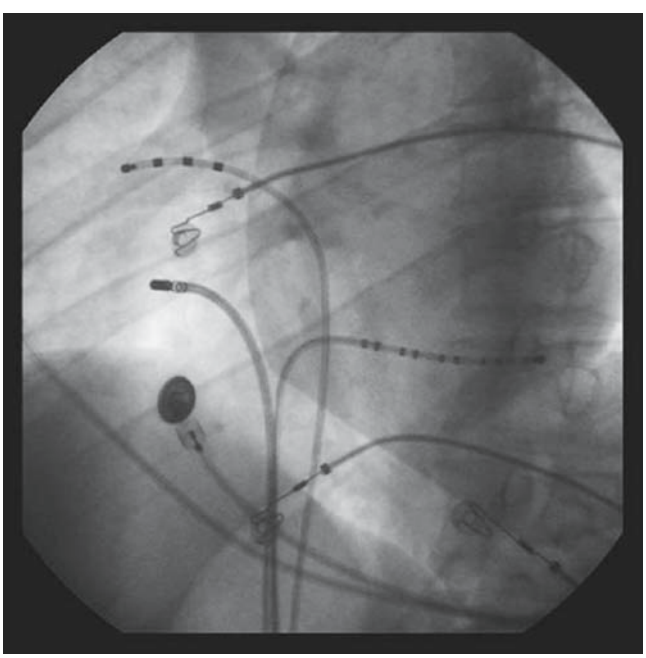


Figure 6.13 The left anterior oblique (*LAO*) view with the ablation catheter in the right posterolateral position. It is also possible to notice a fixed curve quadripolar catheter within the right atrium and a decapolar catheter within the coronary sinus via an inferior approach

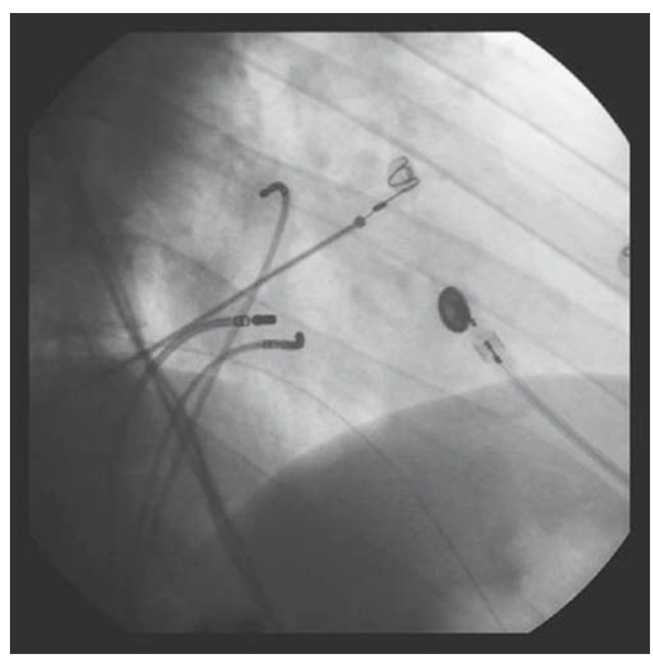


Figure 6.14 Same sequence in the right anterior oblique (*RAO*) view

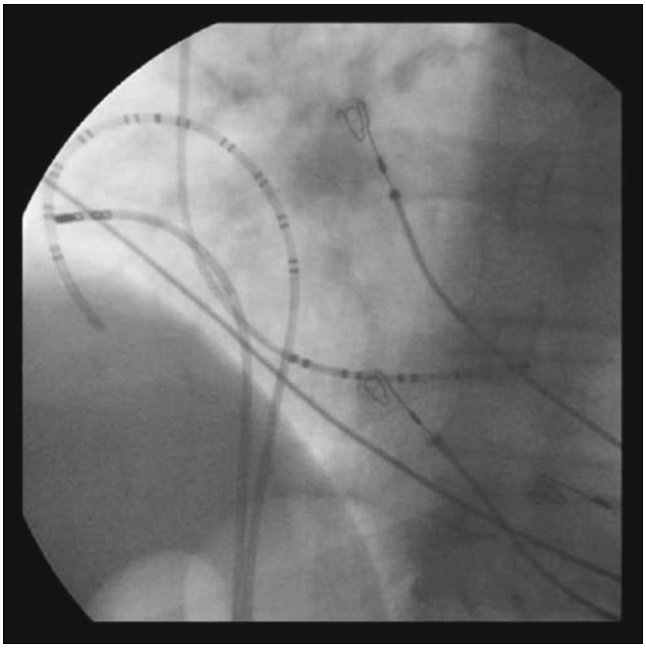


Figure 6.15 The left anterior oblique (*LAO*) view of the ablation of a right lateral accessory bundle. Mapping of the tricuspid ring is performed by means of a 20-polar catheter around the tricuspid ring and a decapolar catheter within the coronary sinus inserted via a superior approach. The ablation catheter is positioned on the lateral region

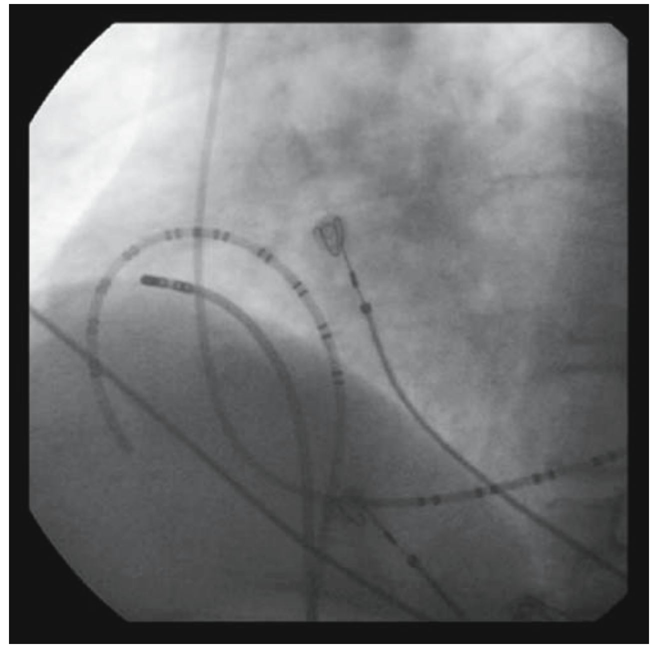


Figure 6.16 The ablation catheter reaches the anterolateral region

the left subclavian vein or the right internal jugular vein so as to be able to hook it onto the ventricular side, below the tricuspid ring.

In the most difficult cases, it is possible to improve stability by employing one of a variety of long sheaths with preshaped curvature to direct the catheter to several different locations along the tricuspid valve (Figure 6.22).

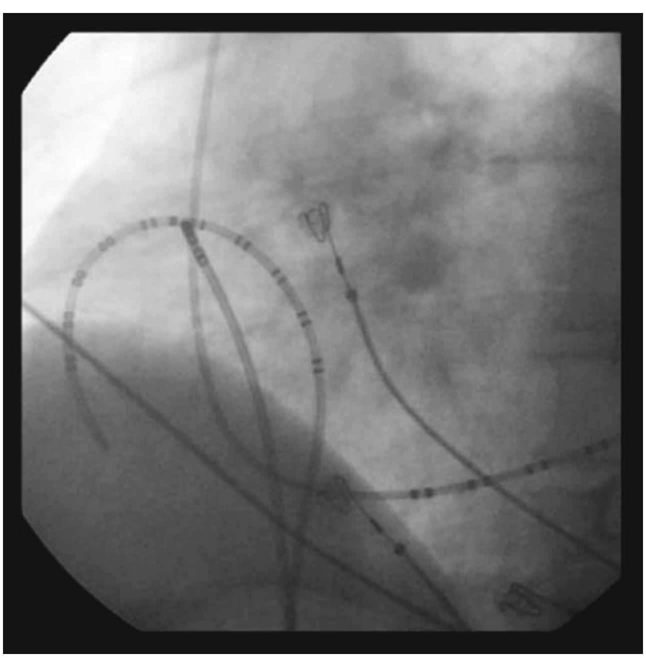


Figure 6.17 The ablation of a right anterior accessory pathway in the left anterior oblique (*LAO*) view with mapping catheters positioned like previous figures

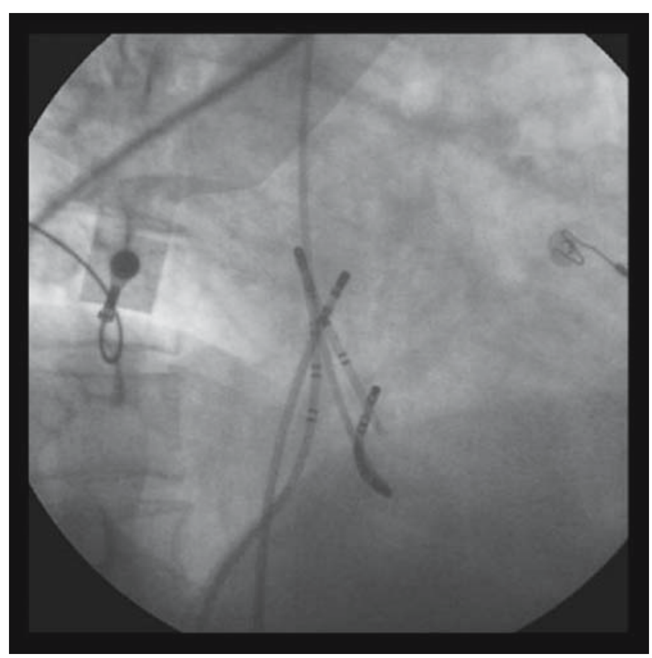


Figure 6.18 The right anterior oblique (*RAO*) view of the same case

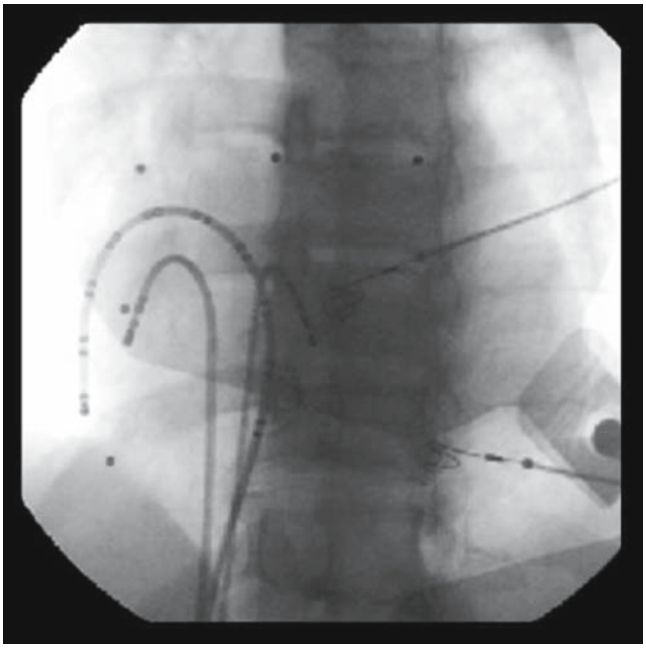


Figure 6.19 The left anterior oblique (*LAO*) view of the ablation of a posterolateral AP. Mapping of the tricuspid ring is performed by means of a 20-polar catheter around the tricuspid valve, a quadripolar catheter is at the right ventricular apex

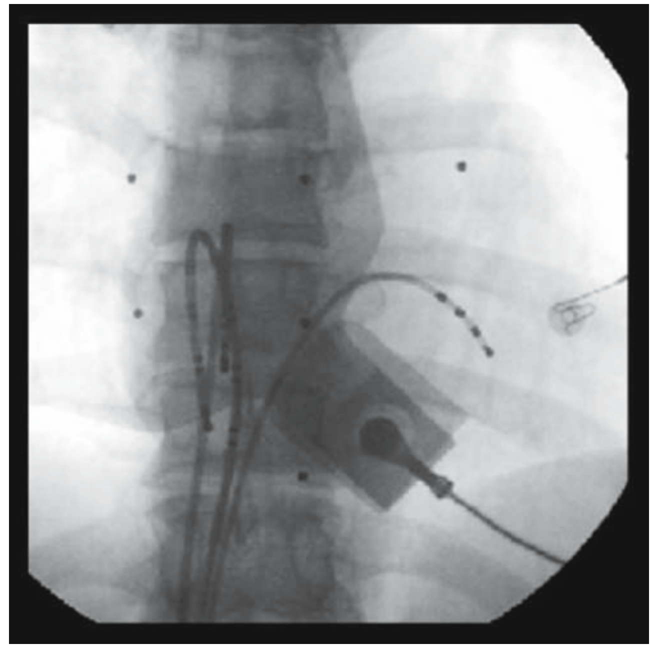


Figure 6.20 The posteroanterior (*PA*) view of the same patient

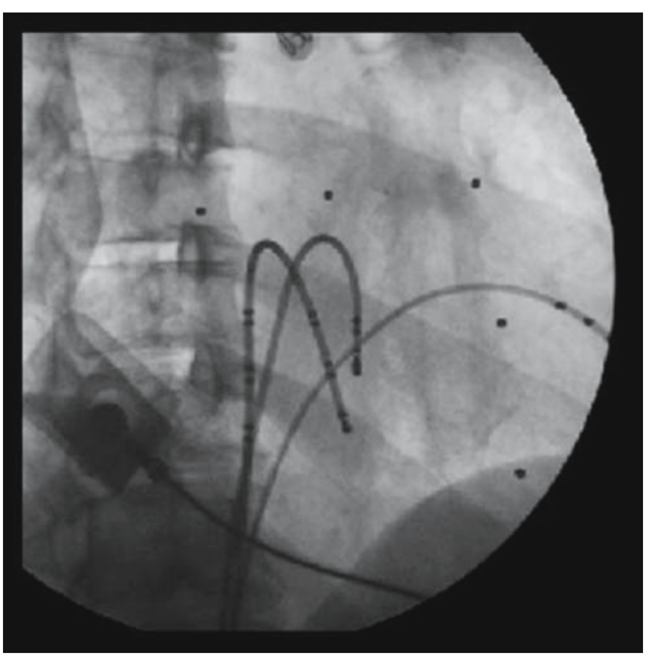


Figure 6.21 The right anterior oblique (*RAO*) view of the same patient

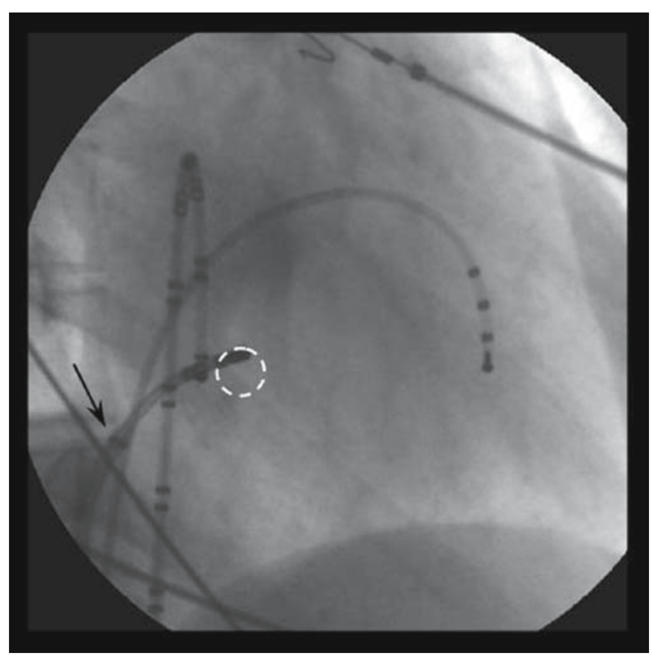


Figure 6.22 The right anterior oblique (*RAO*) view showing the ablation catheter within the posteroseptal region next to the coronary sinus (*CS*) ostium (little radiotransparent area made evident by dotted circle). In this case, the patient has been instrumented with a 20-polar catheter inserted within the right atrium, around the tricuspid valve, and with a quadripolar catheter in the right ventricle's apex. The ablation catheter is stabilized by means of a long sheath (arrow)

6.3 Left-Sided Accessory Pathways

Ablation of the left accessory bundles is commonly carried out through the retrograde arterial approach; the transseptal approach can be preferred, instead, by operators who are familiar with transseptal catheterization.

In the studies where the two different approaches have been compared, no significant differences concerning procedure success were noticed. An AP's location does not seem to be involved into procedure success differences between the two techniques even if lateral and anterior pathways can be reached more easily via a transseptal approach. Furthermore, no significant differences have been found out with regard to complications. Usually, one can prefer the transseptal approach in patients with patent foramen ovalis, with aortic valvulopathies, with peripheral arteriopathy, or with left ventricle hypertrophy. The retrograde approach has, instead, to be preferred in case of patients with congenital cardiopathies, with important aortic bulb dilation, and with heart's rotations following severe scoliosis or pneumectomy, because the risk connected with transseptal puncture is higher in this sort of patients. In both approaches, an effective anticoagulant treatment with heparin is required to minimize thromboembolic risk.

To map left-sided APs, a diagnostic catheter is usually inserted within the CS and advanced over the AP location: the catheter will be proximal if the pathway is posterior, or it will be pushed forward distally in case of a lateral pathway. At this point, we want to remember that the catheter within the CS does not always identify the mitral valve plane exactly. As a matter of fact, the CS runs along the AV ring on its atrial side; the CS distance from the valve ring is maximum in its posterior position, while it decreases at its proximal and distal end. Swerving of the catheter in the CS from the valve plane is consequently maximum when mapping posterior and posterolateral APs; in these cases, mapping has to be extended anteriorly to the CS catheter's course using the RAO projection. Usually the ablation catheter is a deflectable medium curve 4-mm-tip catheter; for recidivisms, more powerful catheters can be used, 8-mm- or cooled-tip catheters. Ablation may be performed on the atrial or on the ventricular insertions of the AP according to localization, catheter stability, and operator skill.

Should the retrograde approach be employed, the ablation catheter is positioned within the left ventricle according to the previously described technique. In the RAO view, one withdraws the catheter as far as its tip is before the mitral ring, and then the catheter's tip must be bent in a J-like shape with its aperture turned backward toward the atrium (the catheter can be posteriorly placed by a counterclockwise twisting); at the same time, it is pushed so that it springs within the left atrium. Inside of the atrium, the curvature is opened and the tip is pulled back as far as the valve ring; this position can be ascertained by checking the balanced atrium and ventricle bipolar and unipolar potentials' recording. Catheter's movements toward the lateral or septal portion are carried out in the LAO view by clockwise (septal) or counterclockwise (lateral) rotations, being always careful not to withdraw the catheter, which, otherwise, would slip into the ventricle. When mapping the left ventricle by the retrograde approach, we remind that, so as to move toward the septum, it is necessary to twist clockwise, whereas if we want to move toward the free wall, we must twist counterclockwise. The movement to carry out, contrary to what would be spontaneous, is a consequence of a 180° angle rotation carried out by the catheter at the level of the aortic arch and torsion acted upon the catheter's handle is made at the level of the arch of the aorta.

Some operators prefer to map and ablate left APs on the ventricle side, between the myocardium and valve cusps so that the catheter is steadier. In this case, once within the left ventricle, employing the RAO view, one rotates the catheter backward by means of a counterclockwise twisting and then advances under the posterior mitral valve annulus to reach the mitral ring's ventricle's side; then, in the LAO view one moves the catheter toward the septum or toward the free wall (Figures 6.23–6.33).

Should the transseptal approach be employed, the catheter is pushed forward through a long sheath directly into the left atrium. In the RAO view, the catheter is pushed forward as far as the mitral ring, and then the LAO view is utilized to map the mitral ring from the atrial aspect.

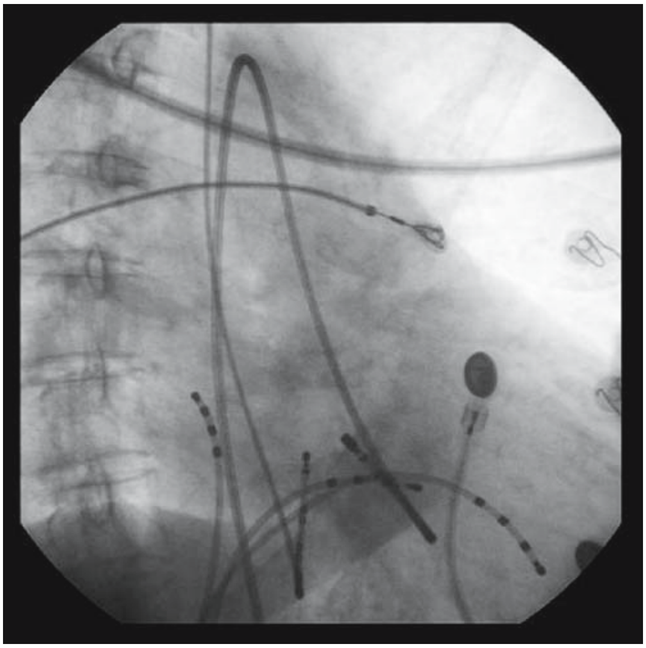


Figure 6.23 The ablation catheter, via the retroaortic approach, lies within the left ventricle; the tip of the catheter is turned backward toward the mitral ring along which the catheters runs into the coronary sinus (*CS*). The right anterior oblique (*RAO*) view

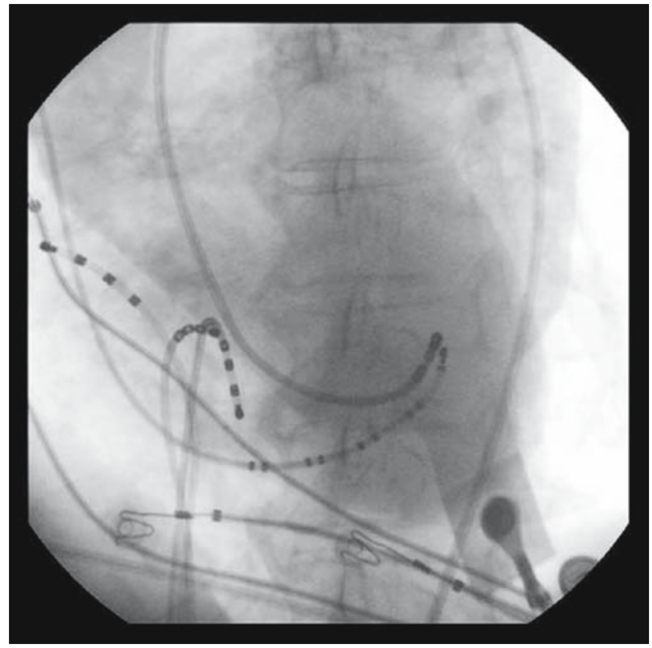


Figure 6.24 In the left anterior oblique (*LAO*) view, the catheter position is localized in the septal or lateral direction; in this case, the ablation catheter lies in a lateral position

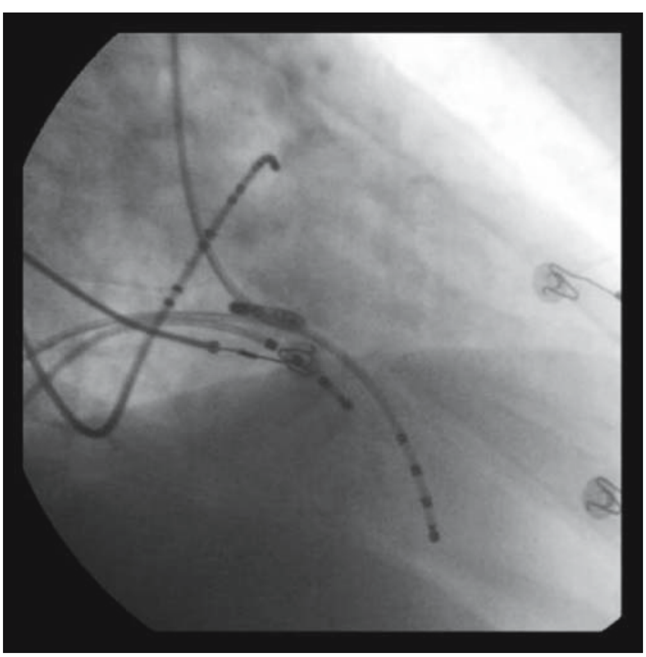


Figure 6.25 The ablation catheter, via the retroaortic approach, lies within the left ventricle. In this case, the catheter tip is within the left ventricle, below the mitral valve in its lateral portion. The right anterior oblique (*RAO*) view

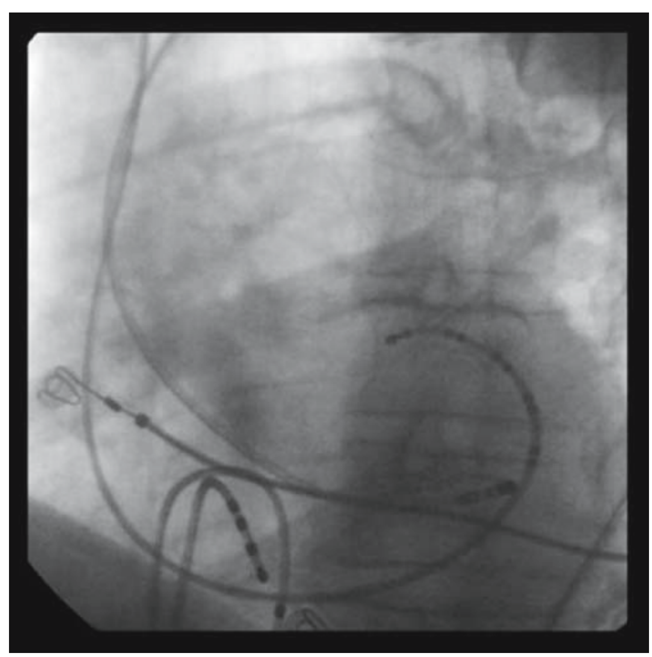


Figure 6.26 In the left anterior oblique (*LAO*) view, one can appreciate how the decapolar catheter has been advanced distally into the coronary sinus (*CS*) to map the whole lateral and anterolateral portion of the mitral ring. The ablation catheter is positioned laterally

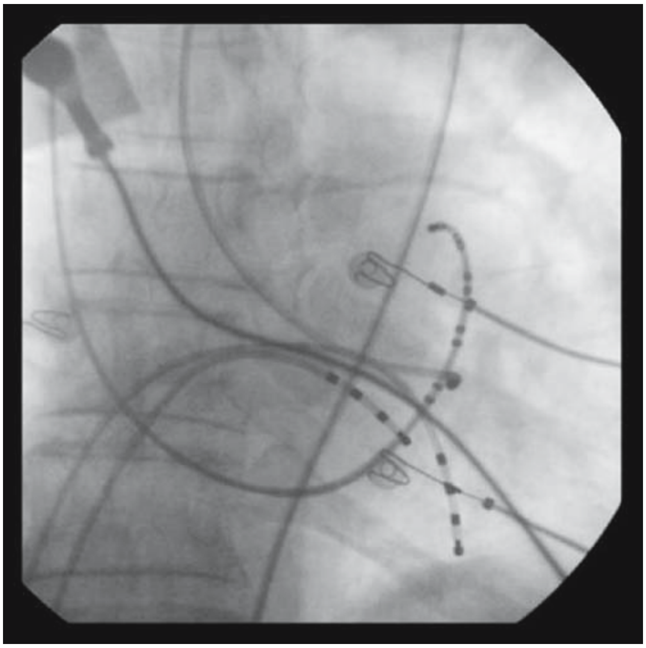


Figure 6.27 The posteroanterior (*PA*) view of the same patient

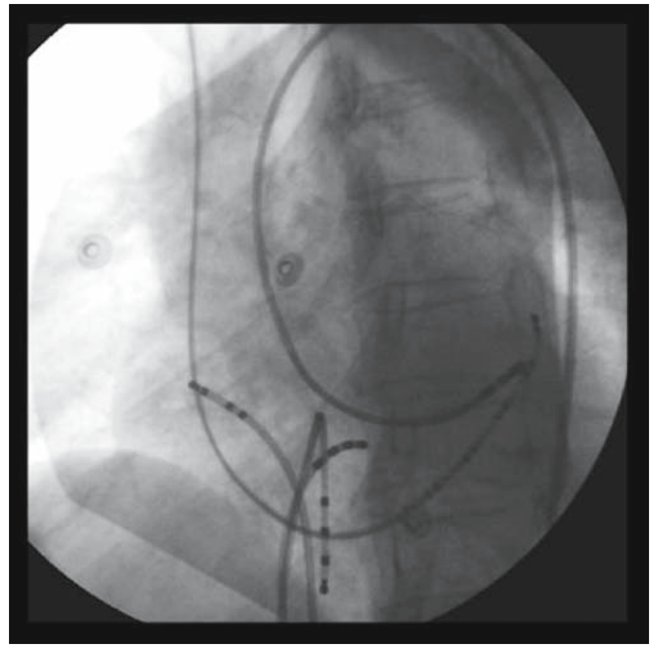


Figure 6.28 The left anterior oblique (*LAO*) view carried out during the ablation of a left anterolateral accessory pathway. The patient has been instrumented with three diagnostic quadripolar catheters, respectively, positioned within the right atrium, His and right apex; one decapolar catheter is placed distally within the coronary sinus

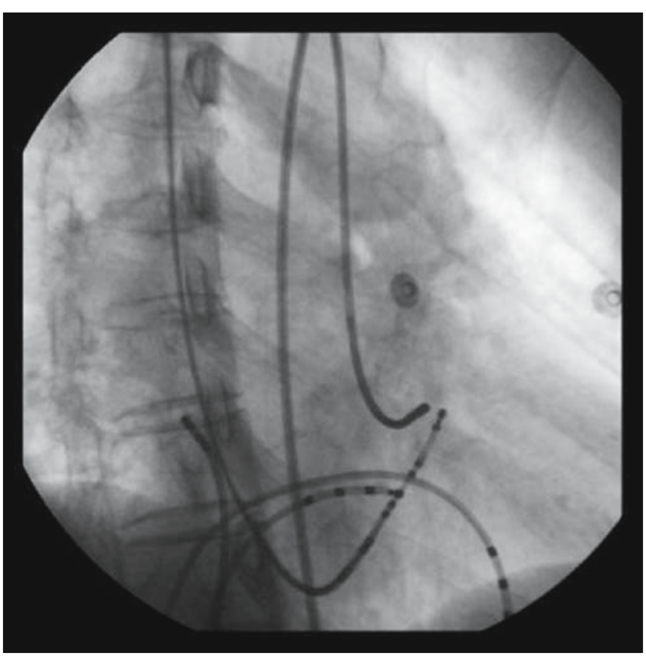


Figure 6.29 The right anterior oblique (*RAO*) view of the same patient

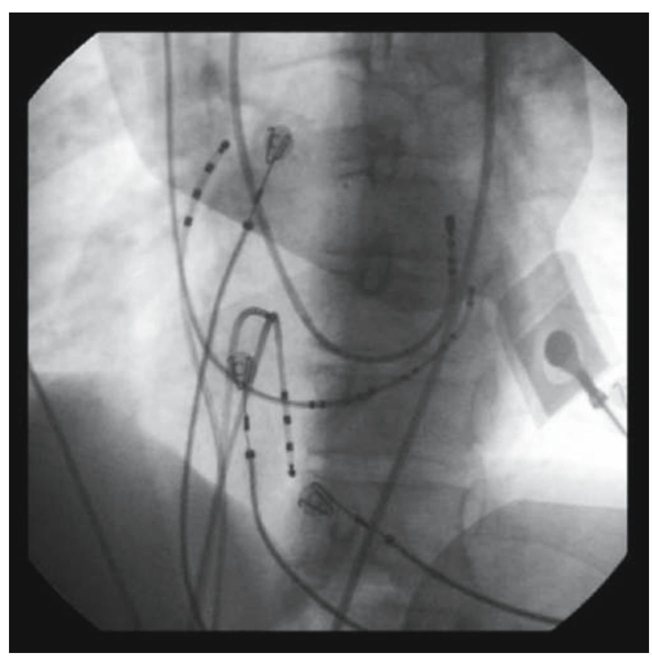


Figure 6.30 The left anterior oblique (*LAO*) view carried out during the ablation of a left anterior accessory pathway. Please notice how the catheter is positioned on the atrial side of the mitral ring

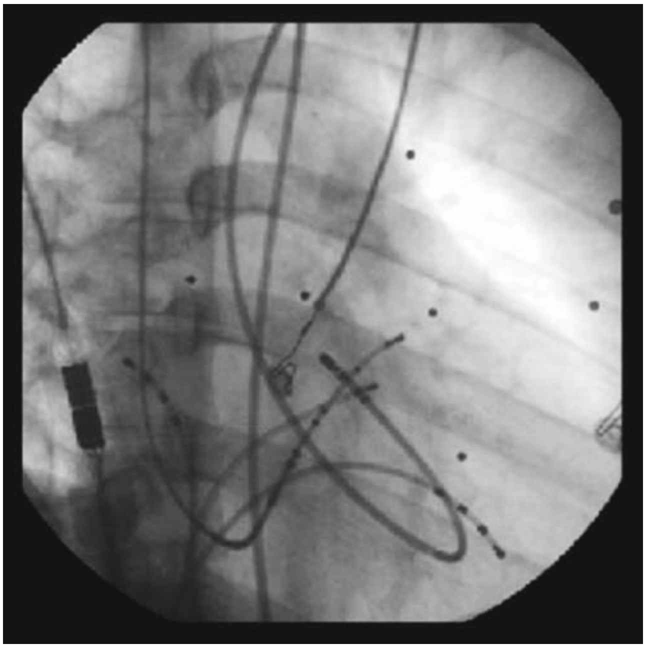


Figure 6.31 The right anterior oblique (*RAO*) view carried out during the ablation of a left lateral accessory pathway. In this case, the ablation catheter makes looping within the left ventricle and its tip reaches the mitral ring's atrial side

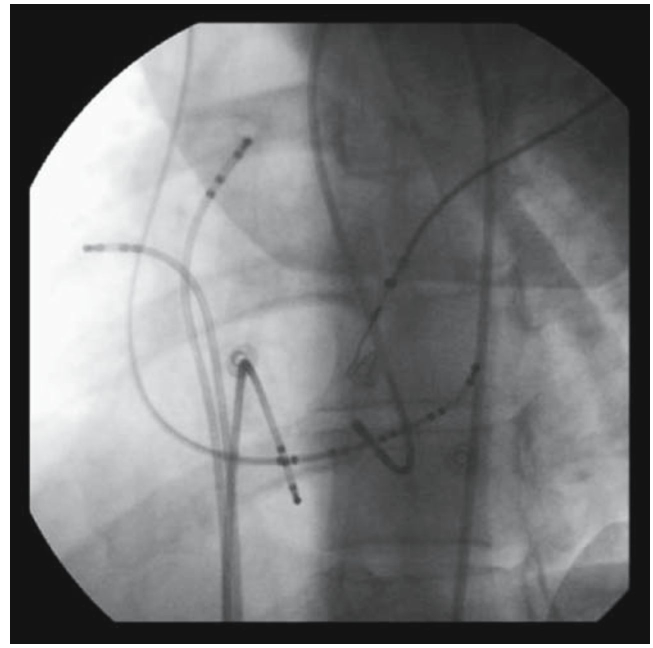


Figure 6.32 In this image, in the left anterior oblique (*LAO*) view, one can see how the ablation catheter has been positioned onto the posteroseptal portion of the mitral ring on its ventricle side

Usually, the catheter is naturally positioned, without twisting, in lateral position; to direct it toward the posterior, or inferior, wall, a clockwise rotation is necessary withdrawing and bending the catheter; to direct it toward the septum, one must rotate it clockwise, and maximally bend the catheter's tip. The posteroseptal position is the most difficult to reach via the transseptal approach; in this case it might be useful to push forward the long sheath into the left

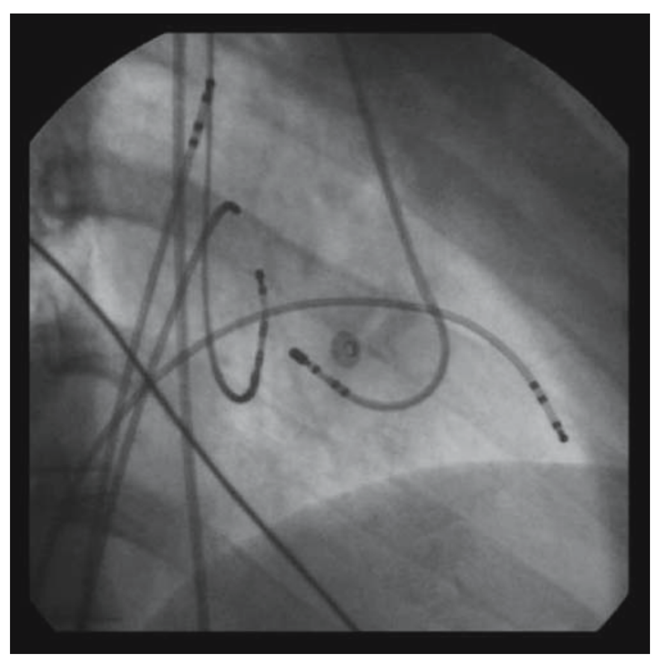


Figure 6.33 In the same patient, the right anterior oblique (*RAO*) projection allow one to see the position of the ablation catheter on the ventricle side, between the myocardium and valve cusps

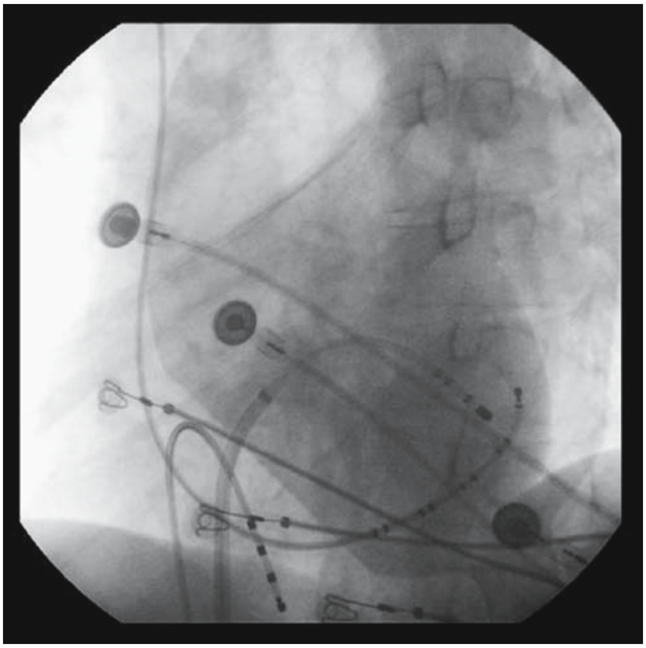


Figure 6.34 Once transseptal puncture is performed, the long sheath spontaneously directs the ablation catheter toward the lateral portion of the mitral ring, as one can see in this image. If, instead, the catheter is turned toward the lateral wall, posteriorly with regard to the valve ring, it is sufficient to slightly twist counterclockwise to move the catheter anteriorly. The left anterior oblique (*LAO*) view

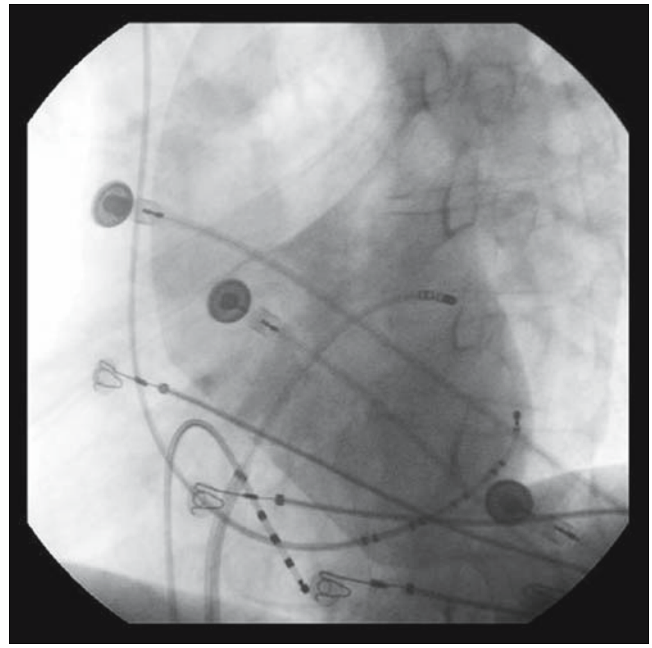


Figure 6.35 By slightly opening the catheter curvature, the catheter runs up along the valve ring, thus reaching its anterolateral portion

atrium so as to give support to the ablation catheter and then to push the catheter forward so that its body rests onto the left atrium's lateral wall, thus enabling its tip to reach the interatrial septum (Figures 6.34–6.41).

Once the site where the accessory bundle is located is reached, the catheter can be pushed forward if one wishes to increase the ventricle's recording or can be slightly withdrawn if one wants to increase atrial recording.

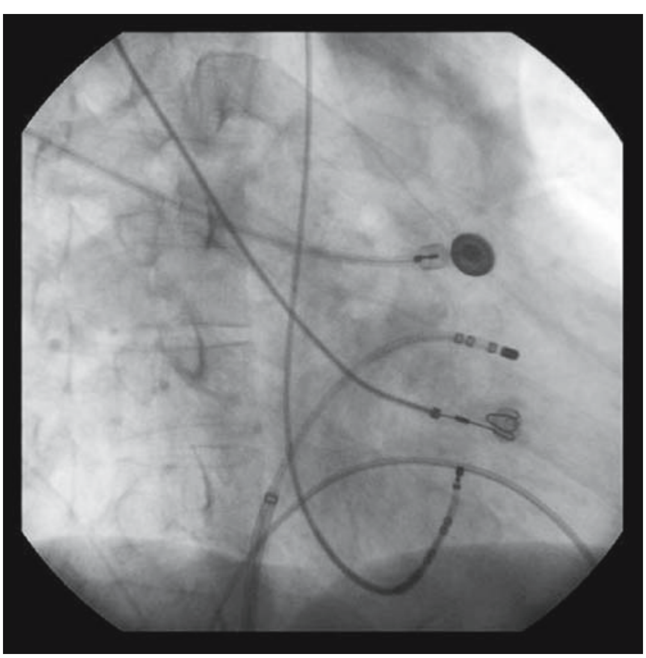


Figure 6.36 The right anterior oblique (*RAO*) view of the ablation catheter positioned into the anterolateral region

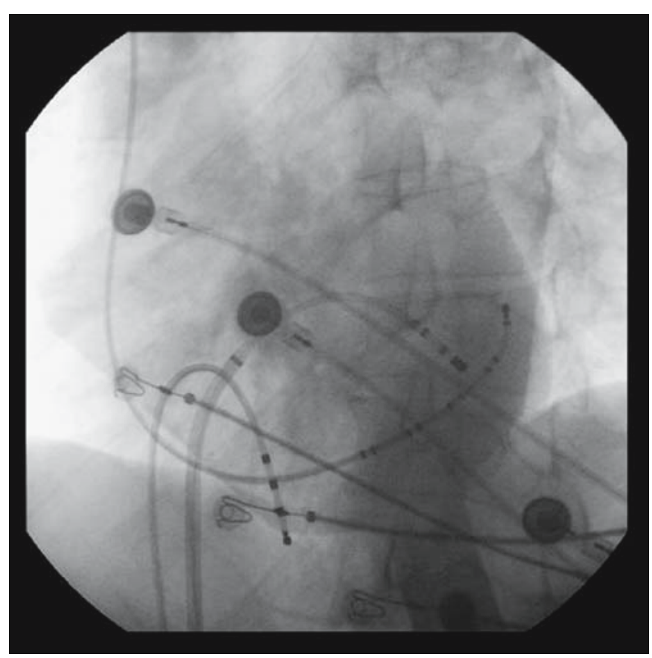


Figure 6.37 In the left anterior oblique (*LAO*) view, by slightly bending the catheter, one moves its tip into the coronary sinus (*CS*) lateral region, particularly between 3–4 and 5–6 catheter's couples within the CS

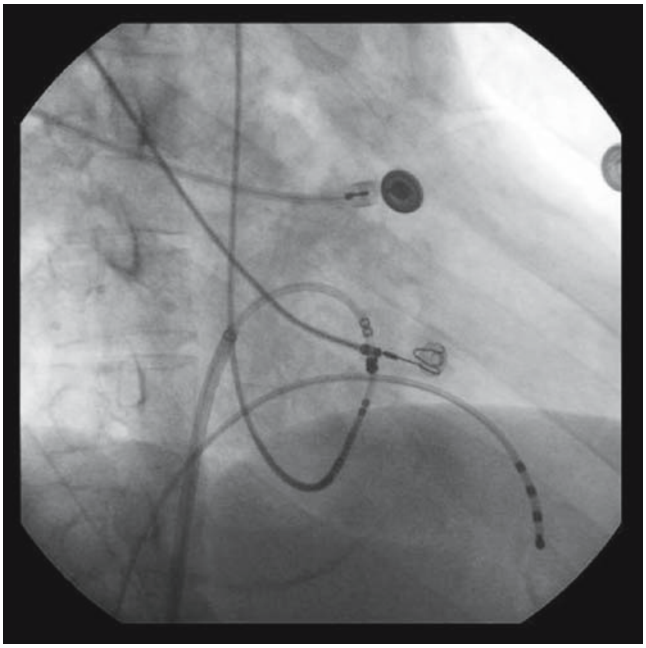


Figure 6.38 In the right anterior oblique (*RAO*) view, one can see how the catheter tip is perfectly corresponding to the mitral ring

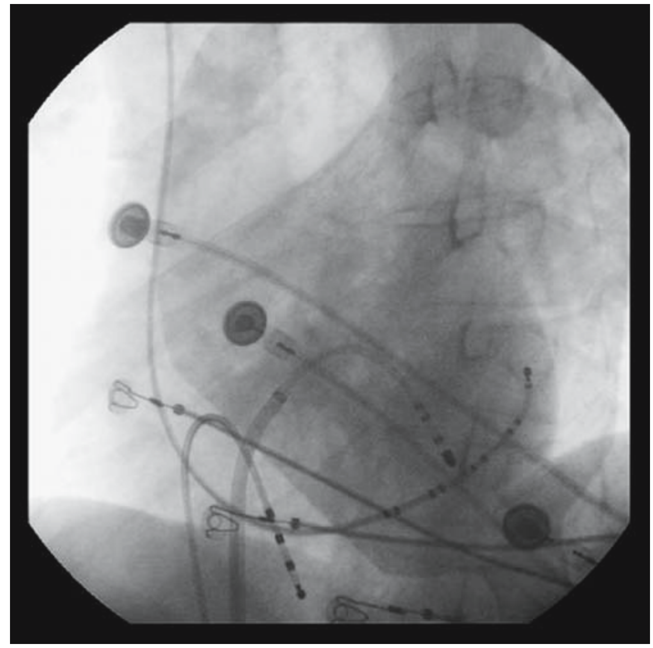


Figure 6.39 In the left anterior oblique (*LAO*) view, by further bending the catheter, one can reach the coronary sinus (*CS*) posterolateral portion, corresponding to 6–7 catheter couple within the CS

Failure of endocardial approaches, transaortic and transseptal, may be due to an epicardial pathway's locations. These pathways have atrial and ventricular inserctions distant from the mitral apparatus, and they pass in a closer proximity to the CS, resulting in large CS pathway potentials and a good susceptibility to ablation from within the CS. In these rare cases, an appropriate mapping of the CS, also with a CS angiography, should be useful, and the ablation is preferably performed using an irrigated tip catheter or a cryoablation catheter.

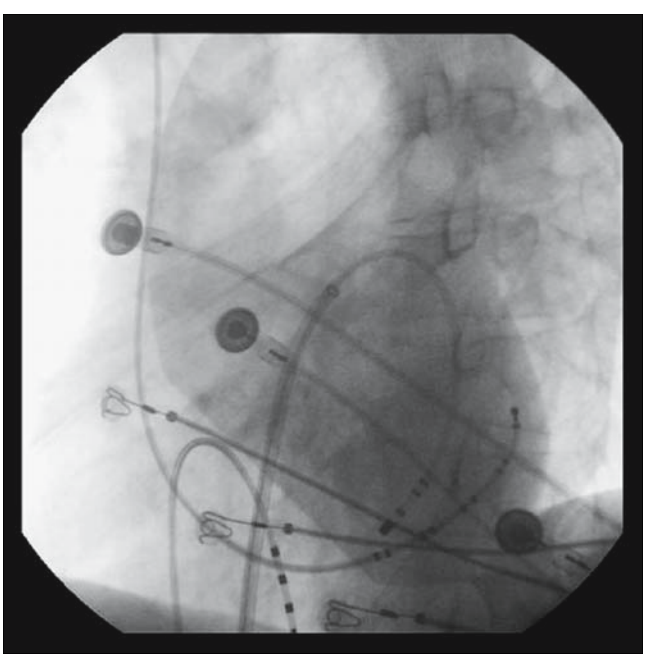


Figure 6.40 Posteroseptal positions are the most difficult to be reached via the transseptal approach. In the left anterior oblique (*LAO*) view, one can see well how the catheter tends to looping within the left atrium; taking advantage of resistance offered by the left atrial lateral wall, the loop succeeds in keeping the catheter's tip steady

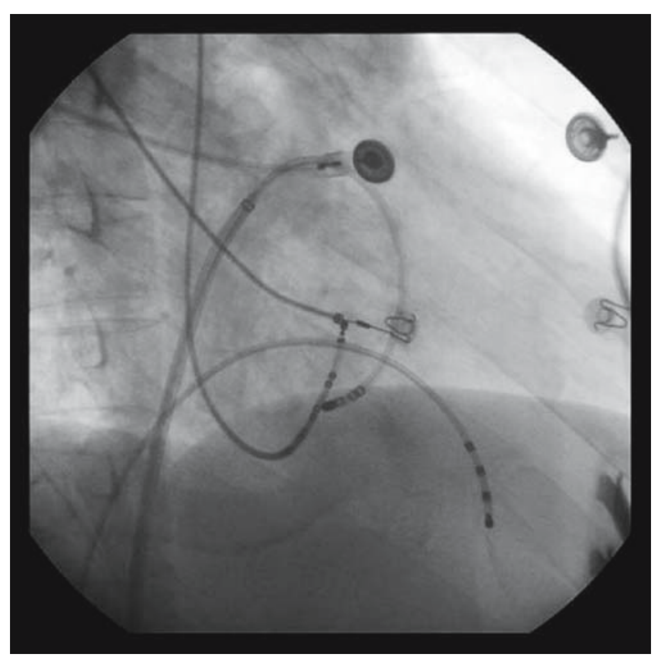


Figure 6.41 In the right anterior oblique (*RAO*) view, one can see the loop formed within the left atrium

7

Atrial Fibrillation Ablation

Atrial fibrillation (AF) ablation has gained much interest among physicians, scientists, and consequently, among biomedical technologists over the past decade. Over this period, the ablation strategies for AF have changed significantly, initially with redirection of attention from the right atrium (RA) to the pulmonary veins (PVs), and subsequently to left atrial/PV junctions and posterior left atrial wall. The focus of attention for most AF ablation procedures now centers on disconnection of the PVs from the left atrium (LA), as the PVs have been shown to be responsible for both triggering and maintaining this arrhythmia. In patients whose pattern of AF is more persistent or permanent, adjunctive lesions frequently have to be deployed to increase the success rate of this procedure.

Different methods have evolved for AF ablation. These include segmental ostial PV isolation, circumferential PV ablation, PV antrum isolation, and ablation strategies primarily targeting areas of fractionated electrograms (Fig. 7.1). In the case of segmental ostial PV isolation, radio frequency (RF) lesions are created at each of the PV ostia. Anatomic characteristics of zone of interest may be obtained through pulmonary venous angiography. Frequently, the ablation strategy requires two catheters to be employed within the LA: an ablation catheter and a mapping catheter. Ablation is aimed at electric isolation of the PVs from the LA and success is validated by electrophysiological criteria. Antral isolation also involves isolation of the PVs, which is performed at a more proximal level. The entire posterior LA is effectively isolated using this approach. Another approach involves left atrial anatomic reconstruction by means of electroanatomic mapping system. Mapping systems also have the capability of allowing integration of an electroanatomic image with the patient's cardiac computed tomography (CT) or magnetic resonance imaging (MRI). This, in theory, improves the guidance of lesion delivery on an anatomic basis. In this type of approach, lesions are placed at the PV antrum; atrial linear lesions can also be added. This more anatomy-based approach to the AF ablation procedure may be performed with only an ablation catheter in the LA. Many centers use a circular mapping catheter as well as the electroanatomic mapping system during AF ablation. The mapping system is then utilized to guide the site of RF lesions, by defining the ostia or antra of the PVs.

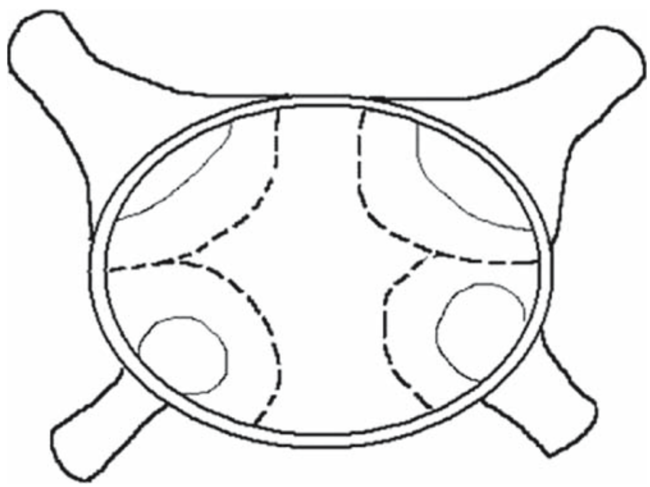


Figure 7.1 Sketch of left atrium as seen in the left anterior oblique view and anteriorly opened; on the posterior wall one can see the four pulmonary vein ostia. The thin solid line shows a circumferential lesion at the venous ostium, whereas the dotted line shows the lesions as would be viewed by an electroanatomic mapping system at the pulmonary vein antra

A mixed approach is more frequently utilized at present. One may use an electroanatomic mapping system with CT or MRI integration, and proceed to disconnection of the PVs from their respective antra. This is accomplished by employing the electroanatomic reconstruction as an aid and also utilizing the circular mapping catheter to identify regions which would be ablated. Electric disconnection is then validated by electrophysiological criteria.

7.1 Pulmonary Vein Angiography

One method to image the PVs is by performing pulmonary venography at the beginning of the ablation procedure. This technique has been developed as an aid to the definition of the PV ostia, such that electrical disconnection may then be performed (Figure 7.2).

Pulmonary vein angiography is performed to evaluate the number and position of the veins, and to define the size of ostia. Anatomic variations, such as common ostia, can also be visualized. The ostium is the junction of PVs with the LA. The true ostium, or more

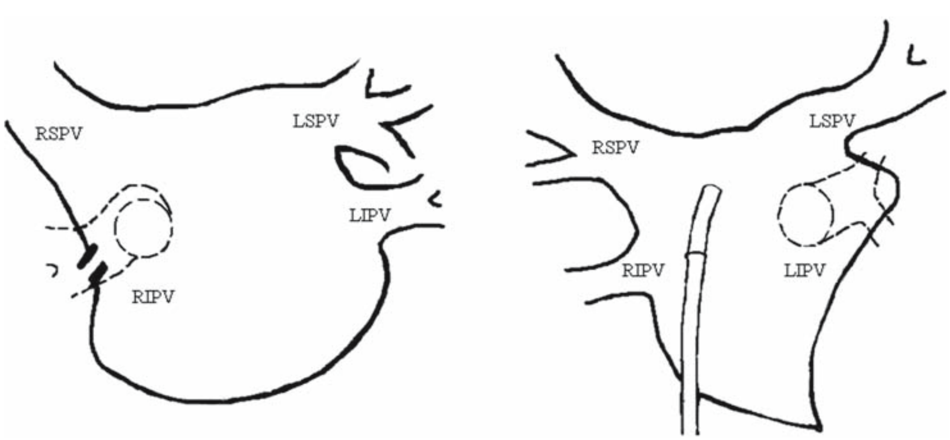


Figure 7.2 Sketch of the left atrium as seen in the left oblique view (on the left) and in the right oblique view (on the right) with representation of the ostia of the four pulmonary veins: left superior pulmonary vein (*LSPV*), left inferior pulmonary vein (*LIPV*), right superior pulmonary vein (*RSPV*), and right inferior pulmonary vein (*RIPV*). In the sketches, we have also shown the long sheath passing at the level of the aperture made by the transseptal puncture in the fossa ovalis

safely the antrum, may then be the target of RF energy delivery. Thus with electrical disconnection of the PVs from the LA no triggering ectopic electric impulses from the PVs will be transmitted to the LA. Therefore, this is a critical area for mapping and ablation for AF ablation cases.

Angiography can be carried out selectively for all four veins or just for the two superior veins. Angiography of the superior veins may enable visualization of the inferior veins as they are passively identified by the contrast in the LA.

Pulmonary vein angiography can be carried out by directly positioning a sheath at the PV's ostium. Usually a scout injection of a small amount of contrast is done to check the correct relative position of the sheath to the PV ostium. Following this, angiography is performed and the angiograms are recorded in both left anterior oblique (LAO) and right anterior oblique (RAO) views. Alternatively, one can insert a mapping or ablation catheter through a long transseptal sheath into the LA. The vein is then engaged with the mapping or ablation catheter, and the long sheath advanced over the catheter into the PV. The ablation catheter is then withdrawn, and radio-opaque contrast may then be injected through the long sheath. To avoid the potential risk of damaging the vascular wall with the long sheath, a further alternative is to employ an angiographic catheter. This catheter, of smaller diameter, is passed through the long sheath, and advanced into the PV. This then permits the injection of the contrast material.

Usually, the left superior pulmonary vein (LSPV) can be easily entered by advancing the long sheath posteriorly and superiorly in a leftward fashion. This may be performed in the LAO projection. If one encounters difficulties in engaging the LSPV ostium, the cause is generally attributable to a too anterior positioning of the sheath, as the LSPV ostium is located at the posterolateral wall. The direction spontaneously chosen by the sheath depends on the position where the transseptal puncture has been performed. If the transseptal puncture is performed too anteriorly, the sheath tends to turn anteriorly. This will direct the sheath toward the left atrial appendage (LAA). The LAA is a thin-walled structure which could be easily perforated by too vigorous manipulation of the sheath if it is displaced anteriorly. Therefore, a more posterior transseptal puncture is preferable; this will direct the sheath toward the posteriorly located veins. Intracardiac echo (ICE) is of great assistance in defining the optimum site for transseptal puncture. The RAO view also helps in moving the sheath into the correct position. The sheath is advanced posteriorly by advancing it with clockwise torque applied.

The LSPV can be reached by employing the mapping/ablation catheter once the long sheath has been positioned in the LA. Correct positioning of the sheath, away from the anteriorly placed appendage, is important. The mapping/ablation catheter is advanced toward the LSPV by applying clockwise rotation while advancing the catheter superiorly. Such a maneuver is performed in either the LAO view or the RAO view. The latter is more useful in assessing anterior/posterior displacement of the catheter.

Angiography may then be performed in the LAO view, which assists in defining the level of the antrum. Angiography of the LSPV may also enable the passive opacification of the left inferior pulmonary vein (LIPV). The LIPV has a more inferior and posterior ostium than that of the LSPV. The RAO view is useful to verify the anterior or posterior antrum orientation (Figures 7.3–7.5).

To engage the right superior pulmonary vein (RSPV), in the LAO view, one withdraws the sheath from the LSPV, such that it is now free within the LA. At this point, one rotates it 180° in a clockwise direction. This enables advancing the sheath rightward and superiorly toward the RSPV. Similar to the LSPV, the RSPV also can be entered with the use of the long sheath only. When performing this maneuver, it is important to ensure that the sheath is directed toward the RSPV; otherwise, advancement of the sheath will cause it to be forced against the LA roof (Figure 7.6).

Preferably, one should engage the RSPV with the mapping/ablation catheter. To accomplish this, it is initially necessary to withdraw the sheath from the LSPV, making it free within the LA. Following this, the catheter should be rotated 180° in a clockwise fashion. It is usually necessary to slightly curve the distal aspect of the catheter, keeping its tip turned toward the septal wall and carefully advancing the catheter until it engages the RSPV. The long sheath is then advanced over the catheter, as before.

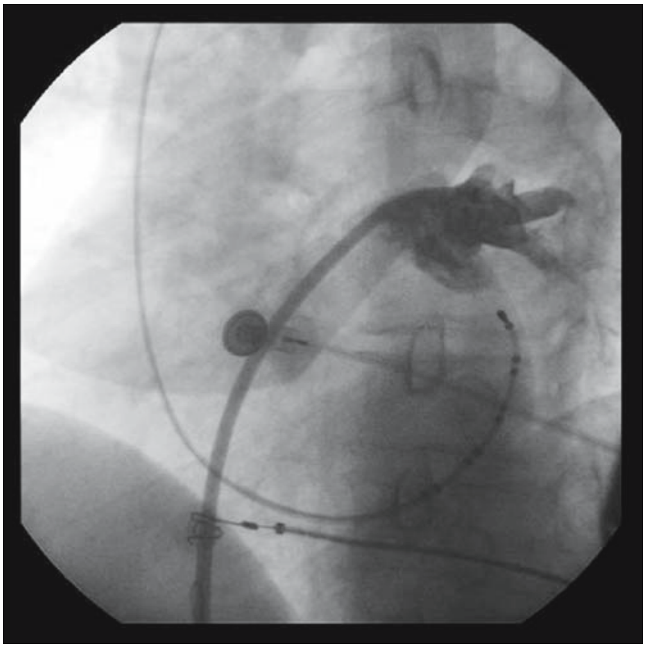


Figure 7.3 Left superior pulmonary vein selective angiography in the left anterior oblique (*LAO*) view

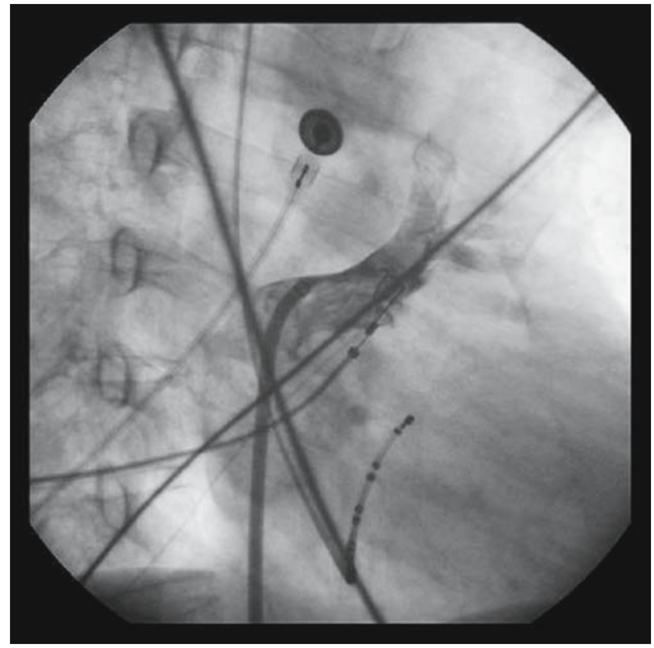


Figure 7.4 Left superior pulmonary vein (*LSPV*) selective angiography in the right anterior oblique (*RAO*) view. In this projection, the pulmonary vein displays the typical course from the left atrial posterior wall anteriorly. In case of doubt, this course enables to distinguish it from the left inferior pulmonary vein, which, instead, is more posterior

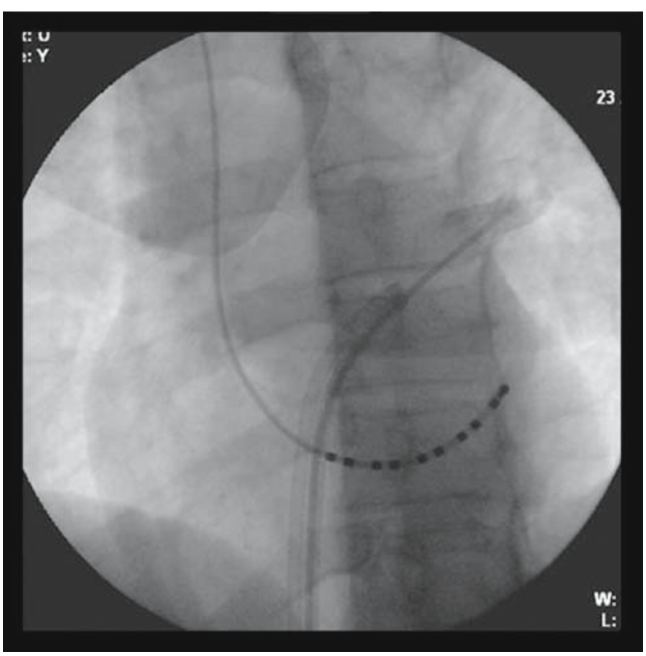


Figure 7.5 On the contrary, in this case, the left superior pulmonary vein (*LSPV*) is made opaque by means of contrast dye injection through an angiographic catheter that has been advanced through the long sheath. The left anterior oblique (*LAO*) view

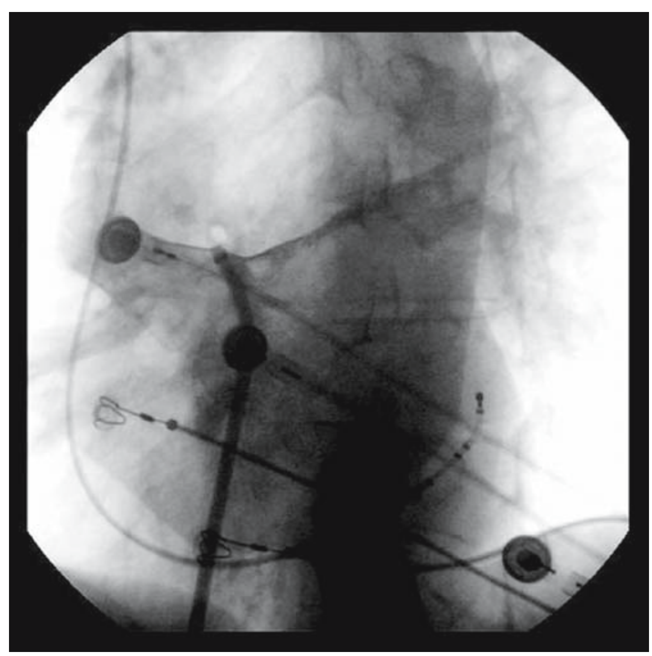


Figure 7.6 Right superior pulmonary vein angiography in the left anterior oblique (*LAO*) view. In this case, the long sheath is pushed against the venous antrum's superior wall. The sheath's border is smooth but can cause damage to the atrial tissue with consequent pericardial effusion and possible cardiac tamponade. Before carrying out pulmonary vein angiography, it is always advisable to give a test injection with a minimum amount of dye, thus verifying the sheath's position. In the case of very small vessels, one can use a thinner and softer and, therefore, less traumatic angiographic catheter

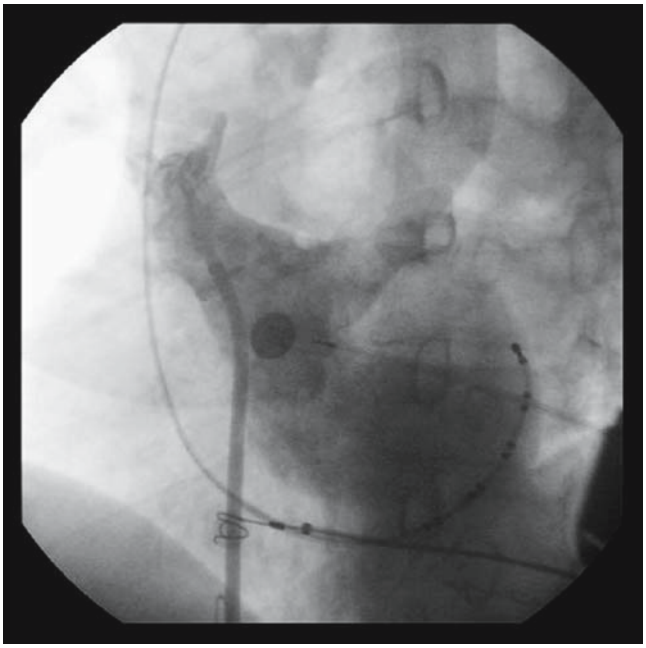


Figure 7.7 Right superior pulmonary vein selective angiography in the left anterior oblique (*LAO*) view

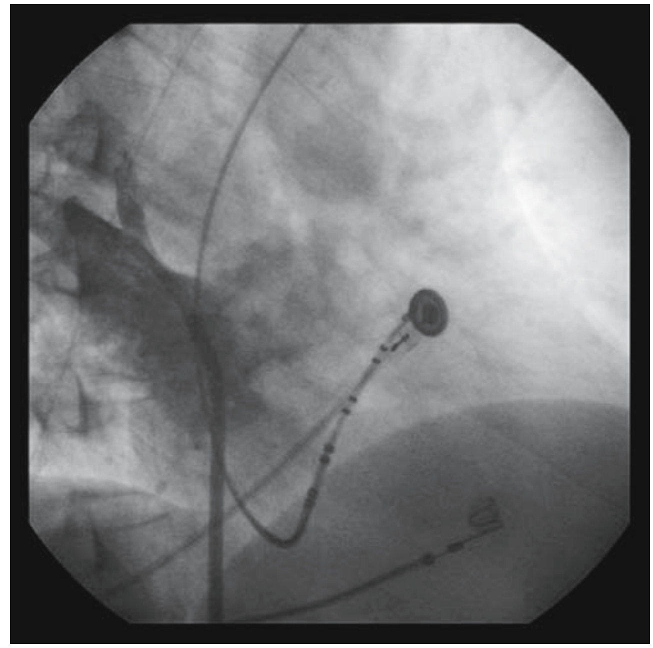


Figure 7.8 Right superior pulmonary vein (*RSPV*) selective angiography in the right anterior oblique (*RAO*) view; the vein is oriented posteriorly and can be easily distinguished from the left superior pulmonary vein that, though lying at the same level, has an opposite orientation

Angiography in the LAO view, once again, shows the level of the antrum as well as the vein's orientation. Similarly, the RAO view orientates one in defining an anterior or posterior orientation. This view also enables visualization of the passive opacification of the right inferior pulmonary vein (RIPV) which lies in a lower and more posterior position (Figures 7.7–7.9).

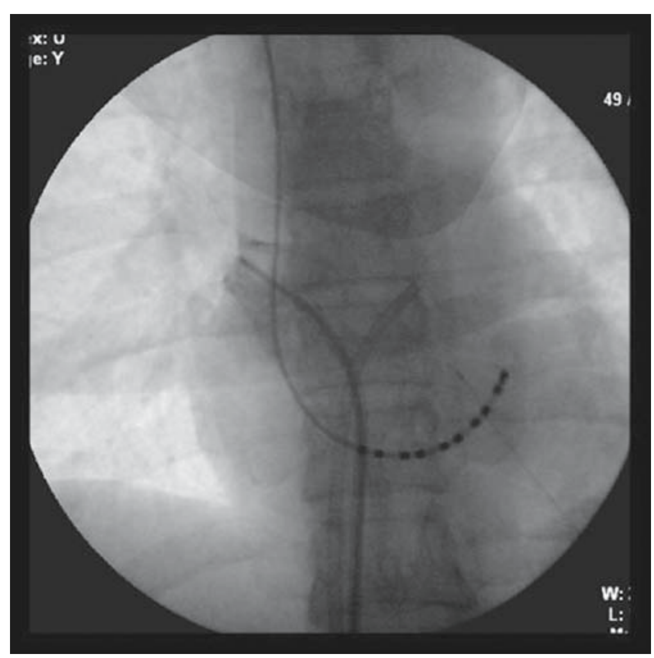


Figure 7.9 In this case, the right superior pulmonary vein (*RSPV*) is made opaque by dye injection through an angiographic catheter advanced through the long sheath. The left anterior oblique (*LAO*) view

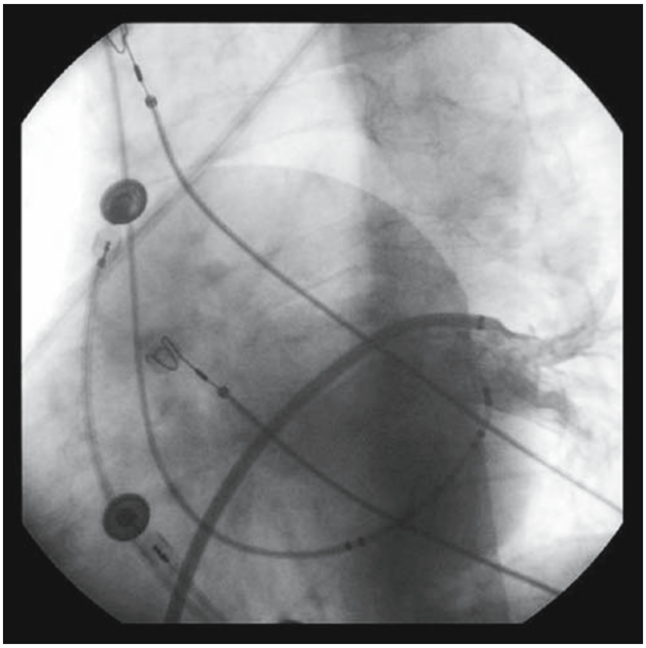


Figure 7.10 Left inferior pulmonary vein selective angiography in the left anterior oblique (*LAO*) view. In this view, one can see the vein's ostium is lower with respect to the left superior vein

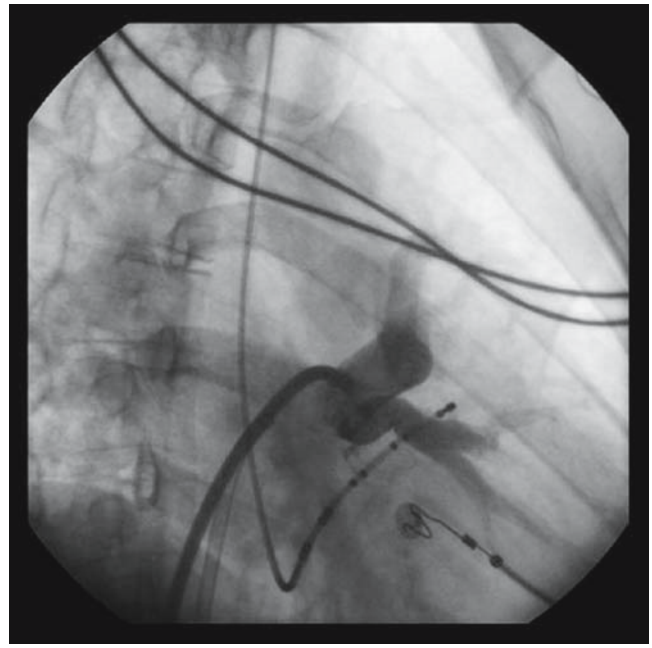
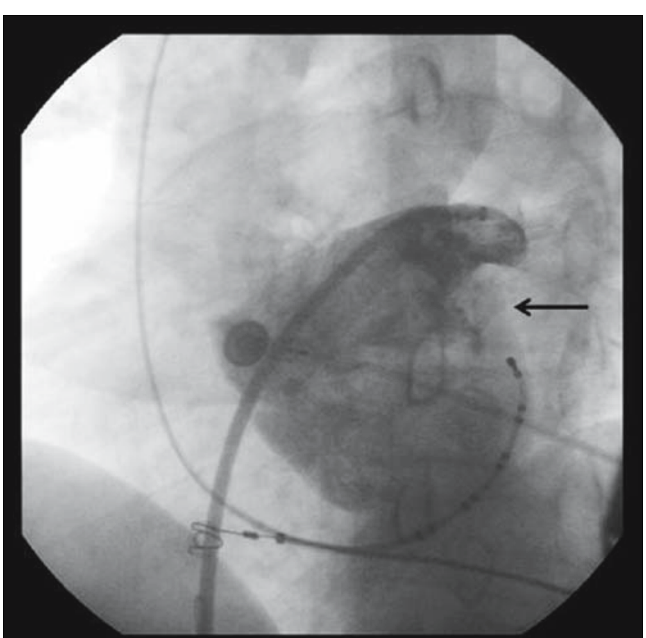
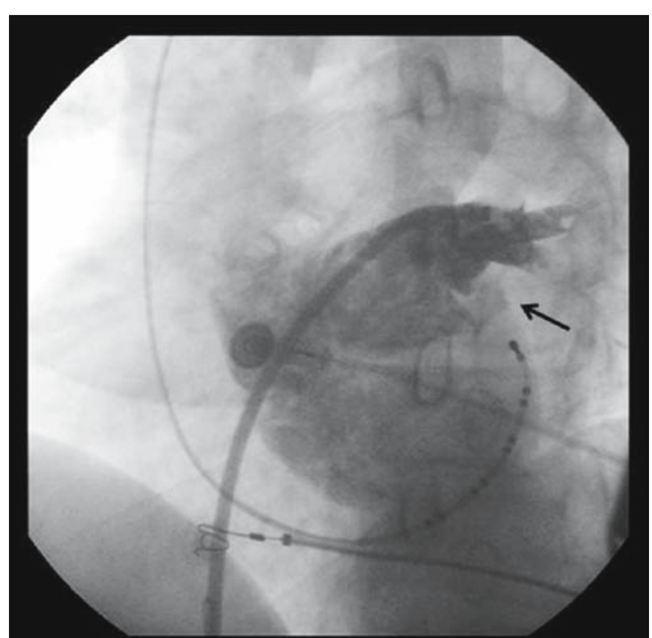


Figure 7.11 Left inferior pulmonary vein (*LIPV*) selective angiography in the right anterior oblique (*RAO*) view. In this view, one can see the vein divides into two branches at its proximal portion

To carry out selective angiography of the inferior veins, it is certainly advisable to locate the veins with the mapping/ablation catheter. The LIPV may be engaged in the LAO view. Through the long sheath, the ablation catheter, with no curvature, is advanced into the LA. After emerging from the sheath, the distal end of the catheter is curved and rotated clockwise (the LIPV ostium is usually more posterior than the corresponding superior vein). By then advancing the catheter, this one should enter the vein. Then, the long sheath is advanced over the catheter. It is necessary to be careful in advancing the sheath so that it does not dislodge the catheter from the vein; this can be verified in the RAO projection (Figures 7.10–7.13).





Figures 7.12 and 7.13 Left superior pulmonary vein (*LSPV*) angiography in the left anterior oblique (*LAO*) view. In the two consecutive sequences, one can appreciate the passive opacification of the left inferior pulmonary vein (*LIPV*) (arrow)

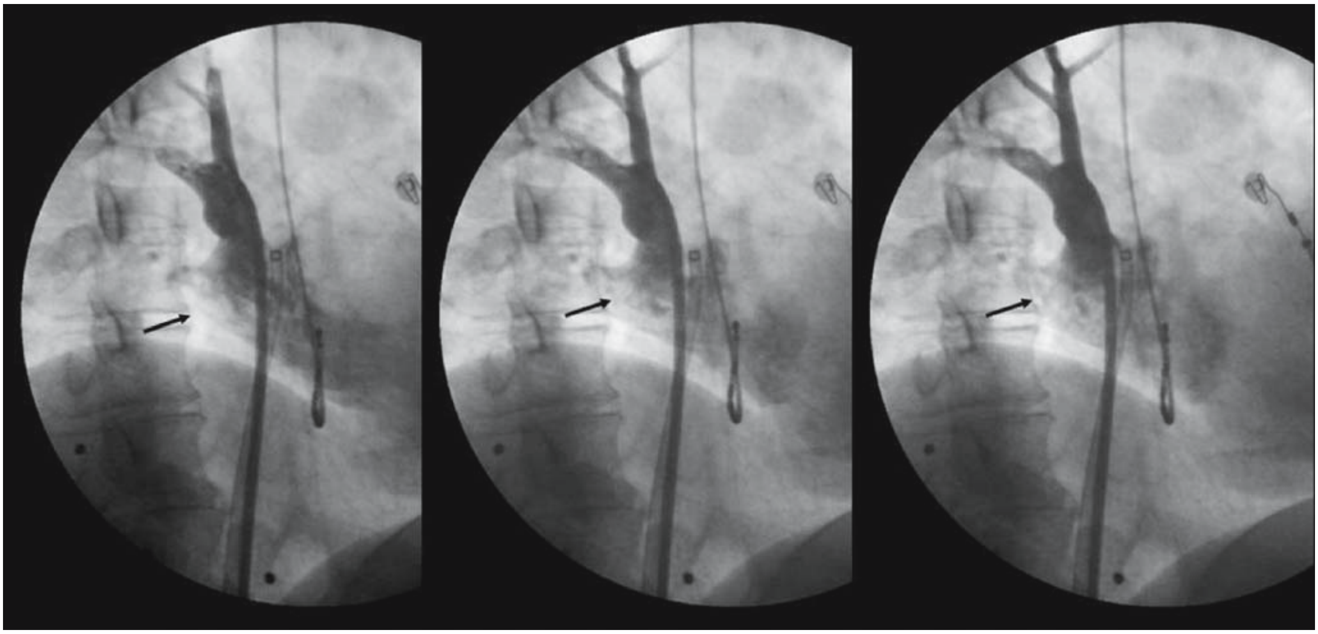


Figure 7.14 Right superior pulmonary vein (*RSPV*) angiography in the right anterior oblique (*RAO*) view. In the three consecutive sequences, one can appreciate the right inferior pulmonary vein (*RIPV*) passively becoming opaque (arrow)

The RIPV may be engaged in the RAO projection. From the RSPV, the mapping/ablation catheter is withdrawn and a distal curvature applied to the tip of the catheter. The catheter is further withdrawn and pulled inferiorly, thus engaging the RIPV. Following this, the distal curvature is released and the catheter advanced into the vein. The long sheath is then advanced over the catheter. Attention is similarly directed to ensure that the long sheath and ablation catheter have the same orientation; otherwise, advancement of the sheath may dislodge the catheter from the vein (Figure 7.14).

The definition of the PV ostia is not only carried out by angiography, as previously described, but also by other fluoroscopic criteria. Advancing the mapping/ablation catheter into the vein results in the catheter being visualized outside the cardiac silhouette. If the catheter is then withdrawn, it may be seen to fall back into the atrium; at this point, the ostium may be defined (Figure 7.15). Furthermore, electrophysiological criteria, particularly the local electrocardiograms and impendence, help in identifying the PV ostium.

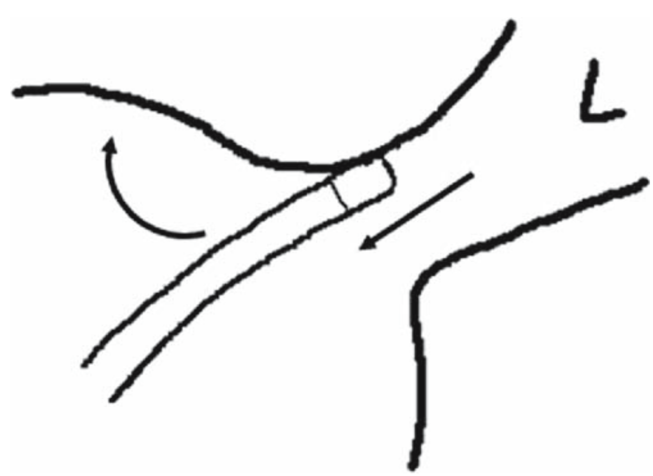


Figure 7.15 Maneuvering to identify the venous ostium in a sketch. The ablation catheter lies inside of the pulmonary vein (*PV*), with its curve thoroughly relaxed: the distal catheter's portion is, however, slightly bent as it adopts the course of the PV. By withdrawing the catheter, its tip moves back as far as the junction of the PV with the atrial wall and here the catheter springs into the atrium

Many centers utilize ICE as an integral part of the AF ablation strategy. ICE may be used to identify the ostia, or more importantly the antra of the PVs. This allows real-time definition of the PV/LA junction and positioning of the ablation and mapping catheters. Utilizing ICE has been shown to substantially improve the safety of the procedure, not least in decreasing the incidence of pulmonary venous stenosis.

7.2 Pulmonary Vein Segmental Disconnection with Mapping Catheter

PV segmental disconnection is carried out with an ablation catheter and a mapping catheter, both sequentially positioned at the four veins. At each vein ablation is circumferentially performed around each venous ostium.

Imaging techniques associated with this kind of procedure include PV angiography (as previously described), ICE, and electroanatomic mapping.

7.2.1 Mapping Catheters

There are different types of mapping catheters (Fig. 7.16). The circular mapping catheter is by far much more frequently employed than the mesh catheter. The circular mapping catheter is typically a 7 Fr deflectable catheter with its distal end in a loop-like shape. The loop's diameter can be fixed (prefixed sizes are 15, 20, and 25 mm; these are also available in loops of 12, 30, and 35 mm, the latter three being less frequently employed). Catheters in which the distal loop can be varied in diameter also exist. This is performed by manipulation of a special mechanism on the catheter handle, enabling one to close or widen the ring, thus getting diameters ranging between 15 mm and 25 mm. The distal loop of the circular mapping catheter contains a number of electrodes, usually 10 or 20.

The mesh catheter is an 8-Fr device which has at its distal end a spindle-shaped mesh which can be opened by a special tie-rod mechanism on the catheter handle. The maximum diameter is 25 mm, and 32 electrodes are placed on the mesh. This catheter has a fixed curvature and to position it, a special long deflectable sheath is employed.

Other mapping catheters include a 7 Fr deflectable mapping catheter where the distal end is subdivided into five branches each of 3 Fr size. Each branch has four electrodes. This has

Figure 7.16 Sketch of the pulmonary vein (*PV*) mapping catheters. From the left: the circular mapping catheter (10 or 20 electrodes), the mesh catheter (32 electrodes), and the flower-like catheter (20 electrodes). For spatial localization of the catheters, the mesh catheter has three fluoroscopic markers, two to times 12 and one to times 3, while the flower-like catheter has a fluoroscopic marker at distal electrode couple upon spline A and a fluoroscopic marker at proximal electrode couple upon spline B

been likened to having the appearance of the spokes of a wheel or a flower. This mapping catheter is employed in various kinds of ablation procedures, including AF ablation, either for assistance in confirming PV isolation or for mapping fragmented atrial potentials.

The mapping catheter is always inserted within the LA through the long sheath. The circular mapping catheter automatically assumes its "circular" appearance once outside of the long sheath. Frequently, the long sheath is withdrawn into the RA to lower systemic thromboembolic risk or to reduce interference between the mapping and ablation catheters. If difficulty is found in engaging the PV with the circular mapping catheter, it is sometimes necessary to engage the vein with the ablation catheter and then advance the sheath over the catheter to the level of the ostium. The ablation catheter can then be exchanged for the mapping catheter and this can then directly engage the vein. This is a less preferred strategy, as frequent catheter exchanges, while within the LA, may result in introduction of air into the LA, which may embolize.

Movements of the circular mapping catheter should be small and are usually performed with clockwise or counterclockwise torque. Additionally, when using a variable-loop mapping catheter, the catheter is advanced and retracted into the long sheath while at its maximum diameter. Once the catheter is located in the LA, it is possible to reduce the diameter and insert the catheter into the vein. The diameter is then increased again and withdrawn slowly to be securely in contact with the venous ostium.

In the following sequence of images (Figures 7.17–7.31), the positioning of the circular mapping catheter is shown.

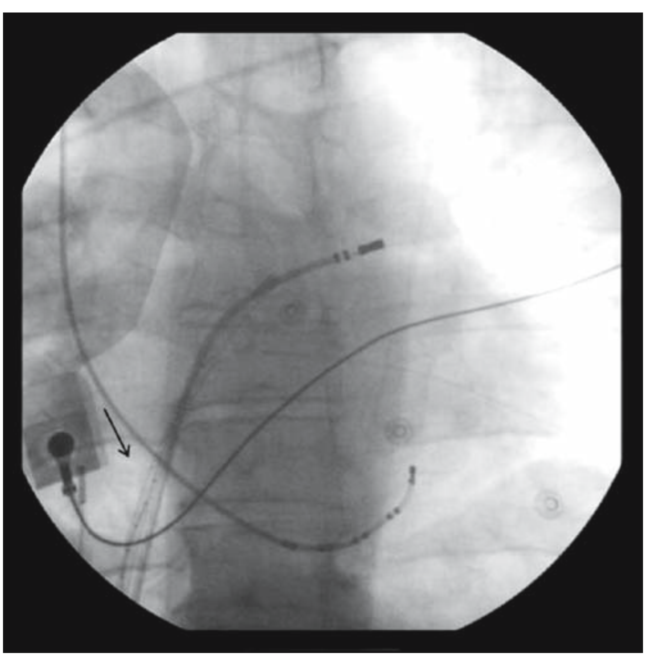


Figure 7.17 In the left anterior oblique (*LAO*) view, one identifies the left superior pulmonary vein ostium with the ablation catheter. Through the long sheath one advances the circular mapping catheter (arrow)

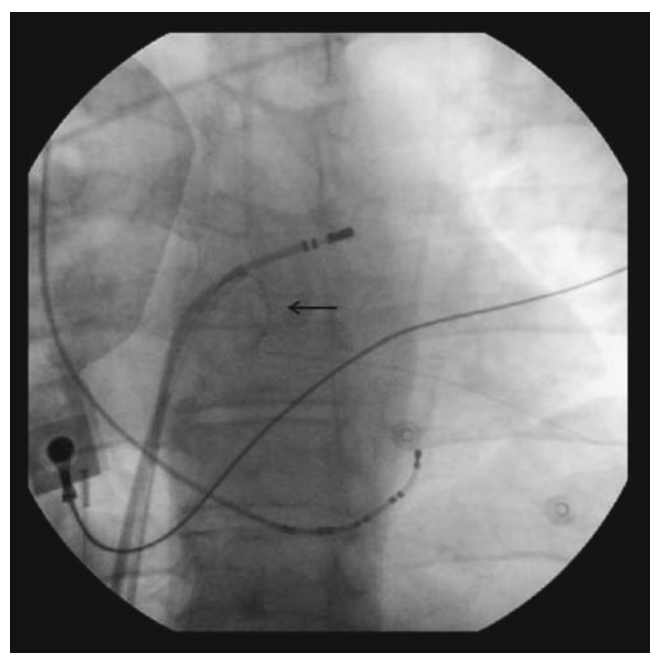


Figure 7.18 Advancing the circular mapping catheter (arrow) which after emerging from the long sheath reverts to its circular shape

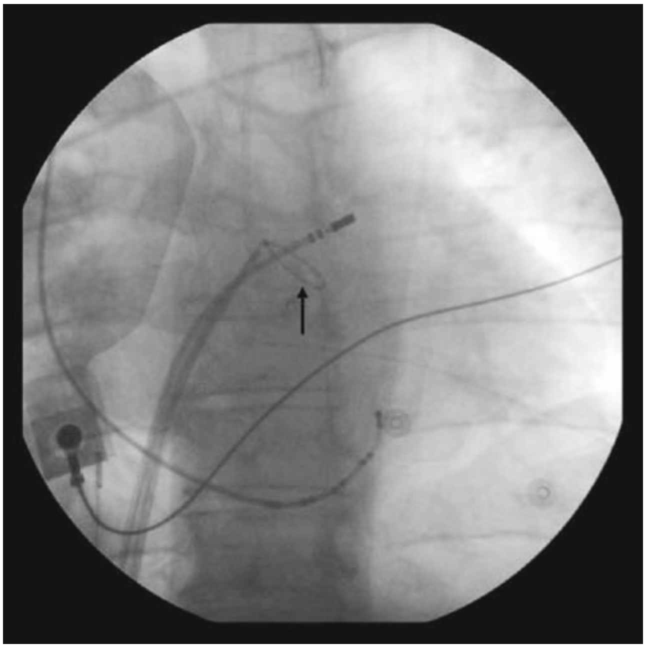


Figure 7.19 Circular mapping catheter (arrow) is now entirely within the left atrium

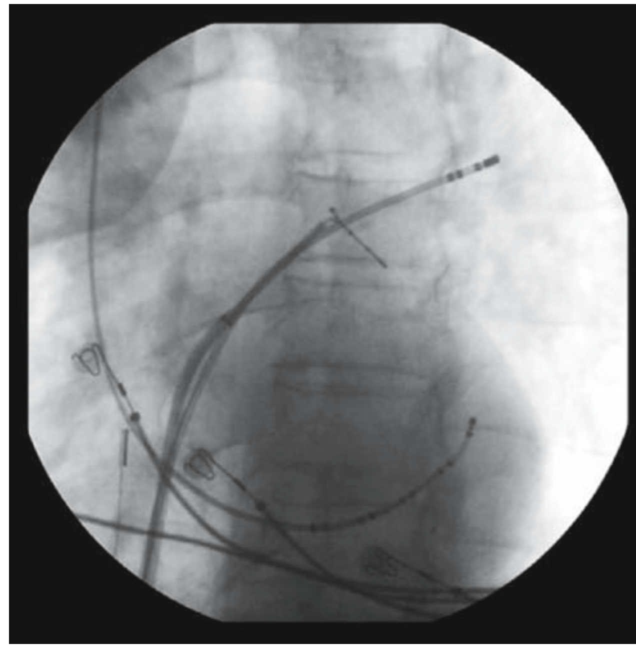


Figure 7.20 Advancing the mapping catheter toward the posterolateral wall's superior portion, where the left superior pulmonary vein antrum is located

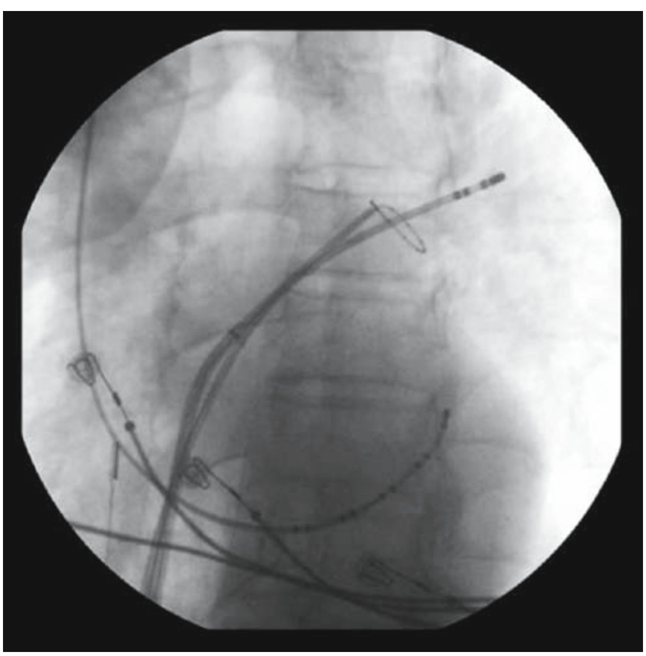


Figure 7.21 The mapping catheter is at the pulmonary vein ostium. By pushing the catheter toward the venous ostium, a "springing" can be perceived at the narrow surface. At that point, the catheter is barely beyond the venous ostium. When inside the vein, the mapping catheter has to be rotated clockwise to prevent the distal end from pushing against the venous wall. Now the catheter can be slightly withdrawn, such that a springing motion is perceived. This corresponds to the catheter coming out of the vein's cylindrical portion toward the venous antrum's funnel-shaped portion. However, one may leave the mapping catheter inside of the vein, where it is steadier. Radio frequency (*RF*) applications are, thereafter, performed more proximal to the ostium or at the antrum. Finally, please note how the mapping catheter rests barely outside of the cardiac silhouette, a further fluoroscopic confirmation of its positioning just beyond the venous ostium

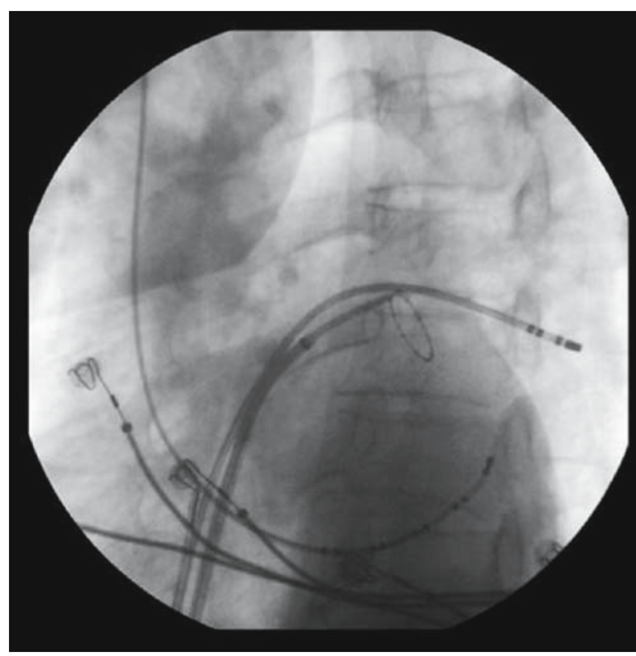


Figure 7.22 In this case, the ablation catheter lies within the left inferior pulmonary vein. In the left anterior oblique (*LAO*) view, one brings the mapping catheter into the left atrium and slightly bends it to turn it toward the posterolateral wall

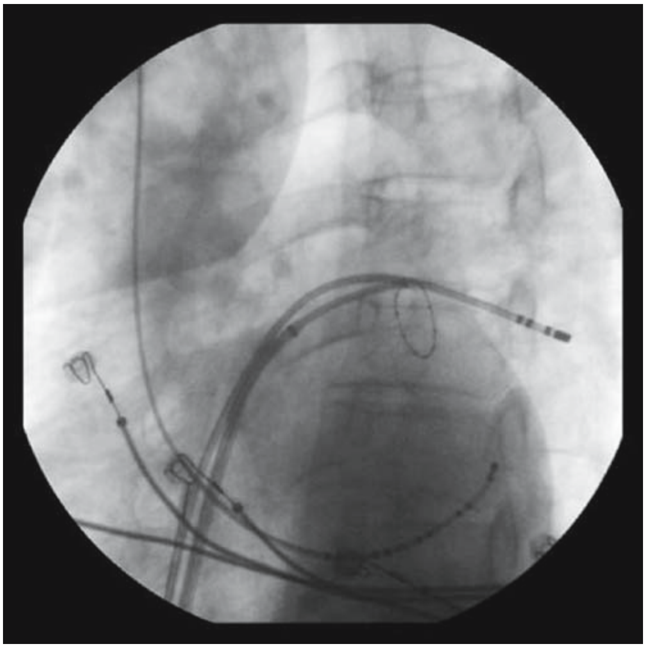


Figure 7.23 The catheter is pushed toward the posterolateral atrial wall. When there is contact with the venous ostium, the catheter is advanced by slightly torquing it clockwise so to ease it into the vein

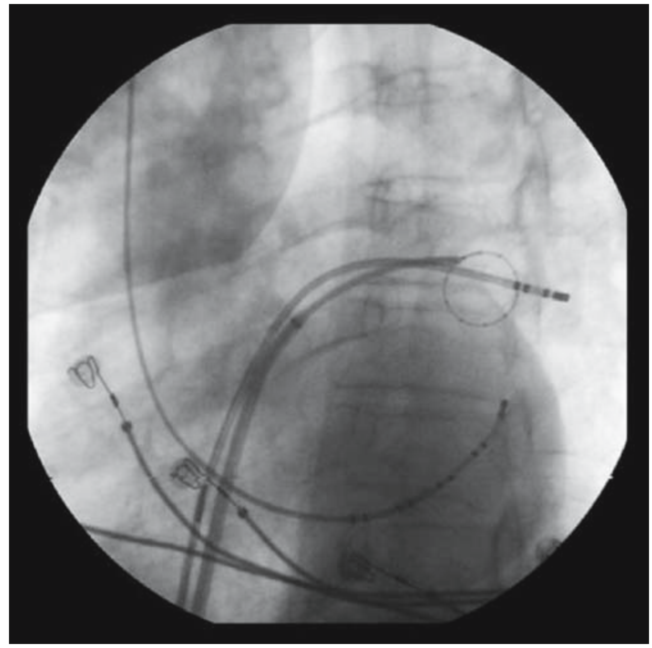


Figure 7.24 The catheter enters the pulmonary vein

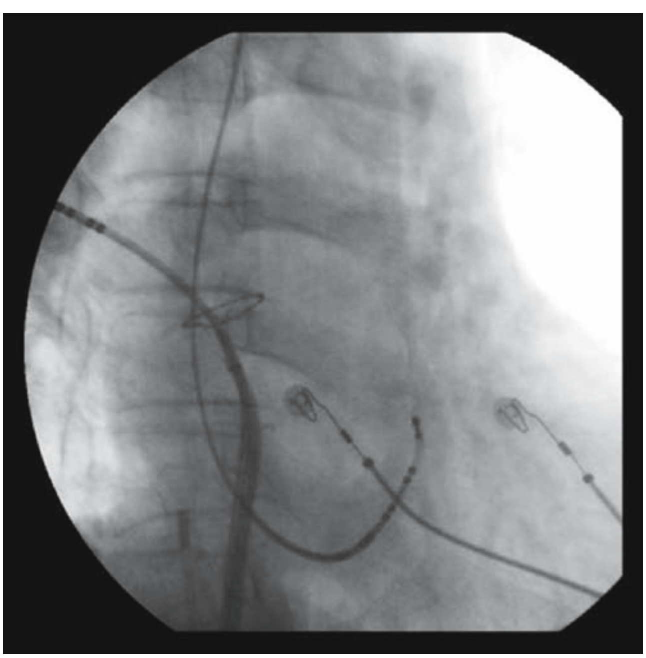


Figure 7.25 In this sequence, the circular catheter's positioning within the right superior pulmonary vein in the right anterior oblique (*RAO*) view is shown. Positioning in the RSPV may be performed in the left anterior oblique (*LAO*) view too (employing such a view is a later sequence in positioning the mesh catheter). The catheter then enters the pulmonary vein. In this case, in the RAO view, the ablation catheter is advanced into the right superior pulmonary vein. The long sheath has been rotated toward the posteroseptal wall. Through the long sheath the mapping catheter (with no curvature) is advanced

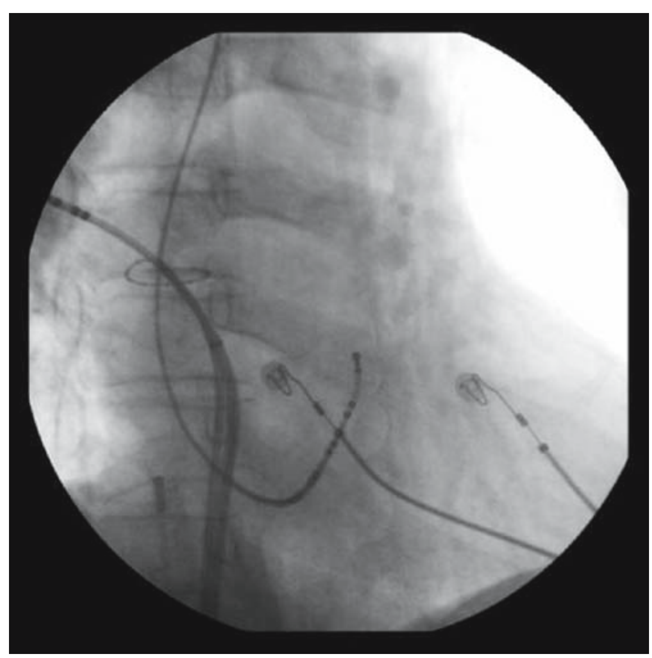


Figure 7.26 The mapping catheter at the level of the venous ostium. In the image, one can see how the circular catheter's posterior portion tends to go within the vein, while its anterior portion is held by the roof

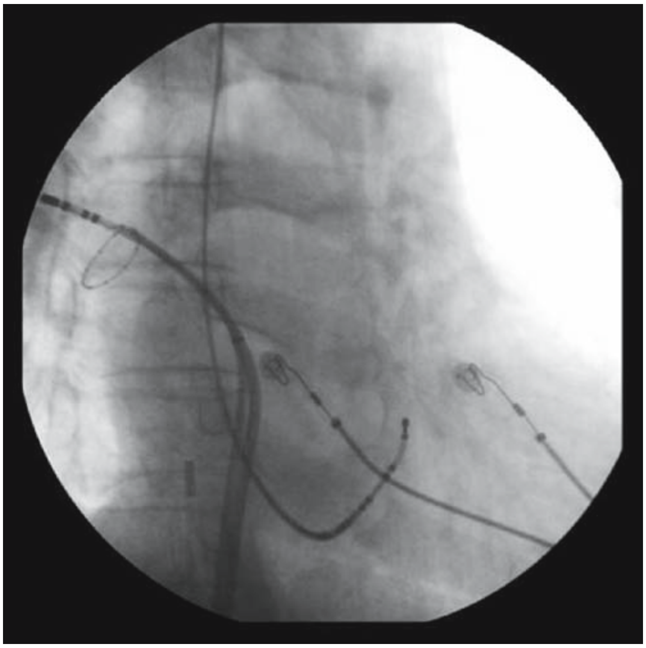


Figure 7.27 By advancing the mapping catheter with a slight clockwise torque, the entire mapping catheter's circular portion enters the pulmonary vein

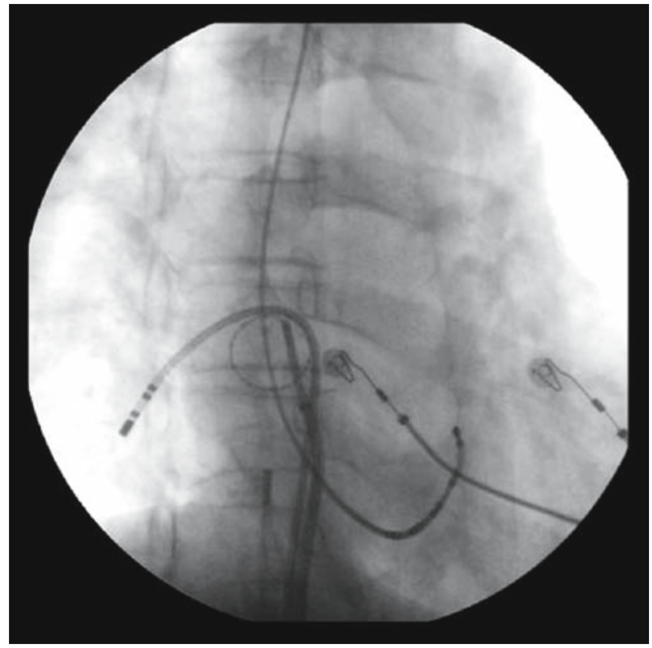


Figure 7.28 In the right anterior oblique (*RAO*) view, the mapping catheter is positioned in the right inferior pulmonary vein. The ablation catheter is advanced into the pulmonary vein and the curvature is relaxed; the curve seen on the catheter body is that of the vein's course

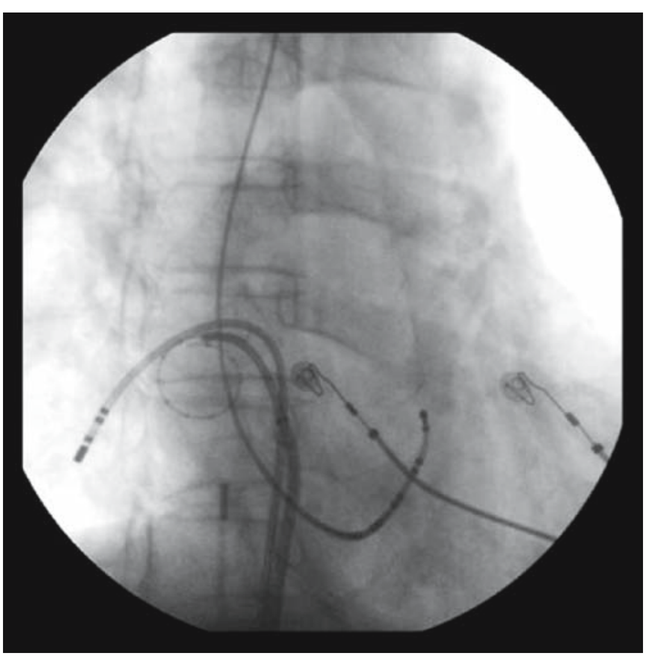


Figure 7.29 Following the ablation catheter's path, one advances the mapping catheter to be in contact with the atrium's posterior wall. The right inferior pulmonary vein (*RIPV*) is located at a lower level and posteriorly to the right superior pulmonary vein (*RSPV*)

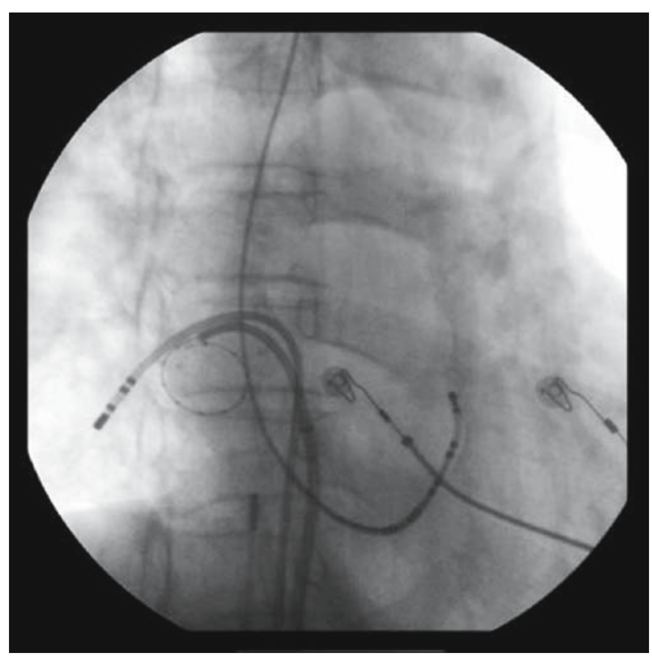


Figure 7.30 By advancing with the aid of a slight clockwise torque, the catheter is inserted into the vein. Also after relaxing the curvature, the catheter remains within the vein, with the catheter following the course of the vein

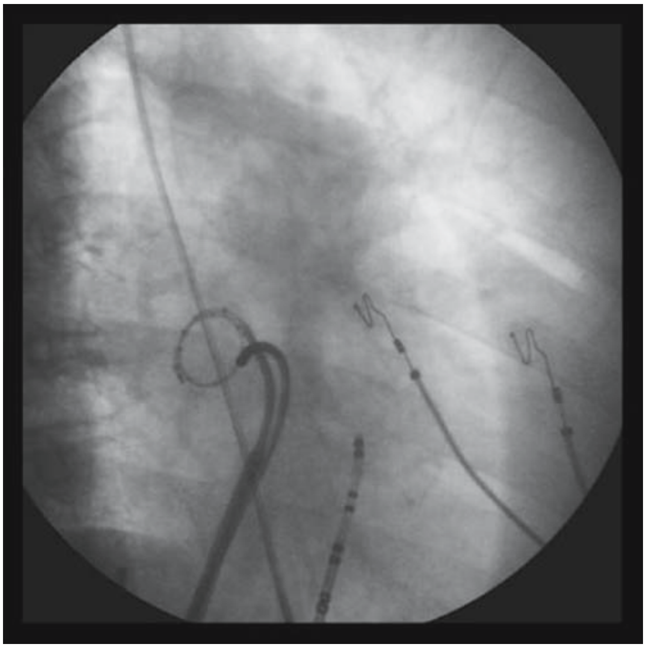


Figure 7.31 A variable-loop circular mapping catheter is positioned at the right inferior pulmonary vein (*RIPV*) ostium in the right anterior oblique (*RAO*) view

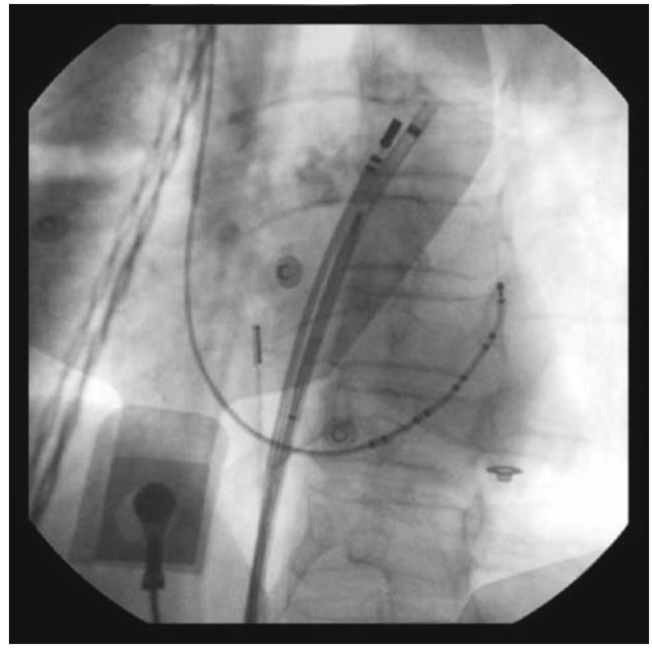


Figure 7.32 In the left anterior oblique (*LAO*) view, the long sheath is positioned into the left superior pulmonary vein; the mesh catheter (arrow) is inside the sheath. To identify the vein's position, one can first place the ablation catheter at the level of the venous ostium. Thus, the ablation catheter acts as a guide in locating the vein's position

With regard to the mesh-mapping catheter, it is often necessary to position the long deflectable sheath[1] at the PV antrum. Then the mesh catheter is advanced so that the mesh rests thoroughly outside of the sheath. Next, while releasing the catheter, one must slightly withdraw the long sheath in such a way that the catheter's tip does not go forward too distally within the vein. Finally, the mesh is opened and this should come into direct contact with the venous antrum (Figures 7.32–7.44).

The "flower-like" catheter can be used for PVs mapping. This mapping catheter can be very useful and its positioning at the PVs' ostium is performed with the same maneuvers as that for the circular mapping catheter. In the following images, examples of PV mapping with a "flower-like" catheter are shown (Figures 7.45–7.48).

[1] For mesh catheter positioning, which has a fixed curve catheter, it is advisable to employ a long deflectable sheath. The facility of bending the sheath is very useful for searching and entering the pulmonary vein. When it is necessary to advance the mesh catheter, it is advisable to relax the sheath's curvature, since too marked a curvature can make it difficult to advance the catheter. It is important to remember that when operating with a long sheath, one must orientate the sheath and the catheter in the same plane as much as possible, to ensure the best stability of the whole unit.

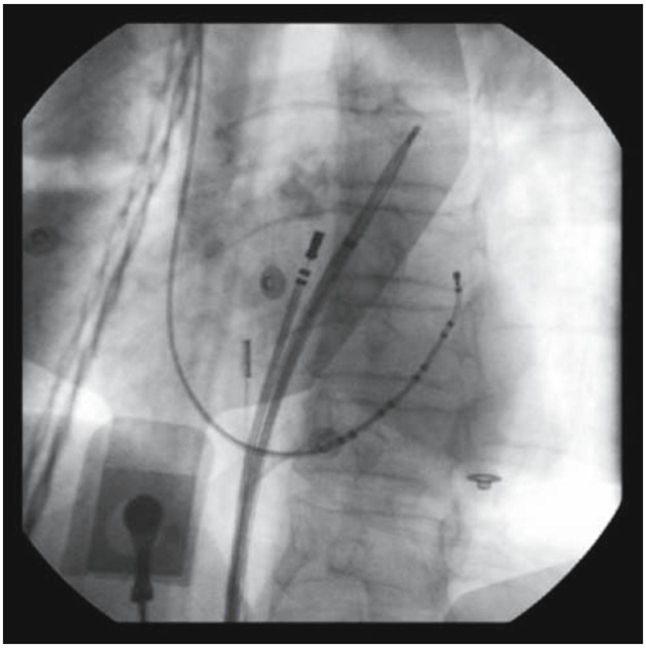


Figure 7.33 Advancing the mapping catheter forward with its mesh closed and, while advancing the catheter, the long sheath is slightly pulled back

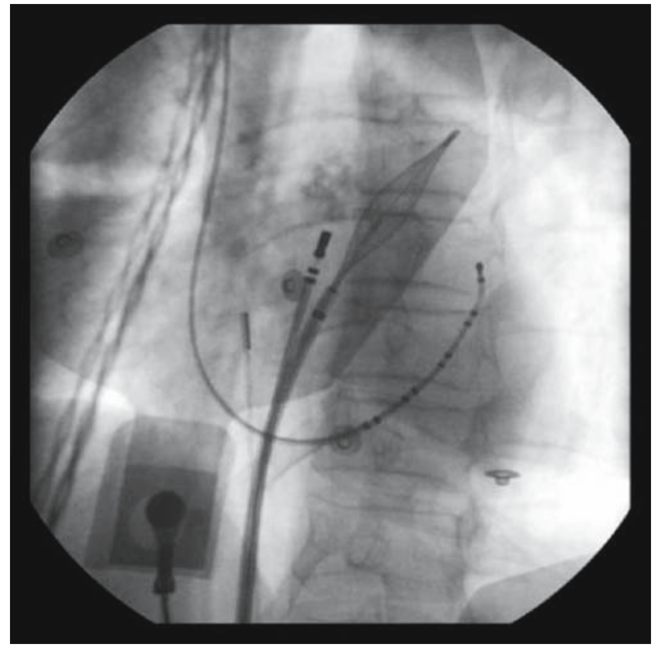


Figure 7.34 Once the mesh is thoroughly out of long sheath, it is opened

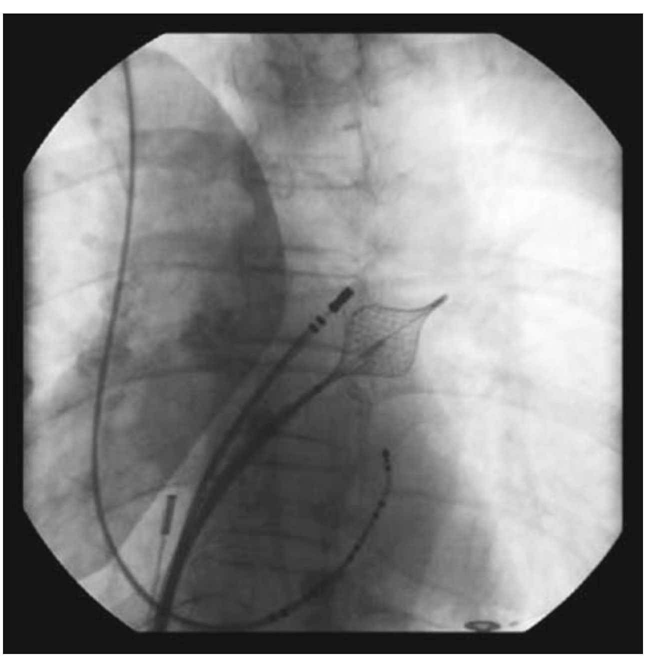


Figure 7.35 The mesh will be opened to appose the walls of the vein's ostium. In such a position, the mapping catheter ensures optimum stability

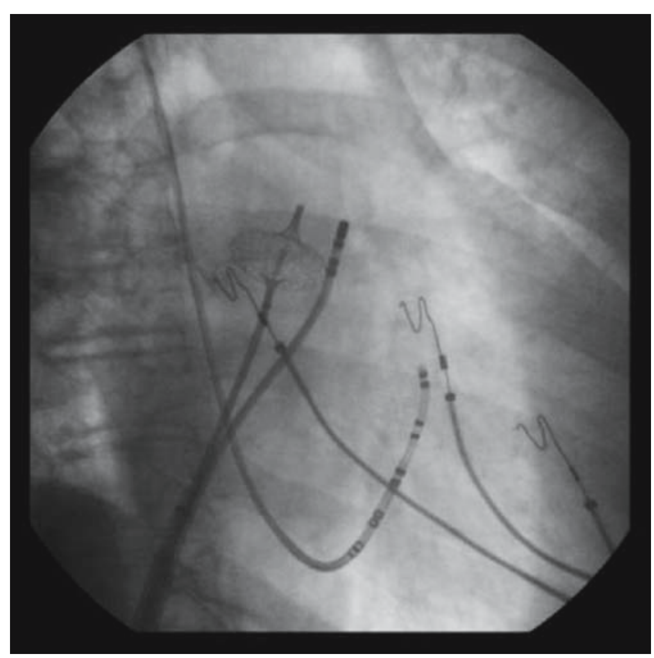


Figure 7.36 Same image in the right anterior oblique (*RAO*) view

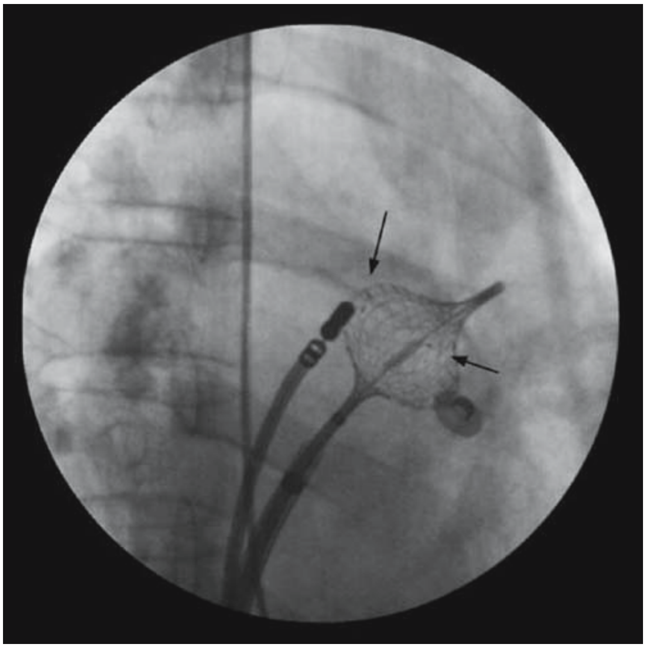


Figure 7.37 This image is a magnification of the mesh catheter placed at the left superior pulmonary vein (*LSPV*) ostium. The magnification allows recognition of the fluoroscopic markers (arrows at 12 o'clock and 3 o'clock)

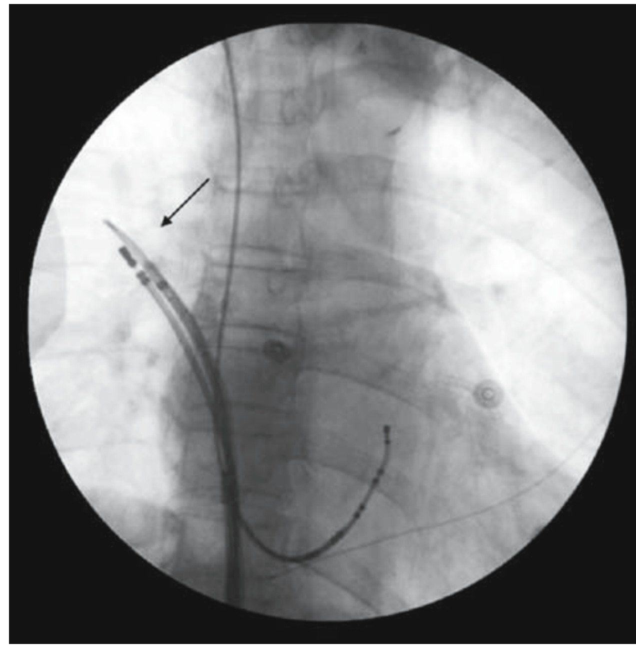


Figure 7.38 The left anterior oblique (*LAO*) view enables positioning the mapping catheter in the right superior pulmonary vein too. In this image, one can see the long sheath at the vein's ostium along with the mesh catheter (arrow) beginning to come out. In this case also, the ablation catheter has been positioned as an anatomic landmark

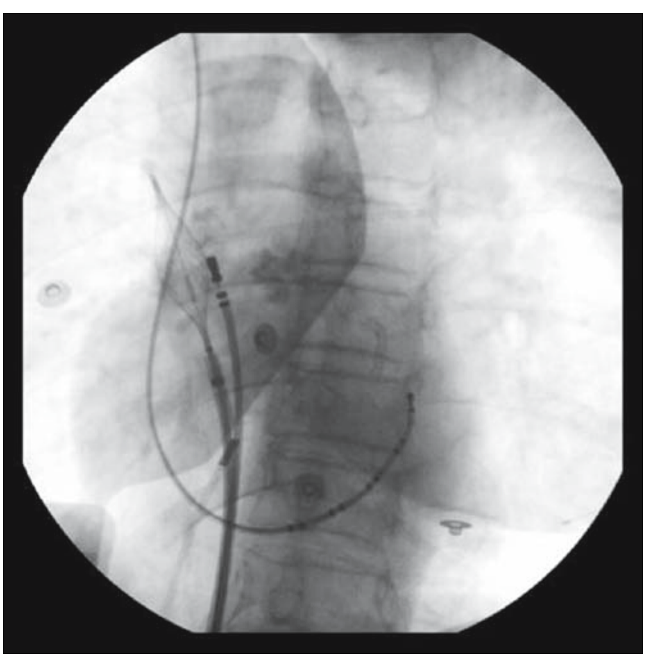


Figure 7.39 The mesh is opened as far as being in contact with the pulmonary vein ostium. In the case of small size veins, as in this case, the mesh appears less opened

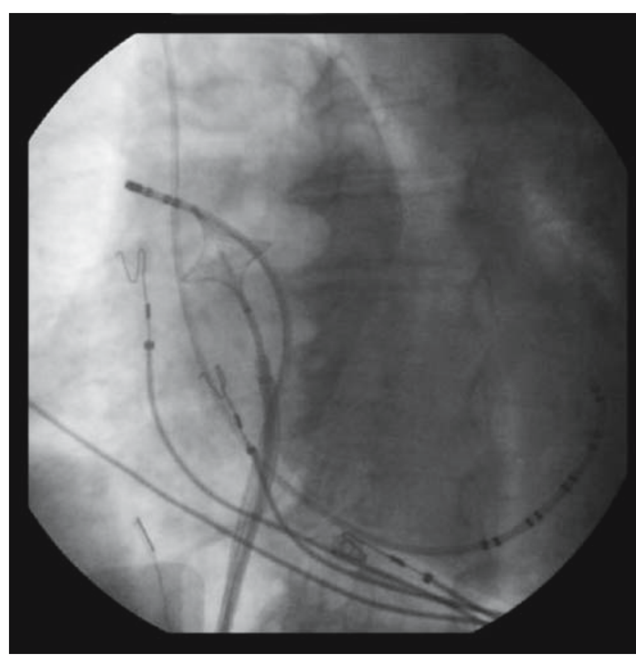


Figure 7.40 In the case of large veins, the mesh is completely opened up to apposition of the catheter against the vein's ostium, ensuring optimum stability

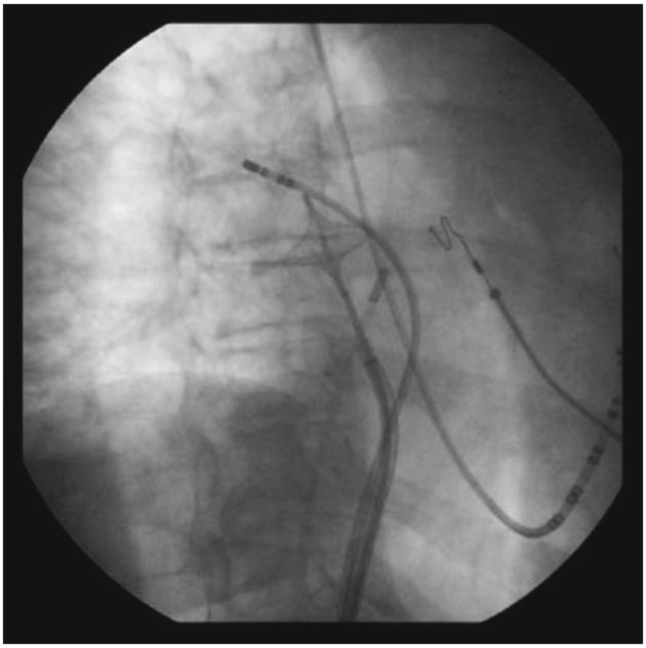


Figure 7.41 The same image in the right anterior oblique (*RAO*) projection

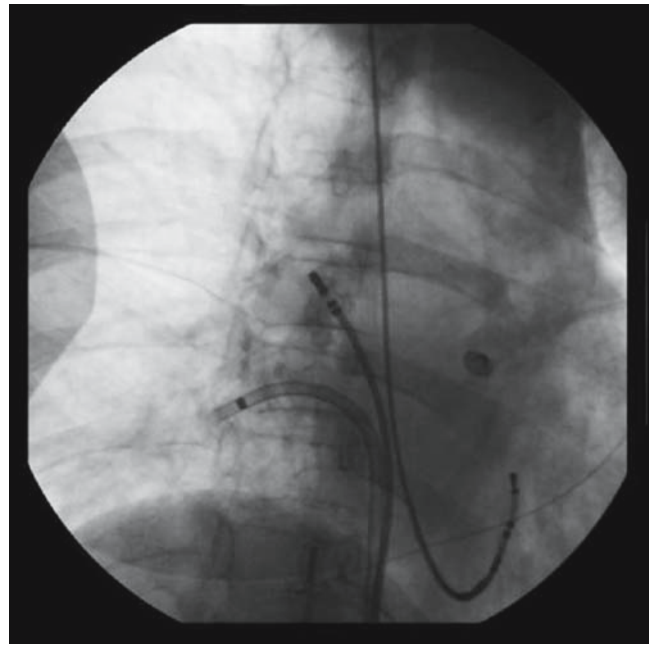


Figure 7.42 In this case, the right inferior pulmonary vein (*RIPV*) has been cannulated with a deflectable long sheath in the right anterior oblique (*RAO*) view

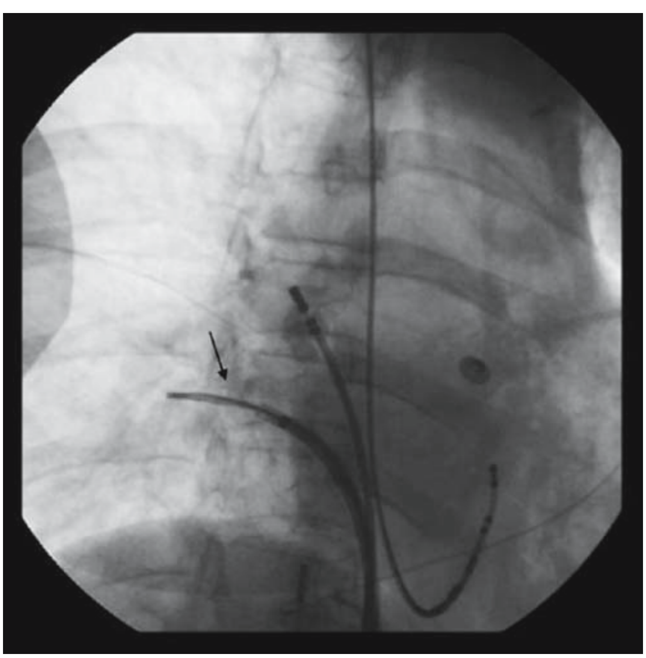


Figure 7.43 The mesh catheter (arrow), inserted in the long sheath, is coming out. Advancing the mapping catheter, the long sheath slightly loses its curvature

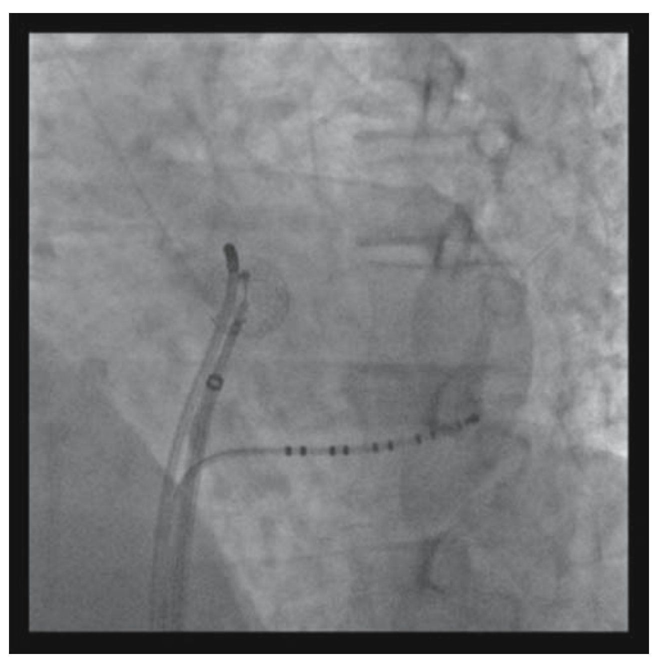


Figure 7.44 The mesh-mapping catheter positioned within the right inferior pulmonary vein in the left anterior oblique (*LAO*) view. Note the coronary sinus (*CS*) cannulated by an EP catheter by an inferior approach

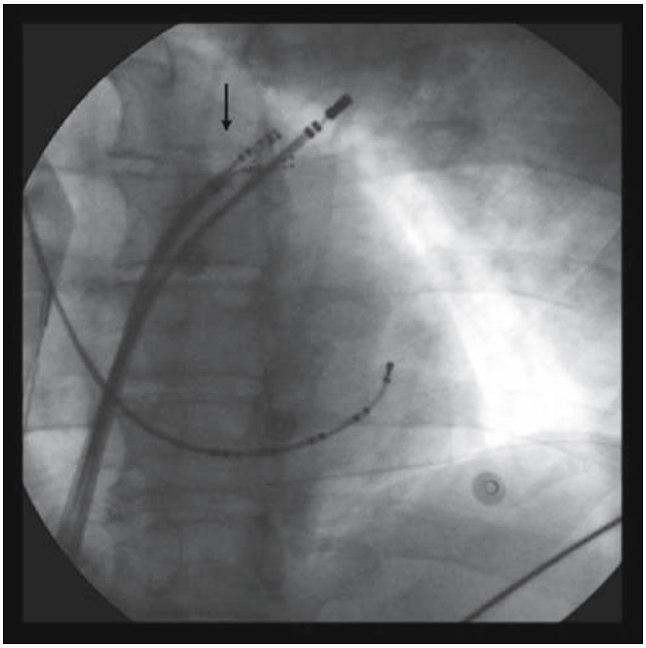


Figure 7.45 In the left anterior oblique (*LAO*) view, the ablation catheter identifies the left superior pulmonary vein (*LSPV*). The long sheath is positioned at the vein's antrum and the flower-like mapping catheter (arrow) begins to appear from the sheath

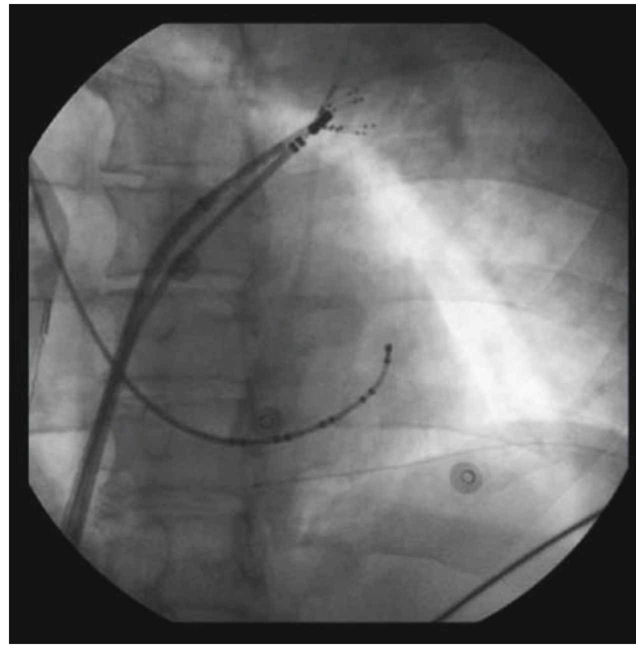


Figure 7.46 By further advancing, the mapping catheter lies within the vein

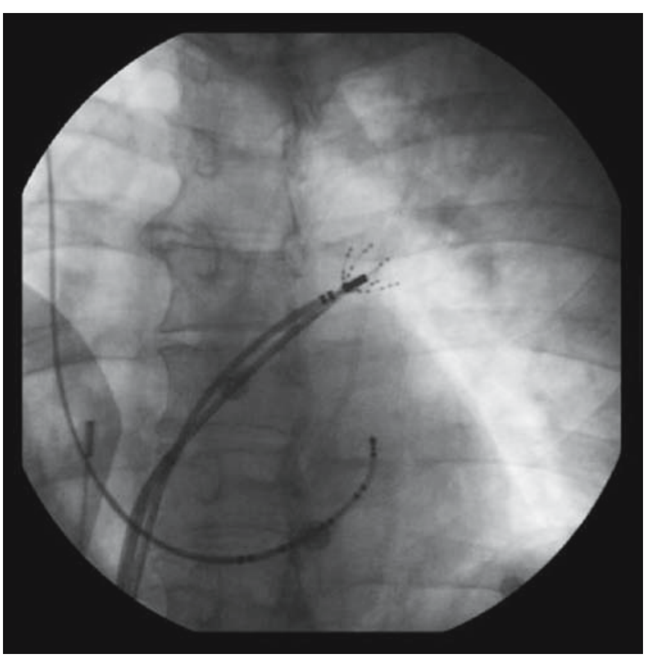


Figure 7.47 At this point, the mapping catheter is slightly withdrawn until its branches are open and rest against the venous antral–ostial junction

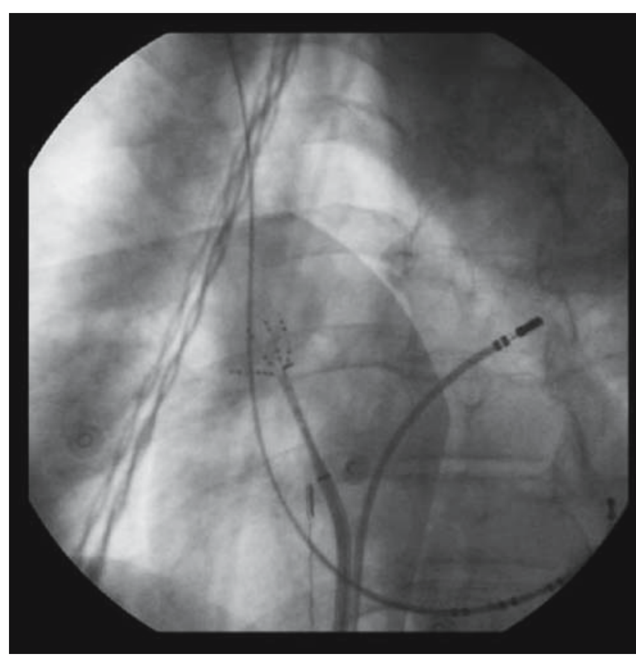


Figure 7.48 Image showing the position of the flower-like mapping catheter at the venous antral–ostial junction of the right superior pulmonary vein (*RSPV*) in the left anterior oblique (*LAO*) projection

7.2.2 Pulmonary Veins' Ostial Disconnection

To carry out the ablation, it is necessary to position the ablation catheter at the PV ostium, or more safely the PV antrum, where the mapping catheter is positioned. Usually, for AF ablation, the most commonly used catheters are 8-mm or irrigated tip ones with a large curve. Therefore, ablation catheters are inserted into the LA either directly or more frequently by means of a second long sheath, according to operator preference.

For LSPV isolation, the catheter may be positioned in the LAO view. Usually, the vein can be entered by advancing the catheter as described previously. Should one come across difficulty in engaging the vein, the RAO view can help to localize the vein's ostium. In summary, the ablation catheter is placed freely within the LA, the distal tip curved, and it is advanced superiorly and posteriorly by applying clockwise torque. Once close to the roof's level, the distal curve is released and the catheter engages the LSPV.

Then, the ablation catheter must be able to reach all points forming the ostium's circumference. The LAO view enables us to identify the venous ostium's plane. In this plane, the more superior points can be reached by opening and releasing the catheter's curvature; conversely, the inferior points can be reached by increasing the catheter's curvature. The RAO view allows us to visualize the anterior points, which are reached by means of a counterclockwise rotation and the posterior points by means of a clockwise rotation (Figs. 7.49 and 7.50).

The LIPV is searched for in the LAO projection by placing the ablation catheter free in the LA, applying a distal curvature and then clockwise rotation to see the curvature turned toward the left lateral wall. At this point, the catheter is advanced and it should enter the LIPV. As in the case of the ipsilateral superior PV, the vein could lie posteriorly to the plane toward which the transseptal puncture directs one. This is particularly the case if the interatrial septum is punctured in too anterior a plane. In this case, in the RAO view, it is necessary to apply further clockwise torque to the catheter so that its tip is turned toward the PV ostium. The LAO view enables one to identify the PV plane along with its superior and inferior portion, whereas the RAO view allows one to reach the anterior (counterclockwise rotation) and posterior portion (clockwise rotation) (Figures 7.51–7.54).

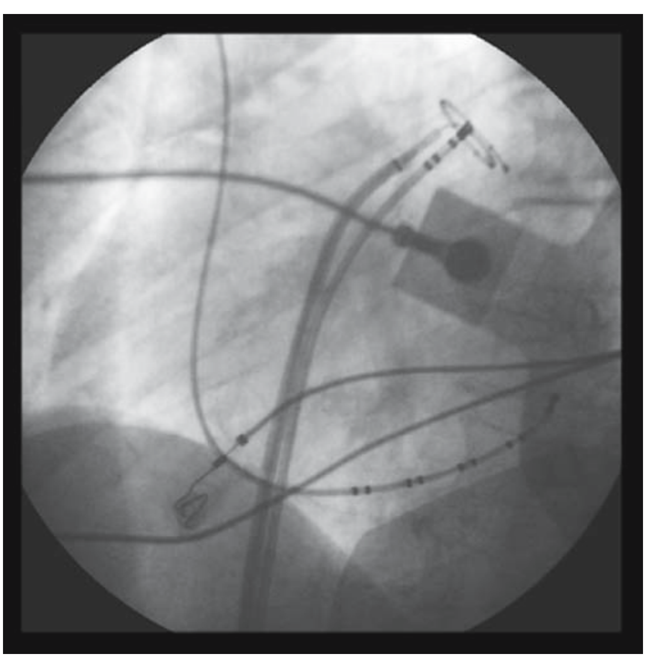


Figure 7.49 The left anterior oblique (*LAO*) view. A circular mapping catheter positioned at the left superior pulmonary vein ostium. The ablation catheter rests at the ostium's anterior portion

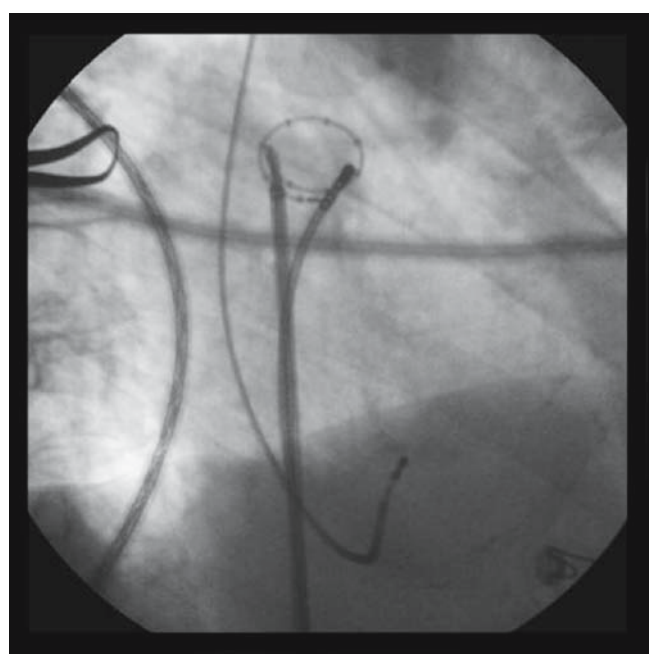


Figure 7.50 Left superior pulmonary vein in the right anterior oblique (*RAO*) view. In this view, it is possible to verify the ablation catheter's exact position; in this case, it lies at the level of the ostium's anterior portion

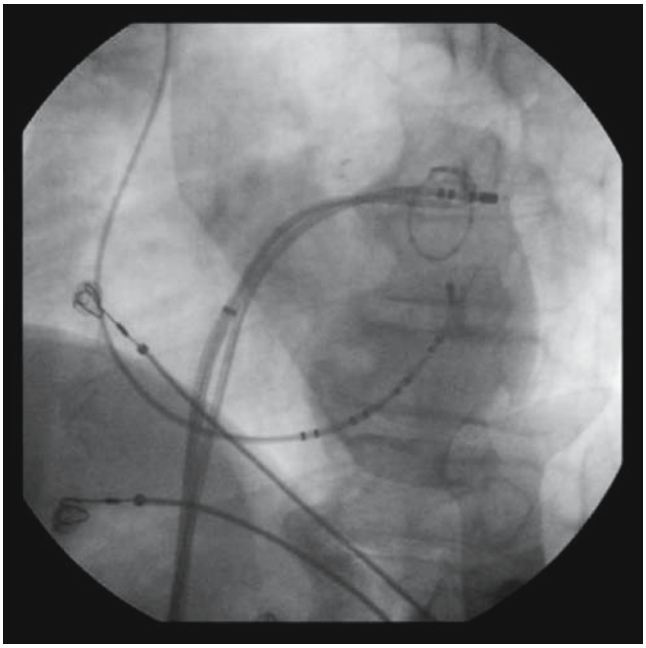


Figure 7.51 Circumferential mapping catheter positioned at the left inferior pulmonary vein ostium. The ablation catheter lies on the ostium's midsuperior portion

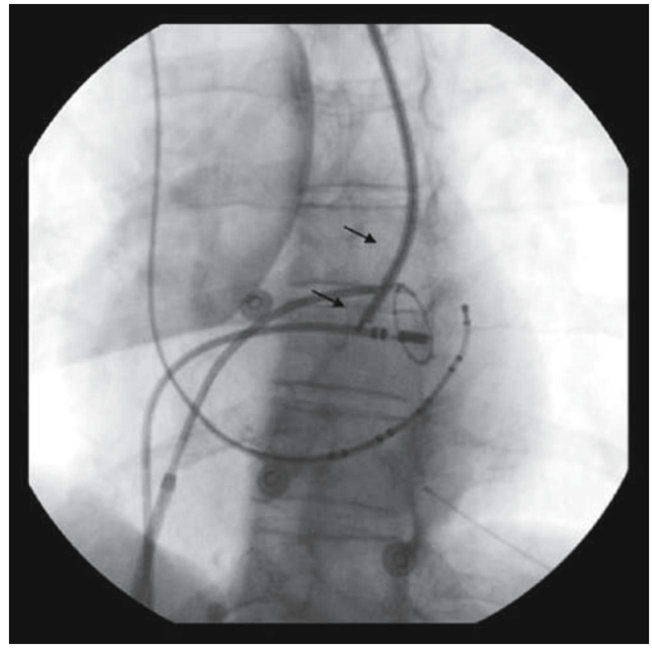


Figure 7.52 In this case, as well as the endocardial catheters, an additional catheter (arrows) has been inserted in the esophagus. This catheter has the capability to monitor the esophageal temperature, and thus give a marker for the left atrium posterior wall temperature, during radio frequency (*RF*) applications. Furthermore, this catheter, being radio-opaque, shows the oesophageal course, which could be placed leftward, rightward, or centrally. During pulmonary vein (*PV*) disconnection, the catheter may be placed less or more distally to monitor the region closest to the ablation site

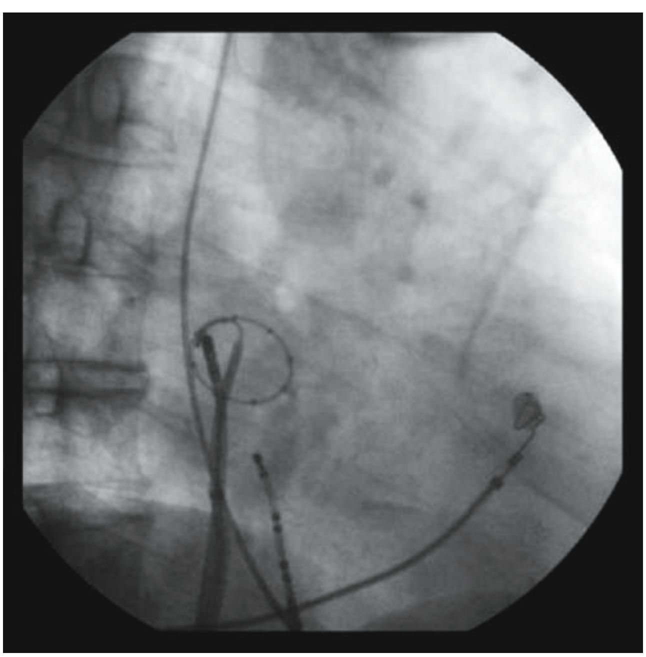


Figure 7.53 The right anterior oblique (*RAO*) view of the left inferior pulmonary vein (*LIPV*). In this view, one can see that ablation catheter lies at the level of the ostium's posterior portion

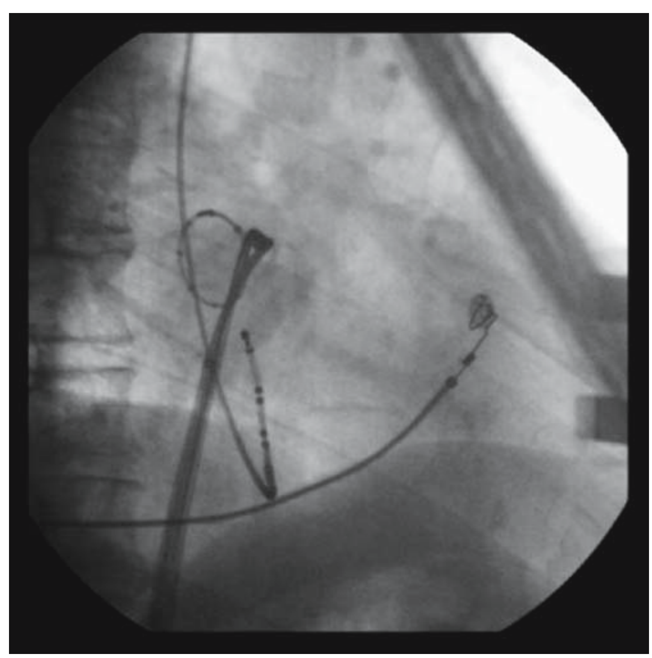


Figure 7.54 The right anterior oblique (*RAO*) view of the left inferior pulmonary vein (*LIPV*) with the ablation catheter on the anterior side

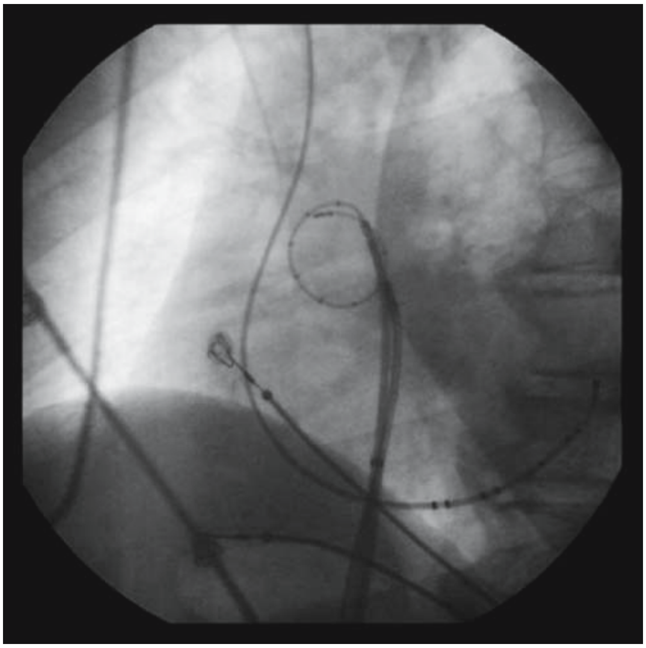


Figure 7.55 Right superior pulmonary vein (*RSPV*) in the left anterior oblique (*LAO*) view with the ablation catheter corresponding to the ostium's antero (septal) -superior portion

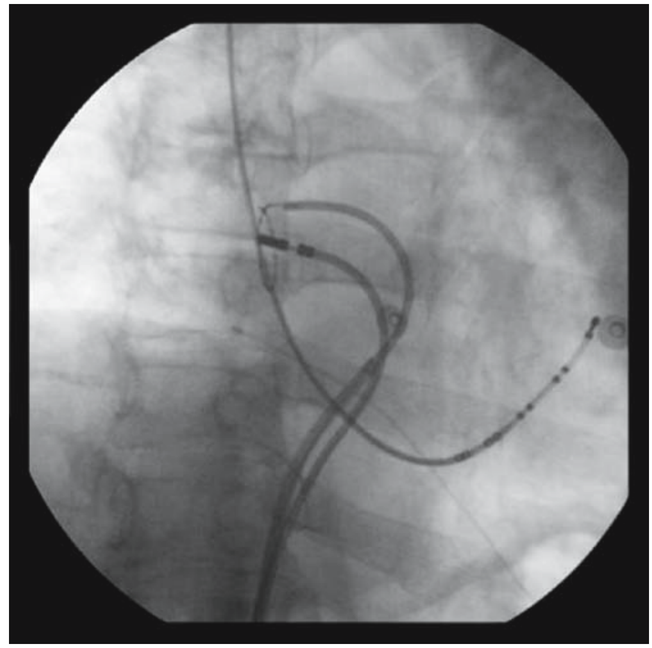


Figure 7.56 Right superior pulmonary vein in the right anterior oblique (*RAO*) view with the ablation catheter in the ostium's mid-superior portion

The RSPV may be engaged in the LAO view. It is necessary to ensure the ablation catheter is free within the atrium, and then with a distal curve applied it is rotated about 180° clockwise; in this way, the catheter is turned toward the septal wall. From this position, the catheter is advanced and the curvature gently released such that it engages the PV. If the vein is not entered with this procedure, differing distal curvatures can be applied to search for the venous ostium. For the right veins, the RAO view identifies the ostium plane and enables one to reach the superior portion by straightening the catheter, and the inferior portion by curving the catheter. The LAO view, instead, allows identification of the anterior or septal segments by means of a clockwise rotation, and the posterior segments by means of a counterclockwise rotation (Figures 7.55–7.57). It should be noted that movements

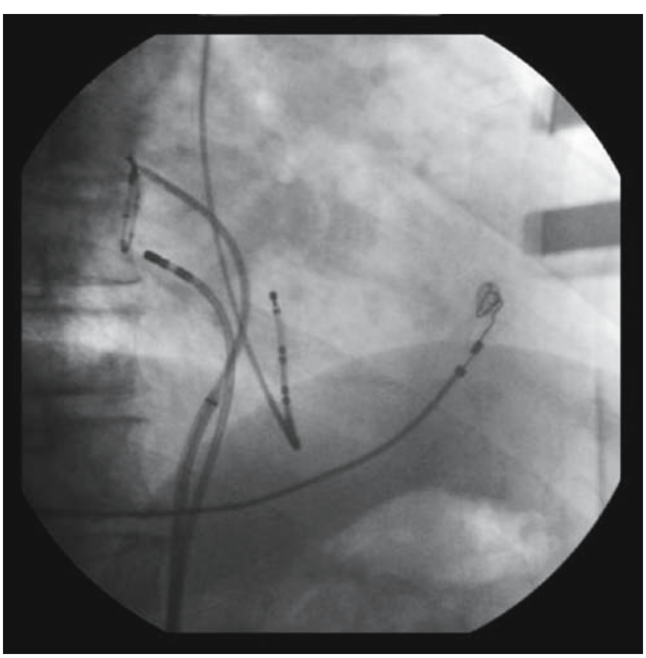


Figure 7.57 Right superior pulmonary vein in the right anterior oblique (*RAO*) view with the ablation catheter on the ostium's inferior border

directing the catheter anterior or posterior are diametrically opposed when operating near the right PVs with regard to the left PVs. This is because initially a 180° rotation has been carried out, which turns the catheter toward the opposite direction.

The RIPV may be located using the RAO projection. From the RSPV the catheter is pulled back and then a distal curvature is again applied; in this way, the catheter's tip is in contact with the septal atrial wall. Next, the catheter is further withdrawn, which may now hook in the PV's ostium. At this point, the curvature is released so that it can slide within the vein. Frequently, after withdrawing the catheter from the RSPV, application of a curve and inferior manipulation of the catheter results in engaging of the RIPV. The circumferential mapping catheter is inserted with the same maneuvers. However, sometimes positioning of this catheter is difficult due to the small size of this vein and its proximity to the transseptal puncture site. The RAO view is the one which enables one to identify the ostial plane as well as superior and inferior segments. The LAO view distinguishes the septal border, which can be reached by means of clockwise rotation, from the posterior border, which can be reached by means of counterclockwise rotation (Figures 7.58–7.62).

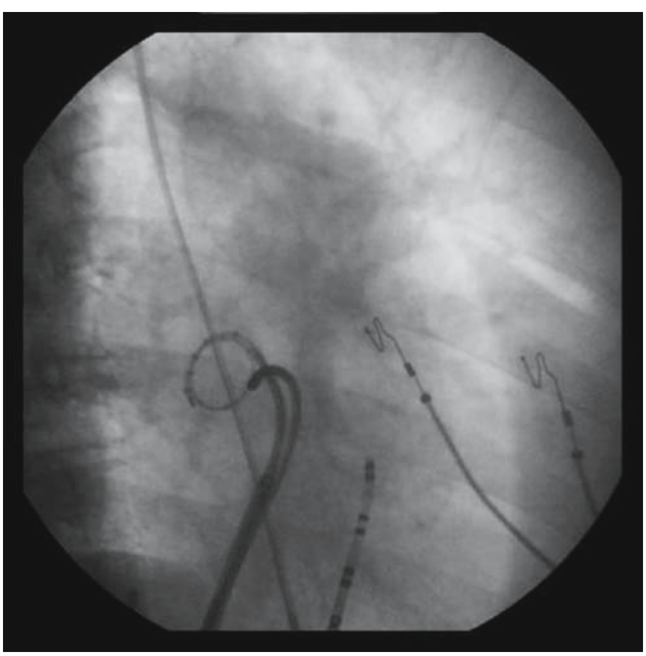


Figure 7.58 Right inferior pulmonary vein in the right anterior oblique (*RAO*) view. A variable-loop circular mapping catheter is positioned at the RIPV ostium and the ablation catheter corresponding to the ostium's septal (or anterior) portion

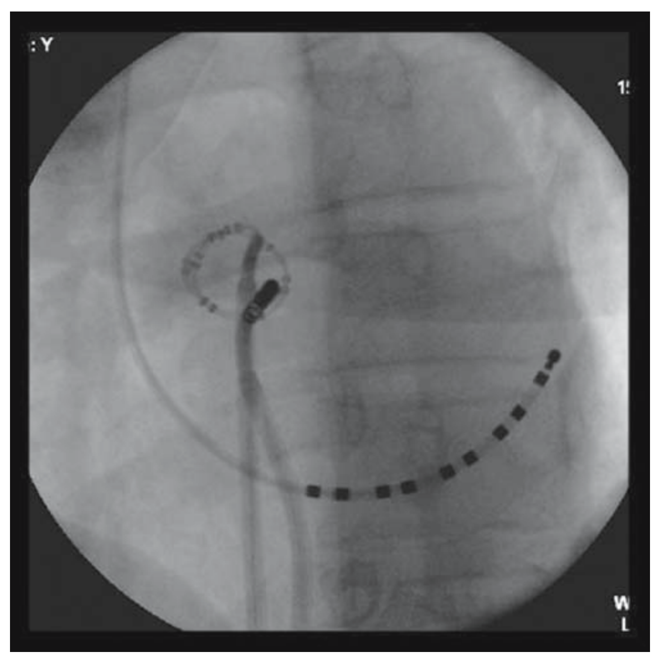


Figure 7.59 In this case, at the right inferior pulmonary vein (*RIPV*), the circular mapping catheter and the ablation catheter have been positioned turned toward the ostium's posteroinferior sector. The left anterior oblique (*LAO*) view

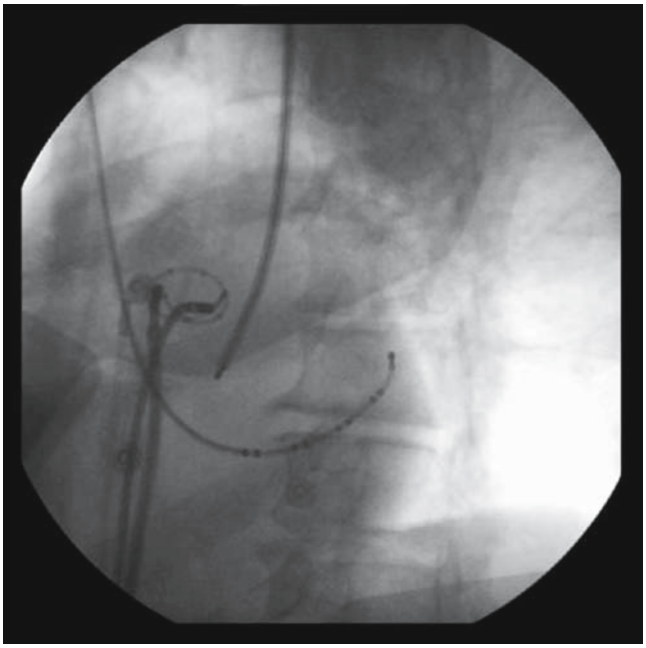


Figure 7.60 This image shows the case of right inferior pulmonary vein (*RIPV*) isolation where an esophageal catheter has been placed to monitor the temperature in close proximity to the region where radio frequency (*RF*) applications are delivered

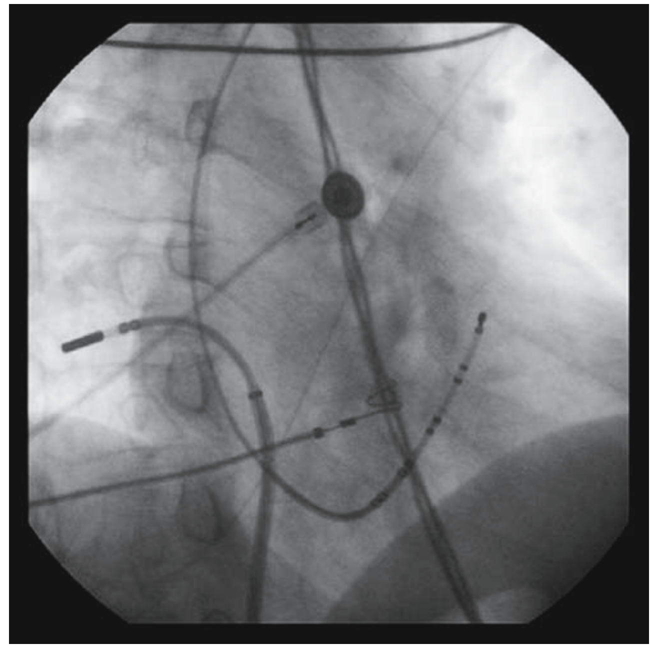


Figure 7.61 Ablation catheter in the right inferior pulmonary vein (*RIPV*) in the right anterior oblique (*RAO*) view. In this case, the mapping catheter has not been positioned at this region

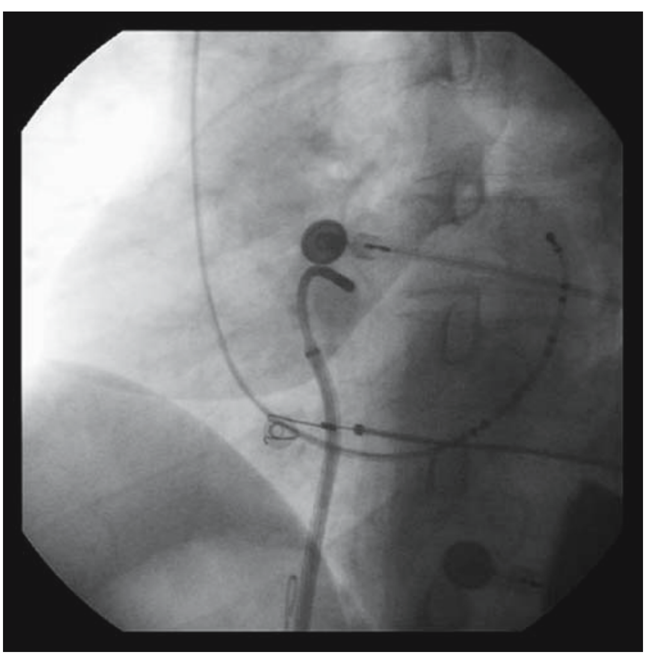


Figure 7.62 The left anterior oblique (*LAO*) view permits visualization of the catheter orientation toward the venous ostium's posterior portion

7.3 Pulmonary Vein Circumferential Isolation

Pulmonary vein circumferential isolation is carried out by some centers. This is performed with an ablation catheter only which is guided by an electroanatomic mapping system. The aim is to make circular lesions at the PV antra and, at times, outside of venous antra in regions within the LA.

This type of approach is based upon a more sophisticated imaging system compared to PV angiography since reconstruction of the entire LA's anatomy is necessary. We shall briefly describe the two main electroanatomic mapping systems which have software allowing the electroanatomic map to integrate with a CT image or cardiac MRI.

Frequently, a mixed approach is undertaken with segmental or antral isolation and taking advantage of the anatomic information furnished by mapping systems. Furthermore, electrophysiological confirmation of isolation is detailed by dedicated mapping catheters.

7.3.1 Electroanatomic Mapping Systems with Integration of Angio-CT/MRI Images

Two electroanatomic mapping systems with integration of CT/MRI images are presently available: CARTO (CARTOSync and CARTOMerge versions) and EnSite-NavX (NavX-Verismo and NavX-Fusion versions).

CARTO is a three-dimensional (3-D) nonfluoroscopic mapping system making use of a magnetic field generated around the patient's thorax by three coils placed under the cardiac catheterization table. One dedicated mapping catheter, which possesses a magnetic passive sensor, is located within the magnetic field. In this way, it is possible to use the catheter's tip as a sort of endocavitary digitizer which, sequentially moved within the cardiac cavity under study, defines its 3-D endocardial outline by associating with each point the local electrical potential. Thus, it is possible to build up, in real time, the electroanatomic image of the structure under interest. The instantaneous position of the catheter itself can therefore also be visualized.

The new technologies have allowed importation and visualization of images obtained by means of a cardiac MRI or CT exam into the CARTO 3-D system. The MRI/CT image, once imported into the CARTO system, can be elaborated to extrapolate the particular cardiac chamber of interest. In the CARTOSync system, the single image is made visible upon a special window separated from the corresponding electroanatomic mapping window (Figure 7.63). With the development of the CARTOMerge module, the virtual anatomic image obtained from mapping can be made to overlap the MRI/CT anatomic image. During the procedure, therefore, one has visualization in real time of the mapping catheter moving within the patient's anatomy. Furthermore, the opportunity to section the MRI/CT image in various planes (sagittal, coronal, frontal, etc.) enables visualization, from within the heart chamber, of particular structures such as arteries and veins. This then gives a direct appreciation of the endocardial aspects of the chamber in question (Figures 7.64–7.73).

Similar to CARTO, the NavX system is a mapping and 3-D nonfluoroscopic intracardiac browsing system which can reconstruct, in real time, geometry as well as the electric activation of the heart chamber of interest. NavX technology makes use of six surface patch electrodes that, once correctly positioned on the patient's skin, generate an electric field. Within the electric field, it is possible to locate in real time the position of every electrophysiology catheter employed during the procedure. Up to 12 catheters can in fact be located and visualized with the NavX system. To carry out the 3-D reconstruction of the heart chamber of interest, it is not necessary to utilize a dedicated mapping catheter (as with CARTO). Any electrophysiology catheter, employing up to 24 electrodes simultaneously, can be used. This peculiarity of the NavX system therefore enables a reconstruction of the virtual anatomy of the interested heart chamber much quicker compared with the CARTO system. It also allows the simultaneous visualization of the ablation and mapping catheters in the 3-D construct.

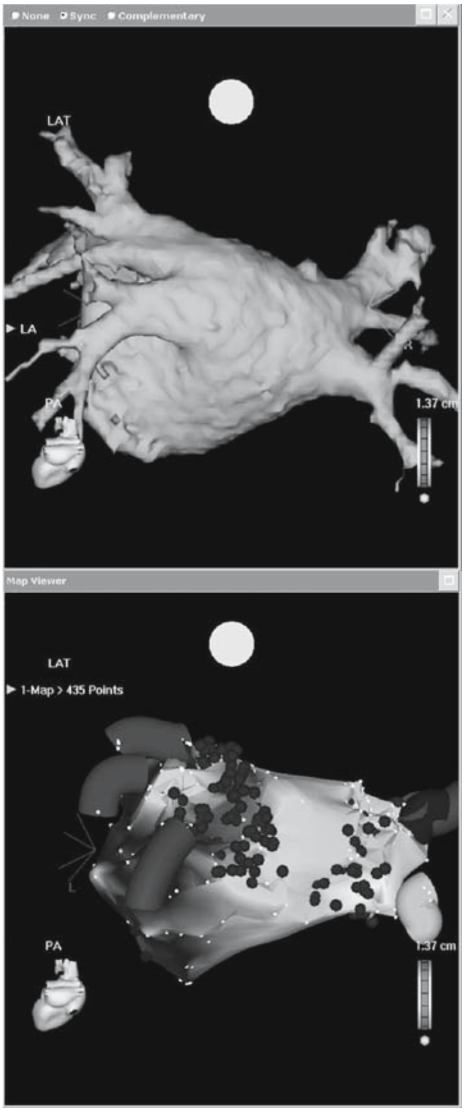


Figure 7.63 CARTOSync visualization window. In this image, the left atrium is shown in the anteroposterior (*AP*) view. On the left, one can see the electroanatomic map carried out by mapping of successive points. On the right is the corresponding image extrapolated from the patient's cardiac computed tomography (*CT*). This view enables visualization of the left atrial posterior wall and the venous antrum's extension into the posterior wall. Very often it is difficult to define the passage between the venous antrum and the posterior wall, because these two structures have an embryological common origin. As a matter of fact, during the first phases of embryonic development one single pulmonary vein (*PV*) is present developing as an excrescence of the left atrium's posterior wall, just to the left of the primary septum. In a subsequent developing phase, this vein, along with its first four branches, grows, thus forming the left atrial posterior wall. Furthermore, the two frontal views, both AP and posteroanterior (*PA*), also enable immediate visualization of the left atrial roof's curvature. The roof can be flat, concave, or convex

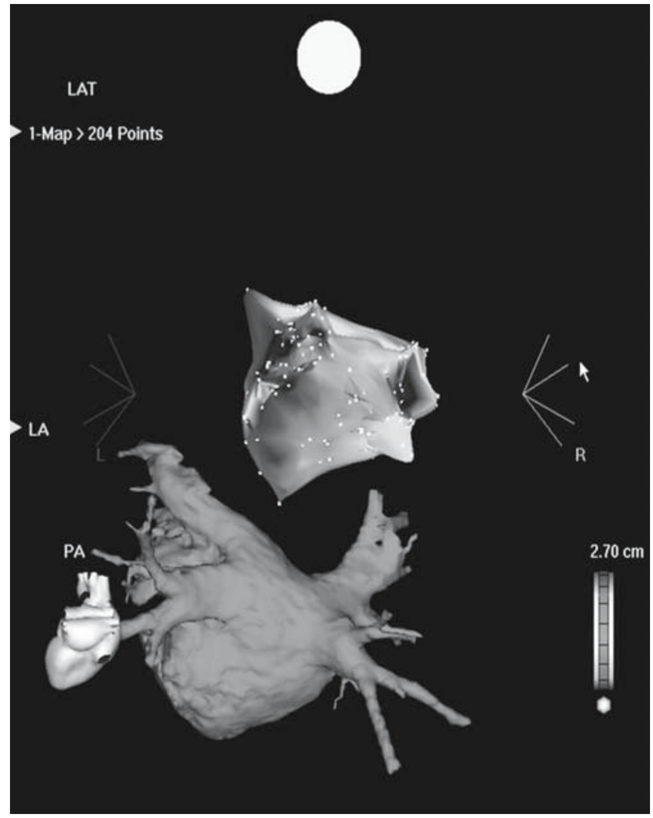


Figure 7.64 This image is a synthesis of CARTOSync and CARTOMerge systems. On the two left atrial representations, the electroanatomic map and the angio-computed tomography (*CT*) image, overlapping points are chosen (ranging between 1 and 3, or more, according to the practice and to the map's accuracy). Such points allow fusion of the electroanatomic map with the real anatomic image

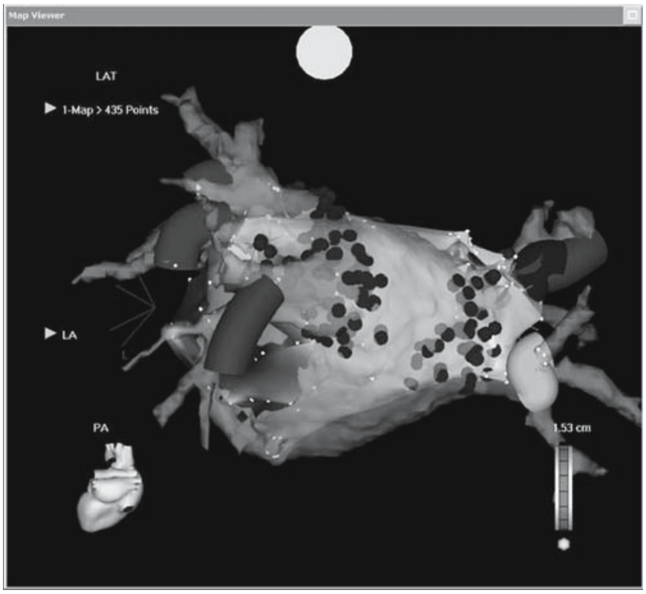


Figure 7.65 In this image, the electroanatomic map and the computed tomography (*CT*) image are superimposed. The two maps are still recognizable to check the optimal degree of overlapping. After that, the electroanatomic map is rendered transparent and the ablation is guided by the real anatomy CT image

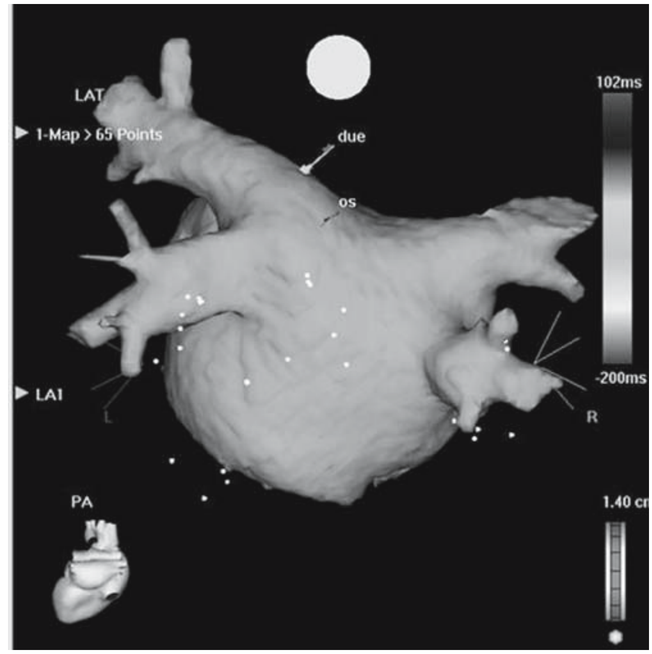


Figure 7.66 Left atrial CARTOMerge map in the posteroanterior (*PA*) view. In this case, four veins are recognized with separate ostia. The two left veins, although having separated ostia, have confluent antra. The roof is slightly concave

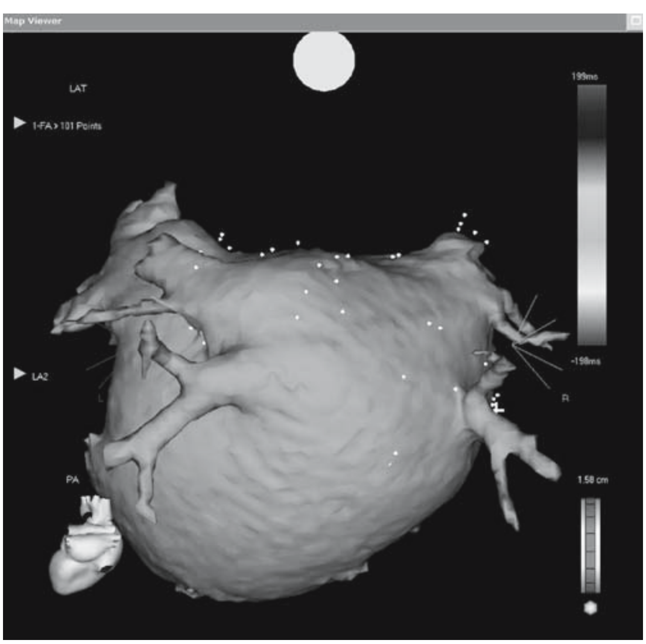


Figure 7.67 Still in the postero-anterior (*PA*) view, it is possible to see the CARTOMerge image of a dilated left atrium with the four veins having small ostia. The roof is slightly convex

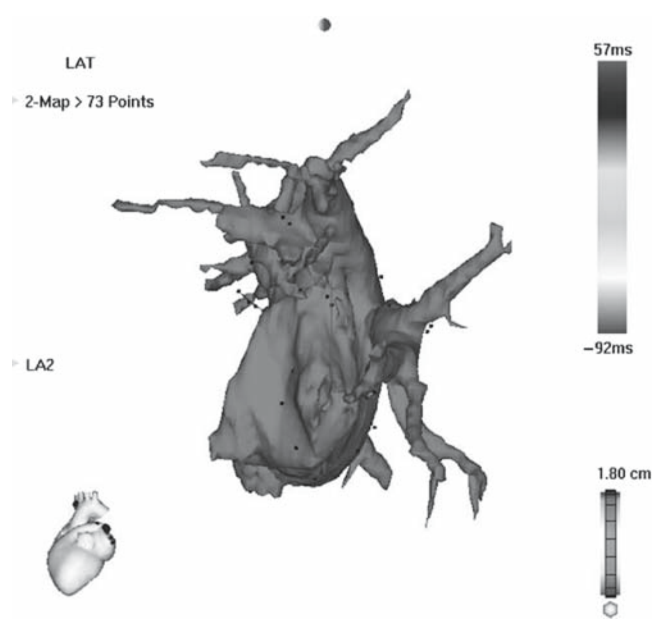


Figure 7.68 The left anterior oblique (*LAO*) view demonstrates the relationships of the two left pulmonary veins and also the atrial appendage which rests anteriorly. Furthermore, this view enables visualization of the left mitral isthmus (the line joining the left inferior pulmonary vein ostium with the mitral ring)

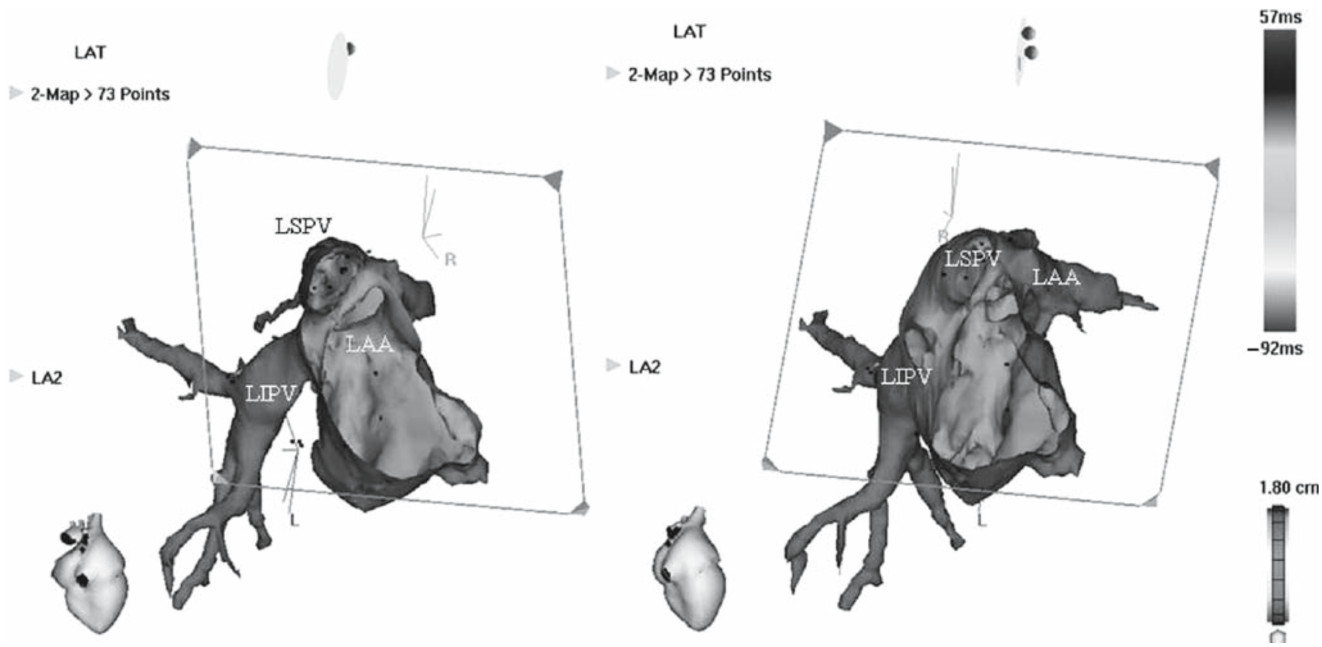


Figure 7.69 The left lateral internal views show, from the inside, the ostia of the left superior and inferior veins as well as their intervenous septum. The intervenous septum between the left veins is usually thin since the two veins have contiguous ostia. This “cardioscopic” view enables also to evaluate the relation between the pulmonary vein ostium and the atrial appendage ostium, which is anteriorly placed. In this case, the tissue separating the atrial appendage and the venous structures, or venous-atrial appendage ridge, is thin and makes an acute angle. *LAA* left atrium appendage

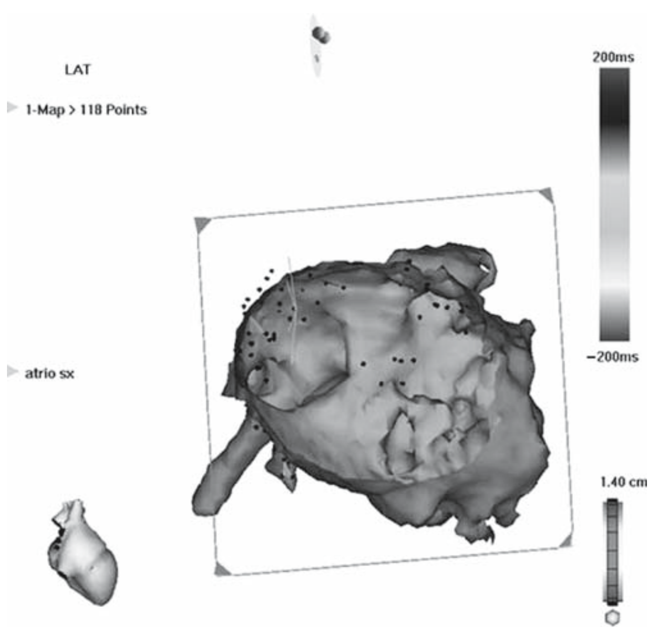


Figure 7.70 In this case, the ridge between the left pulmonary veins and the atrial appendage is, instead, wide and rounded. The venous-atrial appendage crest is a critical zone for the left pulmonary veins isolation. Radio frequency (*RF*) applications are delivered at the ostium’s anterior side at this ridge and, if the ridge is thin with an acute angle, it can be very difficult to hold the ablation catheter steady. *LAA* left atrium appendage

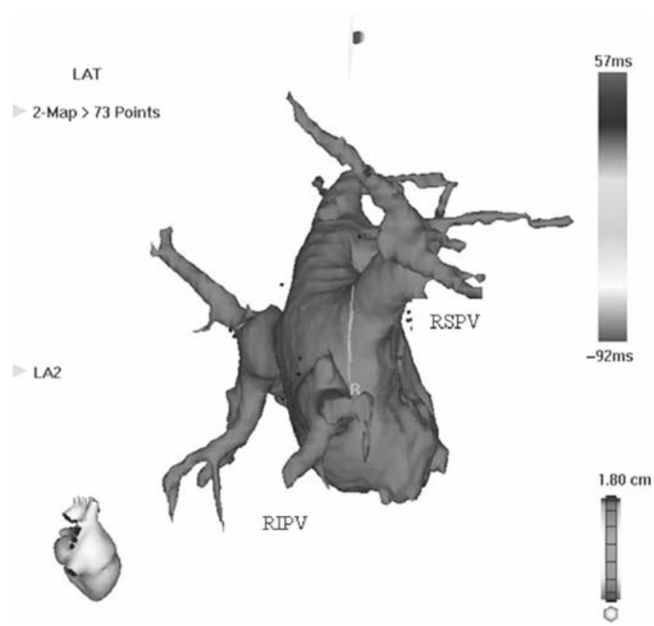


Figure 7.71 The right anterior oblique (*RAO*) view allows visualization of the right pulmonary vein ostia and their relationship to each other

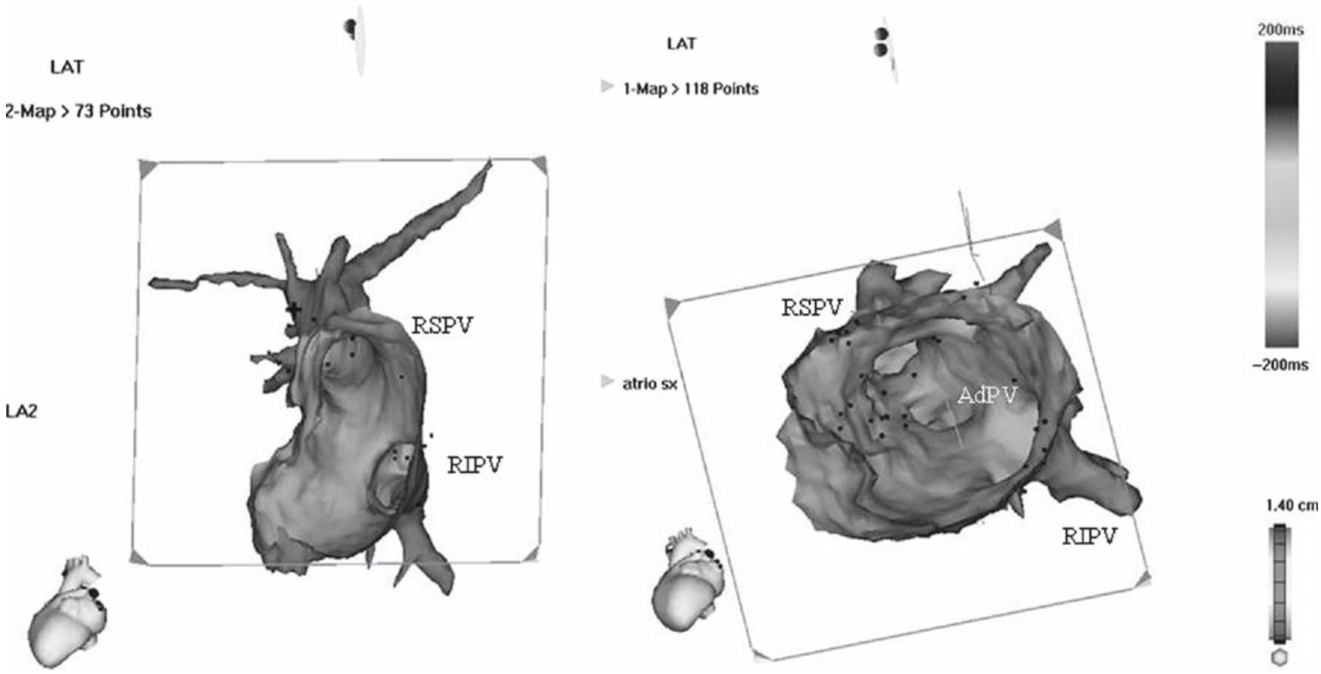


Figure 7.72 The right lateral cardioscopic view enables one to visualize the ostia of the right pulmonary veins (*PVs*). The intervenous septum of the right veins is, as usual, wide because the two veins' ostia are not contiguous. They rest on different planes: the right superior PV's ostium opens on the postero-septal superior wall, whereas the right inferior PV's ostium opens upon the posterior wall and toward the septum. An intermediate right venous branch (on the right) may be present. This venous ostium usually lies on the line joining the two other veins' ostia. Occasionally, the three ostia may be contiguous. *AdPV* additional PV

The Ensite-NavX system's functionality is also easily extended with additional software to import the patient's CT/MRI cardiac image and to selectively visualize the interested heart chamber. The NavX-Verismo system, like the CARTOSync system, enables visualization of the preacquired MRI/CT anatomic image in a window, along with the one obtained by the virtual electroanatomic reconstruction (Figures 7.74–7.81). NavX-Fusion enables, like the CARTOMerge system, overlapping of virtual anatomy, reconstructed with mapping, and real anatomy, acquired by means of angio-CT or by MRI. In this case also, all the catheters connected with the system are visualized in real time within the patient's anatomy, for example, allowing a representation of the antra and PVs (Figures 7.82–7.85).

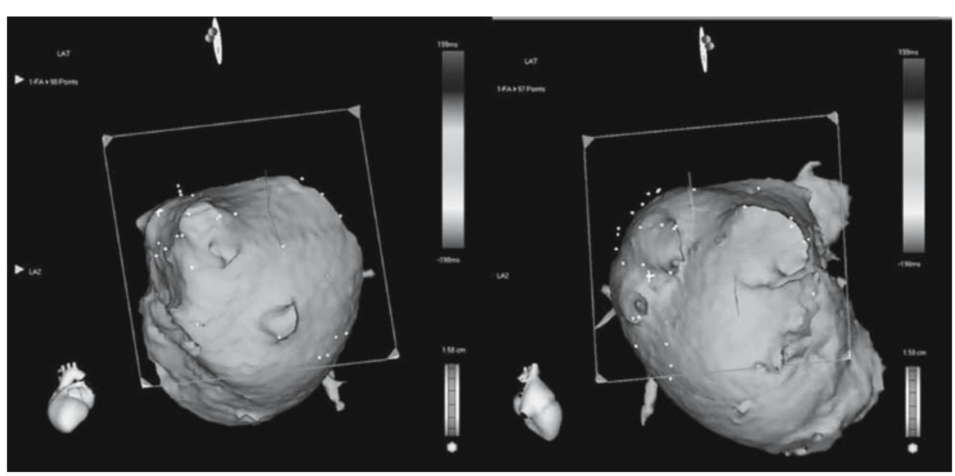


Figure 7.73 Right lateral (on the left) and left lateral (on the right) cardioscopic views from the patient shown in Figure 7.67

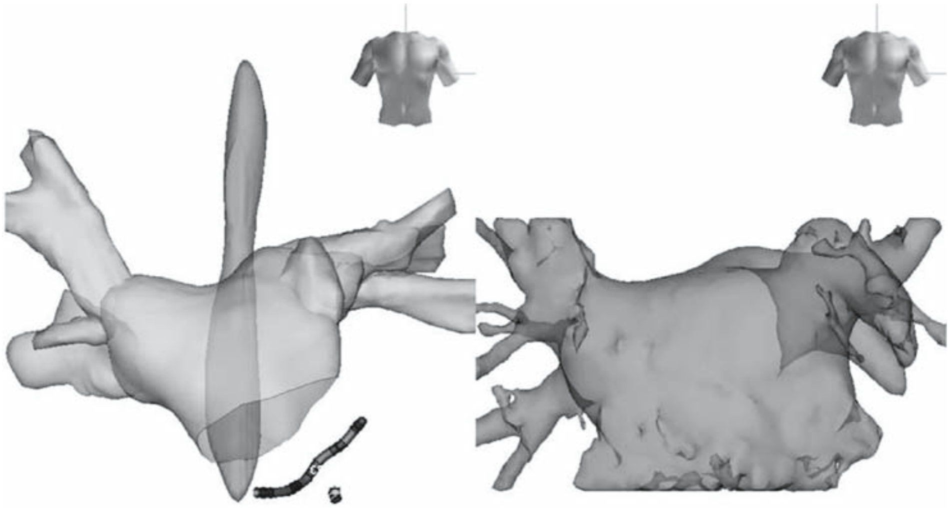


Figure 7.74 Visualization window of the NavX-Verismo system. In this image, one can see the left atrium in the anteroposterior (*AP*) view. On the left is the electroanatomic map created by mapping. On the right is the corresponding image extrapolated by the patient's cardiac computed tomography (*CT*). Of difference from the CARTO system, NavX enables one to visualize not only the ablation catheter but also all catheters connected with the system. In this example, the catheter within the coronary sinus is also visualized. Furthermore, the use of a nasal–esophageal probe, for monitoring esophageal temperature during ablation, enables visualization of esophagus, its course and relation to the posterior wall

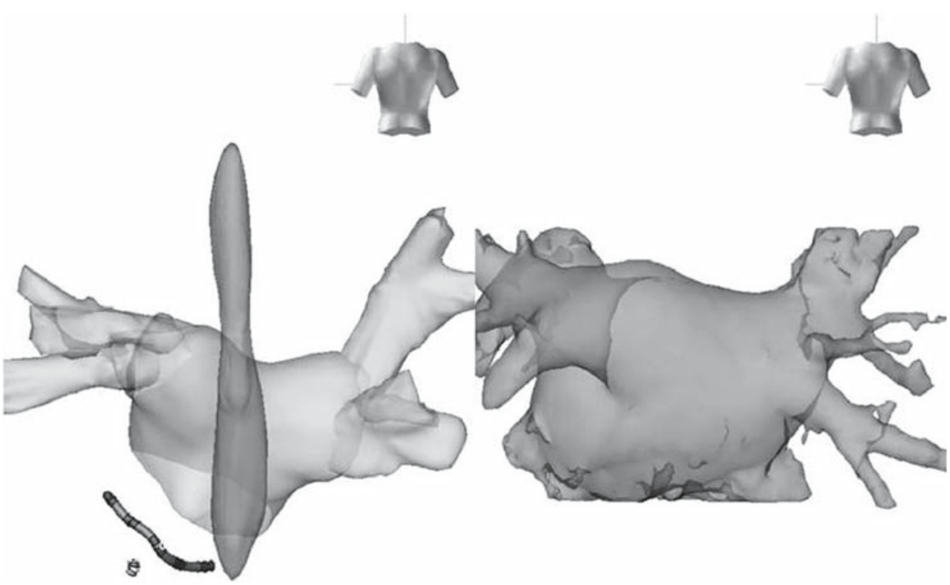


Figure 7.75 Postero-anterior (*PA*) view of the same case. This is the view that better defines how the venous antrum is extended. In this case, the left pulmonary veins (*PVs*) have separated ostia but a common antrum. The esophagus lies behind the left portion of the left atrial posterior wall

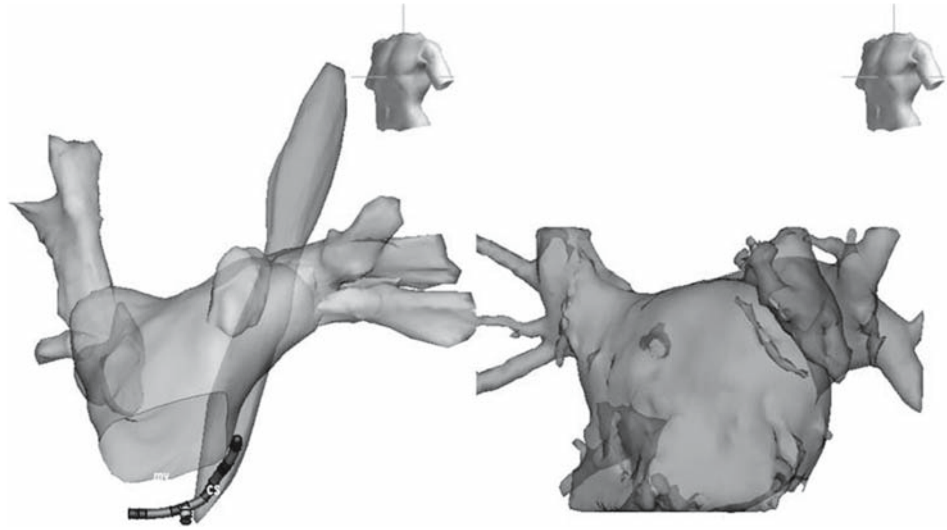


Figure 7.76 The left anterior oblique (*LAO*) view enables one to identify the left pulmonary veins' relations with themselves and with the atrial appendage. This projection shows very clearly the common antrum of the left veins. This view venables visualization of the left mitral isthmus, a very long one in this specific case

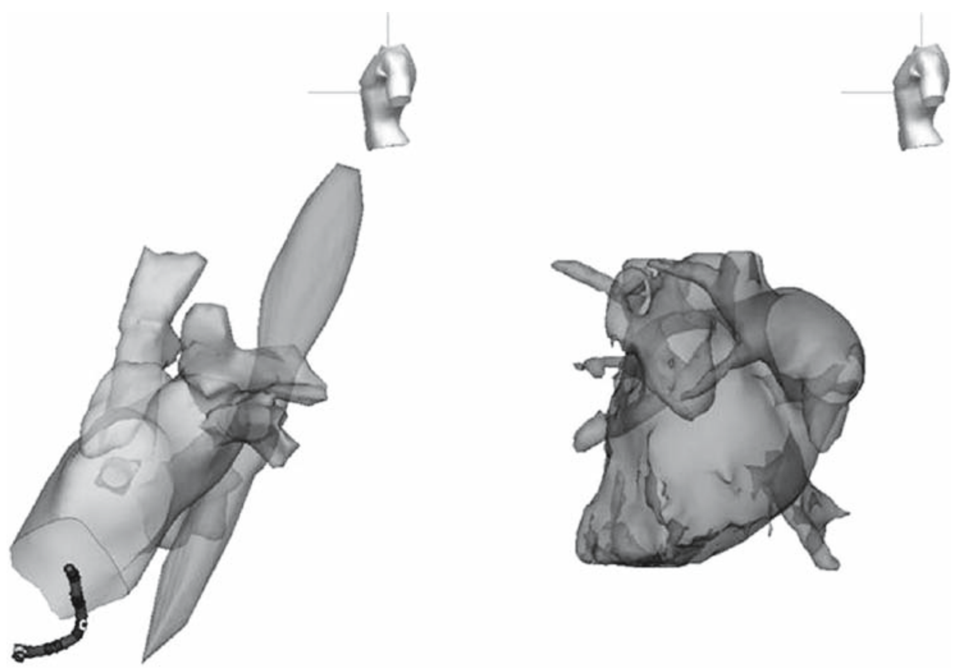


Figure 7.77 Increasing the obliquity to the left demonstrates the left lateral view, which reveals the relationship of the pulmonary veins to the atrial appendage and makes the epicardial aspect of the venous-atrial appendage ridge evident

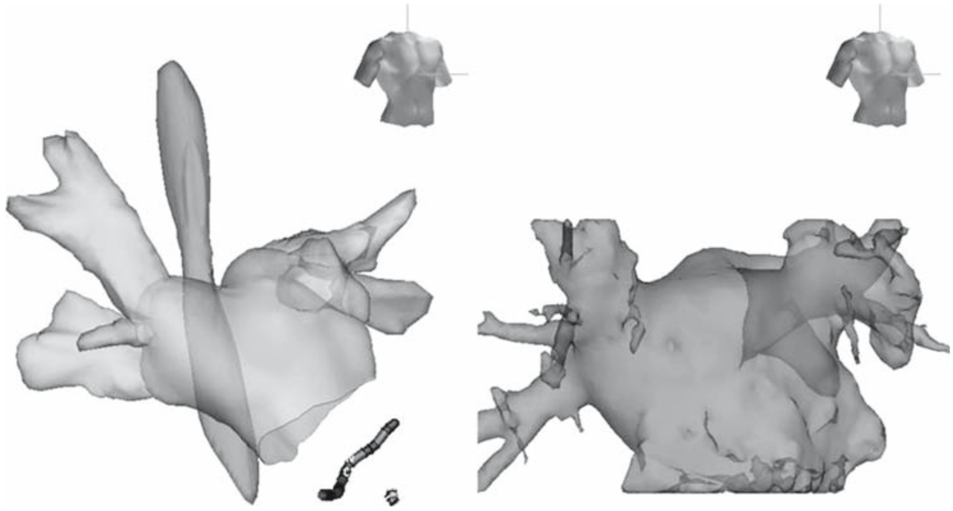


Figure 7.78 The right anterior oblique (*RAO*) view enables visualization of the right pulmonary veins' ostia and their relations. In this case, an additional right PV, leading to the right superior pulmonary vein (*RSPV*) antrum, is evident

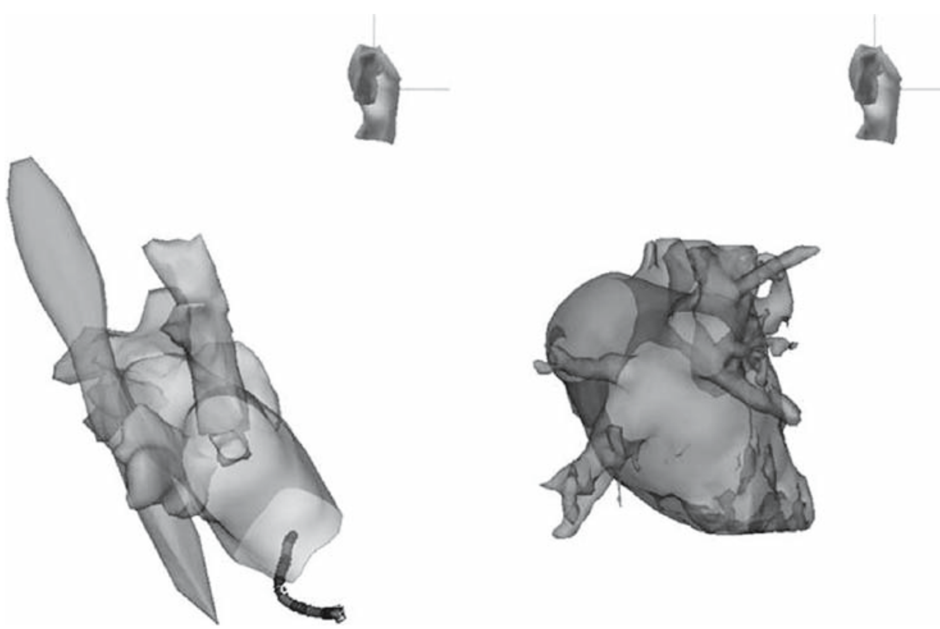


Figure 7.79 By rotating the map, one obtains the right lateral view that better demonstrates the definition, the epicardial aspect of the right intervenous septum

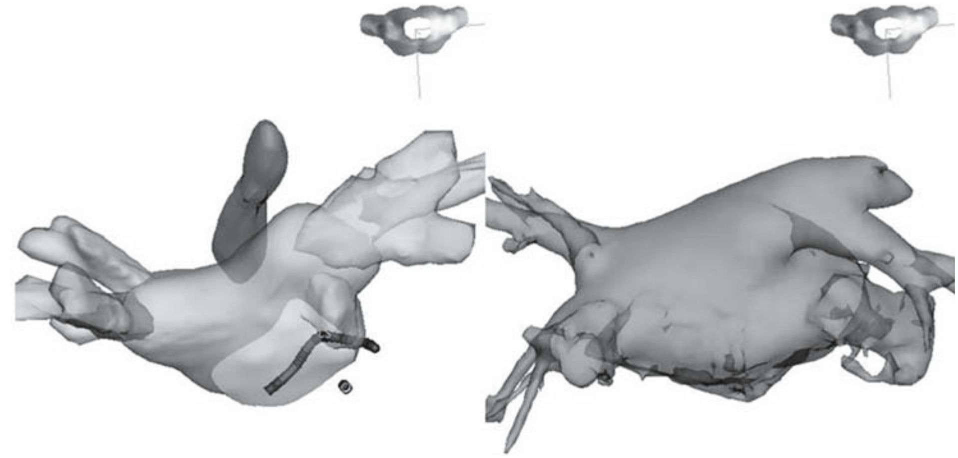


Figure 7.80 Further additional views are the cranial and caudal ones. The cranial view, here represented, shows the left atrium from the top. This view puts on the foreground the left atrial roof. Such a view is useful in ablating the antrum's superior aspect and creating a linear roof lesion set

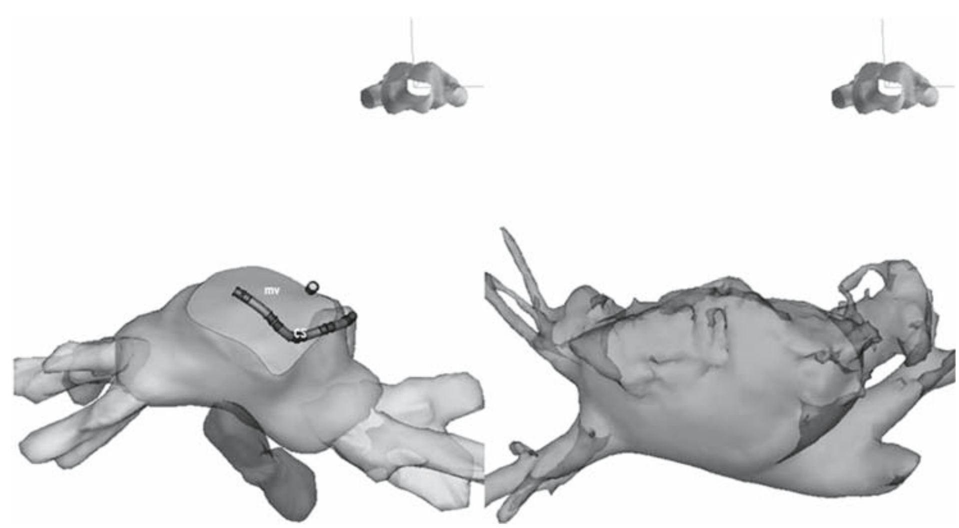


Figure 7.81 The caudal view demonstrates the atrium from below and identifies the floor as well as the coronary sinus' course

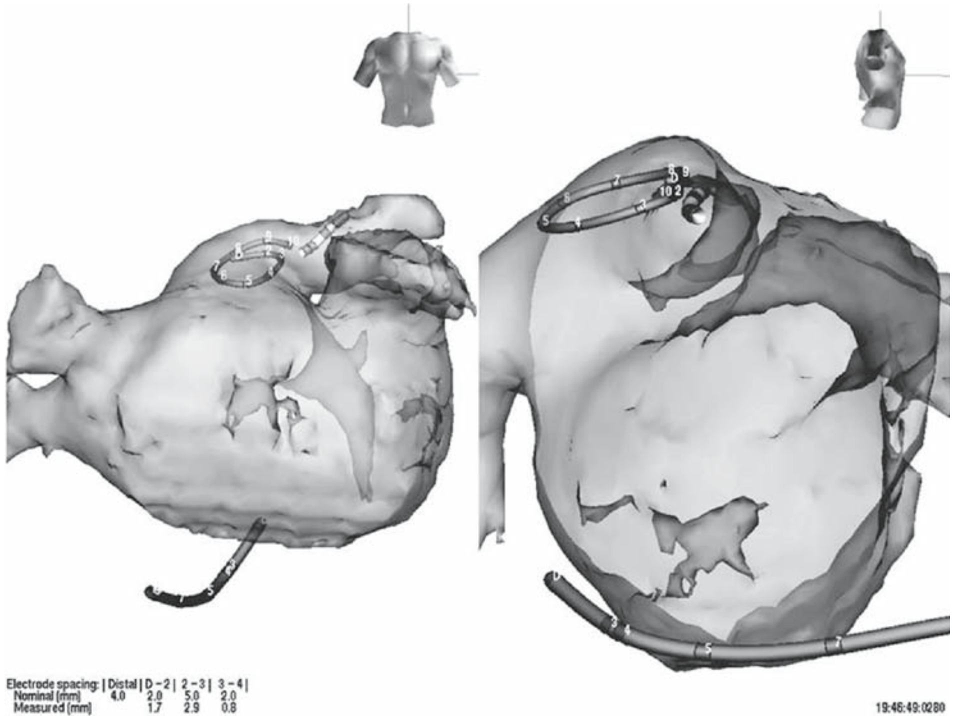


Figure 7.82 Left atrium NavX-Fusion map. On the left, an anteroposterior (*AP*) view; the transparency allows recognition of the ablation catheter in a very large left superior pulmonary vein (*LSPV*) and the circular mapping catheter at the LSPV antrum. On the right, the left lateral cardioscopic view. The two left veins have a common antrum but separate ostia. The ridge between the left pulmonary veins and the atrial appendage is very wide and rounded. In the two maps, the coronary sinus (*CS*) catheter is also visualized

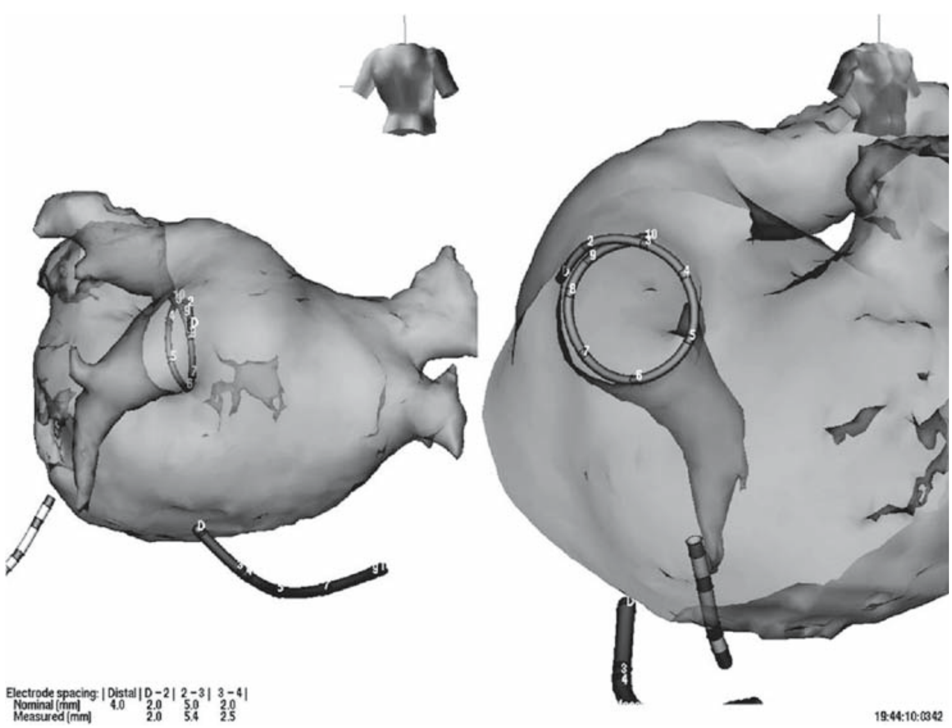


Figure 7.83 Left atrium NavX-Fusion map of the same patient. On the left, a slightly rotated posteroanterior (*PA*) view with the circular mapping catheter at the left inferior pulmonary vein (*LIPV*) ostium and the ablation catheter very deeply in the vein (out of the map). On the right, the left lateral cardioscopic view; the transparency allows visualization of the direction of the LIPV

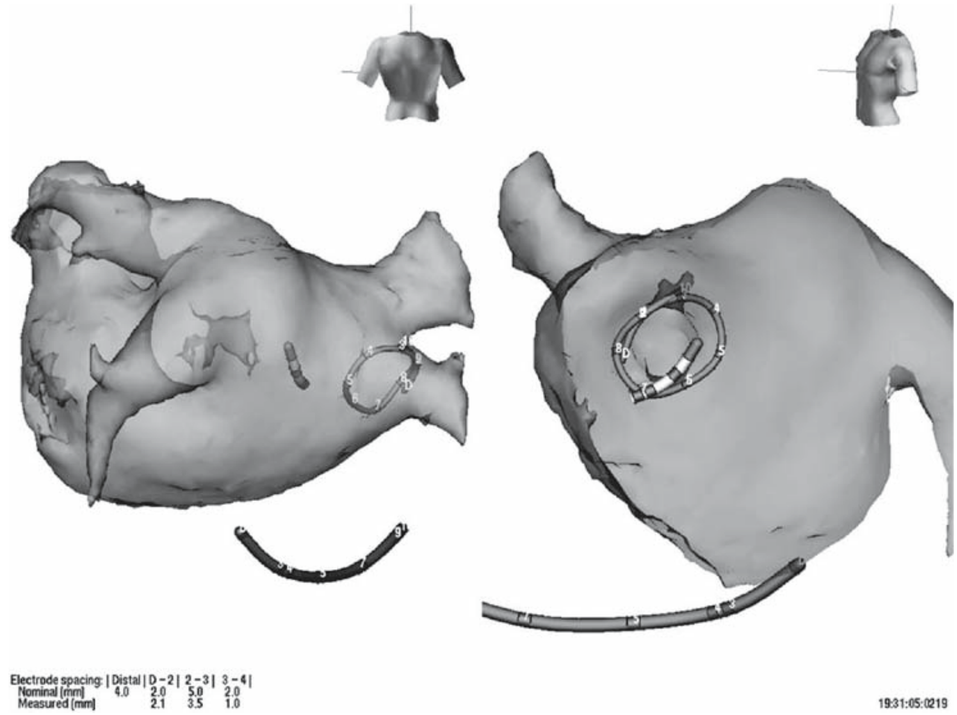


Figure 7.84 Left atrium NavX-Fusion map of the same patient. On the left, a slightly rotated posteroanterior (*PA*) view where the ablation catheter, the circular mapping catheter, and the coronary sinus (*CS*) catheter are visualized. On the right, the right lateral cardioscopic view allows one to see the correct position of the circular mapping catheter at the right inferior pulmonary vein (*RIPV*) ostium

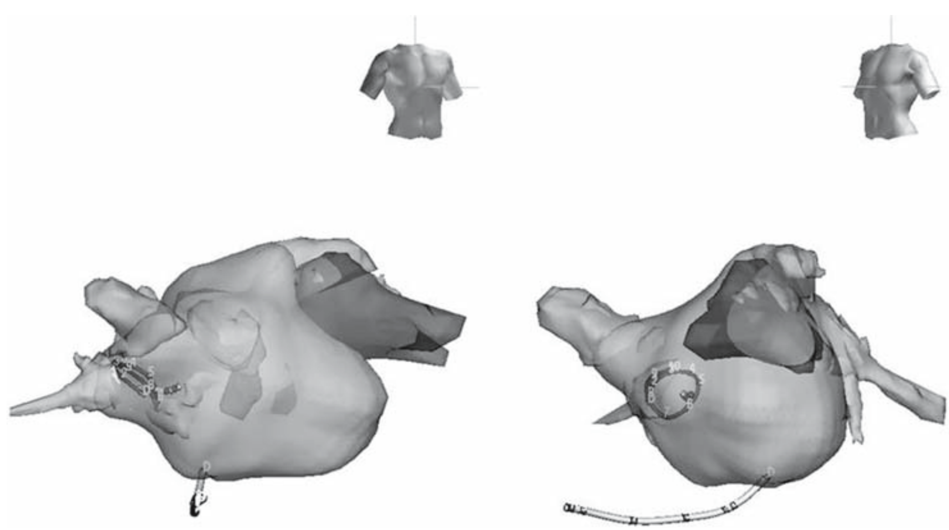


Figure 7.85 Right anterior oblique (*RAO*) (on the left) and left anterior oblique (*LAO*) (on the right) views of the left atrium. The circular mapping catheter is obliquely placed at the right inferior pulmonary vein (*RIPV*) ostium. This event can occur when the vein is too small to place the mapping catheter entirely within the vein. The large left atrial appendage is dark grey colored

7.3.2 Left Atrial Mapping and Ablation

In mapping systems with CT/MRI integration, it is firstly necessary to carry out mapping of the left atrial chamber so that the virtual 3-D map can then overlap the CT/MRI anatomic map.

Mapping, by using the CARTO system, is performed only with the distal electrode of a dedicated ablation ("Navistar") catheter. By using the NavX system, mapping can be carried out with any ablation catheter or even with a diagnostic catheter, for example, the circular mapping catheter. Furthermore, not only the distal electrodes but also all of the catheter's electrodes (up to 20, if a 20-polar circular mapping catheter is used) provide their spatial coordinates for the chamber of interest, thus making the mapping phase quicker.

As usual, mapping of the LA starts with identification of the PVs. The PVs are located by utilizing movements previously explained within paragraphs dealing with PV angiography and ablation. The localization of the PVs is made easier, however, by knowing a priori their anatomy and possible variants such as common antra or additional PVs. Moreover, it is advisable to extend mapping also to the PVs' proximal portion, by entering about 2–3 cm into the vein itself and then slowly withdrawing the catheter, thus reconstructing the path of the vein. One must be particularly careful in mapping the ostia as well as the venous antrum zones, as these are the sites where ablation will be performed. Therefore, 3-D definition of the anatomy is performed as detailed as possible, such that the two maps overlapping should be as optimum as possible. The antrum zone must, in particular, be three dimensionally defined. Therefore, it is necessary to acquire points of the upper and lower portions (by straightening and curving the catheter); of the anterior and posterior portions (in the left veins, anticlockwise rotation reaches the anterior portion, whereas clockwise rotation reaches the posterior portion; in the right veins, movements are exactly the opposite: clockwise rotation reaches the anterior portion, whereas anticlockwise rotation reaches the posterior portion); and naturally, of all the intermediate portions. When reconstructing the venous antrum funnel-shaped structure, it is important never to force the catheter in order not to warp the anatomy; this would make overlapping of the two maps difficult and inaccurate (Figures 7.86 and 7.87). Once mapping of the PVs, including ostium and antrum, is completed, the next step is mapping of the left atrial body.

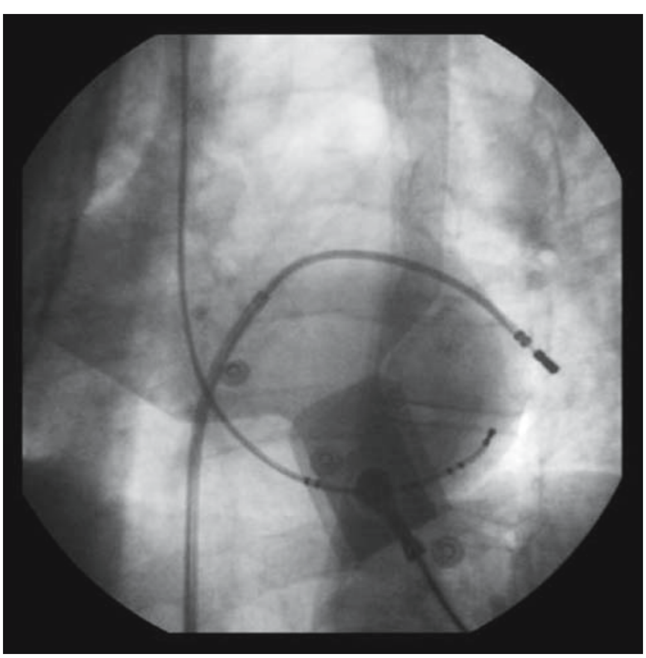


Figure 7.86 In the left anterior oblique (*LAO*) view, left inferior pulmonary vein (*LIPV*) mapping is shown; the mapping/ablation catheter is deep in the vein, probably in an inferior branch, and its tip lies outside the cardiac silhouette

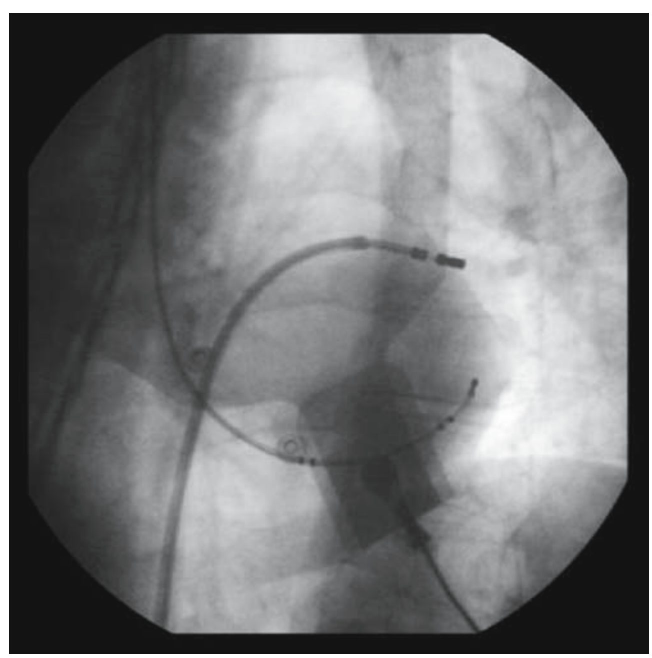


Figure 7.87 In the same view, the catheter is pulled back slowly to the level of the ostium. In this case, the mapping/ablation catheter is without curvature, enabling definition of the superior edge of the vein and of the ostium. Usually, dragging-back is repeated with the catheter curved to define the inferior edge of the vein and of the ostium

Conceptually, the LA can be sketched as a cube characterized by a superior wall or roof, inferior wall or floor, anterior wall, posterior wall, left lateral wall, and right lateral wall (or septum). The mitral valve opens inferoanteriorly, almost thoroughly occupying the inferior–anterior wall. To these structures the atrial appendage and vestibule are to be added. The LAA is a finger-like tubular structure where thrombi may form. Its junction with the atrial wall is well defined, and usually the LAA orifice is at the lateral wall or is centered at the junction of the anterior and lateral walls of the LA. Endocardially, the LAA orifice is placed anteriorly to the LSPV ostium from which it is separated by a muscular crest. The LAA axis is usually directed anterosuperiorly covering, with its inferior wall, the left coronary fossa where the left main coronary artery divides into the left anterior descending coronary artery and the left circumflex coronary artery. Furthermore, the LAA is in close proximity to the course of the left sinus node artery, arising from the proximal portion of the left coronary artery and passing beneath the LAA to reach the LA anterior wall. The LAA is also in close proximity to the course of the posterior sinus node artery, arising posterior to the LAA orifice and passing between the LAA and the LSPV. Variations in the LAA axis are represented by a LAA directed laterally or, less frequently, inferiorly toward the ventricle or superiorly beneath the pulmonary trunk. Finally, all the pectinate muscles in the LA are virtually confined within the LAA. The vestibule is the smooth and thin circumferential area surrounding the orifice of the mitral valve; against its posterior portion directly lays the atrial wall of the coronary sinus (CS).

The lateral wall is almost thoroughly occupied by the left PV antra, and so accurate mapping of the left veins, usually, makes the map of the lateral atrium complete. To better define the portion of the PV-LAA ridge, some points of the atrial appendage are acquired, mainly at the level of the ostium. The LAA is easily defined as it rests at the same level of the LSPV, but it is located more anteriorly. Once the LSPV ostium is identified, and with visualization in the RAO projection, the catheter is freed from the venous ostium and turned slightly counterclockwise, such that it is seen to move to another tubular structure. In the posteroanterior (PA) or LAO view one may very well identify the catheter positioning inside the LAA due to the typical fibrillatory movement of this structure, if the patient is in AF. More obviously, local electrocardiogram recordings will reveal positioning within the atrial appendage by means of very high atrial potentials, clearly higher than those ones that are in general found in the remaining part of the atrium or antra. The LAA is, however, a very delicate structure and it is always advisable not to push the catheter inside it. The ostium of the LAA may be mapped in all directions with the catheter with delicate curvature and torquing movements (Figures 7.88 and 7.89).

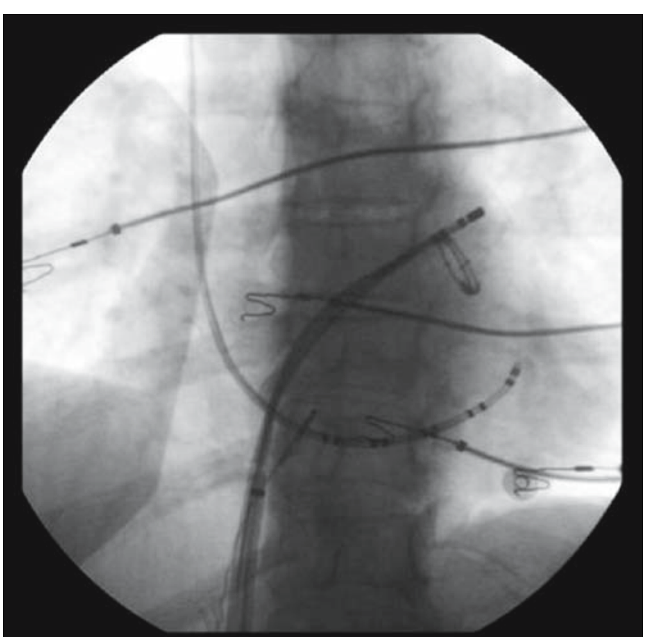


Figure 7.88 In the left anterior oblique (*LAO*) view, the mapping/ablation catheter is at the superior portion of the left atrium appendage (*LAA*) ostium

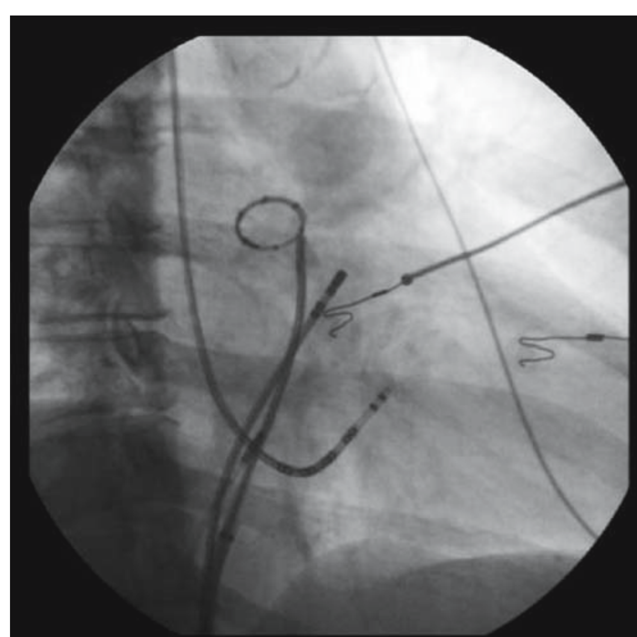


Figure 7.89 The right anterior oblique (*RAO*) projection enables visualization of the anterior location of the left atrium appendage (*LAA*) with respect to the left superior pulmonary vein (*LSPV*) ostium

Mapping of the roof, which is the portion included between the left and right superior PVs, can be carried out in two ways, both utilizing the LAO projection. In the first case, the mapping/ablation catheter is positioned within the LSPV and the long sheath must be withdrawn at the level of the interatrial septum or into the RA. The catheter has to be free within the LA so that not only its tip but also the whole catheter's distal portion comes into contact with the higher portion of the venous antrum. With the catheter's curvature completely relaxed, one begins to slightly retract the catheter, which therefore will slide upon the roof's left portion. In withdrawing the catheter, its curvature will tend to decrease, until the catheter becomes thoroughly straight within the LA and just its distal tip is in contact with the atrial wall. This position corresponds to the leftward boundary of the roof. Starting from this position, with a 180° clockwise torque applied, the catheter is advanced toward the RSPV by progressively curving the catheter until it enters the RSPV antrum. At this point, the catheter's curvature is again relaxed and the catheter retracted so that it is possible to redefine the aspect between the antrum and the roof on the right side. Incidental artifacts created by too sharp movements are deleted from the acquired map. It is important to exactly define the roof in a continuous and linear fashion without outlying points, as these generally represent excessive catheter pressure and indentation of the atrial wall. Usually, the roof's definition is repeated on a slightly more posterior and afterward slightly more anterior plane, to give a more accurate representation of the roof's anatomy. To define the posterior roof line, one starts from the LSPV ostium's posterior–superior portion; the catheter is held on the posterior aspect by application of a minimum clockwise torque. This clockwise torque has to be kept constant during the dragging motion of the catheter along the LA roof toward the RSPV. To perform more an anterior line, one begins at the LSPV ostium's superior–anterior portion, by means of a slightly anticlockwise torquing. In this case, with the catheter at the roof, the rightward rotation will be carried out on the anterior aspect, by means of an anticlockwise manipulation and thereafter continuing toward the septum. Mapping of the roof upon the anterior and posterior aspects can be carried out with the aid of the long sheath. In this case, the long sheath is advanced into the LA such that it is almost in contact with the roof. The preshaped curvature is then anteriorly or posteriorly oriented, according to the line one wants to map. The catheter's distal portion is carefully advanced out of the sheath so that the distal electrodes come into contact with the atrium. At this point, with clockwise or counterclockwise torque of the sheath–catheter unit, it is possible to map the roof line with optimal stability (Figures 7.90–7.94).

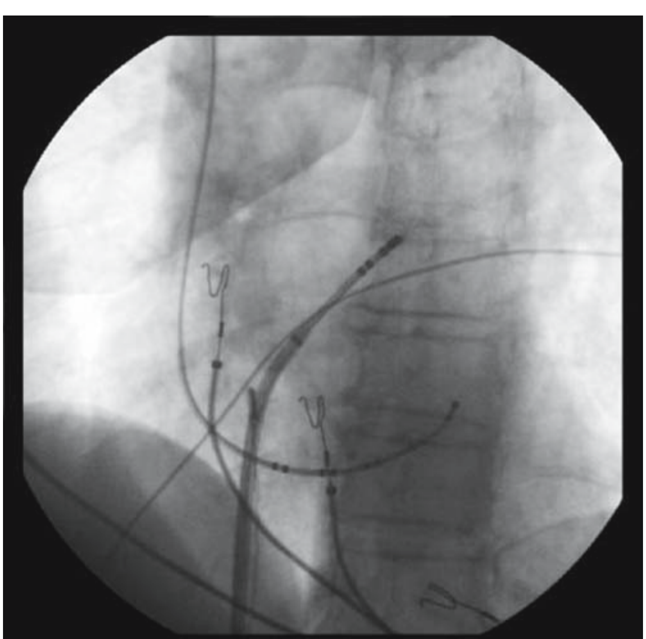


Figure 7.90 The mapping/ablation catheter, without curvature, is at the left superior pulmonary vein (*LSPV*) ostium. The left anterior oblique (*LAO*) view

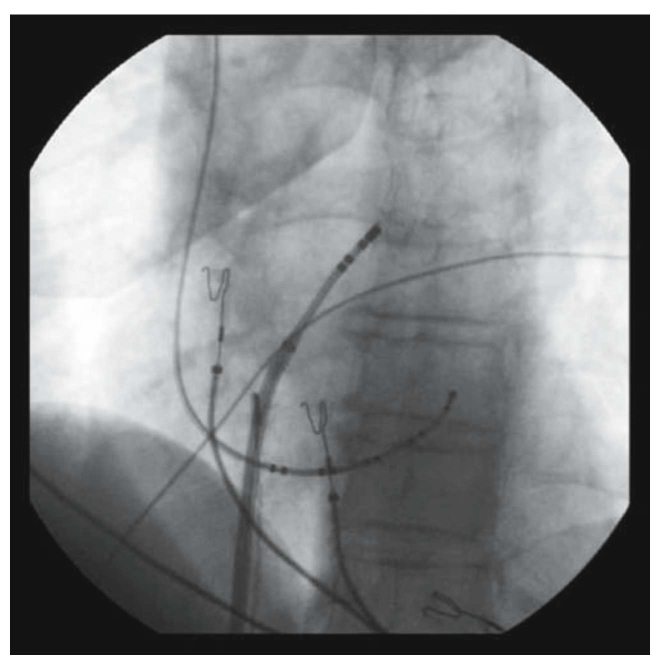


Figure 7.91 The mapping/ablation catheter is pulled back slowly along the left superior pulmonary vein (*LSPV*) antrum maintaining a good contact with the roof

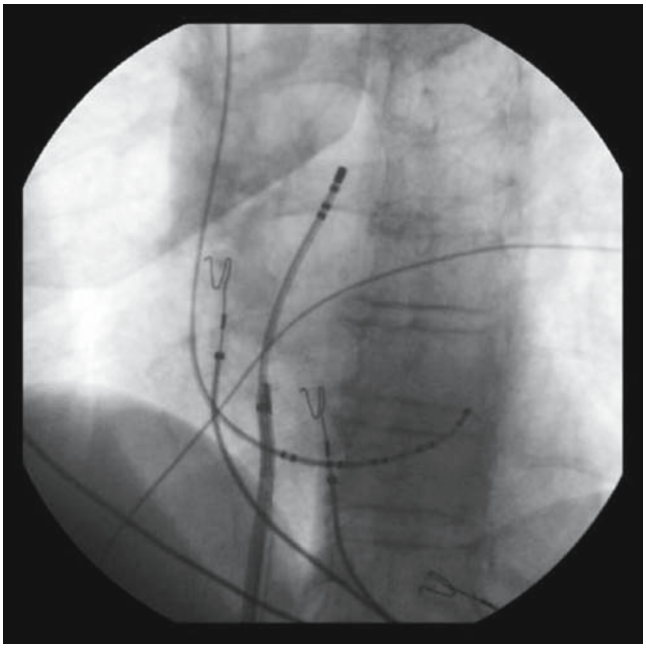


Figure 7.92 At this point, the mapping/ablation catheter is out of the left superior pulmonary vein (*LSPV*) antrum, and its tip is at the middle of the roof line joining the superior pulmonary veins (*PVs*)

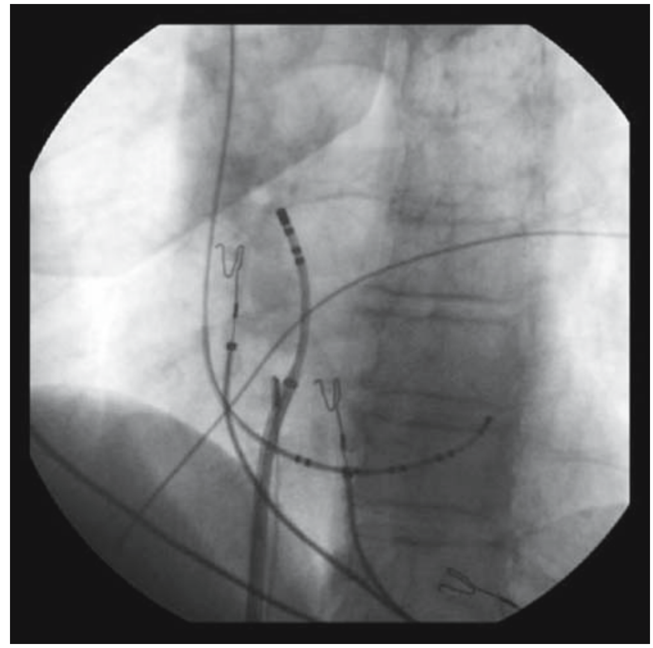


Figure 7.93 The mapping/ablation catheter is torqued clockwise and slightly curved to map the right side of the roof

An alternative way of outlining the roof is positioning the catheter into the RSPV having withdrawn the long sheath to the level of the interatrial septum. From here, one advances the long sheath and the distal aspect of the catheter is curved. The sheath and the catheter are manipulated gently as it is possible to cause the catheter to engage more deeply within the RSPV or alternatively to suddenly disengage the vein if too much sheath is advanced. Using this technique, the curves on the catheter and the sheath are positioned in opposing

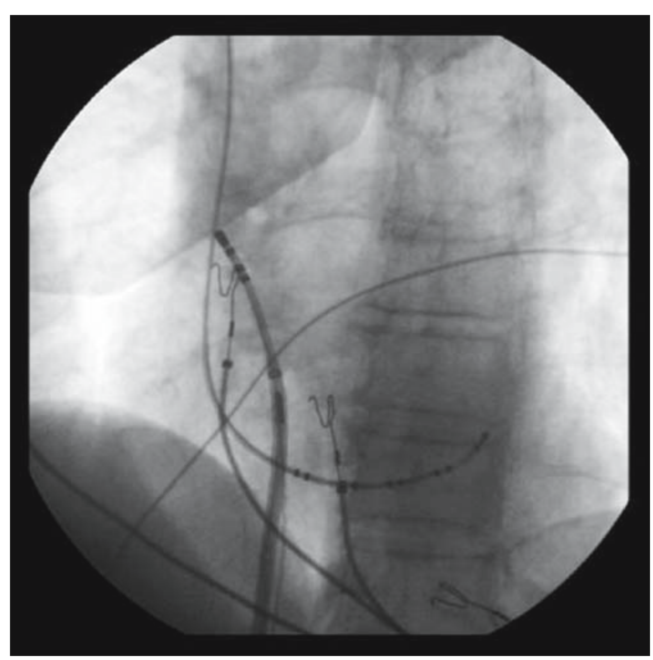


Figure 7.94 Gently advancing the catheter, it reaches the right superior pulmonary vein (*RSPV*) antrum and ostium, completing the roof outline

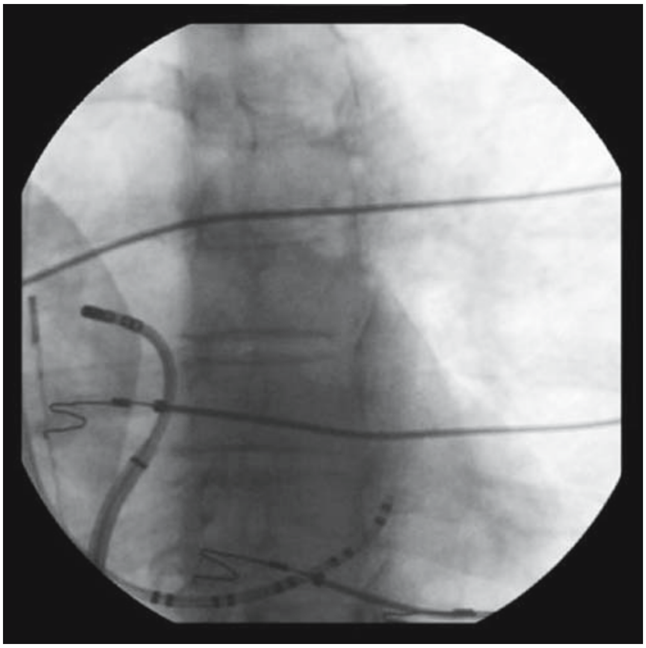


Figure 7.95 The starting position for defining the roof is with the mapping/ablation catheter at the right superior pulmonary vein (*RSPV*) ostium and with the long sheath within the left atrium (*LA*). Note that the sheath has its curvature toward the lateral wall and not toward the septum. The left anterior oblique (*LAO*) projection

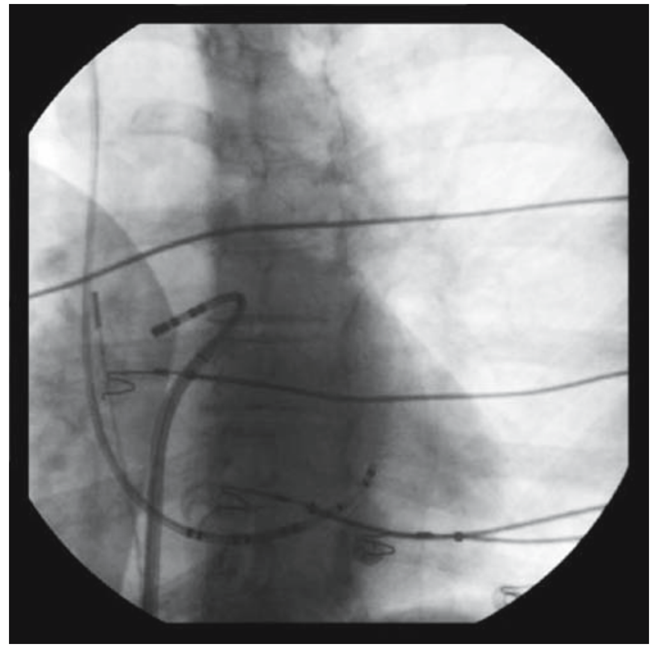


Figure 7.96 The catheter and the sheath are gently advanced simultaneously. Note that the catheter is advanced further than the sheath to create a loop within the left atrium (*LA*)

directions. The long sheath must be turned toward the left lateral wall, as if looking for the left veins, and the catheter faces the right so that its body rests upon the roof, optimally bending at the level of the LSPV. From this position, holding the sheath steady, one progressively pulls the catheter back so that it slides over the roof from the right toward the left. The anterior–posterior aspects of the roof can be acquired by repeating the maneuver, by regular clockwise or counterclockwise catheter rotations along the line (Figures 7.95–7.98).

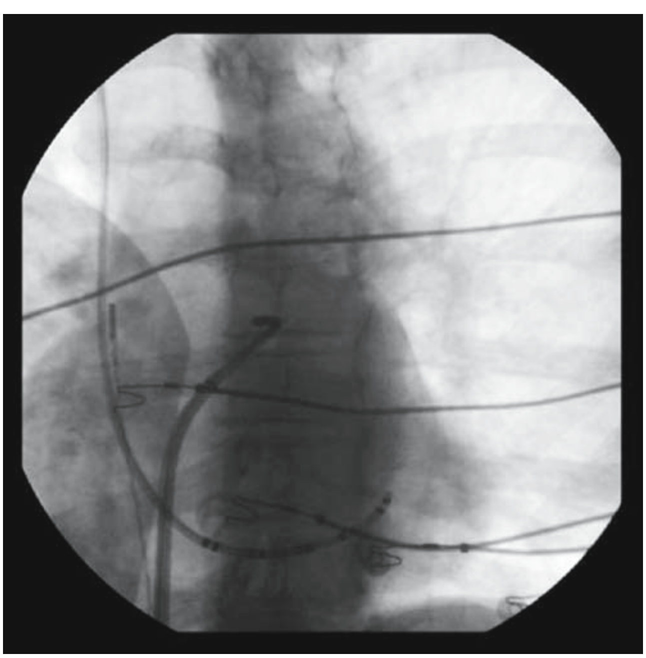


Figure 7.97 At this point, the roof outline is easily created by withdrawing the mapping/ablation catheter

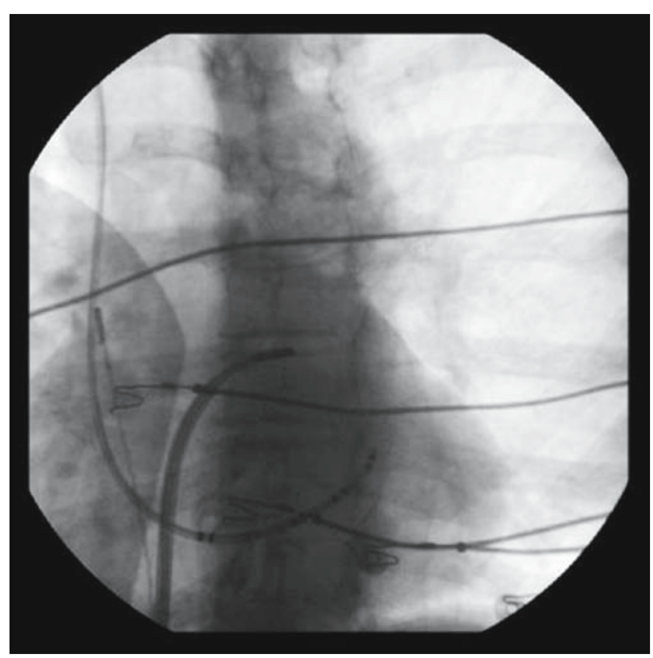


Figure 7.98 The roof outline is completed when the mapping/ablation catheter reaches the left superior pulmonary vein (*LSPV*) antrum

The septal aspect too can be mapped using two alternative ways: a direct method and a method involving looping the ablation catheter. As usual, creation of a loop within the LA enables one to place the catheter so that mapping movements are in fact dragging movements, thus getting a continuous and homogeneous map. Furthermore, the loop does not allow excessive force to be applied to the catheter tip, therefore minimizing distortion of the atrial wall. The disadvantage of this method is a decreased level of maneuverability as there are two fulcrum points—at the level of the transseptal puncture and at the apex of the catheter curvature. This disadvantage can, however, be minimized by utilizing the long sheath as support. Usually mapping of the septum begins in the LAO projection, from the RSPV. This corresponds to the superior septal portion. Maximum curvature is applied to the catheter (thus acquiring an upside-down U-like shape) such that the catheter's distal electrodes rest on the inferior aspect of the antrum. Then the catheter is slowly pulled back making its distal portion slide over the septum, with gentle clockwise and counterclockwise motions to acquire points at the septum's anterior and posterior aspects (Figures 7.99–7.104). This kind of approach usually does not enable one to acquire the basal portion of the septum as the risk of coming out of the LA is very high here as the transseptal access site is in that position. To avoid losing the transseptal aspect at this point, it is advisable to advance the long sheath slightly inside the LA, beyond the interatrial septum. A small amount of sheath in the LA should not impede such curvature being applied to the sheath and retains access to the LA[2].

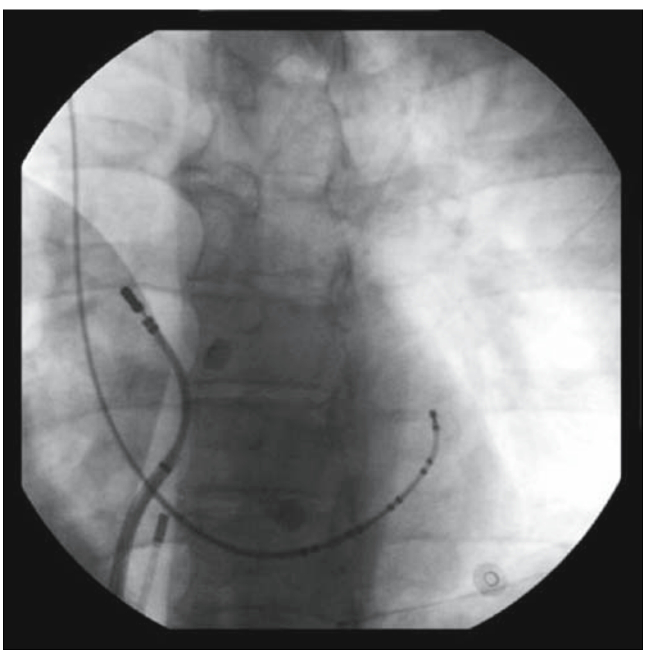


Figure 7.99 Initially, the septum may be mapped by directly withdrawing the mapping/ablation catheter from the right superior pulmonary vein (*RSPV*), such as in this image. The catheter is positioned at the inferior portion of the RSPV antrum using the left anterior oblique (*LAO*) view

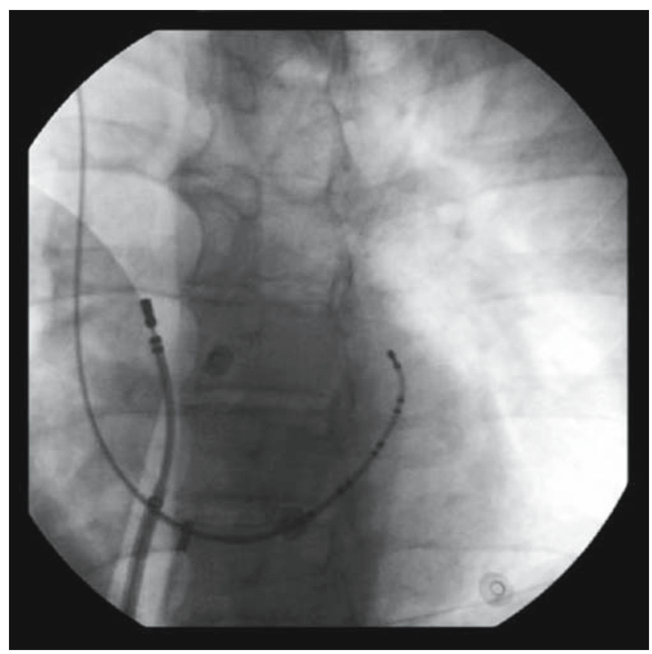


Figure 7.100 The mapping/ablation catheter is slightly withdrawn along the septum

[2] With reference to this subject, it is possible, during the mapping phase for the ablation catheter to dislodge into the right atrium. Such an occurrence, if only one transseptal puncture has been carried out with one single long sheath, causes the access to the LA to be lost. In this case, access to the LA can usually be again obtained without the necessity of a separate transseptal puncture. The deflectable ablation catheter can be inserted inside the long sheath within the right atrium. When the ablation catheter is in the right atrium the long sheath is retracted into the inferior vena cava so that one can more freely move the ablation catheter. The previous transseptal puncture site is identified in the manner similar to the original puncture. The ablation catheter can usually be passed through this aperture with the back of the long sheath advanced into the right atrium. The long sheath is then advanced over the ablation catheter into the LA. When mapping is over and only a single transseptal puncture has been performed, the catheter may be exchanged for another catheter as described in paragraph 5.4 and Figures 5.106–5.115.

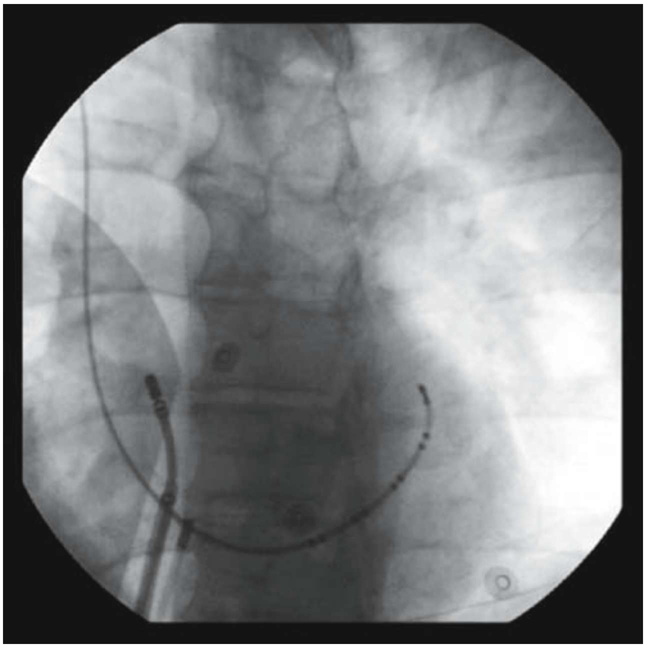


Figure 7.101 Continuing to withdraw the mapping/ablation catheter, its tip comes very close to the transseptal puncture site; here there is a risk of coming out of the left atrium (*LA*)

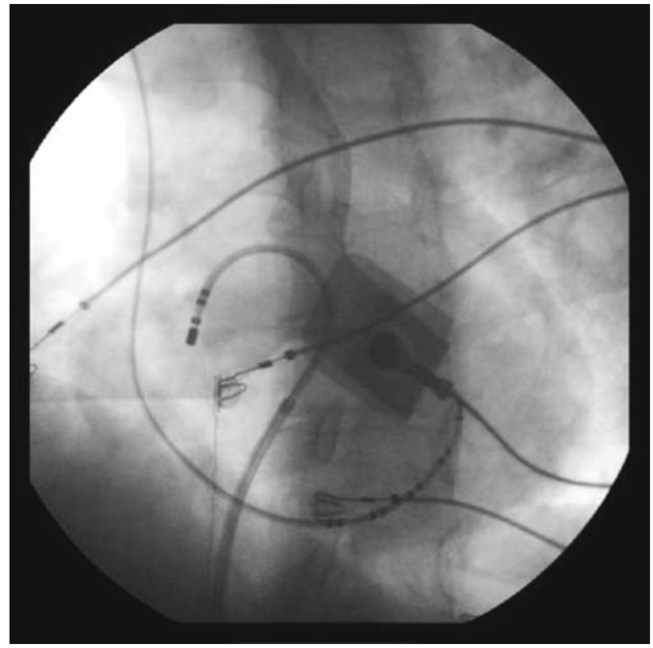


Figure 7.102 In the left anterior oblique (*LAO*) view, the long sheath is advanced within the left atrium (*LA*) and the mapping/ablation catheter is curved, creating a loop with an upside-down U-like shape

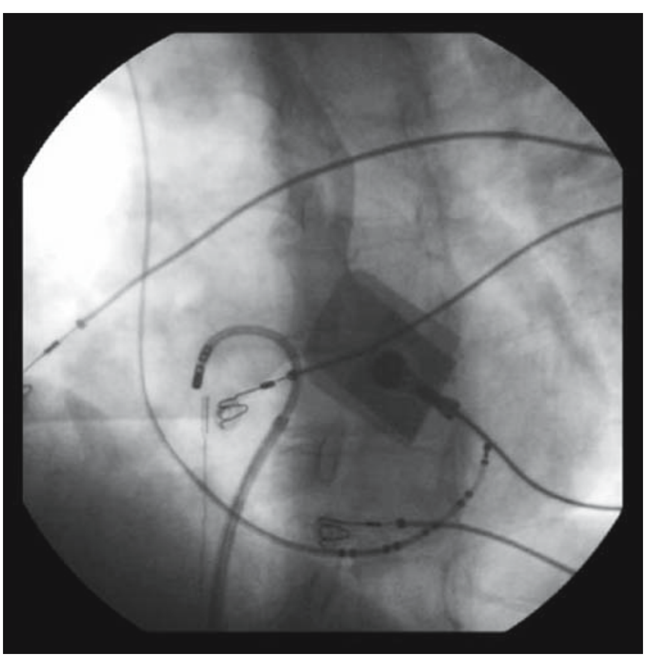


Figure 7.103 The catheter is withdrawn and maximally curved to map the middle portion of the septum, with little risk of coming out of the left atrium (*LA*)

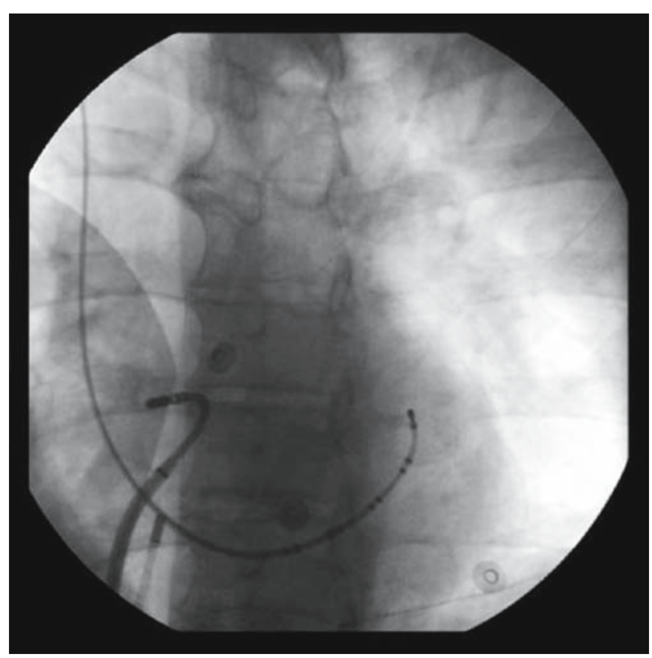


Figure 7.104 Clockwise and counterclockwise torque allows acquisition of mapping points in the posterior or anterior septal portion, respectively

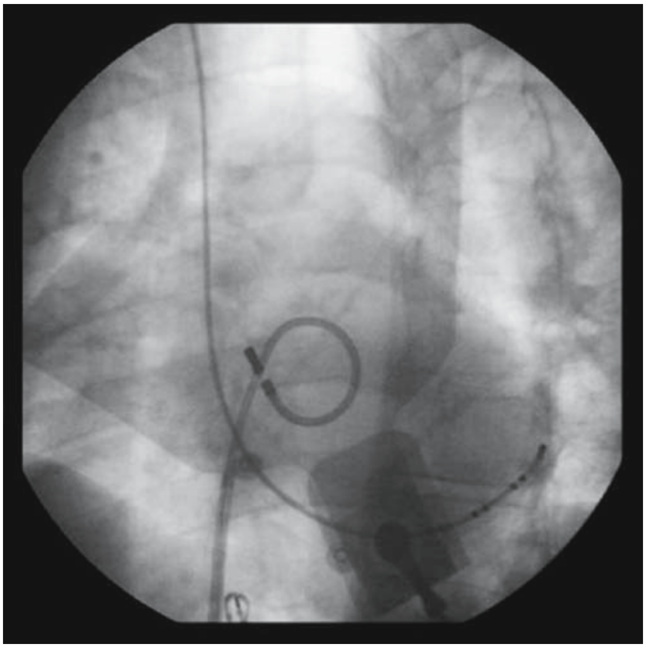


Figure 7.105 A loop can be made within the left atrium (*LA*) maximally curving the catheter, using the left anterior oblique (*LAO*) view

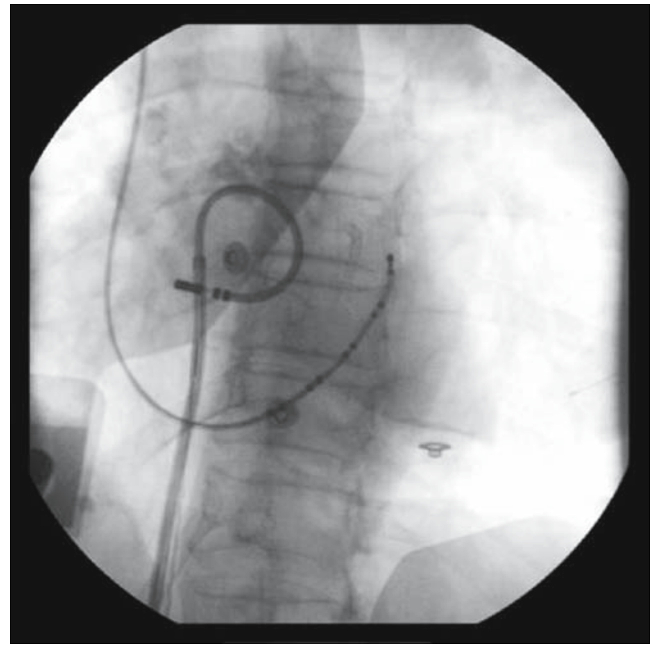


Figure 7.106 The long sheath-catheter complex is advanced to reach the middle-superior portion of the septum

Another, perhaps more secure, method is mapping by forming a wide loop within the LA with the long sheath directed toward the left veins. The body of the catheter then rests on the lateral wall and on the floor of the LA. The distal tip is then able to be positioned, following this loop, such that it is at the septal aspect, mainly in its basal portion. By delicate clockwise and anticlockwise torquing movements, it is possible to define the anterior–posterior aspect of the septum. The LAO is an optimal projection (Figures 7.105–7.107). The caveat to this looping method is that the distal tip of the catheter may not reach the septum in patients with dilated atria.

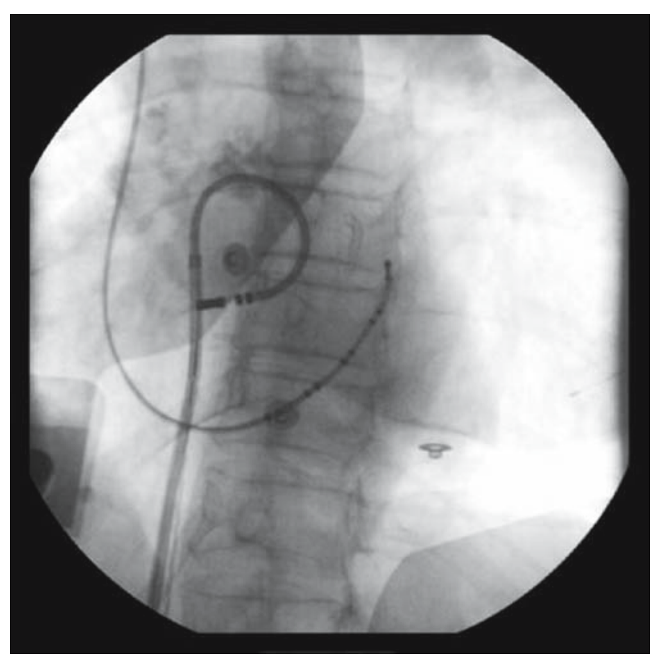


Figure 7.107 Withdrawing the sheath and slightly opening the catheter curvature, the middle-inferior portion of the septum may be mapped

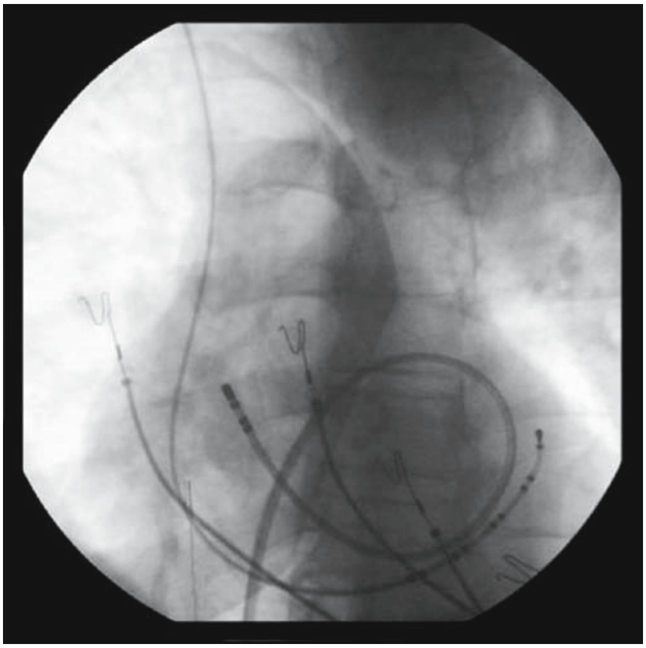


Figure 7.108 The mapping/ablation catheter is advanced until a large loop is created within the left atrium (*LA*). This position allows completion of the septal map and commencement of mapping the LA floor. The left anterior oblique (*LAO*) view

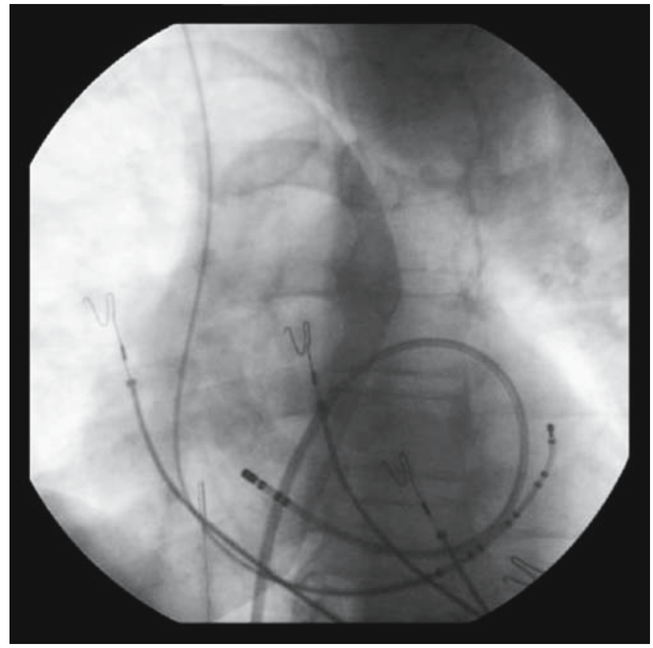


Figure 7.109 The mapping/ablation catheter is withdrawn until it reaches the region between the septum and the floor

Mapping of the LA floor is also accomplished by forming such a loop with the ablation catheter. By withdrawing the catheter from the septum, the floor is defined, overlapping in the LAO view the course of the CS. To complete the construction of the floor, delicate clockwise and counterclockwise torque fills in the anterior–posterior aspect (Figures 7.108–7.111).

At this stage, after having created out an accurate map of the PV antra, roof, and floor, the posterior wall is usually already defined. The posterior wall, as a matter of fact, is almost thoroughly made of the venous antra, and on the endocardial surface it is difficult to define

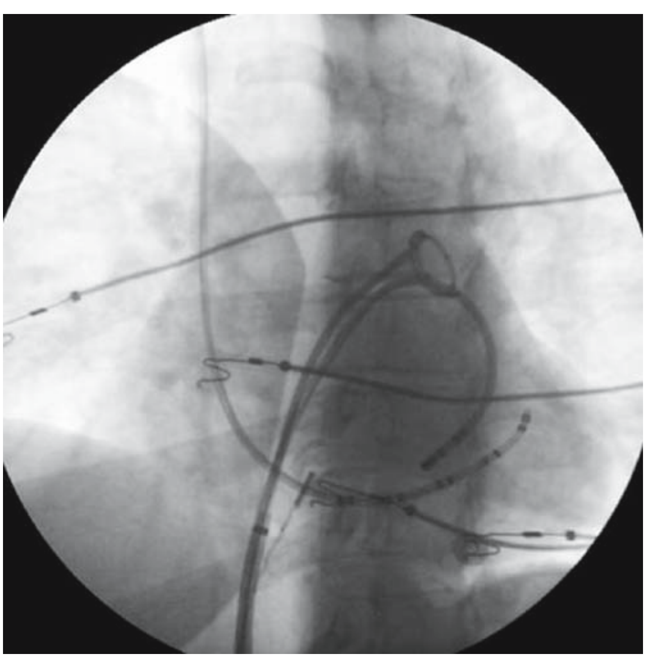


Figure 7.110 The mapping/ablation catheter is further withdrawn and the tip is at the center of the floor

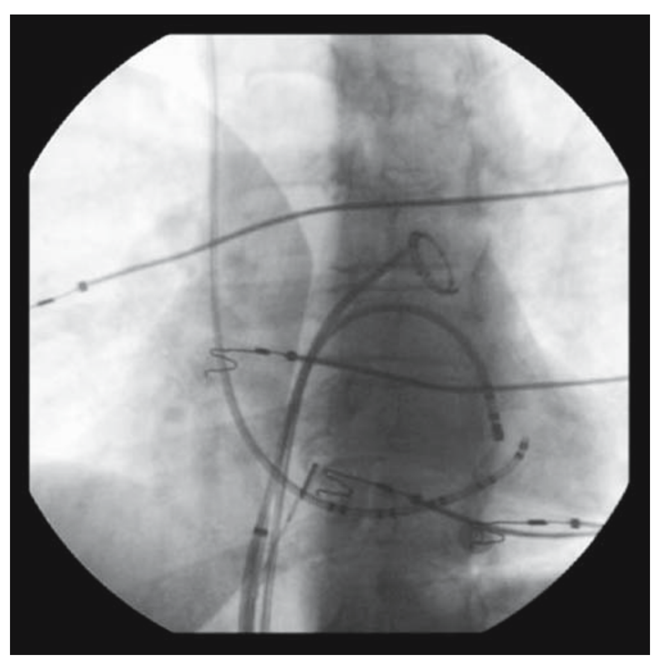


Figure 7.111 The mapping/ablation catheter is withdrawn to the posterolateral portion of the mitral valve, completing the floor's outline

exactly the passage between the venous antrum and the atrial wall. The important point is that the ostia are defined, so that ablation can be performed in the antrum, thereby minimizing complications. Single points can, however, be acquired mainly for better definition of the anterior–posterior thickness of the constructed virtual anatomy. Additional points are not infrequently acquired on the right side of the LA, near the RIPV. To accomplish further refinement of the map the catheter is freed in the LA and slightly curved; the long sheath can be positioned within the RA or the LA. In the RAO projection, the catheter's tip is pushed toward the posterior wall and then, in the LAO view, the catheter is advanced to come into contact with the wall. Sequential curving and releasing of the curve enable the acquisition of superior and inferior points, while slight clockwise and counterclockwise rotation allows one to acquire more septal and lateral points.

The anterior wall is not usually mapped completely. The map is confined to acquiring some points at the mitral ring to define the atrium's anterior–posterior aspect. The superior limit of the anterior wall is marked by the interatrial or Bachmann's bundle. This bundle is the largest muscle bundle of the LA. It is an important electrical bridge between the right and left atria. It connects the anteromedial wall of the RA with the junction of the anterior and superior walls of the LA; two branches partially encircle the orifices of the superior vena cava (SVC) on the right, and the LAA on the left. Just below Bachmann's bundle, a very thin horseshoe-shaped area is located. Little musculature is found at this location. It is important to be aware of the presence of this area, not only due to the thinness of the wall but also for its close proximity posteriorly to the aortic sinus.

In mapping the anterior aspects of interest in the LAO projection, the ablation catheter and the sheath are rotated in a counterclockwise direction about 90° from a leftward looking position to the anterior wall. This maneuver should take the catheter to the level of the mitral valve apparatus; this can be confirmed in the RAO view. In the LAO view, the counterclockwise rotation of the catheter can be seen to bring the catheter into contact with the mitral ring's superior side. This is confirmed by recording of atrioventricular potentials from the mapping catheter. From the mitral's superior wall, one slightly withdraws the sheath, keeping the counterclockwise torque, and advances the catheter with a slight deflection of the distal tip to reach the valve ring's septal portion. From this position, gentle clockwise rotation, release of the curve, and advancement of the catheter to the basal portion of the annulus may be mapped. Finally, slightly advancing the sheath and further releasing the counterclockwise torque will bring the catheter into contact with the lateral mitral annulus (Figures 7.112–7.115).

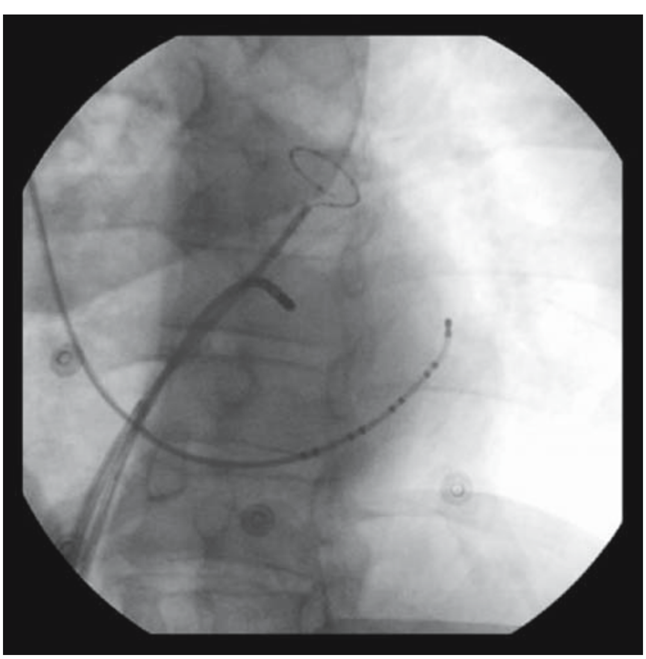


Figure 7.112 The mapping/ablation catheter is at the superior aspect of the mitral valve. The valvular position is confirmed by the atrioventricular potentials recorded from the distal bipole. The left anterior oblique (*LAO*) projection

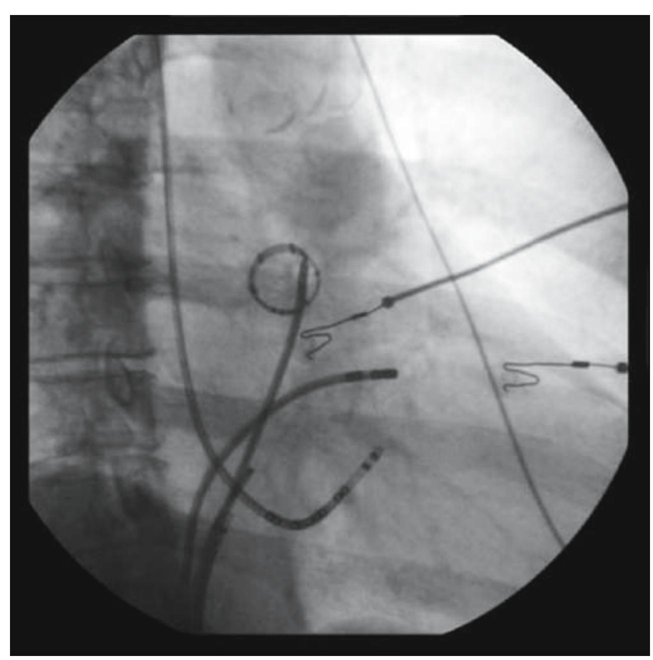


Figure 7.113 The right anterior oblique (*RAO*) view allows confirmation of the direction toward the left ventricle

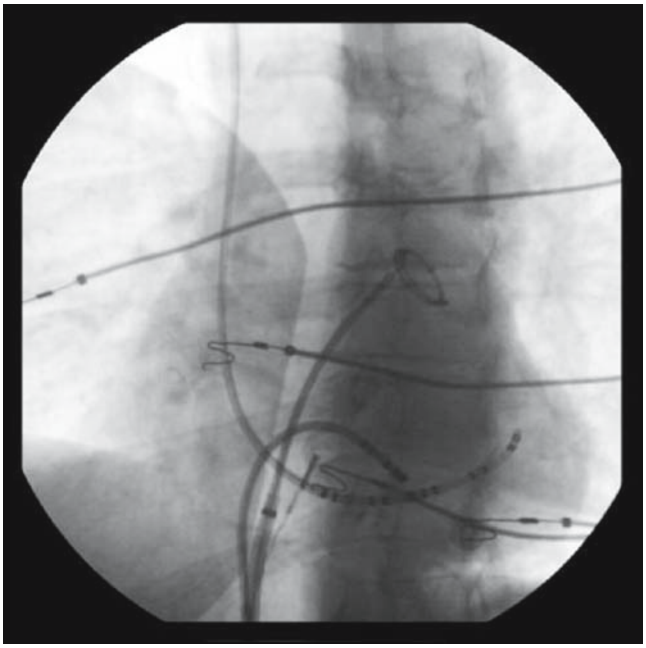


Figure 7.114 The mapping/ablation catheter is at the mitral valve inferior portion. The valvular position is confirmed by the atrioventricular potentials recorded from the tip. The left anterior oblique (*LAO*) projection

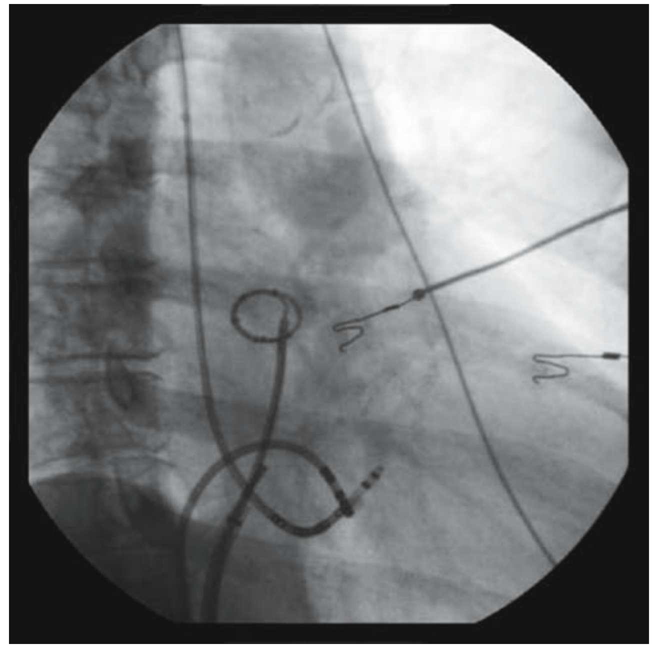


Figure 7.115 The right anterior oblique (*RAO*) view allows confirmation of the direction toward the left ventricle

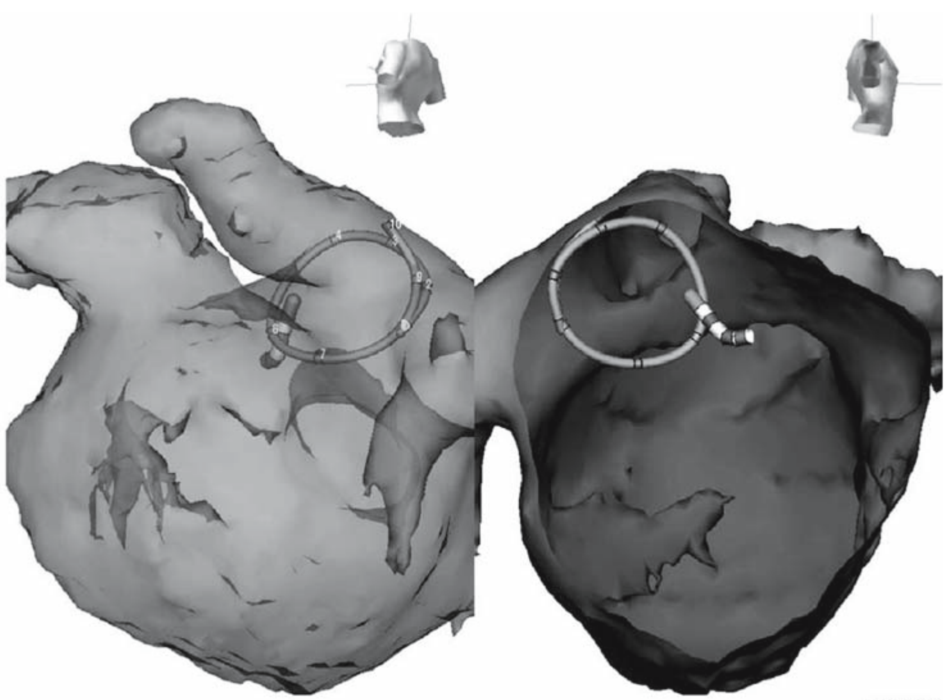


Figure 7.116 Left atrium NavX-Fusion map. On the left, a left lateral view, while, on the right, the left lateral cardioscopic view. In the maps, the circular mapping catheter, placed at the left inferior pulmonary vein (*LIPV*) ostium, the ablation catheter, and the coronary sinus (*CS*) catheter are visualized. The cardioscopic view allows one to see the first radio frequency (*RF*) applications (white dots) at the anteroinferior portion of the ostium. As for anatomy, the left pulmonary veins (*PVs*) show different ostia but a common antrum with a wide pulmonary vein-left atrium appendage (*PV-LAA*) ridge. Furthermore, this LA reconstruction enables one to visualize the vestibule, the thin circumferential area surrounding the orifice of the mitral valve

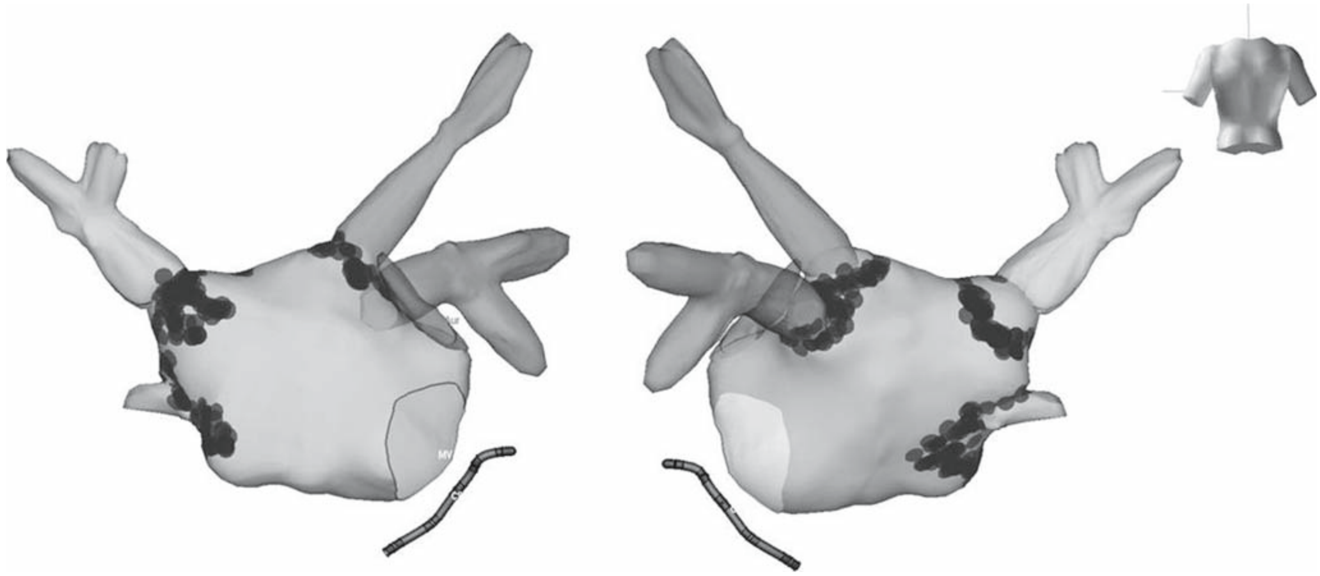


Figure 7.117 Left atrium (*LA*) NavX-Verismo map. On the left, the electroanatomic reconstruction with the circular radio frequency (*RF*) lesion (black dots) seen around the pulmonary veins (*PVs*) ostia in the AP view. On the right, the corresponding image in the posteroanterior (*PA*) view

Once the left atrial map is created, it is possible to fuse the virtual map and the real anatomic map obtained from a previous cardiac CT or MRI examination. At this point, ablation is guided by both nonfluoroscopic mapping and fluoroscopy. Fluoroscopy times are decreased with the aid of the electroanatomic map. In the following series of images, we show the lesions delivered at the PV antra with the assistance of electroanatomic mapping systems (Figures 7.116–7.125).

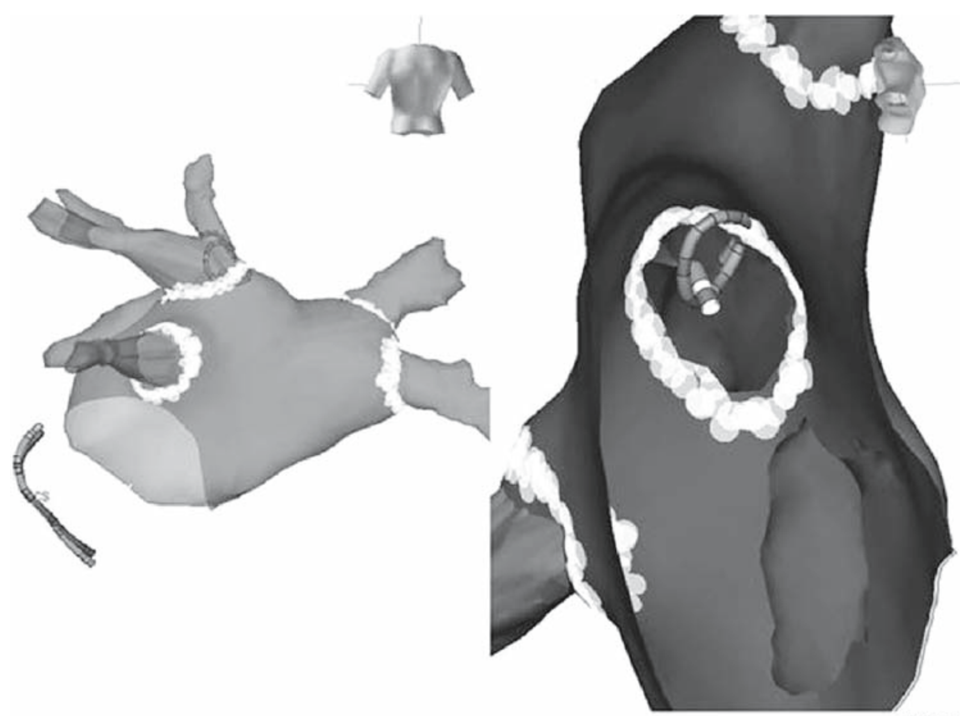


Figure 7.118 In this patient, the left cardioscopic view, on the left, allows one to see the circular radio frequency (*RF*) lesions (white dots) at the left superior pulmonary vein (*LSPV*) ostium. On both the maps, the posteroanterior (*PA*) and the left cardioscopic views, it is possible to appreciate how the circular mapping catheter has advanced into the superior branch of the vein

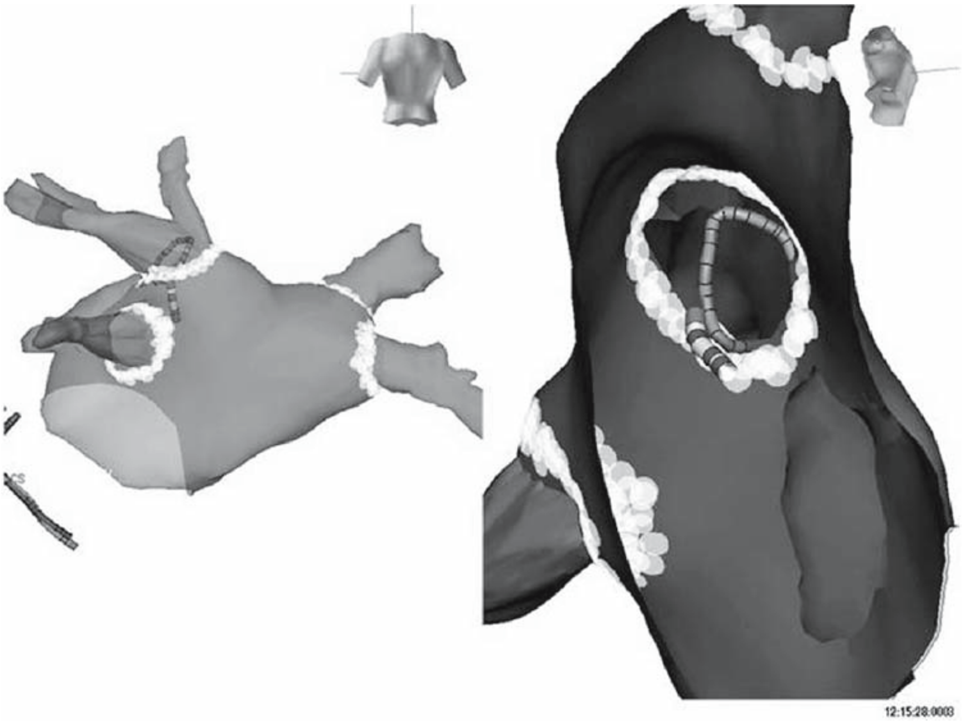


Figure 7.119 In the same patient, the mapping catheter has been changed with a mesh catheter that gave better stability at the pulmonary vein (*PV*) ostium

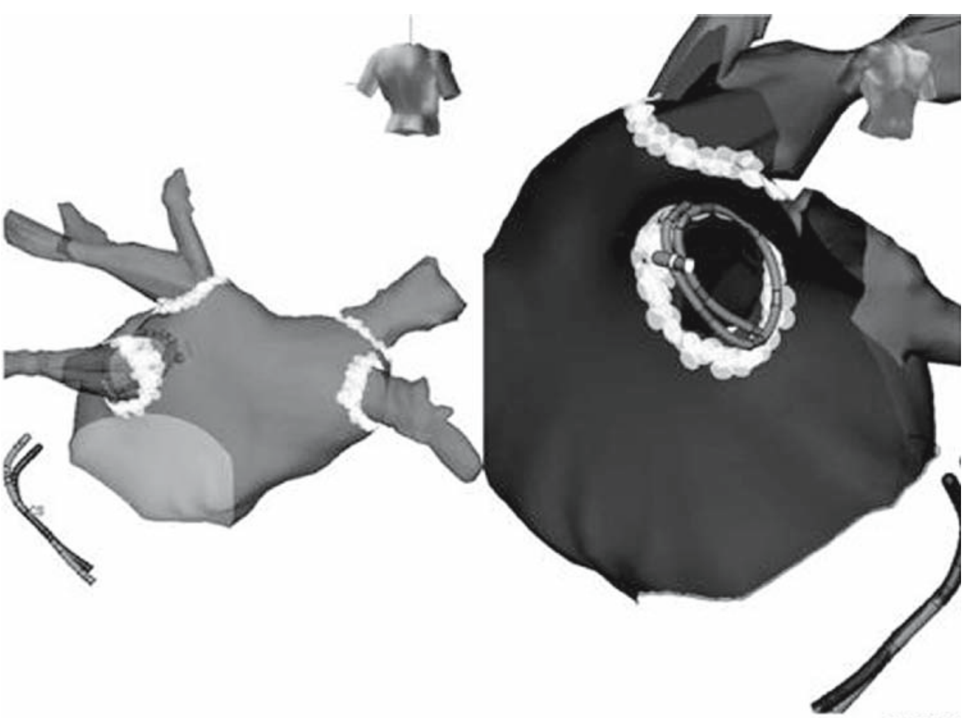


Figure 7.120 The posteroanterior (*PA*) view on the right, and the left cardioscopic view on the left, allows one to see the circular mapping catheter at the right inferior pulmonary vein (*RIPV*) ostium and the ablation catheter performing radio frequency (*RF*) lesions (white dots)

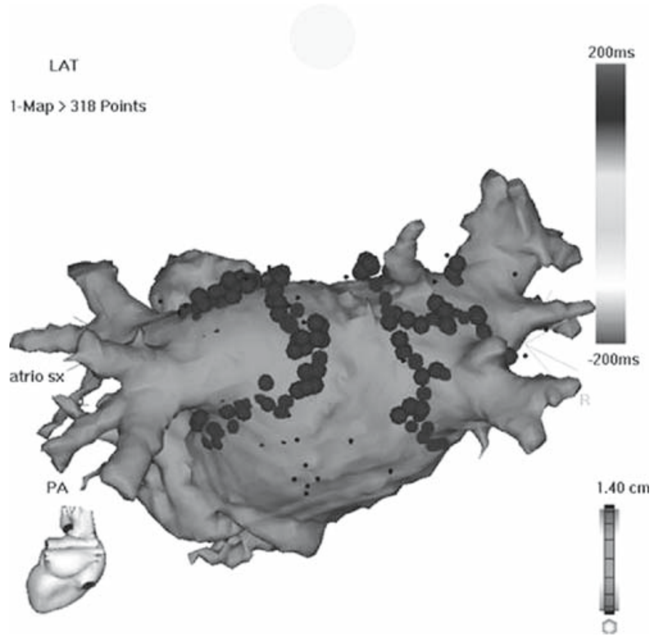


Figure 7.121 CARTOMerge map in the posteroanterior (*PA*) view where it is possible to appreciate the antral lesions (black dots) around the pulmonary veins (*PVs*). The right veins are encircled by a large lesion, and finally lesions are created around the entire PVs, including the additional one

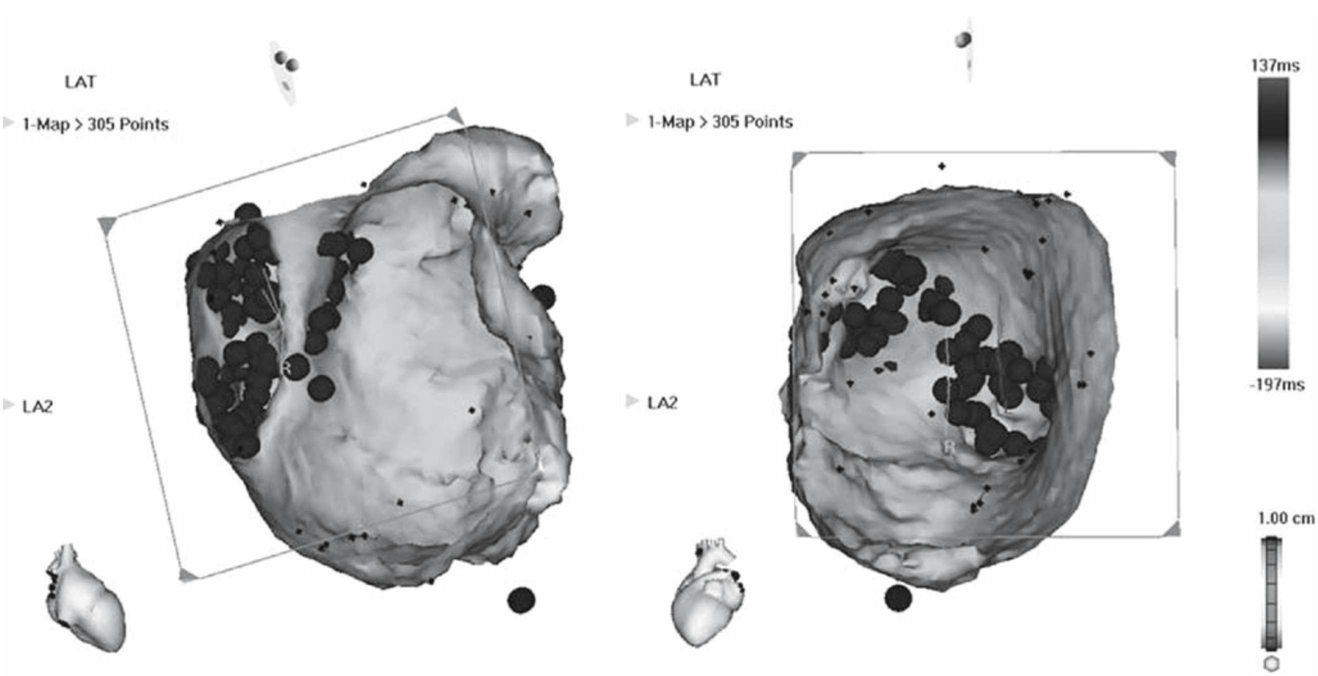


Figure 7.122 Cardioscopic views: on the left, the left veins' ostia are shown, while on the right, the right veins' ostia are shown. Note that in the left lateral cardioscopic view the radio frequency (*RF*) lesion at the venous-atrial appendage ridge have been performed at the appendage ostial aspect

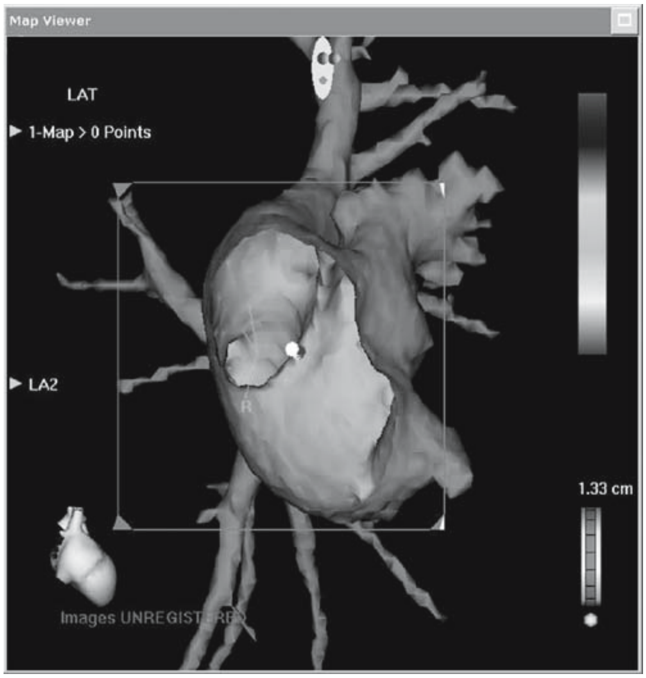


Figure 7.123 CARTOMerge cardioscopic view that allows to see directly the thin and acute angle ridge between left veins' common antrum and the left atrial appendage ridge. In this map, the tip of the ablation catheter is visualized confirming its stable position upon the ridge

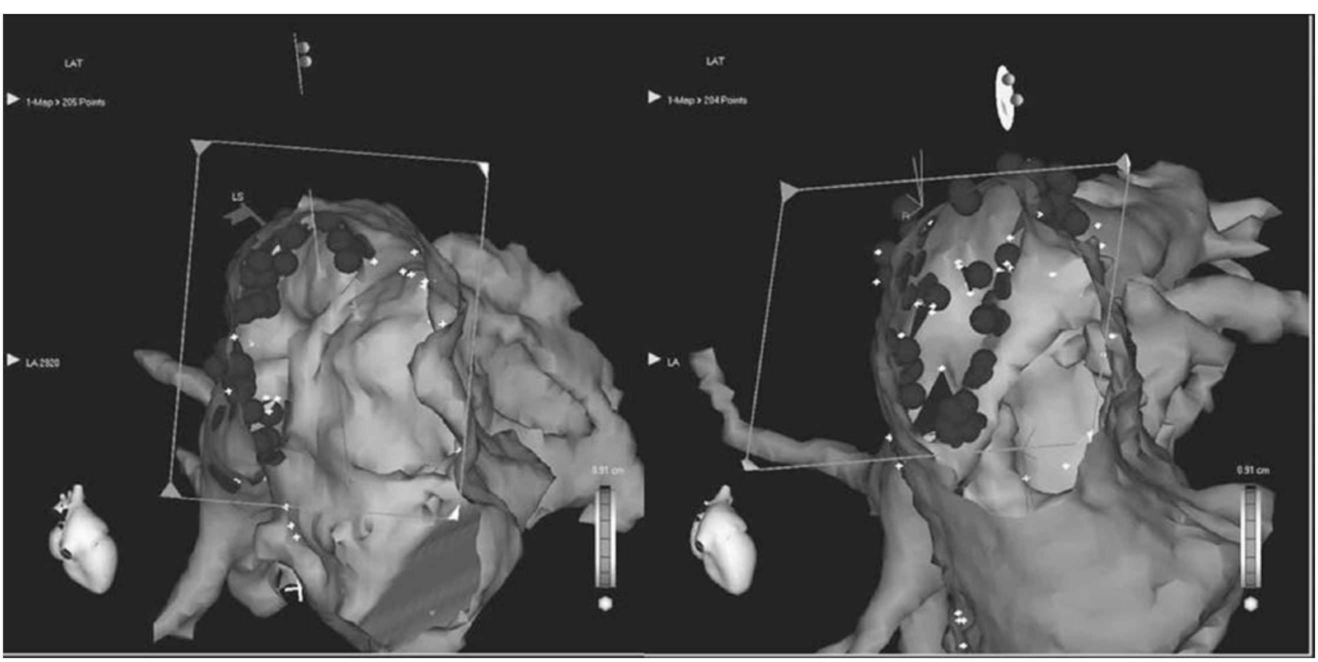


Figure 7.124 Left lateral cardioscopic views from two different patients. On the left, the venousatrial appendage ridge is thin and makes an acute angle, making it difficult to stabilize the catheter tip and to deliver radio frequency (*RF*). On the right, the ridge between the left pulmonary veins (*PVs*) and the atrial appendage is wide and rounded allowing RF ablation to be more easily performed

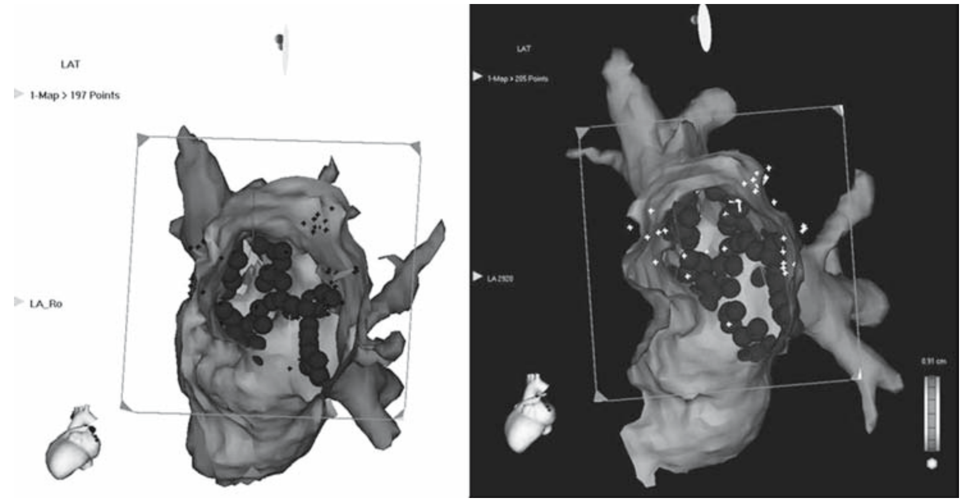


Figure 7.125 Right lateral cardioscopic views from two different patients. On the right, the pulmonary veins' (*PVs*) ostia are distant and the veins are encircled separately. On the left, the proximity of the two ostia permitted a single circumferential lesion set, joined at the middle

LA mapping may also be performed using the real-time imaging provided by ICE. In this case, the circular mapping catheter or the ablation catheter is sequentially moved to reach the PV ostia and antra. Every atrial region where ablation must be performed is systematically mapped. The intracardiac image is used to define, in real time, the appropriate positioning of the catheter, allowing more accurate definition of the left atrial regions of interest. This is particularly the case in defining the PV antra, as relying solely on fluoroscopic and 3-D reconstructed images may give less precise definition of this region. Delivery of lesions beyond the level of the PV antra has been shown to result in an increased rate of subsequent PV stenosis. ICE also aids in providing real-time localization of the esophagus, which may be damaged during ablation of the posterior LA. ICE has also been shown to be invaluable in power-titration during RF delivery when an 8-mm tip catheter is used, by watching for the appearance of micro-bubble formation. Micro-bubbles are a marker of tissue overheating and their appearance may herald a tissue-pop phenomenon. Using ICE, the ablation is performed at the same time as the mapping phase without the need to come back to target zones at a later time (Figs. 7.126–7.137). Thus, ICE imaging plays a very important role in identifying anatomic landmarks, assisting accurate placement of mapping and ablation catheters, monitoring RF lesion creation, and instantly detecting procedural complications (Figures 7.138).

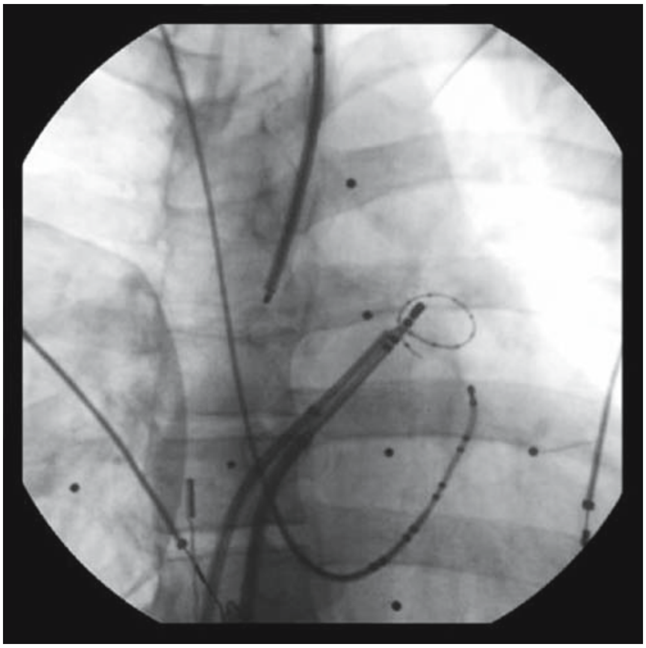


Figure 7.126 Mapping and ablation at the left superior pulmonary vein (*LSPV*) ostium. Posteroanterior (*PA*) is the projection frequently used when the mapping is performed using intracardiac echo (*ICE*), as the real-time echocardiographic imaging allows distinguishing the anatomic landmarks and the spatial localization (anterior–posterior, lateral–septal) in such a way, making the oblique projections less essential. Note the intracardiac probe with its scanning sector facing the interatrial septum and left pulmonary veins (*PVs*). Finally, the additional catheter for monitoring esophageal temperature has been placed

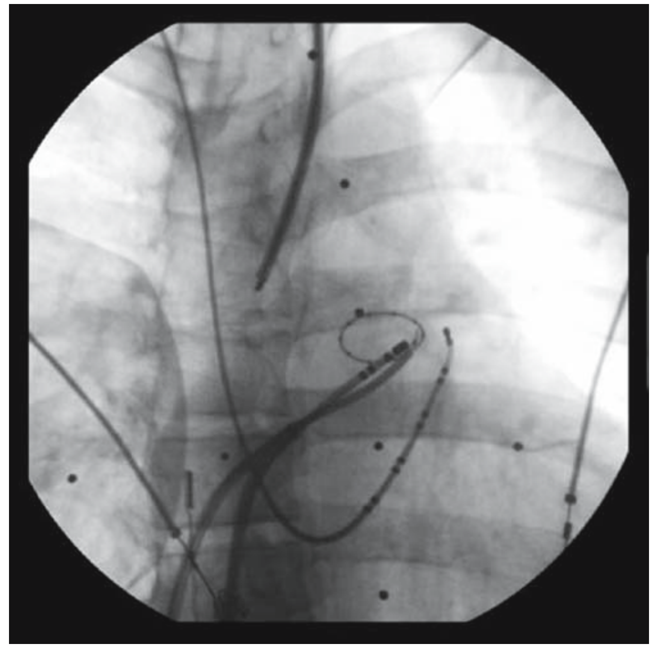


Figure 7.127 Mapping and ablation at the left inferior pulmonary vein (*LIPV*) ostium in the posteroanterior (*PA*) view

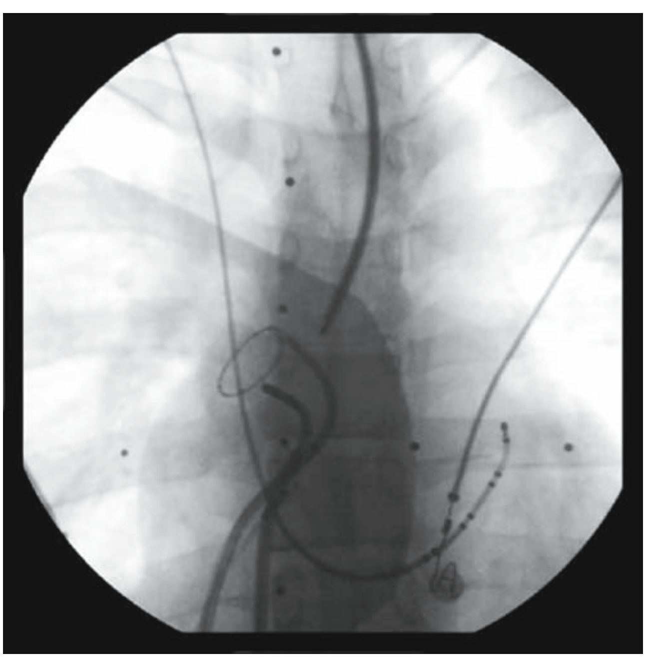


Figure 7.128 Mapping and ablation at the right superior pulmonary vein (*RSPV*) ostium in the posteroanterior (*PA*) view. In this case, the ultrasound catheter is curved toward the septum with the active face turned superiorly to visualize the long axis of the vein. The esophageal catheter is close to the ablation site

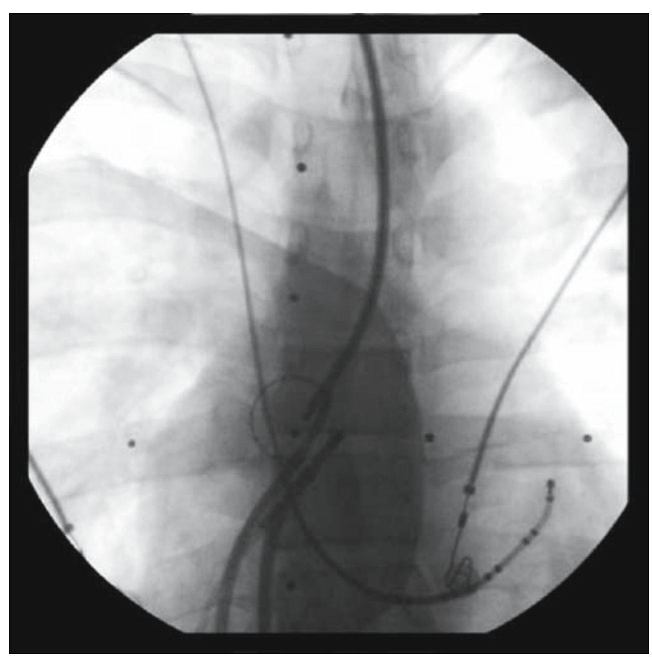


Figure 7.129 Mapping and ablation at the right inferior pulmonary vein (*RIPV*) ostium in the posteroanterior (*PA*) view. The RIPV ostium is inferior and posterior with respect to the right superior pulmonary vein (*RSPV*) ostium

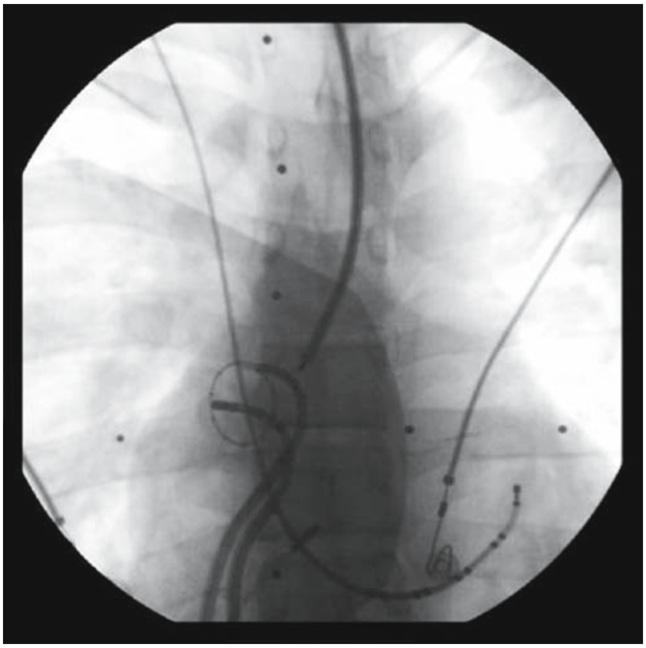


Figure 7.130 This image shows an intermediate position between the right superior pulmonary vein (*RSPV*) and the right inferior pulmonary vein (*RIPV*) in the posterior atrial wall

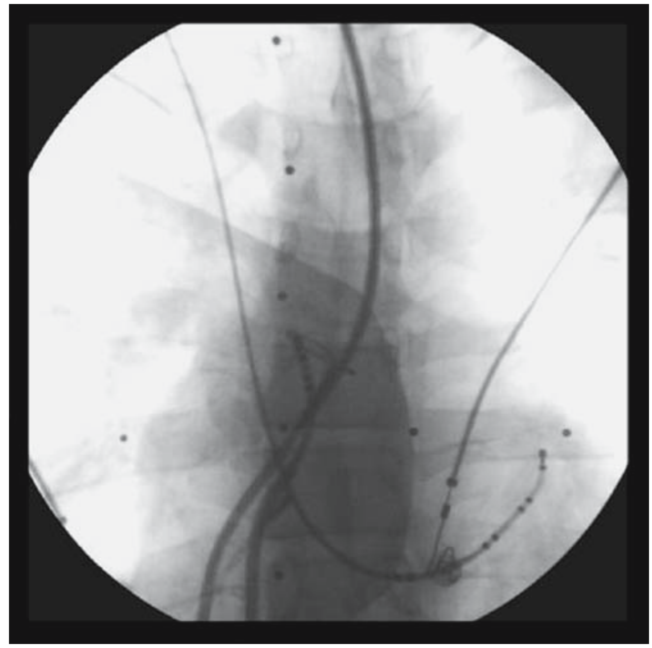


Figure 7.131 The mapping catheter is placed at the left atrium (*LA*) roof, at the junction between the roof and the right superior pulmonary vein (*RSPV*) antrum. The ablation catheter follows the mapping catheter movements to carry on ablation directly

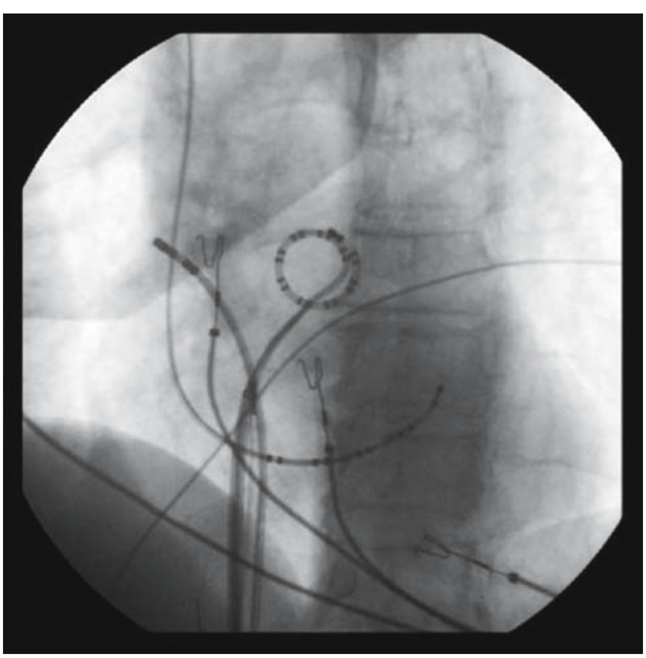


Figure 7.132 Another position of the circular mapping catheter at the left atrium (*LA*) roof

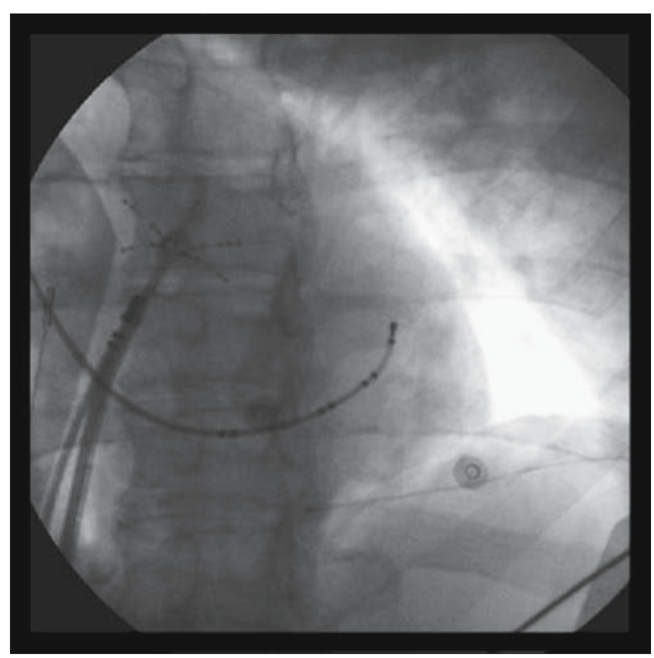


Figure 7.133 Left atrium (*LA*) mapping may be performed with a flower-like mapping catheter as in this image. The catheter is opened against the roof looking for fractioned potentials. The ultrasound catheter checks its position. The left anterior oblique (*LAO*) view

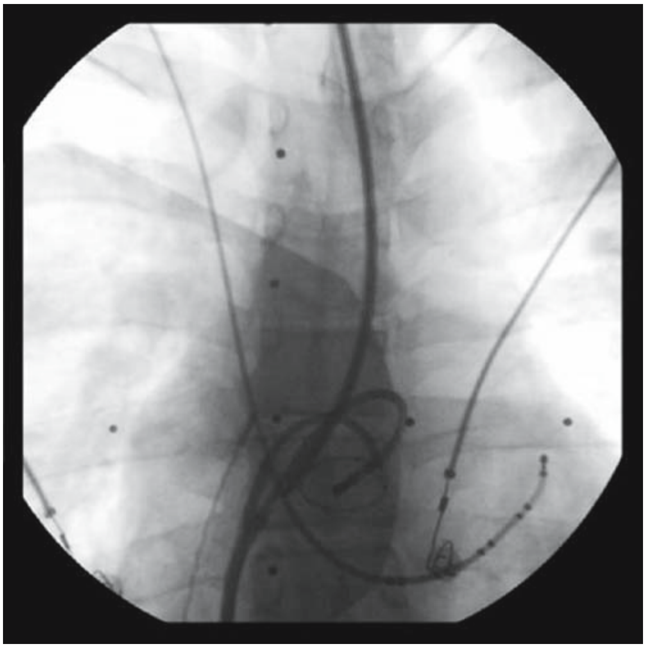


Figure 7.134 Left atrium (*LA*) mapping continues on the floor, curving the mapping catheter. The intracardiac echo (*ICE*) catheter is now at the level of fossa ovalis facing the LA roof. The postero-anterior (*PA*) view

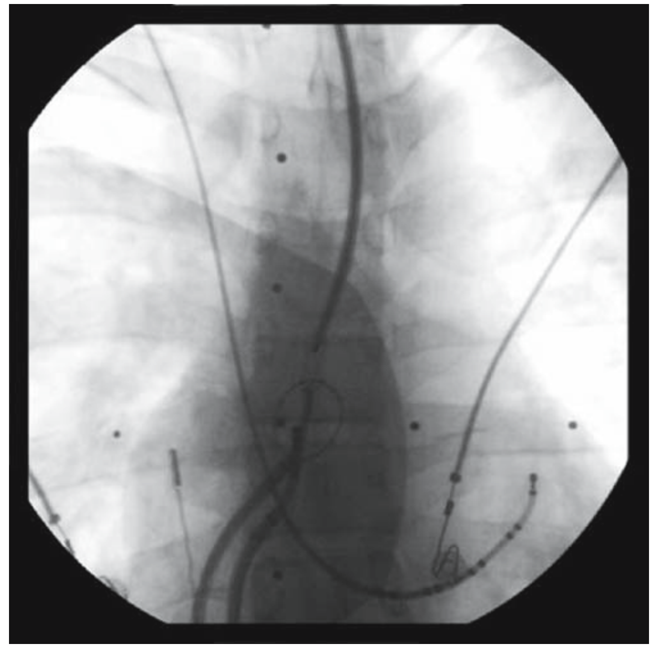


Figure 7.135 The ablation catheter follows the mapping catheter and applies radio frequency (*RF*) to eliminate atrial potentials seen on the mapping catheter

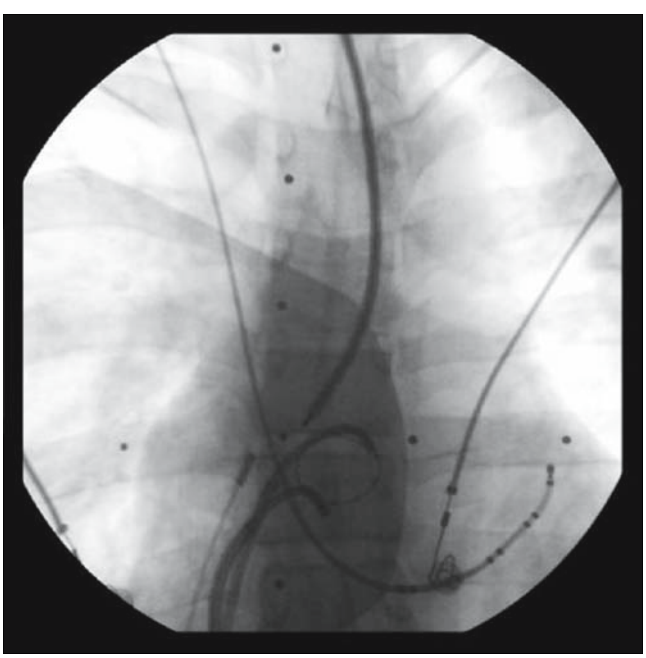


Figure 7.136 In this image, the mapping catheter and the ablation catheter are placed at the posterior atrial wall close to the right inferior pulmonary vein (*RIPV*) antrum

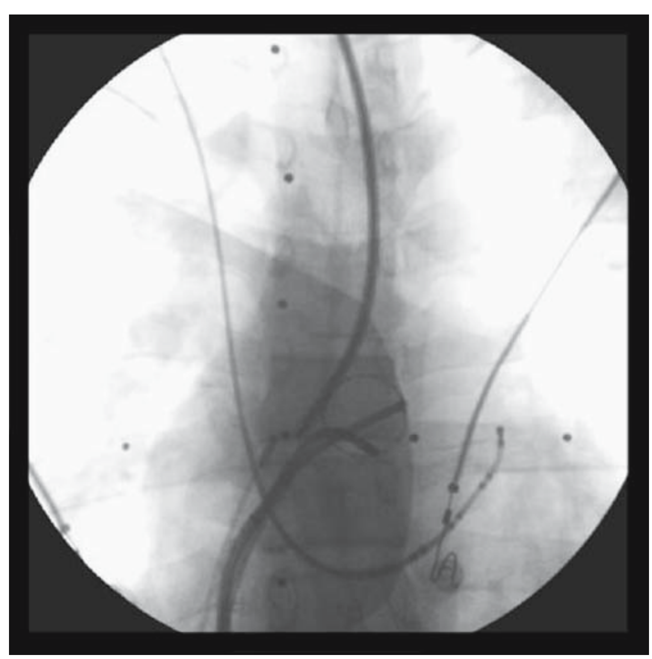


Figure 7.137 Mapping and ablation catheters are moved to the anterior atrial wall just above the mitral valve

Figure 7.138 The real-time intracardiac imaging allows to immediately check for possible complications such as thrombus, as seen in this case. The arrow shows the thrombus at the end of the long sheath

7.4 Linear Lesions: Left Mitral Isthmus and Roof

The AF ablation strategy may involve the deployment of linear lesions. The objective in creating linear lesions by RF energy is to provide lines of conduction block within the LA. The objective of this may be to compartmentalize the LA or to avoid development of circuits capable of supporting reentry arrhythmias. Many linear lesions can be carried out, the most common being at the left mitral isthmus level and the LA roof. These two kinds of linear lesions, in particular the left mitral isthmus line, developed when nonfluoroscopic mapping systems were not routinely utilized and these lesion sets are easily visualized fluoroscopically.

The mitral isthmus is the portion of atrial tissue spanning from the ostium of the LIPV to the mitral annulus. The mitral isthmus is made up of a vertical portion resting at the border between the lateral wall and the posterior wall of the LA and in its lower end it reaches the atrial floor to reach the mitral ring. The mitral isthmus length is extremely variable between patients; in some cases, the left atrial myocardium continues even onto the mitral valve leaflet. Also the atrial myocardial thickness varies considerably along the isthmus and between patients. When ablating along an isthmus line, it is recommended to direct the caterer in a leftward direction from the LIPV. This is such that the epicardial vein encountered in the epicardial fat pad at this location is the great cardiac vein and not the distal part of the CS. In fact, the CS is usually enveloped by atrial myocardium whereas the great cardiac vein is less likely to have an atrial myocardial sleeve. At the atrioventricular groove fat pad, the great cardiac vein accompanied by relatively large branches from the left circumflex artery is located. Usually the vein and the artery are at the epicardial aspect of the fat pad, with the artery's course more ventricular than that of the vein. These structures are embedded within the adipose tissue that effectively works as a protection cushion from RF applications. However, care must be taken as it is not rare for the artery to be located between the atrial wall and the great cardiac vein. In such a case, RF applications from the LA endocardium or from within the CS may damage the artery. Furthermore, the circumflex artery, at the level of the LIPV, gives origin to the posterior sinus node artery. Knowledge of this complex anatomy demands that special care be taken if ablation of the mitral isthmus is to be undertaken.

The anatomic points to follow along the line are the mitral ring, located by means of a catheter within the CS (the CS course is that of the mitral valve in the lateral portion) and the LIPV ostium marked by the circular mapping catheter. If only one catheter is being used within the LA, the mapping/ablation catheter can be positioned at the inferior level of the LIPV ostium, as viewed in the LAO projection. The ablation may then be performed in the PA projection, beginning from the mitral side. While the lesion set is referred to a line, in fact lesions should form more of a triangle, with its narrow base at the level of the CS, where the musculature is thicker.

Starting from a standard position with the catheter free within the LA, the long sheath is advanced so that it is directed toward the lateral wall. The ablation catheter is advanced and slightly curved in such a way that its body pivots on the superior–lateral wall. The curvature of the catheter positions it such that the distal tip now bends downward, coming into contact with the atrial floor. Counterclockwise torque applied to the sheath or the catheter moves the catheter anteriorly; contact with the mitral ring is confirmed in the RAO view as well as by local recording of atrioventricular potentials. In the PA view, the catheter's curvature can be increased should it be positioned too laterally; conversely, the curvature can be gradually released should it be positioned too medially. RF energy delivery usually starts from the mitral side. As stated previously, the lesion set is widened along the valve ring where the musculature is thicker. This is accomplished by gentle opening and closing movements of the catheter tip. To move toward the LIPV, the movement is a gradual and progressive clockwise rotation of the sheath, which moves the catheter posteriorly. As well as application of clockwise torque to the sheath, the catheter is gradually withdrawn while moving toward the posterior wall.

The same maneuver, by utilizing the loop formed within the atrium, can be carried out in a similar fashion with the ablation catheter only. On occasion this is preferable, if the long sheath is directing the catheter away from the mitral annulus. This may be at the expense of decreased stability, which the long sheath usually provides.

In about two thirds of cases, the lesion set so delivered does not ensure conduction block across the mitral isthmus, as defined by electrophysiological criteria. In these cases it is, therefore, necessary to complete the lesion set by performing RF ablation from the epicardial side. This is performed by taking advantage of the path of the CS. To ablate within the CS, it is necessary to use a cooled (irrigated) tip catheter. As an irrigated catheter is nowadays the most frequently used for AF ablation, it is not necessary to utilize a second ablation catheter. The ablation catheter is withdrawn from the LA and inserted into the RA to enter the CS. The CS is usually cannulated by using the LAO projection. When the catheter is located within the CS, the PA view is used to ascertain that the catheter tip is positioned such that it corresponds to the line drawn on the endocardial aspect. The catheter is usually initially positioned at the most lateral aspect of the lesion carried out at the level of the floor on the endocardium. At this point, the catheter is curved so that its tip turns upward. This ensures that catheter's distal electrodes are turned toward the CS portion in contact with the atrium and not toward the vessel's free surface, which is facing epicardially. Delivery of RF lesions away from the atrial aspect of the CS may cause damage to the CS itself, potentially resulting in perforation, pericardial effusion, and cardiac tamponade. The exact catheter position can be checked also in the RAO view where it is possible to see the catheter tip turned upward and posteriorly, directed toward the atrial side (Figures 7.139–7.150).

To deliver the roof lesions, the movements previously described for mapping this zone are replicated with the ablation catheter. When mapping, that could be carried out with or without the use of the long sheath. During ablation, the long sheath provides additional catheter stability. The long sheath utilized should generally have a short preshaped distal curvature rather than sheaths with an exaggerated curvature (frequently used for left-sided accessory pathway ablation). Such sheaths may direct the ablation catheter away from the roof and direct it either toward the anterior wall or the posterior wall (Figures 7.151 and 7.152).

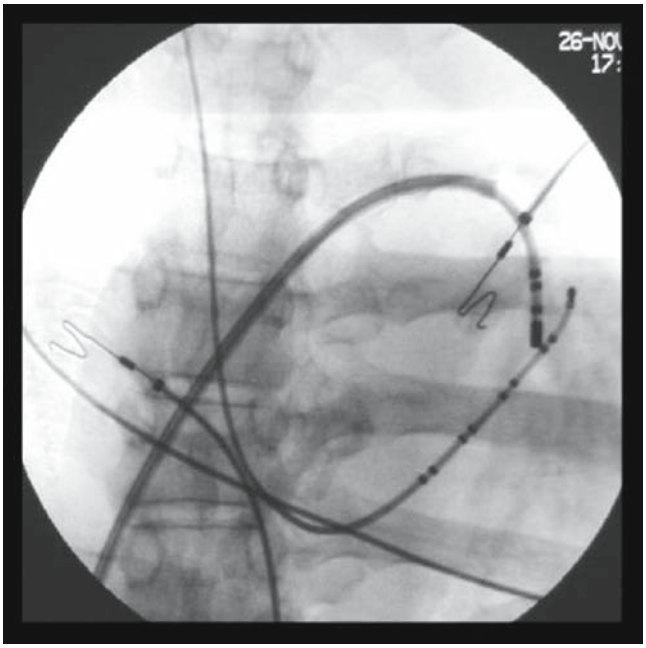


Figure 7.139 In the posteroanterior (*PA*) projection, the ablation catheter is on the mitral side at the level of the coronary sinus (*CS*) bipole 3–4 (1–2 are located at the distal end). The long sheath is notably advanced within the left atrium, toward the lateral wall, to stabilize the catheter. In this position, ablation is started along the left mitral isthmus. The ablation catheter, on the mitral side, enlarges the ablation area by means of slight opening and closing movements of the curve, keeping the applied torque constant

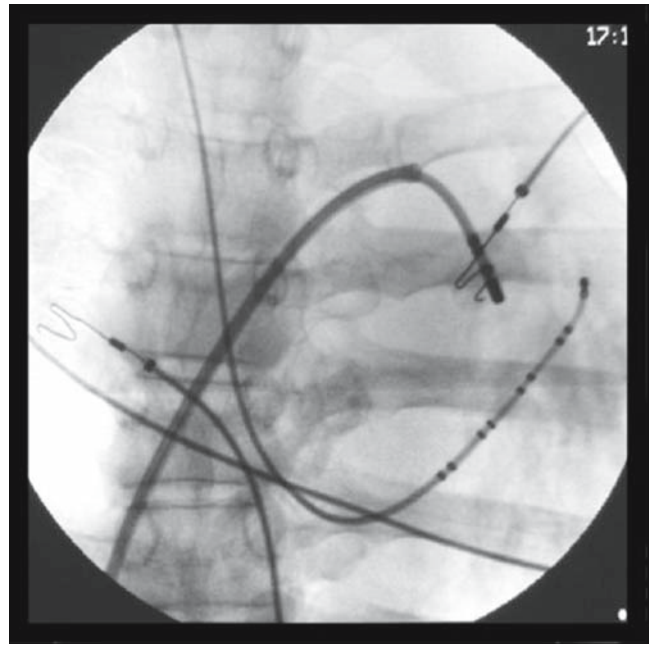


Figure 7.140 By clockwise rotation of the long sheath and slight withdrawal of the catheter, the lesion line is completed. In this case, the catheter tip is at the inferior portion of the left inferior pulmonary vein (*LIPV*) ostium, where ablation has been previously carried out to isolate the LIPV. In this case, the left mitral isthmus appears short

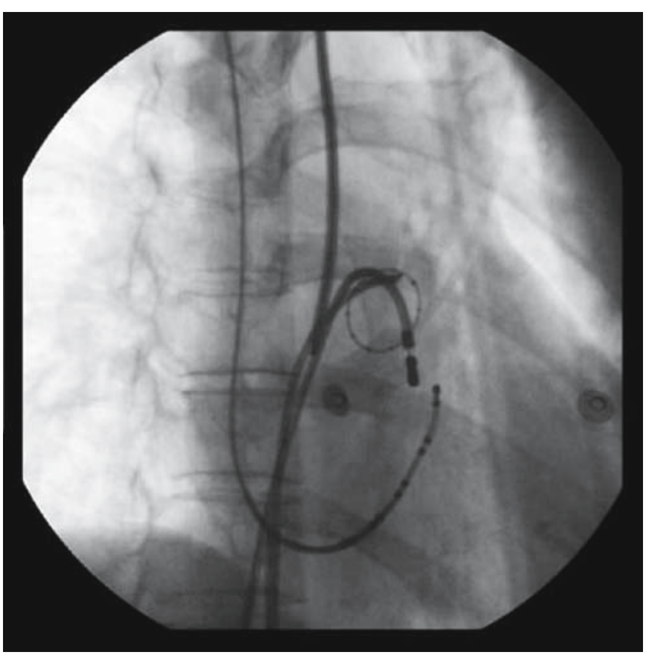


Figure 7.141 The right anterior oblique (*RAO*) projection enables visualization of the isthmus line as an almost vertical line that joins the catheter within the coronary sinus with the left inferior pulmonary vein (*LIPV*) ostium. This projection can be utilized to verify the positioning of the ablation catheter on the correct line, especially if there is concern for anterior or posterior displacement of the catheter

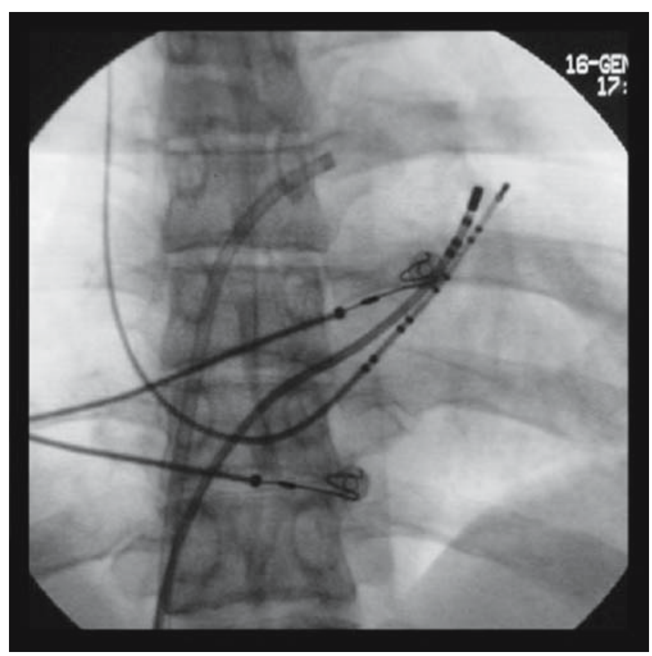


Figure 7.142 Once the isthmus lesion set on the endocardial side is completed, the ablation catheter is inserted within the coronary sinus (*CS*) to deliver lesions on the epicardial side. The catheter has its tip positioned between the CS bipoles 1–2 and 3–4 of the CS (1–2 at its distal end). The tip is bent slightly upward to be turned toward the CS atrial aspect. The long sheath has been left within the left atrium so as to keep access available

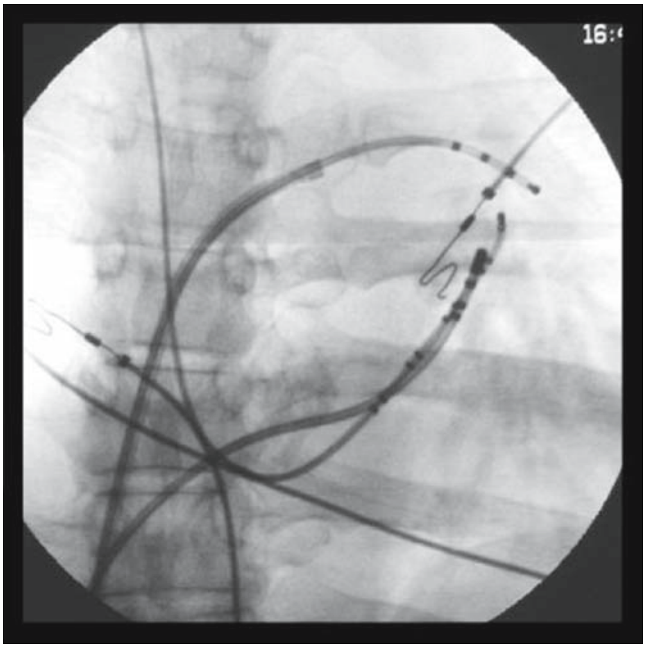


Figure 7.143 This image, similar to the previous one, shows positioning through the long sheath, of a diagnostic quadripolar catheter within the left atrial appendage. This is used to carry out the stimulation maneuvers that are used to verify, electrophysiologically, bidirectional isthmus block

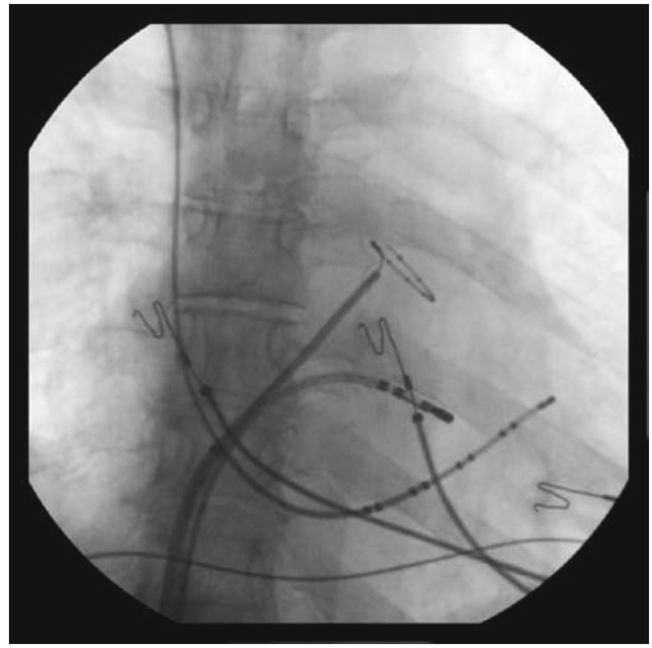


Figure 7.144 In this sequence of images, we show the creation of a left mitral isthmus linear lesion much longer than the previous one. In the postero-anterior (*PA*) projection, one can notice the longer distance between the coronary sinus course and the left inferior pulmonary vein (*LIPV*) ostium. Furthermore, in this case, the circular mapping catheter has been left at the level of the pulmonary vein (*PV*) ostium. The ablation catheter is not stabilized by the long sheath and its tip rests upon the mitral side of the left atrium, between CS 3–4 and 5–6 bipoles. Note how the catheter within the coronary sinus tends to bend in its most distal portion, as if entering a ventricular branch

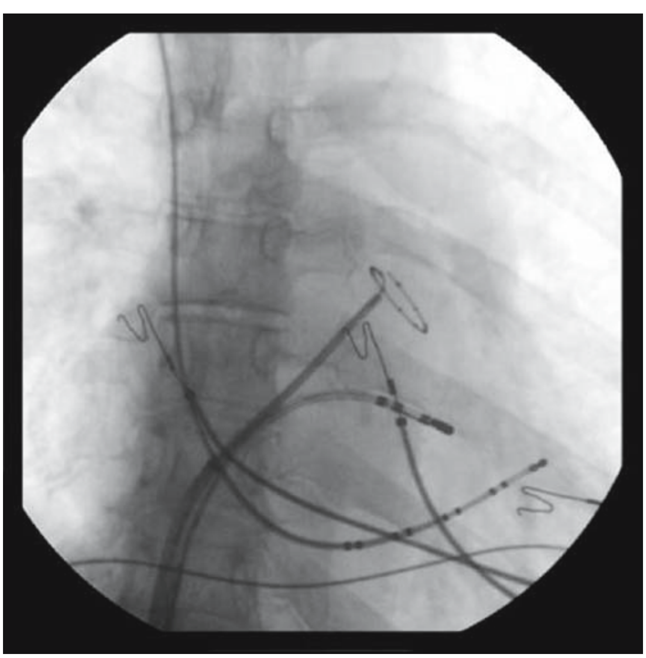


Figure 7.145 After having extended the ablation base with slight opening and closing movements of the curve, the catheter is rotated clockwise and its tip moves posteriorly

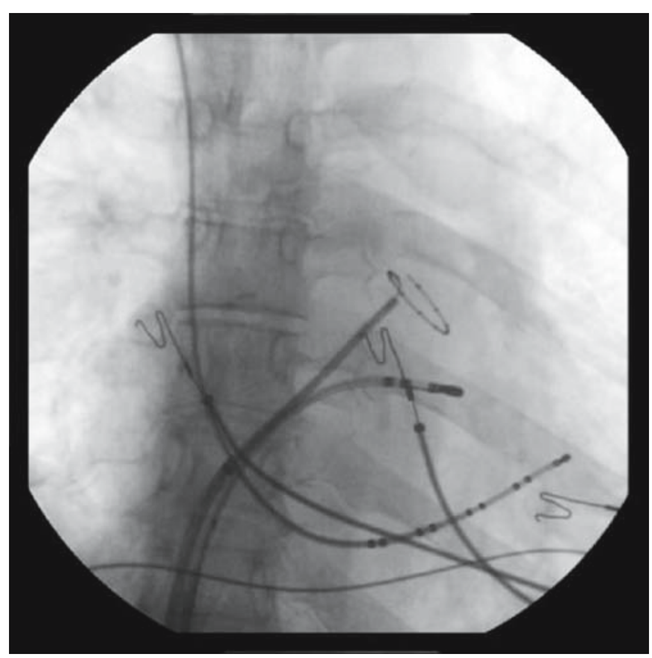


Figure 7.146 Without the aid of the long sheath stabilizing the ablation catheter, the torquing movement must be accompanied by a minimum withdrawal of the catheter and subsequent relaxing of the distal curve. These maneuvers aid in maintaining the catheter's tip in contact with the atrial wall during ablation

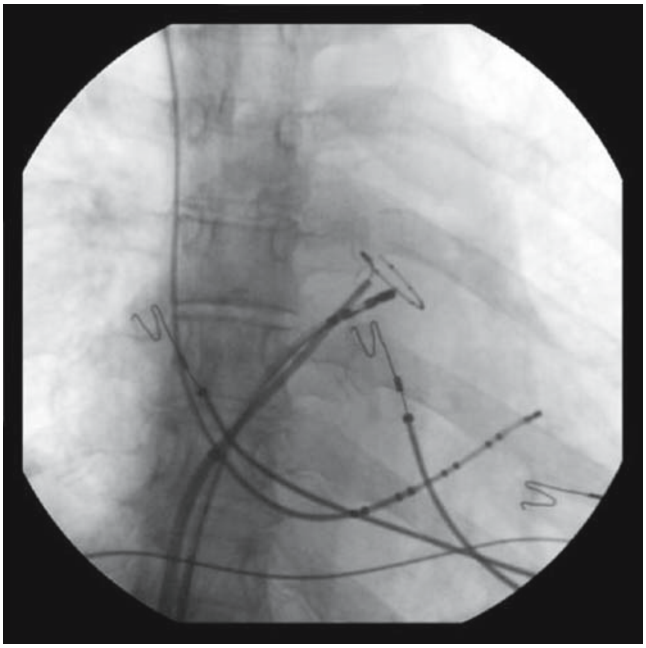


Figure 7.147 The line is completed at the level of the left inferior pulmonary vein (*LIPV*) ostium

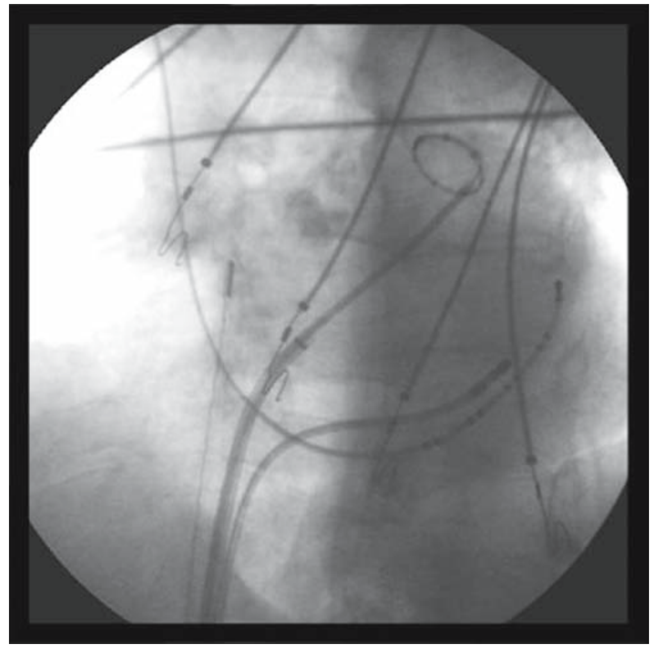


Figure 7.148 Further lesions are delivered at the level of the coronary sinus bipoles 3–4 and 5–6

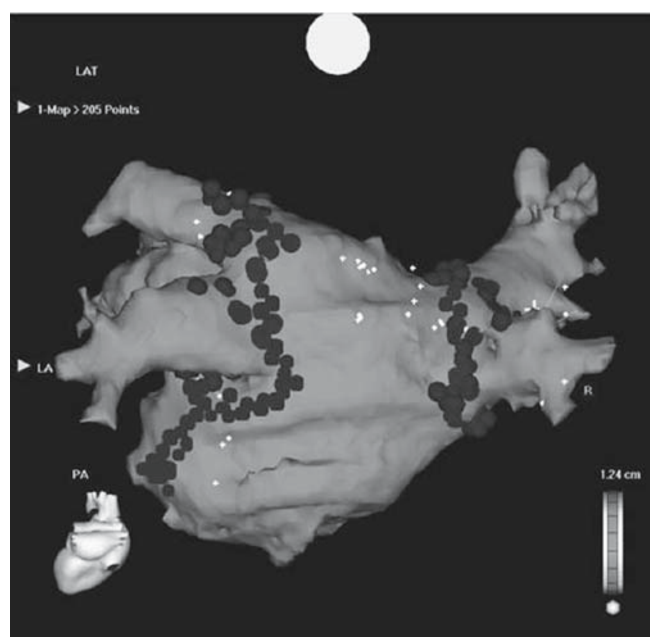


Figure 7.149 CARTOMerge map in the postero-anterior (*PA*) view. The lesion lines (black dots) are visible all around the pulmonary vein (*PV*) antra. A left mitral isthmus line has been added joining the left inferior pulmonary vein (*LIPV*) ostium to the mitral valve

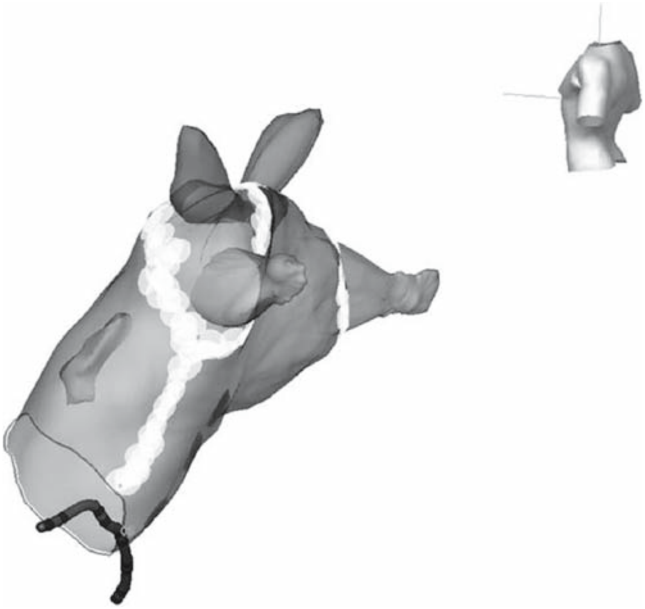


Figure 7.150 NavX-Verismo map of the left mitral isthmus lesion line (white dots) in the left lateral view

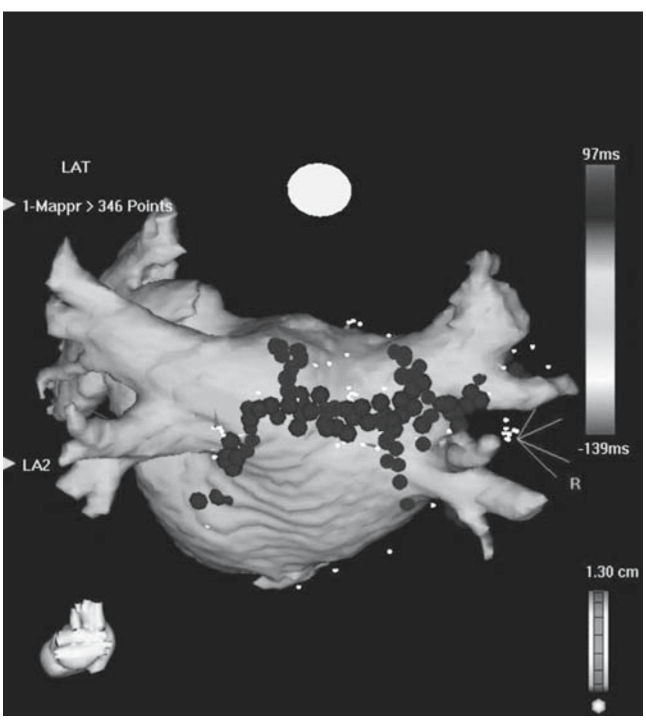


Figure 7.151 CARTOMerge map in the posteroanterior (*PA*) view, demonstrating the roof lesion line (black dots)

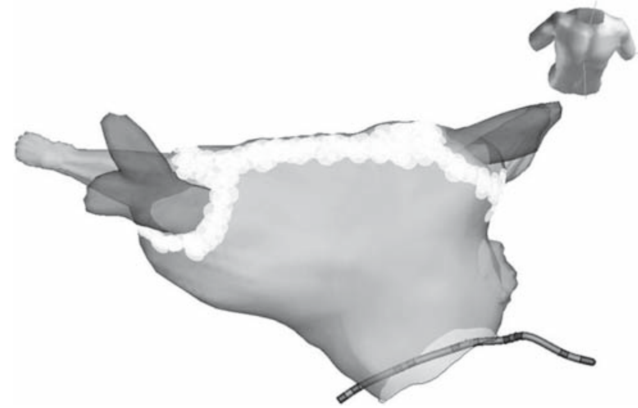


Figure 7.152 NavX-Verismo map in the cranial view showing the roof lesion line (white dots)

7.5 Superior Vena Cava Isolation

Atrial fibrillation ablation strategies may include the deployment of right atrial lesions. These include ablation of the inferior vena cava-tricuspid isthmus, ablation at the crista terminalis and the posterior right atrial wall, and ablation of the right atrial aspect of the septal wall. Ablation at the CS ostium and isolation of the SVC from the RA may also be performed.

With reference to SVC isolation, it has been noted that right atrial musculature often extends a short distance into the SVC where atrial potentials can be recorded. Arrhythmogenic foci may thus arise from the SVC. RSPV arrhythmogenic foci may be difficult to distinguish from such foci as the posterior wall of cavoatrial junction is in close anatomic proximity to the first portion of the RSPV (Figures 7.153–7.155). SVC isolation is best performed using a circular mapping catheter placed at cavoatrial junction; the same ablation catheter as used for PV isolation may be used.

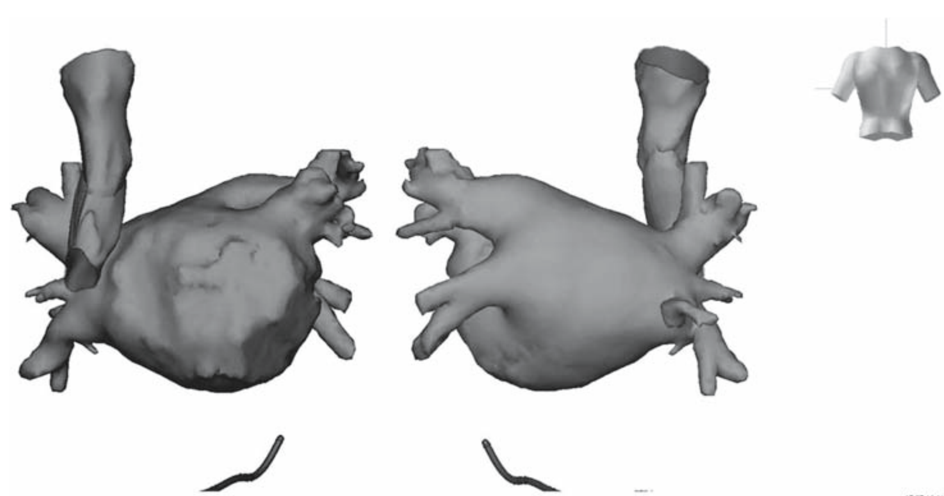


Figure 7.153 Left atrium (*LA*) NavX-Verismo map in the AP view, on the left, and in the right anterior oblique (RAO) view, on the right. In this map the superior vena cava (*SVC*) has been mapped and visualized. In this patient, the SVC course is in front of the common antrum of the right superior and right inferior pulmonary veins (*PVs*)

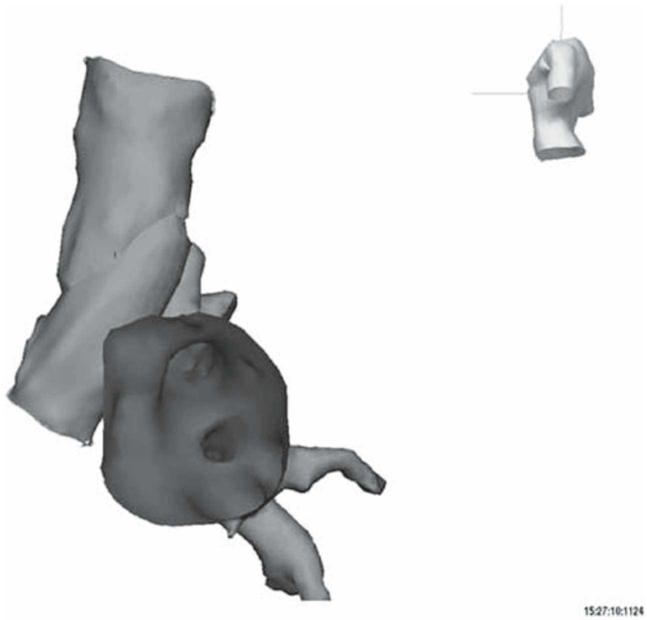


Figure 7.154 Right lateral cardioscopic view showing the right pulmonary veins (*PVs*) antrum

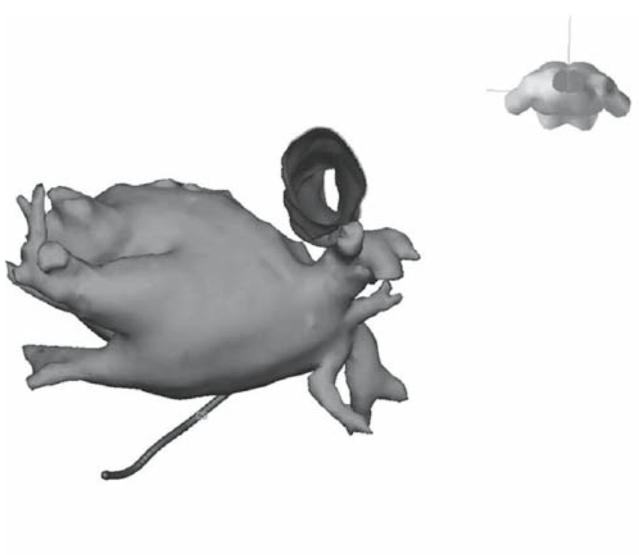


Figure 7.155 The cranial view allow to see the superior vena cava (*SVC*) course just in front of the right superior pulmonary vein (*RSPV*) antrum

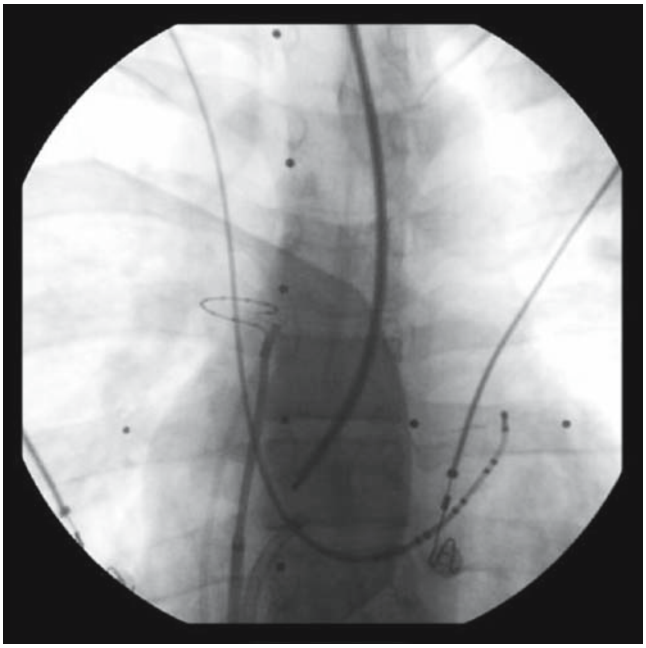


Figure 7.156 The circular mapping catheter is placed at the cavoatrial junction and the ablation catheter, placed at the same level, is directed toward the septal portion. With torsion movements the tip of ablation catheter can reach all the points along the junction circumference. The intracardiac echo is facing the cavoatrial junction. The postero-anterior (*PA*) view

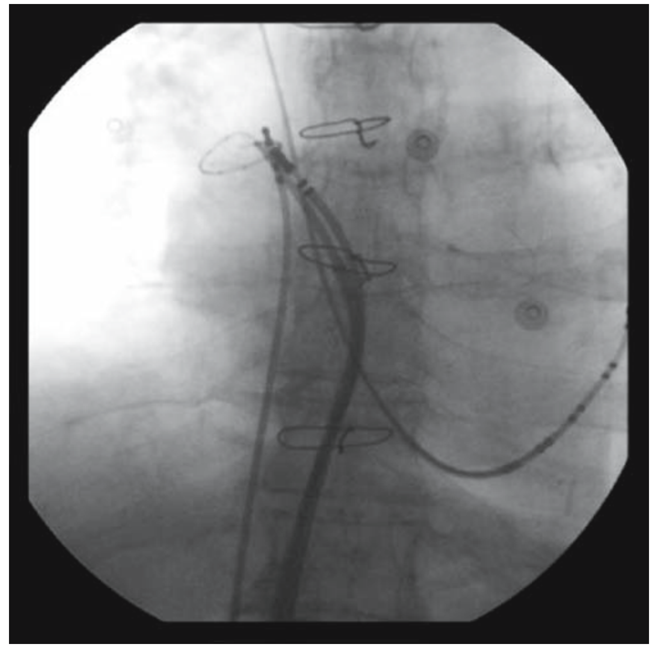


Figure 7.157 This image, in the right anterior oblique (*RAO*) view, shows the circular mapping catheter and the ablation catheter at the right superior pulmonary vein (*RSPV*) ostium; a quadripolar diagnostic catheter has been advanced at the cavoatrial junction to show the close proximity of these two structures in two-dimensional images

Through a long sheath within the RA, the circular mapping catheter, with no curvature, is pushed superiorly until it reaches the SVC. The catheter enters the SVC after clockwise rotation in the RA, thus avoiding the RA appendage. Adjusting movements of the circular catheter within the SVC must be always carried out by clockwise rotation so to prevent the distal end of the catheter from damaging the SVC wall. In addition, if a circular catheter with a variable loop is employed, it is convenient to reduce the diameter and before advancing the catheter into the SVC. Once in the SVC the loop will then be opened to its maximum diameter and then slightly withdrawn to be positioned securely at the cavoatrial junction. This maneuver is usually performed in the PA projection but RAO and LAO views may also be used (Figs. 7.156 and 7.157). The use of ICE is also of benefit in defining the level of the SVC–RA junction.

SVC isolation consists of delivery of RF lesions all around the cavoatrial junction. In the PA view, the ablation catheter is placed at the cavoatrial junction; with a small curvature, the tip comes in contact with the venous wall. Having defined the level at which ablation must be performed, the entire cavoatrial junction circumference is reached with clockwise and counterclockwise movements. The LAO view enables one to distinguish the septal wall from the lateral wall; the RAO view enables one to distinguish the anterior wall from the posterior wall.

Prior to performing SVC isolation, it is necessary to stimulate (via pacing from the distal electrodes on the ablation catheter) each potential ablation point prior to lesion delivery. This is performed to check for phrenic nerve stimulation, if observed ablation is precluded at these points. The right phrenic nerve descends almost vertically along the right antero-lateral surface of the SVC and it veers posteriorly toward the RA lateral wall as it approaches the cavoatrial junction. The right phrenic nerve is separated from the SCV and from the RSPV by variable amounts of fat and connective tissue. This protective cushion explains why ablating in these area will not endanger the nerve in the majority of patients, but in rare cases RF application at the cavoatrial junction or at the RSPV ostium may cause nerve injury and consequentially diaphragmatic paralysis. During delivery, it is also advisable to watch for diaphragmatic stimulation during the early phase of RF delivery. If observed, immediate cessation of RF delivery is mandated. It is also advisable to continuously observe normal diaphragmatic excursion during the deployment of lesions.

8

Ventricular Tachycardia Ablation

Ventricular tachycardias are complex arrhythmias; electrophysiologic mechanisms include increased automaticity, triggered activity, and reentry. Arrhythmogenic foci or reentry circuits can be found in both right and left ventricles; in each ventricle, foci may be in the septum, in the free wall, in the apex, or in the outflow tract. Moreover, foci or reentry can be endocardial, deeper within the myocardium, or even epicardial. This extreme variability can make one easily understand how each ventricular arrhythmia represents a unique case; therefore, it is difficult to be able to reduce to essentials the ablation procedures by means of radiographic images. In this chapter, we will only consider those ventricular tachycardias showing certain repetitiveness of more common exit points. In addition, conventional mapping procedures require the occurrence of arrhythmia and its hemodynamic tolerance for the entire time necessary to perform an accurate map. That is why ventricular tachycardias are more and more studied by employing nonconventional (electroanatomic or noncontact) mapping procedures. Such methods enable one to identify the ablation target in a more precise way compared with traditional methods.

Electroanatomic mapping procedures, employing either the CARTO system or the NavX system, require the ventricular geometry to be reconstructed by successive points. The ablation catheter tip contacts the ventricular myocardium and obtains electrophysiologic information about the local potential as well as anatomic information about the heart chamber. Such electroanatomic reconstruction must be carried out when cardiac rhythm is stable and, if possible, during ventricular tachycardia.

The electroanatomic map, if carried out during sinus rhythm, gives us information about substrate, that is to say, it distinguishes normal areas with well-represented potentials from ischemic regions with low potentials or scarred areas showing absence of recordable electric potentials. The electroanatomic map, if carried out during ventricular tachycardia, indicates the exit point or the critical circuit responsible for arrhythmia maintenance. Ablation guided by electroanatomic mapping system calls for interpretation of a map that lies outside the scope of this radioscopic atlas. Instead, we explain the noncontact mapping procedure as this system requires a special mapping catheter to be positioned.

8.1 EnSite Catheter Positioning

Noncontact mapping systems are based upon the use of a special 64 unipolar electrode (multielectrode) EnSite catheter which is able to map the interested cardiac chamber's endocardial surface without coming into contact with the cardiac tissue. The EnSite catheter is a 9 Fr catheter that, in its distal segment, carries an ellipsoidal balloon covered with a mesh of 64 electrically insulated filaments. Each filament is provided with a noninsulated segment working as a unipolar electrode and recording the endomyocardial surface electric potential compared with a reference electrode made of a metallic ring placed on the catheter body (Figure 8.1). The software, moreover, through inverse Laplace law, filters and amplifies the recorded signals, creating virtual signals reproducing the endocardial potentials that would be recorded should the catheter be placed into contact with the specific site.

Once the catheter has been positioned within the chosen chamber, one employs an ablation catheter to reconstruct the chamber geometry. The ablation catheter's spatial position acquisition system works very quickly, simply moving the catheter; besides there is no need of recording endocardial potentials by successive points. Once the chamber anatomy has been recorded, the EnSite catheter itself records virtual unipolar electrograms continuously. The electroanatomic map is acquired with just a single beat. That is why this system is preferred for ablation of extrasystoles, not sustained ventricular tachycardias or very fast ventricular tachycardias that are not hemodynamically tolerated. A single extrasystole or single beat of tachycardia enables one to get all the electrophysiologic information necessary to guide ablation.

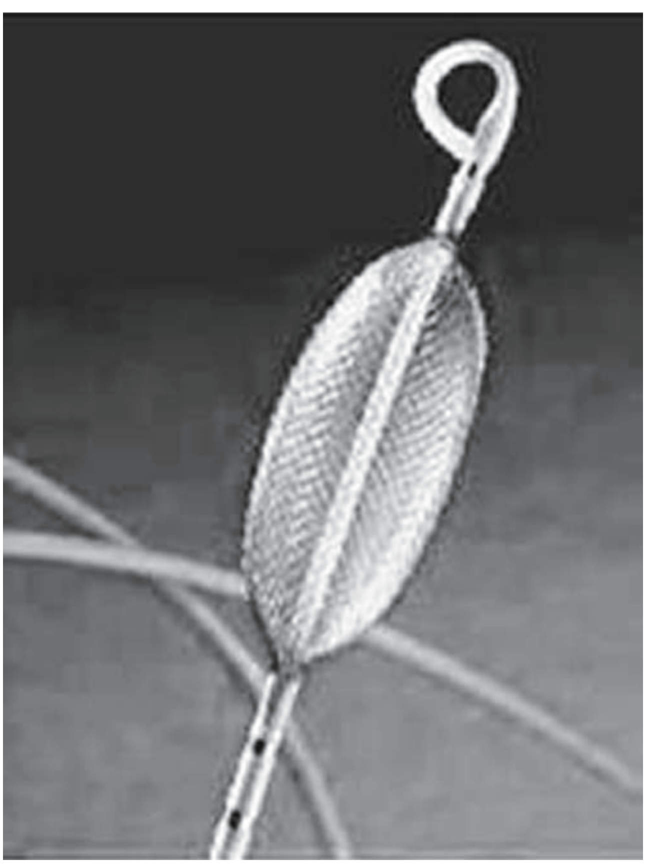


Figure 8.1 Distal portion of the EnSite catheter. At the distal catheter's end, there is a pigtail that allows a nontraumatic positioning of the catheter itself. For the positioning, one also employs a long guidewire that is inserted through the catheter. Next to the pigtail lies the balloon that is filled with a mixture of dye and physiological solution (volume 7.5 ml). Outside the balloon, there is a mesh made of 64 filaments. At the ends of the balloon, there are radiopaque electrodes, enabling easy visualization of the ends during positioning and acting as reference electrodes

Figure 8.2 Diagram of the EnSite catheter positioned within the ventricular right outflow tract. The catheter's balloon segment is thoroughly engaged into the outflow tract, while its pigtail distal portion is straightened by a guidewire that, inserted within a pulmonary artery branch, holds the catheter steady

Noncontact mapping systems can be employed either in supraventricular or in ventricular arrhythmias. However, for its specific peculiarities, it is best suited for use in ventricular tachycardias. Because of the potential thromboembolic risk connected with its use, the EnSite catheter use requires adequate heparinization, with an activation clotting time target of at least 300 ms in the right cardiac chambers, and an activation clotting time target of at least 350 ms in the left cardiac chambers.

In succession, we will show positioning of the EnSite catheter within the right ventricle (Figure 8.2), specifically into the right ventricular outflow tract, and within the left ventricle.

For right ventricle mapping, the EnSite catheter is inserted through the femoral vein. Usually, the left femoral vein is preferred so that, via that vein, only one single catheter is positioned. The use of a dedicated vein works in such a way that the catheter, once positioned, is less likely to be displaced while an adjacent catheter is moved.

Initially, a long (0.032″) guidewire with a J-like tip is advanced into the right ventricle and afterward it is positioned within either the left pulmonary artery or the right pulmonary artery. Guidewire positioning is carried out employing a pigtail angiographic catheter or a multipurpose catheter. Once the guidewire has been anchored within a pulmonary artery branch, the angiographic catheter is withdrawn, leaving the long guidewire in place. By means of an over-the-wire mechanism, the EnSite catheter is advanced as far as the right ventricle outflow tract. While advancing the EnSite catheter, it is necessary to slightly pull the guidewire back, to ease the catheter advancing.

The correct position is defined according to the balloon position, where the balloon is delimited at its two ends by two radiopaque rings. For right ventricular outflow tract tachycardias, the expandable portion should lie within the outflow tract, the distal radiopaque ring lying astride the pulmonary valve and the proximal radiopaque ring lying either at the outflow tract base or within the right ventricular cavity according to the size of the outflow tract itself. At this point, the EnSite catheter mesh is opened and, simultaneously, the catheter is slightly advanced to compensate for the balloon's expansion. Then one begins to slowly infuse the contrast material and physiological solution's mix under radioscopic guide until reaching the previously defined quantity while preparing the catheter. Should the catheter, once thoroughly inflated and filled with contrast material, obstruct outflow, it would be necessary to deflate it until an optimal size is reached. Now it is important to ensure the catheter's stability by fastening both the introducer and the catheter's proximal

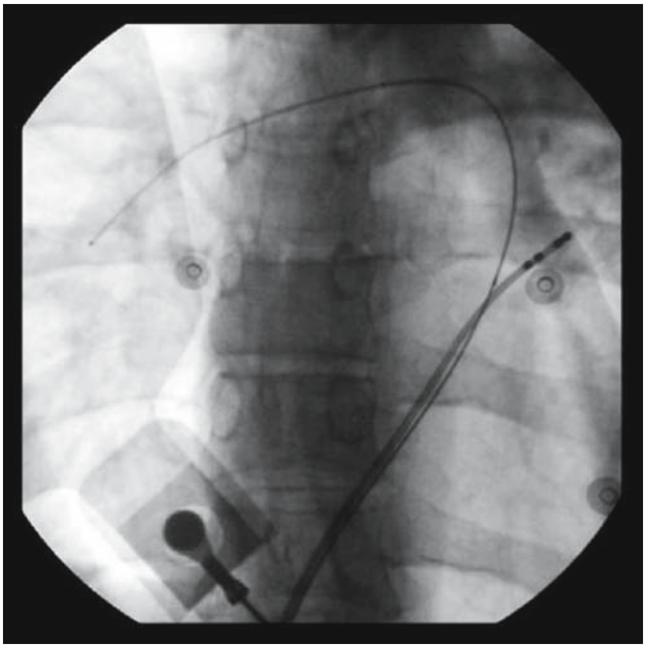


Figure 8.3 In the right anterior oblique (*RAO*) view, it is possible to see the long guidewire going through the pulmonary valve and then steadily anchoring, in this case, within the right pulmonary artery. Also, in this patient, an ablation catheter has been positioned into the right ventricular outflow tract in its anterior portion

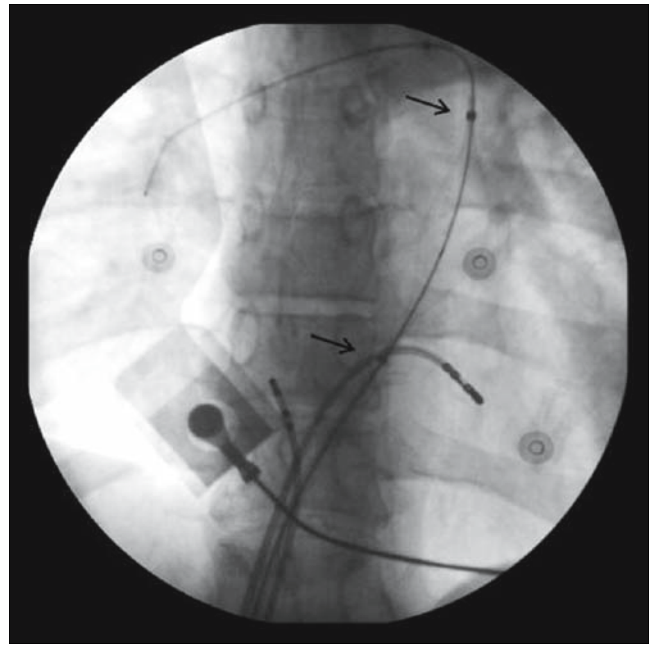


Figure 8.4 The EnSite catheter has been advanced along the guidewire. The two radiopaque rings can be found astride the pulmonary valve and at the base of outflow tract. The catheter mesh has already been opened. Please notice how the long guidewire is left in place even after the catheter has been positioned, adding stability throughout the whole procedure

portion. Moreover, it is useful to carry out radiographies of the catheter's position in right anterior oblique (RAO) and left anterior oblique (LAO) projections to be able to use them as reference, should one suspect displacement.

The sequence of EnSite catheter positioning is shown in the following images (Figures 8.3–8.9).

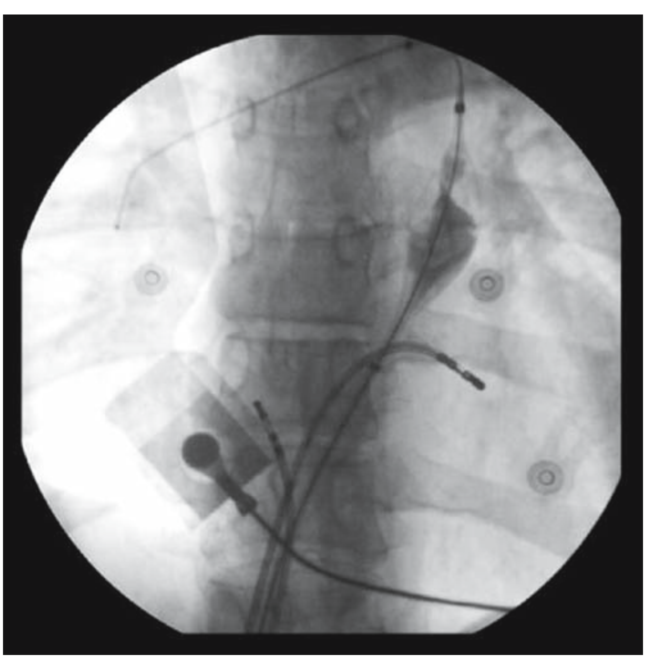


Figure 8.5 At this point, one begins to infuse dye within the catheter. The inside casing begins to inflate and fill with dye

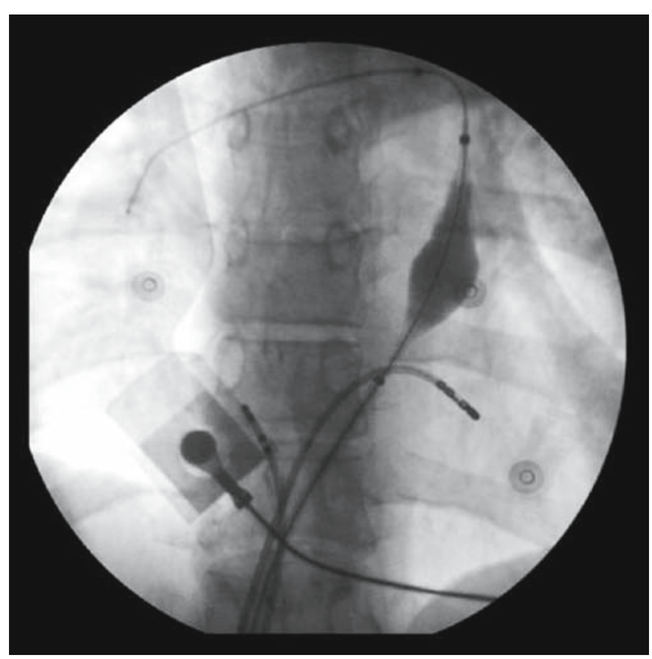


Figure 8.6 One keeps infusing dye within the catheter, which very slowly takes an ellipsoidal shape

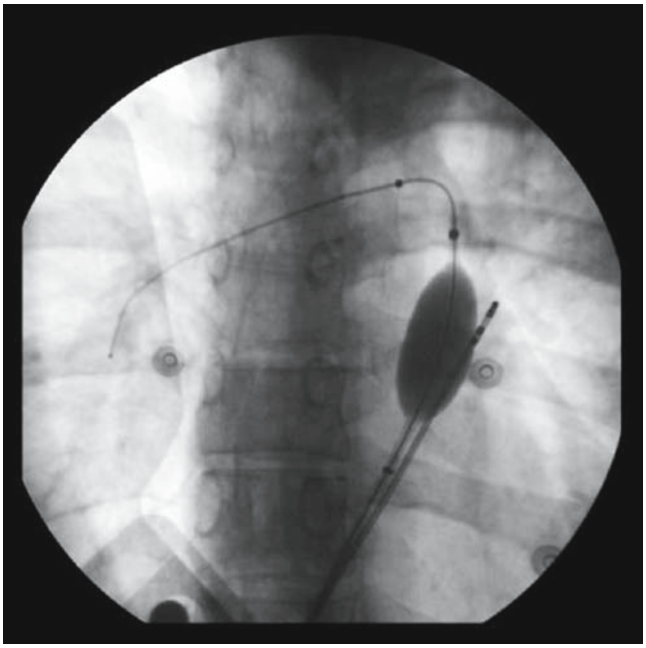


Figure 8.7 At this point, the EnSite catheter balloon is thoroughly filled and has taken its ellipsoidal shape. Thorough balloon expansion, however, does not allow the ablation catheter to travel within the outflow tract

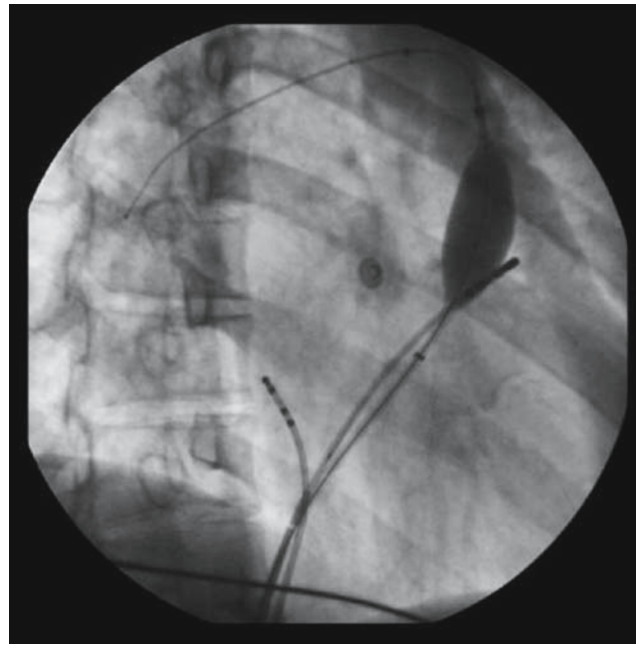


Figure 8.8 The balloon is slightly deflated by withdrawing a small quantity of contrast material. Outflow obstruction due to the EnSite catheter is thus reduced and the ablation catheter can easily move within the outflow tract

If the EnSite catheter position were not optimal or were not steady, one can start repositioning the catheter itself. In this case, it is necessary to thoroughly withdraw the dye and afterward close the mesh. While closing the mesh, one must slightly withdraw the catheter to compensate for its distal segment lengthening. After having positioned the catheter back, one repeats a new opening and fills the mesh.

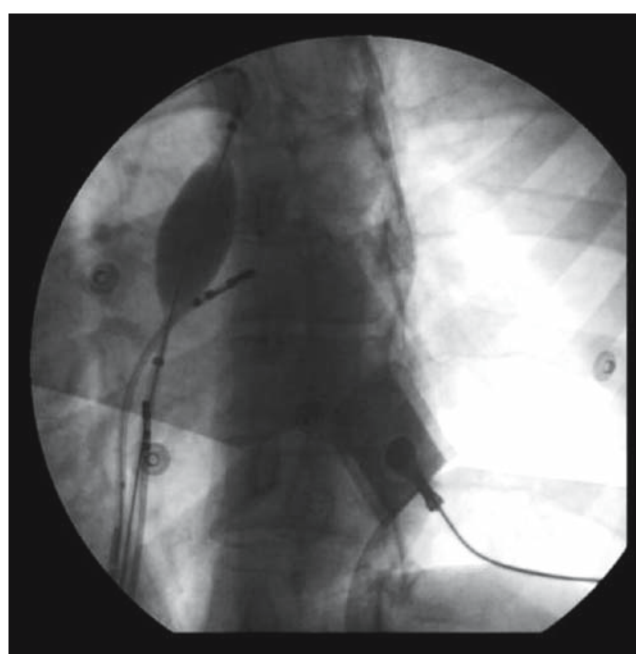


Figure 8.9 Once the optimal position has been reached with the EnSite catheter, fluoroscopy is carried out also in the contralateral oblique view, in this case in the left anterior oblique (*LAO*) view, to memorize the position from which right ventricle geometry recording begins

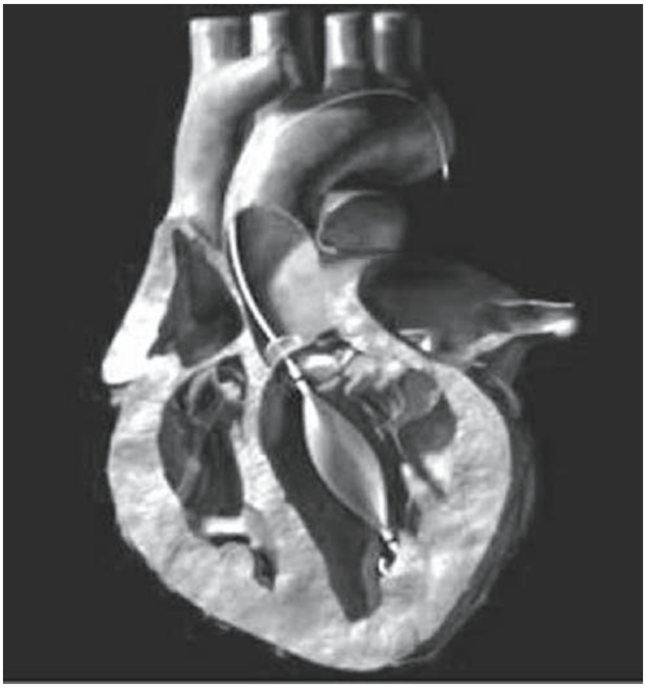


Figure 8.10 The EnSite catheter positioned onto the left ventricular apex via a retroaortic approach. The catheter's balloon segment is positioned within the ventricle; it is necessary to pay special attention so that the balloon does not engage the aortic valve. Please notice also how, unlike positioning within the right ventricular outflow tract, the long guidewire is withdrawn inside of the pigtail

For left ventricular tachycardias, the EnSite catheter is usually placed onto the ventricular apex (Figure 8.10). The ideal position preferably occurs via the retrograde arterial approach.

The EnSite catheter is inserted via the femoral artery approach. Usually, the left femoral artery is preferred, whereas the ablation catheter is inserted through the right femoral artery. As previously stated, use of a dedicated arterial approach works in such a way that the catheter, once positioned, does not risk being displaced while an adjacent catheter is moving.

Initially, a pigtail angiographic catheter carrying an inserted long guidewire with a J-like tip is advanced. It is possible to employ a 0.032″ guidewire as for the right ventricle or, if difficulty is found in going beyond the aortic valve, it is possible to employ a stiffer guidewire, 0.035″, which better supports an angiographic catheter. Usually one advances the angiographic catheter as far as the bulb of the aorta. At first, only the guidewire is passed through the valve plane. Then, having inserted the angiographic catheter into the left ventricle by sliding over the long guidewire, one tries, by fine push and pull movements between the guidewire and the catheter, to reach the left ventricle apex. It is necessary to pay special attention to avoid positioning the guidewire under mitral chordae tendineae. Once the guidewire is positioned into the ventricular apex, the angiographic catheter is withdrawn, leaving the long guidewire in place. By means of an over-the-wire mechanism, the EnSite catheter is advanced into the ventricular apex. While advancing the EnSite catheter, one must put traction on the guidewire to ease the catheter going forward and to prevent the guidewire from embedding within the myocardium. Unlike positioning within the right ventricle outflow tract, the guidewire is thoroughly withdrawn inside the catheter. The pigtail segment is left in contact with the myocardium to avoid any trauma. At this point, the EnSite catheter mesh is opened and, simultaneously, one slightly pushes the catheter forward to compensate for balloon expansion. Then one begins to slowly infuse the contrast material and physiological solution mix under fluoroscopy until reaching the previously fixed quantity when the catheter was prepared. If the catheter, once thoroughly expanded and filled up with dye, should obstruct the aortic valve, it is necessary to deflate it and position it again

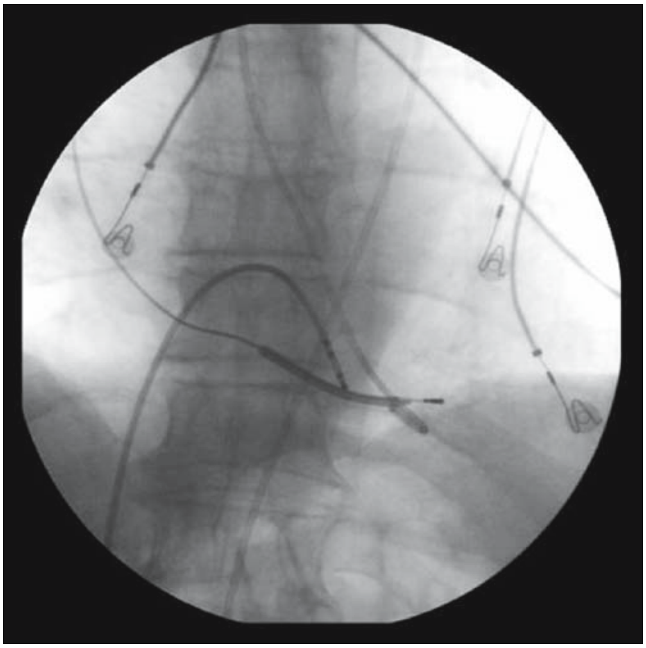


Figure 8.11 In the left anterior oblique (*LAO*) view, a pigtail angiographic catheter has been positioned at the left ventricular apex. In this patient, one can also see within the right ventricle, a quadripolar diagnostic catheter and a defibrillator lead

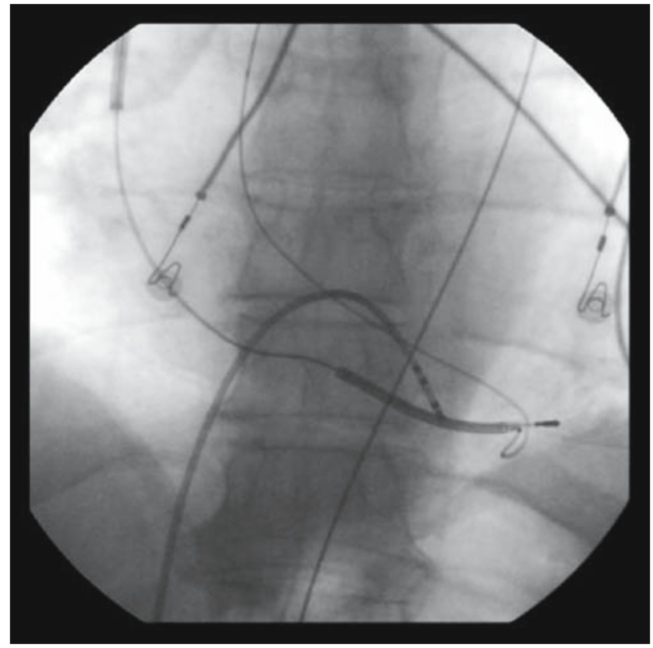


Figure 8.12 The long guidewire is left in place, while the angiographic catheter is removed

more distally. Now it is important to ensure catheter stability by fastening the introducer as well as the catheter's proximal section; besides, it is useful to carry out radiographies of the catheter position in both RAO and LAO projections so as to employ them as reference, should one suspect catheter displacement.

In the following images, the catheter positioning in the left ventricle is shown (Figures 8.11–8.17).

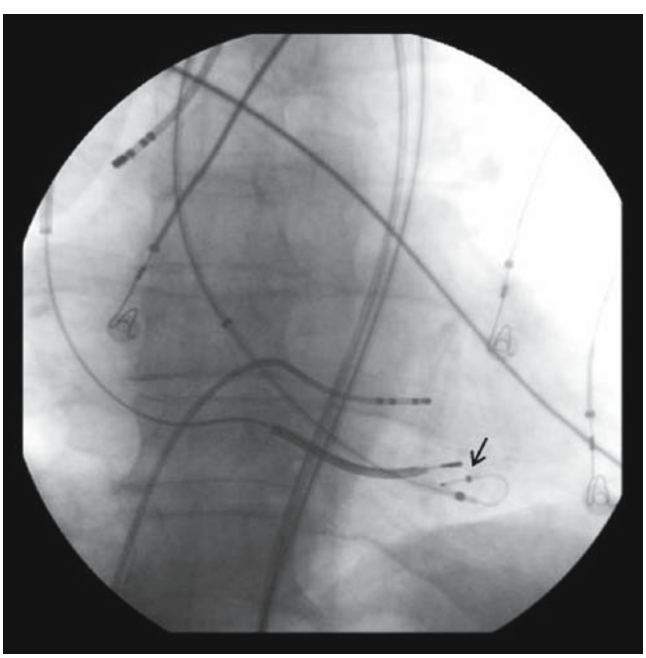


Figure 8.13 The EnSite catheter is advanced as far as the left ventricular apex. The long guidewire is barely protruding out of the catheter tip. The pigtail portion is pointed out by a small radiopaque ring (arrow)

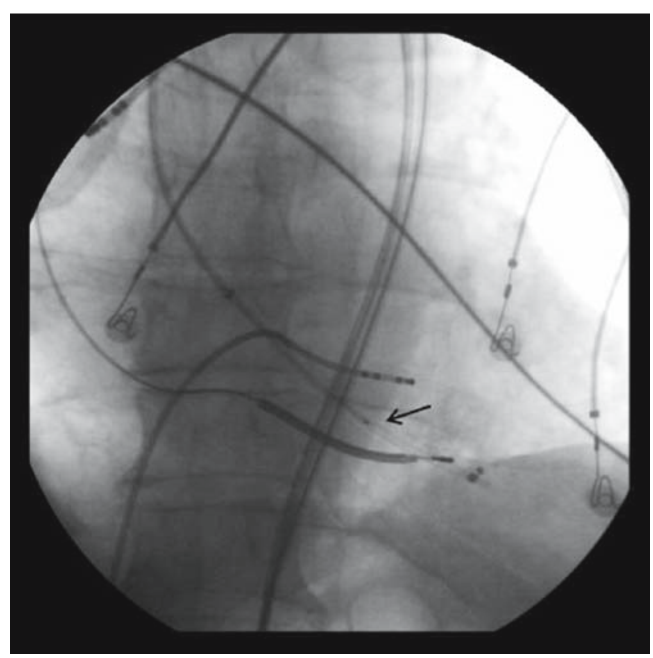


Figure 8.14 The guidewire is pulled back through the catheter body (arrow). The guidewire is not thoroughly removed as it is necessary to stabilize the catheter

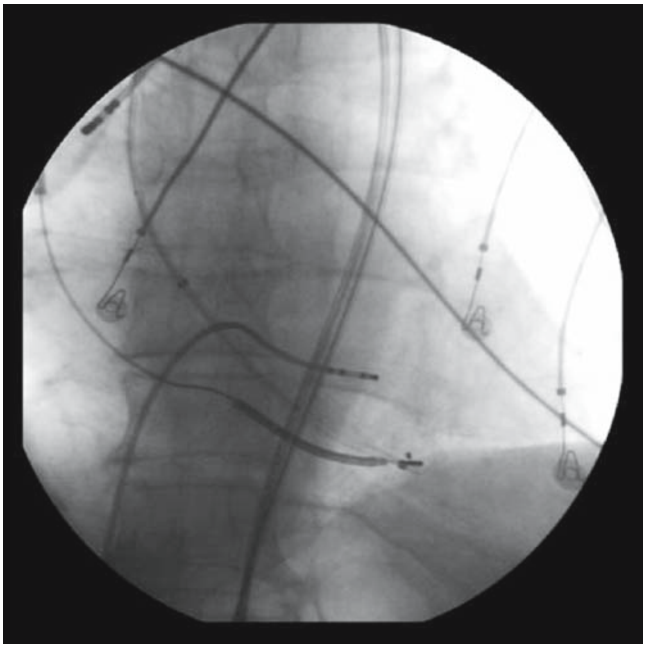


Figure 8.15 One begins to open the mesh and, simultaneously, carefully advance the catheter to compensate catheter tip withdrawal

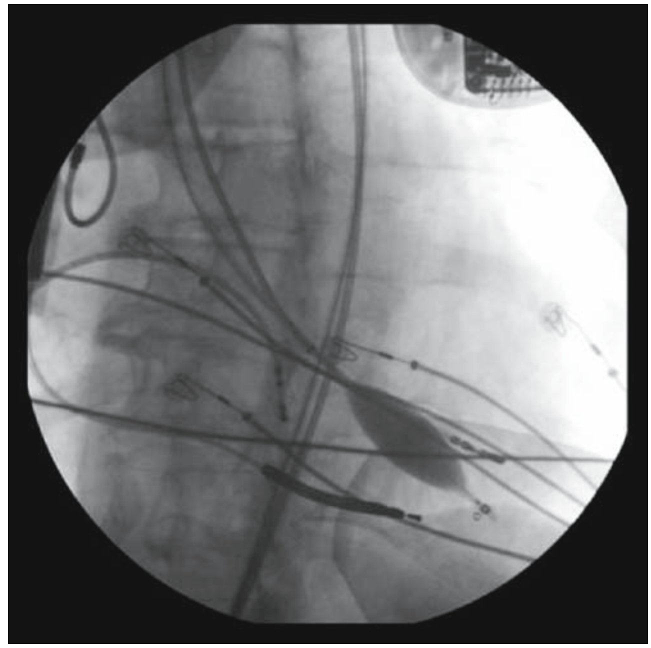


Figure 8.16 The EnSite catheter position, in the posteroanterior (*PA*) view, after having opened the mesh and filled the balloon

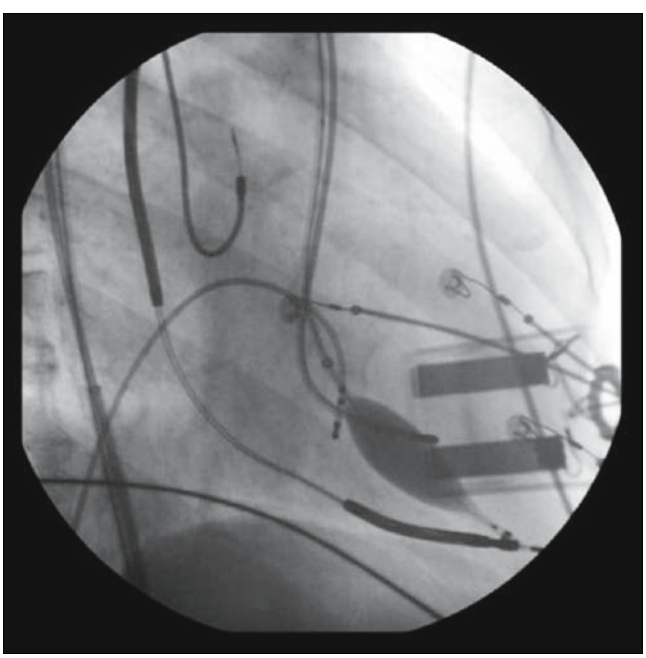


Figure 8.17 The EnSite catheter position in the right anterior oblique (*RAO*) view

8.2 Bundle Branch Reentrant Ventricular Tachycardia

Bundle branch reentrant ventricular tachycardia is an uncommon kind of ventricular tachycardia. It is most often found in patients with left ventricular dilation, prolonged atrioventricular (infrahisian) conduction, and complete or incomplete left bundle branch block.

Underlying this tachycardia, there is a reentry circuit using regular conduction pathways. Usually the right bundle branch is utilized anterograde and the left bundle branch is used retrograde. Rarer are cases with anterograde conduction along the left bundle branch and retrograde conduction along the right bundle branch.

In both cases, the ablation target is the right bundle branch. The right bundle branch is preferred to the left bundle branch as it lies in the right heart, it runs on the endocardial surface, and, ultimately, because it is made of one single bundle for almost its whole length. The left bundle branch would call for a left approach and higher technical difficulties connected with a deeper running and subdivision into two fascicules (Figure 8.18).

Right bundle branch ablation is usually carried out employing a middle curve deflectable catheter with a 4-mm tip. The catheter is positioned, in the RAO view, next to the His region where the widest potential is recorded. Still in the RAO view, one slowly advances the catheter forward along the interventricular septum's superior portion. Employing gradual adjustments of the curvature, a right branch potential is recorded. Slightly rotating clockwise is useful for keeping good contact with the interventricular septum (Figure 8.19).

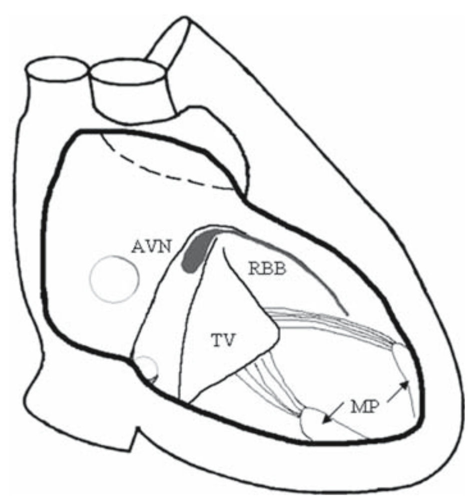


Figure 8.18 The heart seen laterally and opened so that one can see the atrium and the right ventricle septal surface. The atrioventricular node (*AVN*) continues into the His bundle which, afterward, splits into two branches: the right bundle branch and the left bundle branch. The right bundle branch (*RBB*) runs along the interventricular septum as one endocardial bundle, then it emerges at the base of the medial papillay muscle that inserts in the superior portion of the interventricular septum. From there, the RBB descends down the body of the septomarginal trabeculation and divides into the fibres of Purkinje that extend to the apex and are also carried across the ventricular cavity throught the moderator band and other muscular bundle. In this view, we cannot see the left bundle branch because it penetrates the myocardium at the membranous septum to reach the left side of the interventricular septum. *TV* tricuspid valve, *MP* musculi papillares

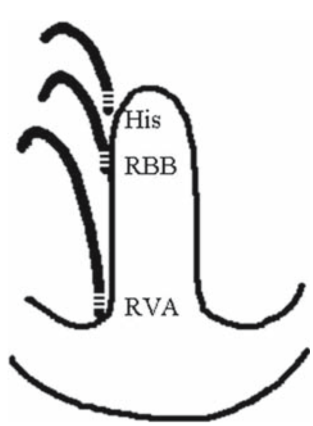


Figure 8.19 The interventricular septum in a perpendicular cross-section. In this image, one can see three catheters positioned on the right side of the septum, which record, starting from top: His bundle, the right bundle branch (*RBB*), and the apex of the right ventricle (*RVA*)

When right bundle branch ablation is carried out, it is always advisable to position a diagnostic electrocatheter in the right ventricular apex. Such a catheter might be useful in two rather frequent occurrences: in carrying out ventricular pacing to locate the right branch when, in sinus rhythm, its recording becomes difficult, and also when backup ventricular pacing is required. Right bundle branch ablation causes ventricular activation through the left branch which can have impaired conductive powers necessitating, at the procedure's end, a permanent pacemaker.

8.3 Right Ventricular Outflow Tract Tachycardia

Idiopathic right ventricular outflow tract tachycardias constitute a benign form of ventricular tachycardia due to focal triggered activity. Arrhythmogenic foci lie, as the name implies, in the right ventricular outflow tract (Figures 8.20 and 8.21). Diagnosis of idiopathic right ventricular outflow tract tachycardia is made by "elimination." One must always exclude arrhythmogenic right ventricular dysplasia or a cardiomyopathy that, initially, might mimic an idiopathic form.

For this procedure, two catheters are usually employed: a fixed curve quadripolar catheter in the right ventricular apex and one middle curve deflectable ablation catheter with a 4-mm tip. It is a venous approach. The ablation catheter is advanced into the right atrium through the inferior vena cava. The maneuver for positioning within the ventricle, as is done for the diagnostic catheter, is carried out in the RAO view. The catheter must be bent so to make a Josephson-like curvature and then it is advanced through the tricuspid ring in its middle portion. When the catheter tip lies on the superior basal portion of the interventricular septum, it is necessary to simultaneously rotate clockwise and advance to make the catheter slide into the outflow tract.

Figure 8.20 Sites from which right ventricular outflow tract tachycardia originates. These kinds of tachycardia mainly originate within the anterior wall or at the base of the outflow tract. Activation site naturally has an effect upon the QRS morphology, during tachycardia

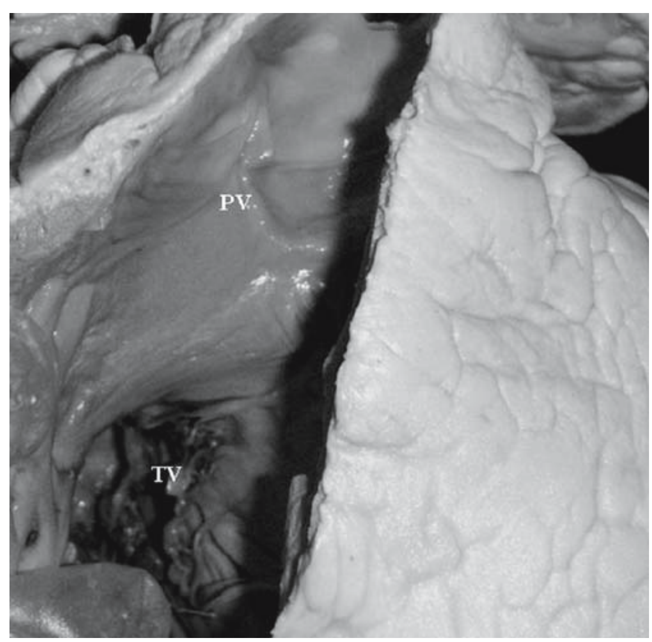


Figure 8.21 In this anatomic image, the right ventricular outflow tract's posterior portion is shown. One can see how the tricuspid valve (*TV*) and the pulmonary valve (*PV*) lie in two perpendicular planes. This wall may be divided into sinus and vestibular portions. The sinus portion forms a hook over the tricuspid valve and faces superiorly. The infundibular portion faces posteriorly and, with the adjoing pulmonary valve's ostium and sinuses, is in contact with the right aortic sinus. Very often right ventricular outflow tract tachycardias originate from the outflow tract base. Since the angle between the tricuspid and the outflow tract is acute, it might be often difficult to keep the catheter steady in that area

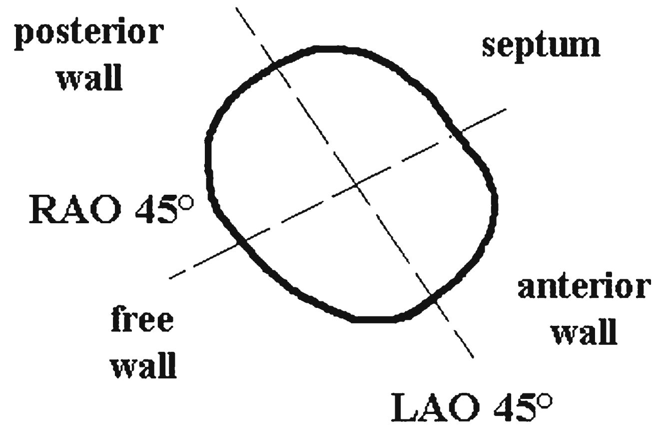


Figure 8.22 Right ventricular outflow tract seen from above with references to standard views. In the right anterior oblique (*RAO*) 45° view, we will be able to distinguish the posterior wall from the anterior one, whereas in the left anterior oblique (*LAO*) 45° view, one can clearly distinguish the anterior portion from the posterior portion

Outflow tract mapping is carried out starting from the pulmonary vein as far as the base along all of the four infundibulum's walls. Employed views are either the RAO view, enabling one to distinguish the anterior wall from the posterior one, or the LAO view, showing septal and lateral sides (Figure 8.22).

In the RAO view, by thoroughly opening the catheter curvature, its tip will move anteriorly. By bending the catheter, its tip will turn posteriorly (Figures 8.23 and 8.24).

In the LAO view, by rotating the catheter clockwise, its tip will adhere to the septum, by rotating counterclockwise, its tip will move toward the free wall (Figures 8.25 and 8.26).

Combined opening movements of catheter's curvature with clockwise rotating will enable mapping of the anteroseptal region. By rotating counterclockwise, one can map the

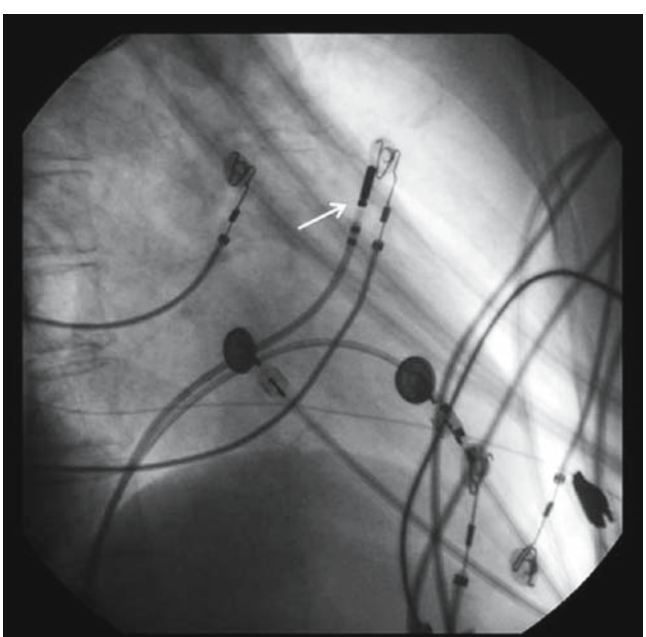


Figure 8.23 The right anterior oblique (*RAO*) view of the ablation catheter within the right ventricular outflow tract. The white arrow shows the curve's opening movement allowing it to reach the pulmonary infundibulum's anterior wall

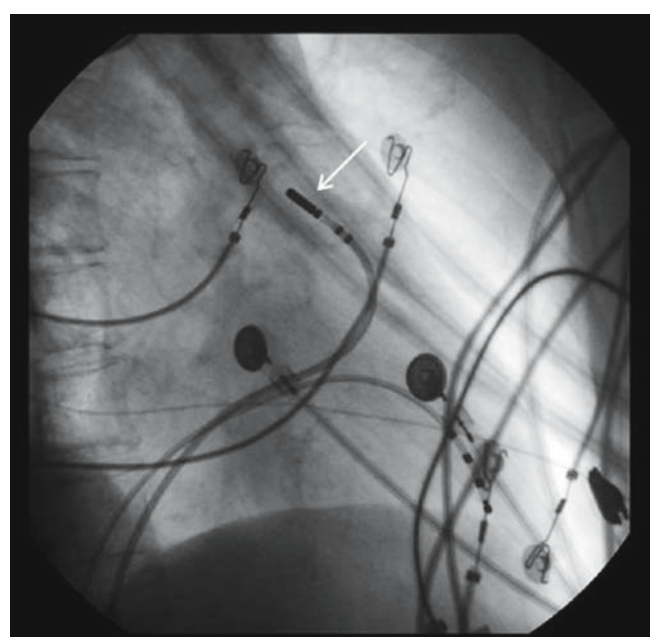


Figure 8.24 The right anterior oblique (*RAO*) view of the ablation catheter within the right ventricular outflow tract. In this case, the white arrow shows the curve's closing movement allowing it to reach the pulmonary infundibulum's posterior wall

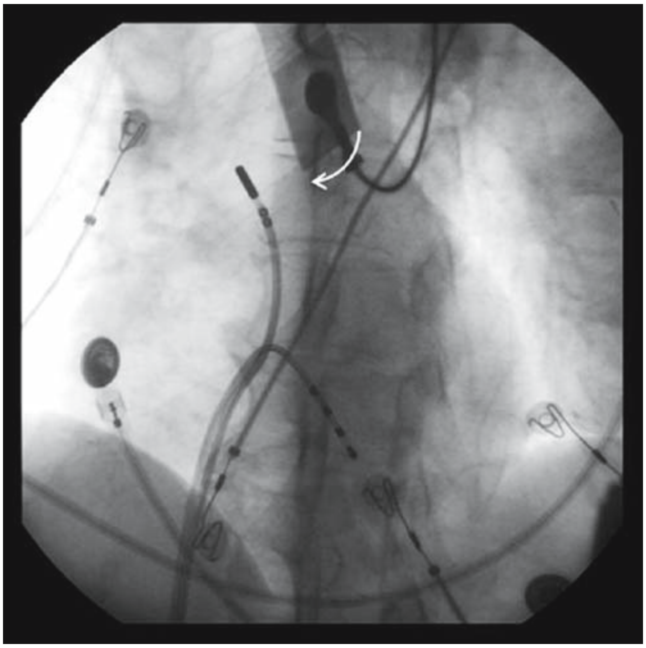


Figure 8.25 The left anterior oblique (*LAO*) view of the ablation catheter within the right ventricular outflow tract. The white arrow shows counterclockwise rotation allowing it to reach the pulmonary infundibulum's lateral wall

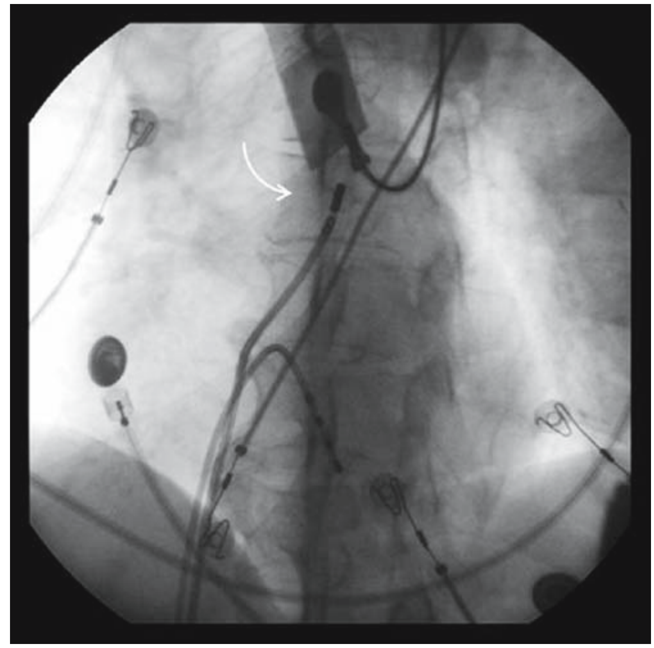


Figure 8.26 The left anterior oblique (*LAO*) view of the ablation catheter within the right ventricular outflow tract. In this case, the white arrow shows the catheter's clockwise rotation to reach the outflow tract's septal portion

anterolateral region. Bending the catheter by rotating it clockwise will move its tip toward the posteroseptal region, whereas a counterclockwise rotating will enable mapping of the posterolateral area.

8.4 Left Ventricular Outflow Tract Tachycardias

Left ventricular outflow tract tachycardias constitute a rare kind of idiopathic tachycardia. Although this kind of tachycardia is distinguished from tachycardia originating within the right ventricular outflow tract owing to a well-represented R wave in V1 and V2, at times, differentiation resting only upon electrocardiographic criteria is unreliable. Frequently, tachycardias with a QRS morphology suggesting an exit point from the right ventricular outflow tract (right bundle branch block, inferior axis, QS complexes in V1 and V2), originate, instead, from the left ventricle.

Very often it is necessary to carry out an accurate mapping of both the right and the left ventricular outflow tracts to locate the arrhythmogenic focus. Superimposition of some electrocardiograghic peculiarities for these two kinds of tachycardia depends on close anatomic contiguity of the two ventricular outflow tracts.

Anatomically, the two ventricular outflow tracts are adjacent in their septal portions, though developing on different planes. The left ventricular outflow tract includes a septal section bordering the right ventriculars outflow tract's septal portion, an anterior wall next to the right ventricular outflow tract's posterior portion, and a lateral free wall. The bulb of the aorta rests in the central and upper position with regard to the interventricular septum. The right and left sinuses of Valsalva continue the left ventricular outflow tract's muscular wall: the right sinus of Valsalva rests upon the interventricular septum, whereas the left sinus of Valsalva rests upon the outflow tract's anterolateral wall. The posterior sinus of Valsalva, instead, extends toward the mitral insertion. The right ventricular outflow tract lies anteriorly with respect to the left ventricular outflow tract and its terminal section rises above the aortic valve plane. Consequently, between the terminal sections of right and left ventricular outflow tracts a pericardial space is left free. The aortic valve, besides being located in a posterior position with regard to the pulmonary valve, lies also caudally (Figures 8.27 and 8.28).

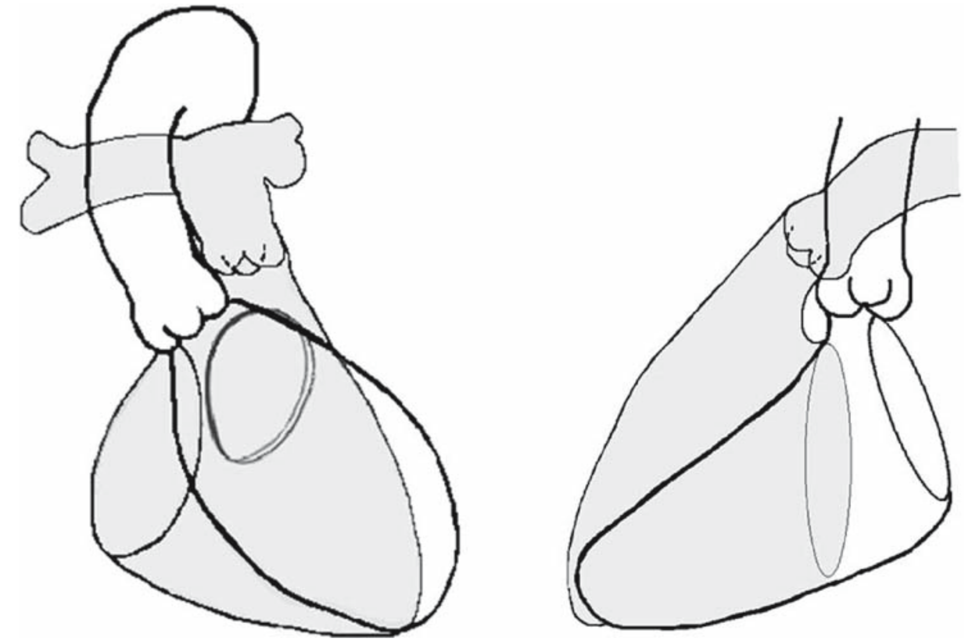


Figure 8.27 The posteroanterior (*PA*) view of the superimposed right and left heart (atria have been removed). The right ventricle and the pulmonary artery are light grey colored, whereas the left ventricle and the aorta are white with thick borders. Left lateral view of the superimposed right and left heart (atria have been removed). In the image, the same coloring criteria are used to distinguish right sections from left sections

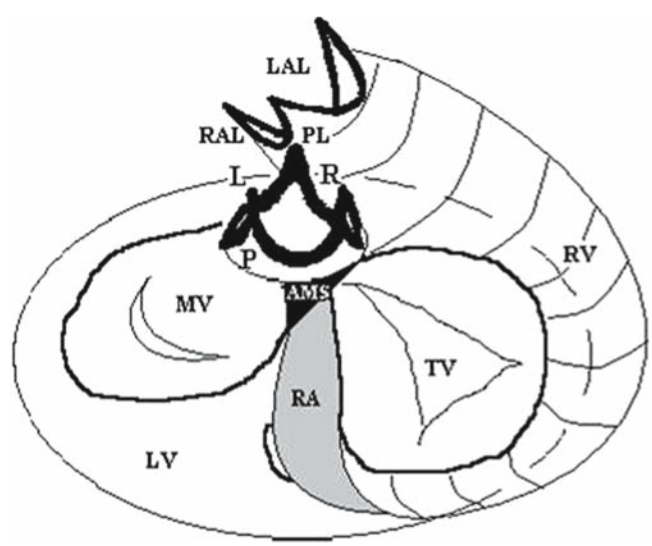


Figure 8.28 The aortoventricular unit after the removal of the atria and of the aortic and pulmonary artery walls. The image is viewed from 240°. In the middle of the image, the aortic valve with its three Valsava sinuses (posterior, left, and right) is represented. Above the aortic valve, the pulmonary valve with its three sinuses (posterior, left anterior, and right anterior) is shown. In this diagram, it is evident that the posterolateral wall of the right ventricle and the adjoining pulmonary ostium and sinuses are in contact with the right aortic sinus and left anterior fibrous trigone. Between these structures, dense connective tissue is present. The black triangle represents the atrioventricular membranous septum and indicates the location of the atrioventricular node with the first portion of penetrating His bundle. The inferior wall of the right atrium lies above the posterosuperior process of the left ventricle. The area of apposition of the right atrium on the left ventricle is shown by the light grey color. *LV* left ventricle, *RV* right ventricle, *RA* right atrium, *TV* tricuspid valve, *MV* mitral valve, *P* posterior sinus of aortic valve, *L* left sinus of aortic valve, *R* right sinus of aortic valve, *PL* posterior leaflet of pulmonary valve, *RAL* right anterior leaflet of pulmonary valve, *LAL* left anterior leaflet of pulmonary valve, *AMS* atrial membranous septum

The origin sites of left ventricular outflow tract tachycardia can be left and right aortic coronary cusps, subvalvular outflow tract, or, anteriorly, any site along coronary veins' course, namely, the anterior cardiac vein. Each of these localizations requires adequate mapping. It is often necessary to position, via the coronary sinus, microcatheters (2.5–3.5 Fr multielectrode catheters, with 8 or 16 electrodes) within cardiac veins. The ablation catheter, usually inserted via the transaortic approach, carries out mapping of both the aortic cusps and the outflow tract. If an ectopic focus is located on a valvular or subvalvular site, it is always suitable to carry out coronary angiography to verify how close coronary ostia are to the site where ablation should be carried out. At this point, it is useful to recall that all procedures carried out within the left cardiac cavities require an effective anticoagulative treatment for the patient, to minimize thromboembolic risk.

In the following figures, some examples of left ventricular tachycardia originating from the outflow tract are shown (Figures 8.29–8.41).

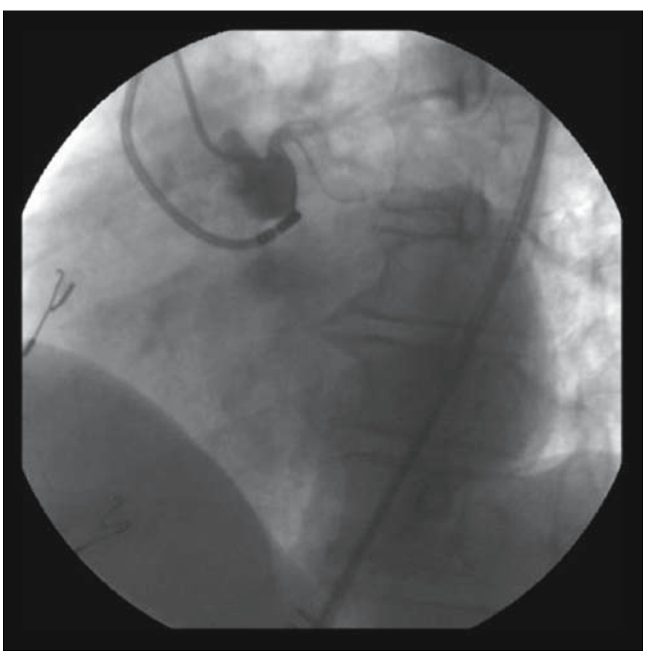


Figure 8.29 In the left anterior oblique (*LAO*) view, one can see the ablation catheter positioned at the left coronary cusp, which is made visible by means of dye injection through the angiographic catheter

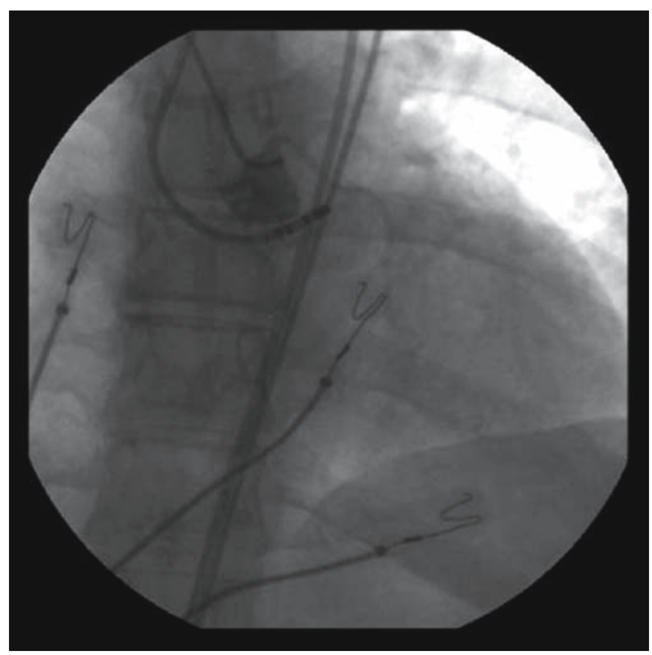


Figure 8.30 In the left anterior oblique (*LAO*) view, one can see the ablation catheter positioned in the aortic subvalvular region, right under the left coronary cusp

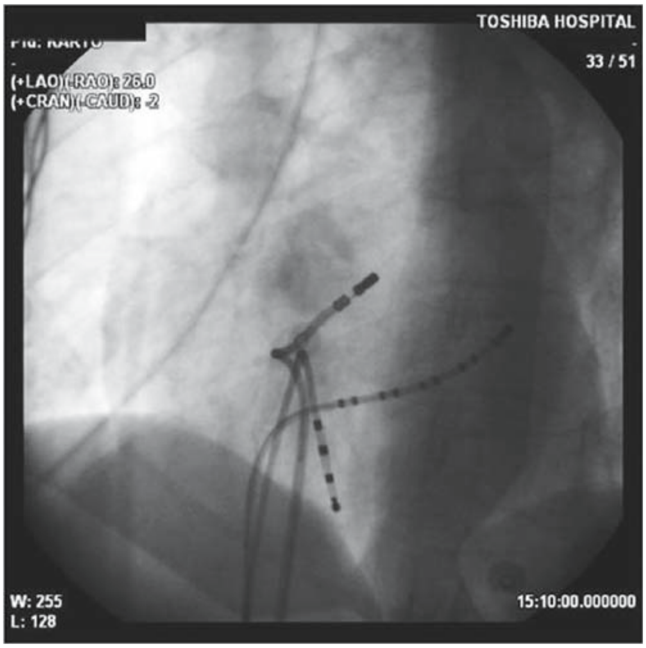


Figure 8.31 The left anterior oblique (*LAO*) view of the set of instruments for a patient with electrocardiographic evidence of left ventricular outflow tract tachycardia. One can see the diagnostic catheters within the right ventricle apex and the coronary sinus, respectively. The ablation catheter is positioned on the right ventricular outflow tract's septal portion to exclude that the arrhythmia originates from the right ventricle

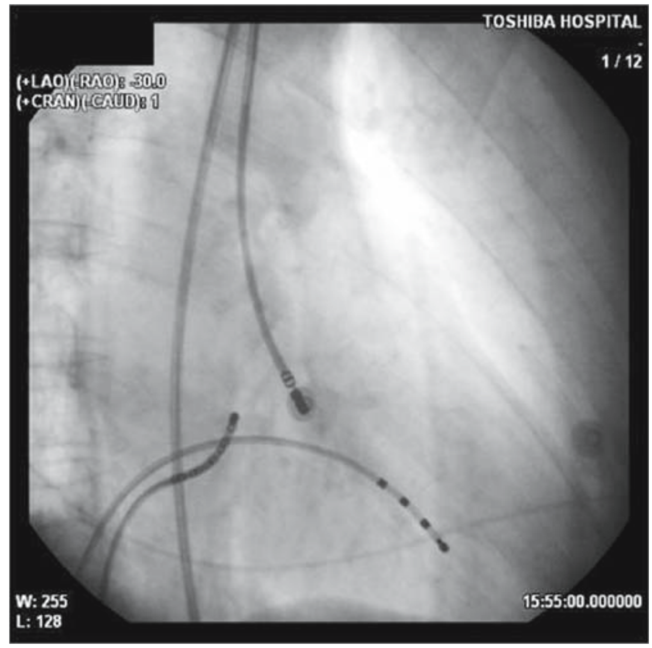


Figure 8.32 In the same patient, the ablation catheter has been positioned, via retroaortic approach, into the left ventricle and then has been pulled back right under aortic valvular plane. The right anterior oblique (*RAO*) view

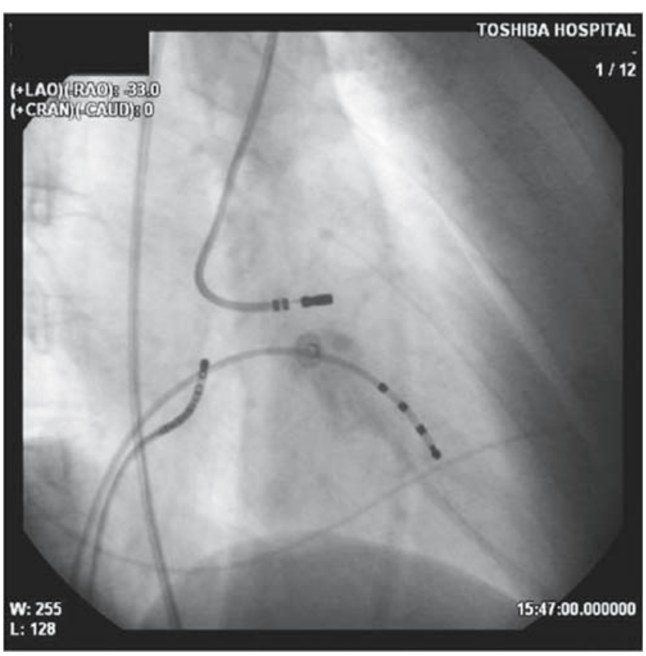


Figure 8.33 Still in the right anterior oblique (*RAO*) view, one can slightly bend the catheter so that its tip comes into contact with the outflow tract's anterior portion

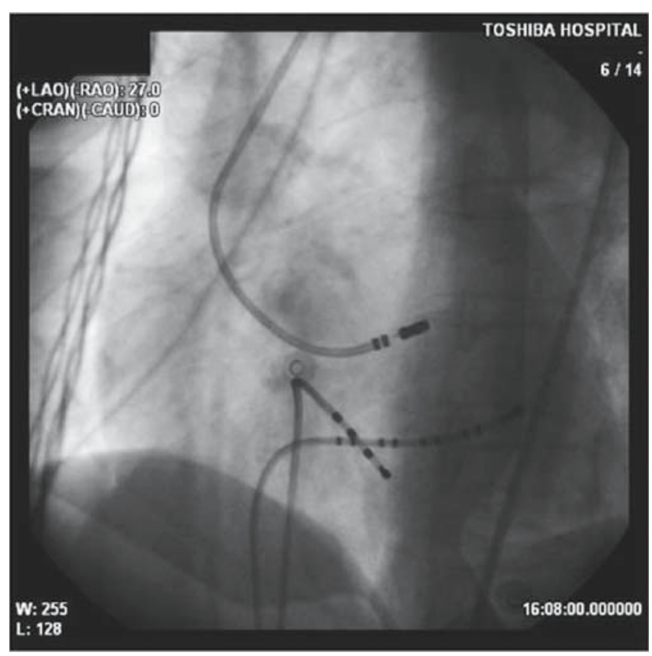


Figure 8.34 In the left anterior oblique (*LAO*) view, one can make visible movements toward the outflow tract's lateral portion; to lateralize the catheter, it is necessary to slightly rotate it counterclockwise

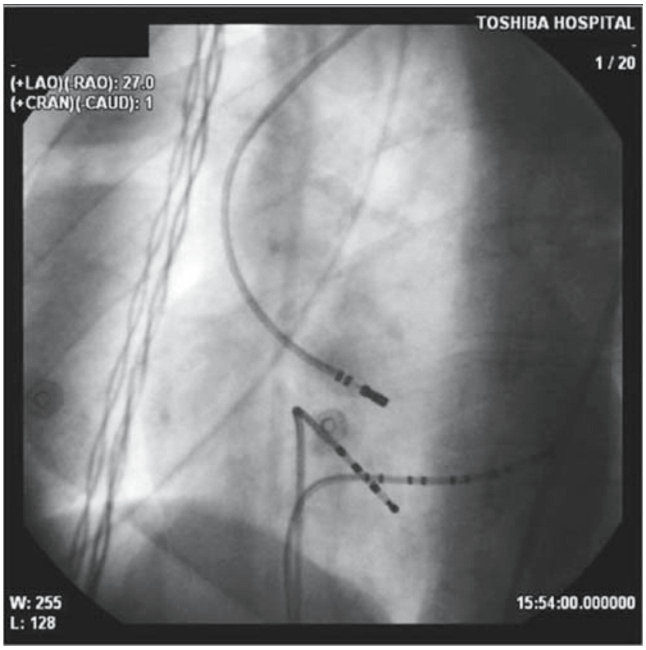


Figure 8.35 In the left anterior oblique (*LAO*) view, one can visualize even movements toward the outflow tract's septal portion. In this case, the catheter's curvature has been slightly relaxed and a little clockwise rotation has been employed

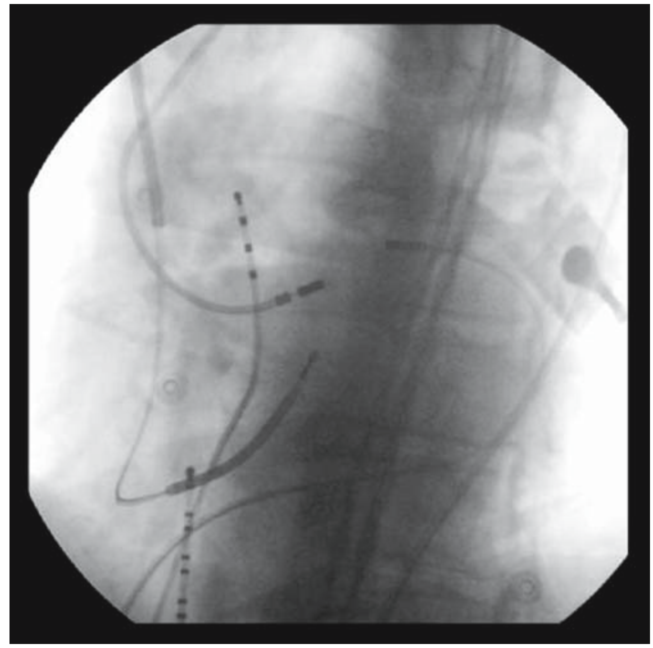


Figure 8.36 In this patient, carrying a single-chamber implantable cardioverter defibrillator (*ICD*), left ventricular outflow tract mapping is carried out. The ablation catheter is positioned within the lateral subvalvular aortic portion. A quadripolar catheter has been advanced into the coronary sinus as far as the mitral ring's anterior portion. A quadripolar catheter is placed within the outflow tract's septal portion. The left anterior oblique (*LAO*) view

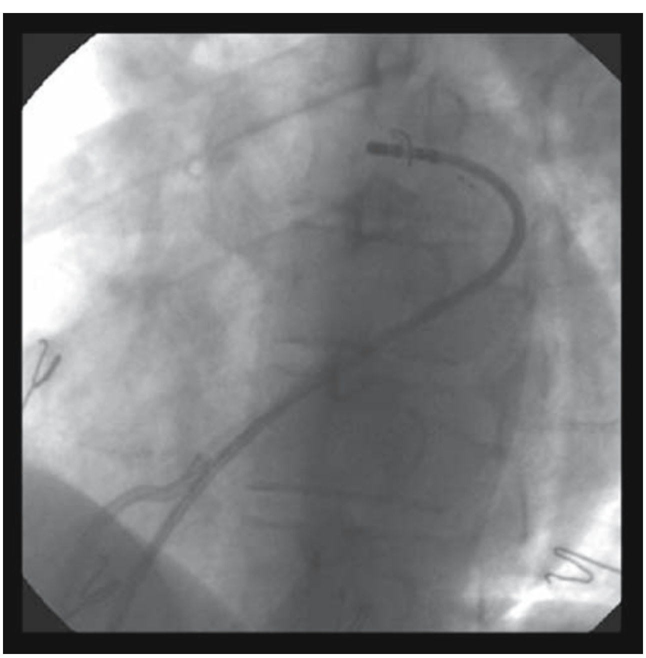


Figure 8.37 In this patient, a microcatheter (arrow) has been inserted within the coronary sinus as far as the anterior cardiac vein's origin. The ablation catheter has been advanced into the coronary sinus as far as the mitral ring's anterior portion. The left anterior oblique (*LAO*) view

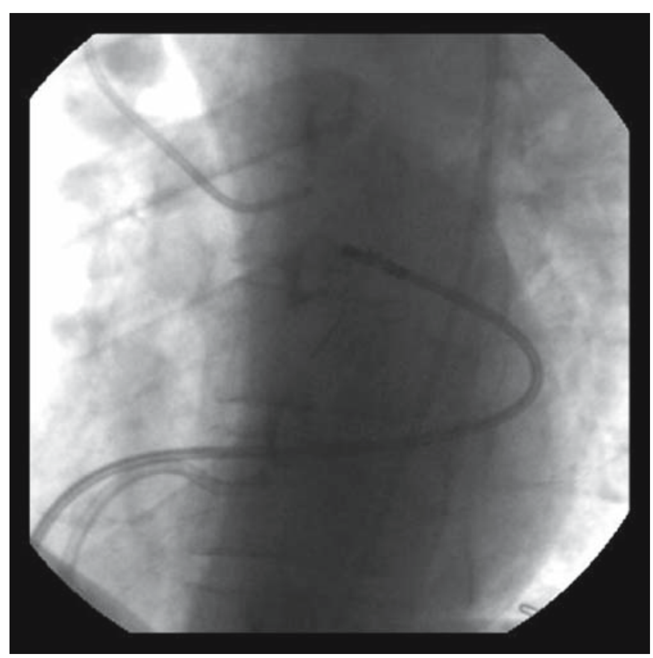


Figure 8.38 In the left anterior oblique (*LAO*) view, afterward, an angiographic catheter is inserted into the left coronary ostium

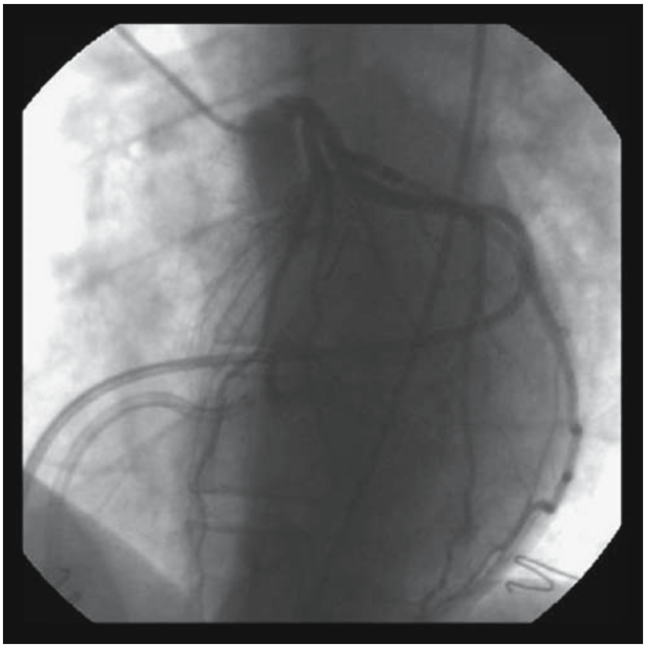


Figure 8.39 In the left anterior oblique (*LAO*) view, coronarography enables visualization of the ablation catheter's proximity to proximal circumflex artery's course

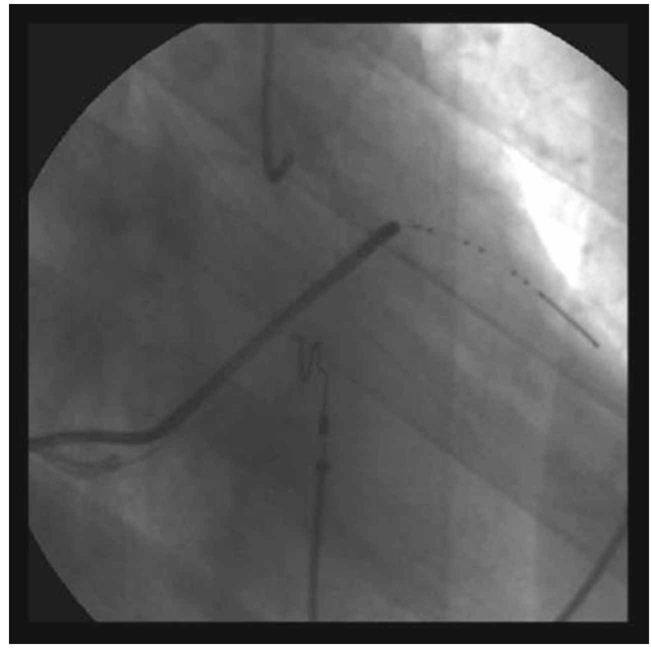


Figure 8.40 The ablation catheter position is checked also in the right anterior oblique (*RAO*) view

Figure 8.41 Coronary angiography is carried out in order to see how close the ablation catheter is to the coronary artery's course. The right anterior oblique (*RAO*) view

8.5 Idiopathic Left Ventricle Tachycardias

Idiopathic left ventricle tachycardias represent ventricular tachycardias often seen in young patients with structurally normal heart. The surface ECG shows a broad QRS, but relatively narrow compared to postischemic tachycardias or tachycardias of patients with dilated cardiomyopathy. QRS shows a right bundle branch block morphology and superior axis or, more seldom, an inferior axis. A peculiarity of this kind of tachycardia is sensitivity to verapamil. Anatomically, the origin site lies on the inferoapical or middle portion of the left interventricular septum. Electrophysiological peculiarities of such a tachycardia have been attributed to both a triggered-activity mechanism and a reentry mechanism. The most credited arrhythmogenic mechanism at present is a microreentry confined within the posterior bundle of the left bundle branch (Figure 8.42).

At the beginning of the procedure, a quadripolar catheter is inserted into the right ventricular apex to carry out ventricular stimulation as well as induction protocols.

There exist arrhythmias with right bundle branch block morphology and axis in aVR, sensitive to verapamil, which are often mistaken for supraventricular tachycardia. This specific kind of ventricular tachycardia is called ARVT or Belhassen. The arrhythmia's axis is diagnostic as it is diverted toward the right and therefore it is incompatible with a supraventricular tachycardia; origin lies into the left IV septum on the inferoapical region. Such tricuspid valve can be induced from the atrium. Therefore, it is advisable to also place a diagnostic catheter within the right atrium.

The ablation catheter, inserted via the right femoral artery, is advanced into the left ventricle through the aortic valve. At this point, it is useful to recall that all procedures carried out within the left cardiac cavities require an effective anticoagulative treatment for the patient, to minimize thromboembolic risk.

Mapping is initially concentrated upon the inferoapical septum. The RAO view is employed to place the catheter into the ventricular apex; in this view, the radiographic apex corresponds to the left ventricle's apex. The catheter is simply advanced with a relaxed curvature, if necessary, rotating clockwise or counterclockwise to keep it free from trabeculation, which, within the left ventricle, is highly marked. The LAO projection enables one to

Figure 8.42 The heart opened on its left side. The left branch originates from the His bundle's subdivision deep within the interventricular septum at the same height of the aortic valve. The left branch, then, is subdivided into two bundles, the anteroseptal bundle and the posterior bundle running over the left endocardial surface of the interventricular septum. Then bundles fan out into Purkinje fibers

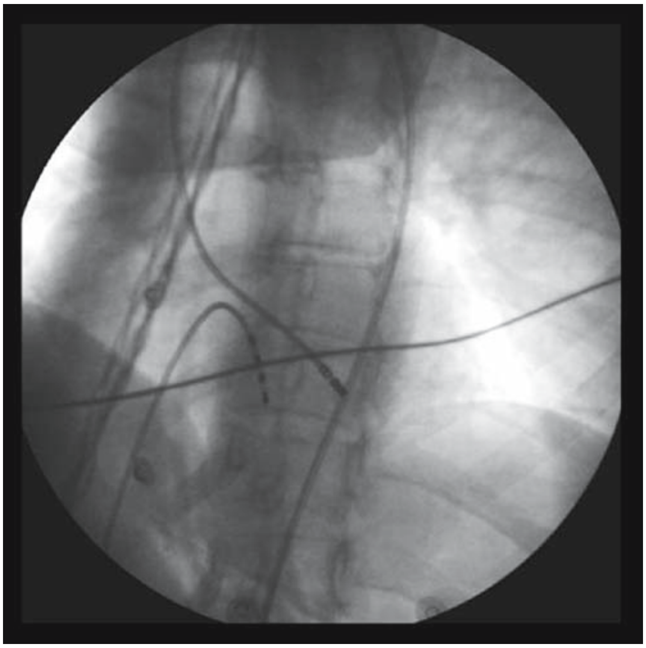


Figure 8.43 In the left anterior oblique (*LAO*), the ablation catheter has been positioned, via retroaortic approach, into the left ventricle; a clockwise rotation gets the catheter close to the interventricular septum

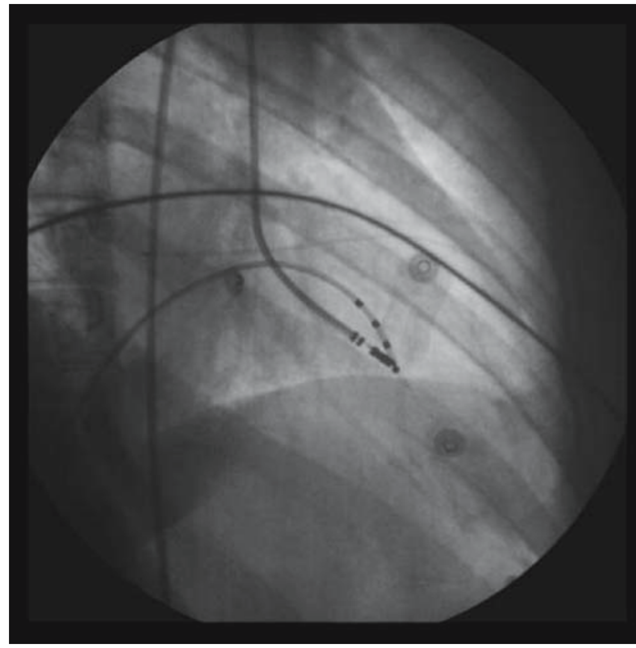


Figure 8.44 The right anterior oblique (*RAO*) view confirms the catheter position at the level of the midseptal area

get close to the interventricular septum by rotating clockwise and slightly bending the tip, thus getting good contact. If a good Purkinje potential cannot be found in this area, one can move the catheter toward the midseptal area by slowly withdrawing the catheter back still using the LAO view (Figures 8.43 and 8.44).

8.6 Postischemic Ventricular Tachycardias

Postischemic ventricular tachycardias are usually reentry tachycardias where the critical circuit is represented by slow conduction areas that take place when passing from healthy myocardium to diseased myocardium. The infarct site and the infarct extent influence chances that potentially arrhythmogenic border-line zones will develop. It is difficult to make an exhaustive review of these kinds of tachycardia. In this paragraph, we wanted to underline some of the common peculiarities in treating postischemic ventricular tachycardias.

To reach the left ventricle we use, as a rule, a transaortic retrograde arterial approach by insertion via the right femoral artery. Braided sheaths or long sheaths may become necessary in these patients with coronary heart disease, and often with a peripheral artery disease, due to existence of tortuosities of the femoral artery or the iliac artery. These sheaths enable one to go through tortuous or stenotic areas by means of an "over the wire" system, thereby minimizing trauma. A further advantage connected with such sheaths is stabilization of the catheter within the left ventricular cavity.

Another less frequent approach is the transseptal one which is employed only in conditions of important peripheral vascular disease, of prosthetic aortic valve, or when the retrograde approach does not allow good contact with the left ventricle's septal regions. In each case, effective anticoagulation is required to minimize thromboembolic risk.

For mapping and ablation, usually, we employ a deflectable ablator with middle or wide curve, according to patient's anatomy. As a rule, ablation catheters with irrigation device are preferred. Some operators prefer to employ ablation catheters with bidirectional curvature to carry out the left ventricle's mapping in a simpler and quicker way compared to what is allowed by a catheter with monodirectional curvature.

Because of the large number of possible types and the complex substrate, these kinds of tachycardia are usually mapped with nonconventional systems, either electroanatomic or noncontact systems. Besides the ablation catheter, a diagnostic catheter is usually positioned into the right ventricular apex to carry out ventricular stimulation, diagnostic maneuvers such as entrainment or overdrive to interrupt arrhythmia. In some cases, one can also position one catheter into the coronary sinus or microcatheters within cardiac veins to carry out epicardial mapping.

Lastly, very often, ablation, in these patients, represents part of a hybrid therapy. Patients with previous cardiac infarction, with reduced left ventricular function and with ventricular arrhythmias, also often require an implantable cardioverter defibrillator. Therefore, ablation is carried out in those with frequent recurrent tachycardia, responsible for frequent implantable cardioverter defibrillator discharge.

In the following series of images, some examples are shown (Figures 8.45–8.61).

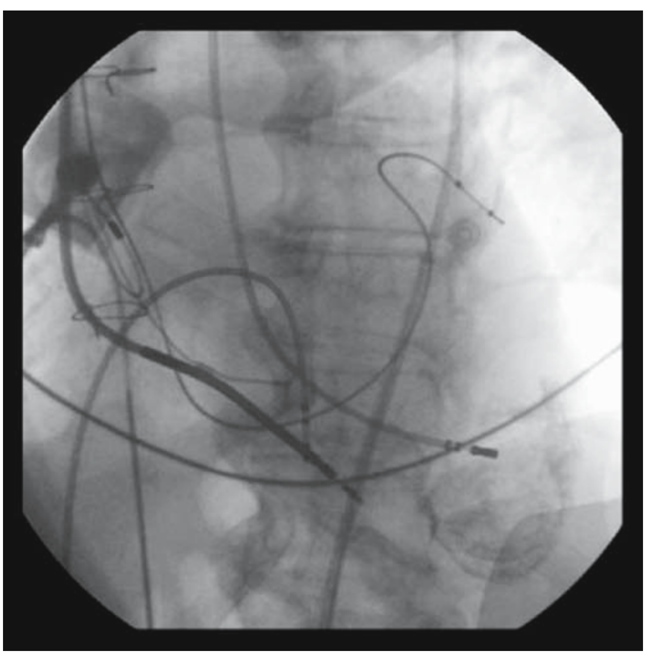


Figure 8.45 In the left anterior oblique (*LAO*) view, image of patient carrying biventricular implantable cardioverter defibrillator (*ICD*). The left ventricular apex is involved because of aneurismal dilation that can be clearly seen thanks to calcification. The patient has been instrumented with a diagnostic catheter positioned in the right ventricular apex. The ablation catheter, with cooled tip, has been inserted via the retrograde approach employing a long braided sheath. Mapping of the hemodynamically stable tachycardias has been carried out with CARTO electroanatomic mapping system

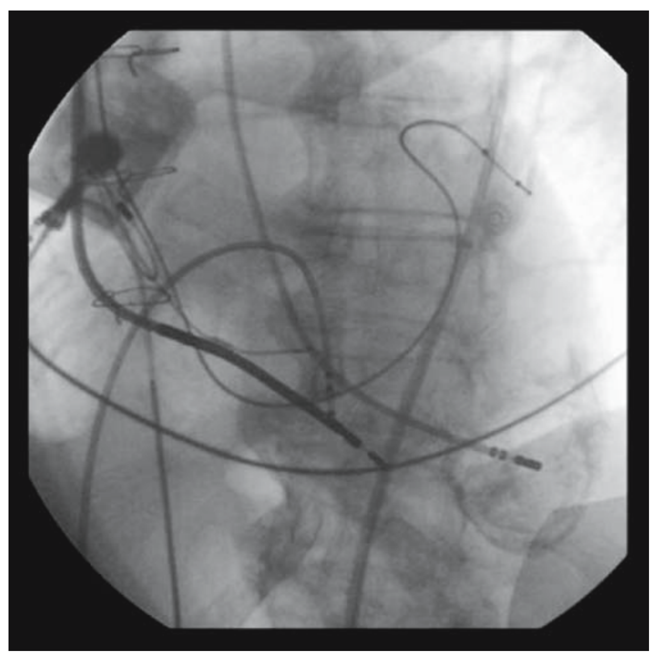


Figure 8.46 With regard to the previous image, the catheter's curvature has been slightly relaxed to enable mapping of the aneurysm neck

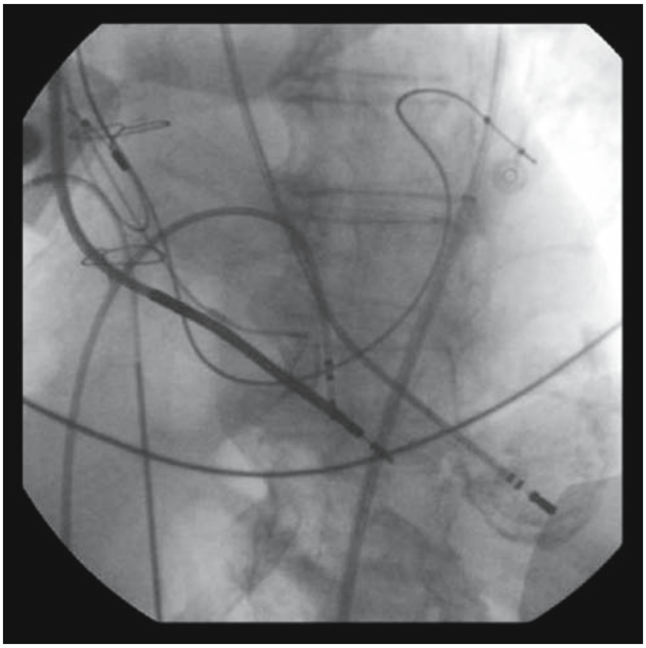


Figure 8.47 With thoroughly relaxed curvature, one delicately advances the ablation catheter to reach the aneurysmal dilation's apex

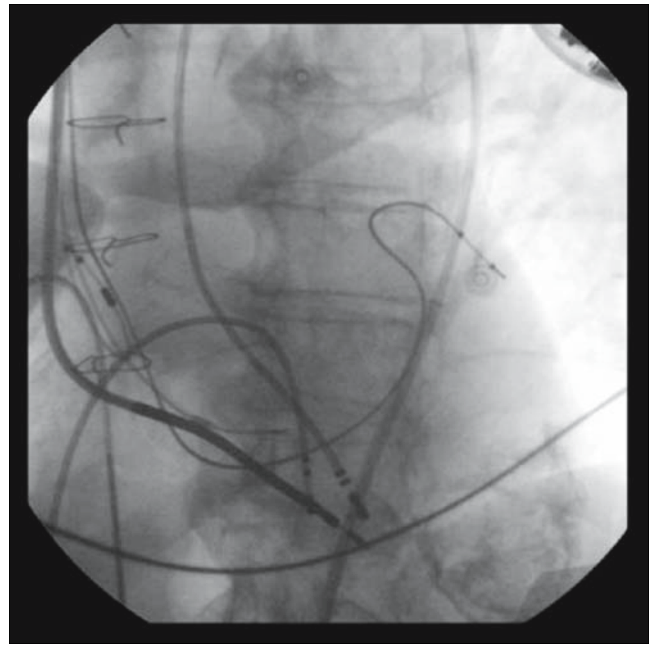


Figure 8.48 Still in the left anterior oblique (*LAO*) view, the catheter is pulled back slightly rotating clockwise, to map the aneurysmal neck's septal portion. When mapping the left ventricle, to move toward the septum, it is necessary to rotate clockwise, whereas to move toward the free wall, one must rotate counterclockwise. The movement to carry out, contrary to what would be spontaneous, is a consequence of a 180° angle rotation carried out by the catheter at the aortic arch

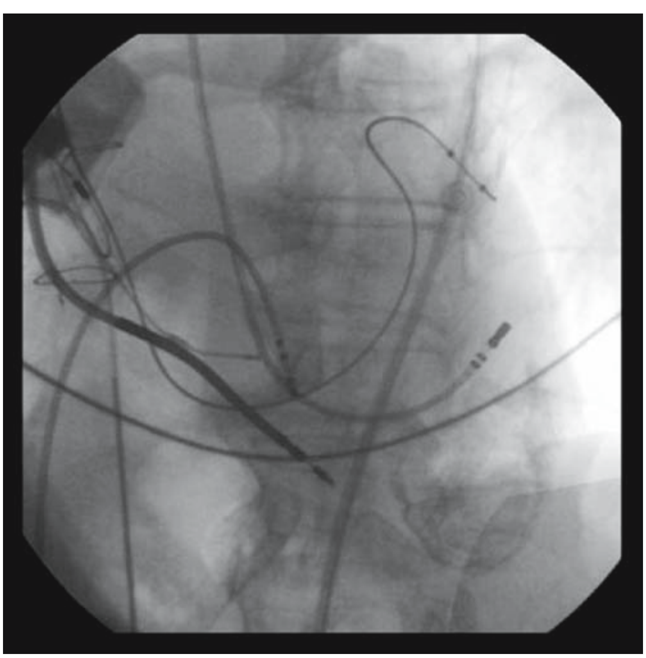


Figure 8.49 In this image, instead, from an apical position, the catheter is bent and slightly rotated counterclockwise, thus reaching the anterolateral wall

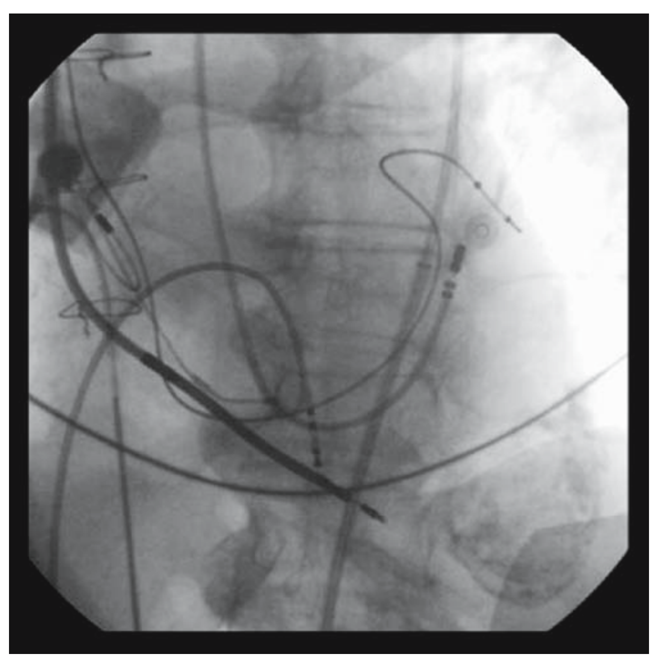


Figure 8.50 In the left anterior oblique (*LAO*) view, the catheter is further bent

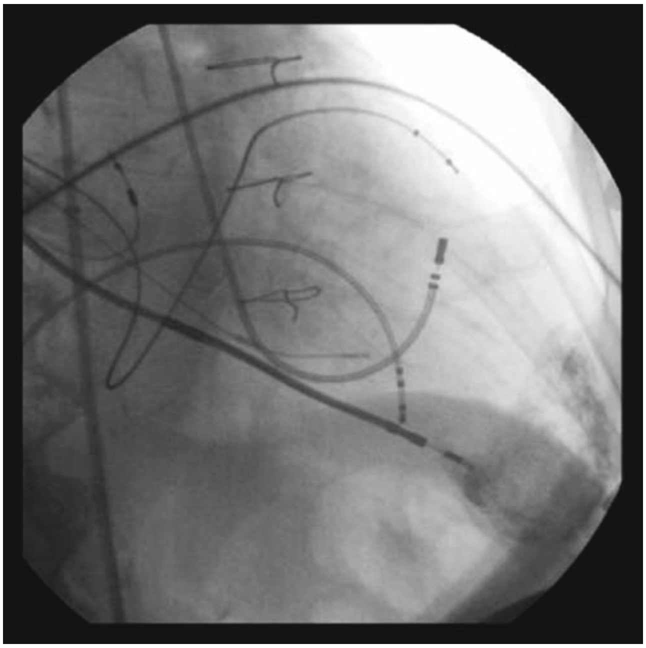


Figure 8.51 Corresponding the right anterior oblique (*RAO*) view, showing how the catheter is positioned at the height of the anterolateral wall in its basal portion

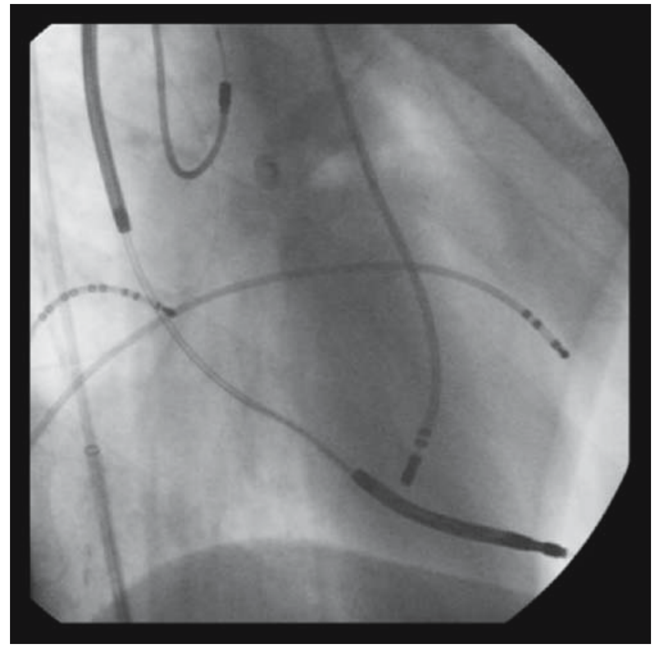


Figure 8.52 The right anterior oblique (*RAO*) view of another patient. The ablation catheter has been inserted via the retrograde approach through a long braided sheath. In this case, the catheter has been positioned upon the left ventricular diaphragmatic wall in its basal portion. To reach such a position, it is necessary to pull the catheter back until it is free within the left ventricle, then markedly rotate it clockwise or counterclockwise. At this point, slightly bending its tip and pushing the catheter forward, it comes into contact with the myocardium

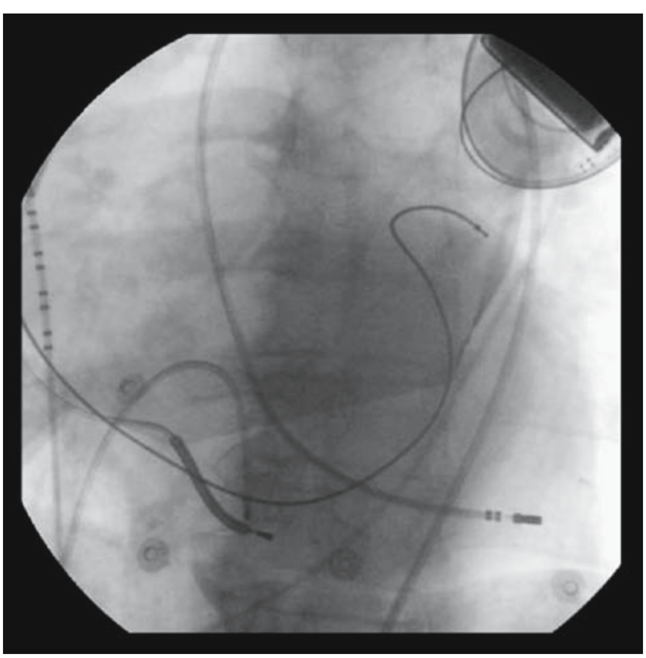


Figure 8.53 The left anterior oblique (*LAO*) view of another patient carrying a biventricular implantable cardioverter defibrillator (*ICD*). In this case, the ablation catheter has been inserted via the retrograde approach through a short braided sheath. The catheter is positioned at the left ventricular apex

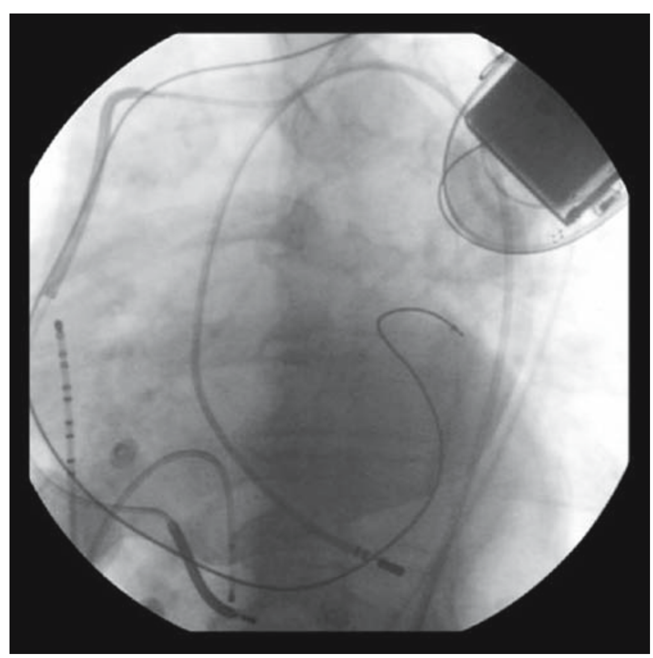


Figure 8.54 The ablation catheter is slightly withdrawn with its thoroughly relaxed curvature to run over the inferior wall

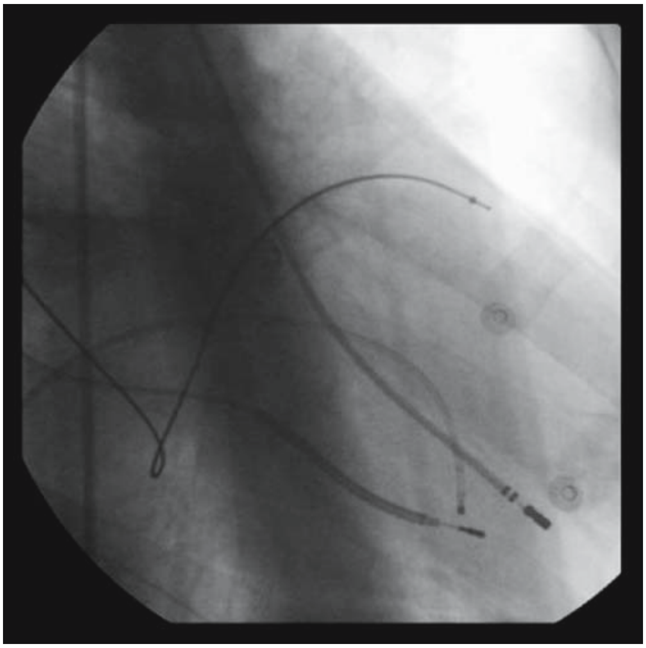


Figure 8.55 Corresponding image in the right anterior oblique (*RAO*) view

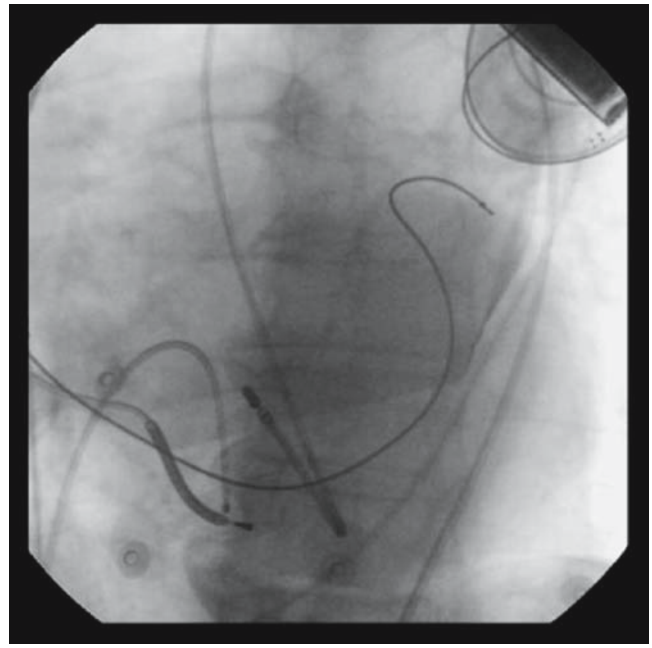


Figure 8.56 The catheters' maneuvrability within the left ventricle is much more difficult compared to the right ventricle due to some anatomic peculiarities. Besides the angle imposed by the aortic arch, the left ventricle contains marked trabeculations, papillary muscles with chordae tendineae and strong contractility. Very often, to reach the target areas, looping must be carried out with the catheter. In this image, in the left anterior oblique (*LAO*) view, the catheter has been markedly bent, to map the perimitral septal side

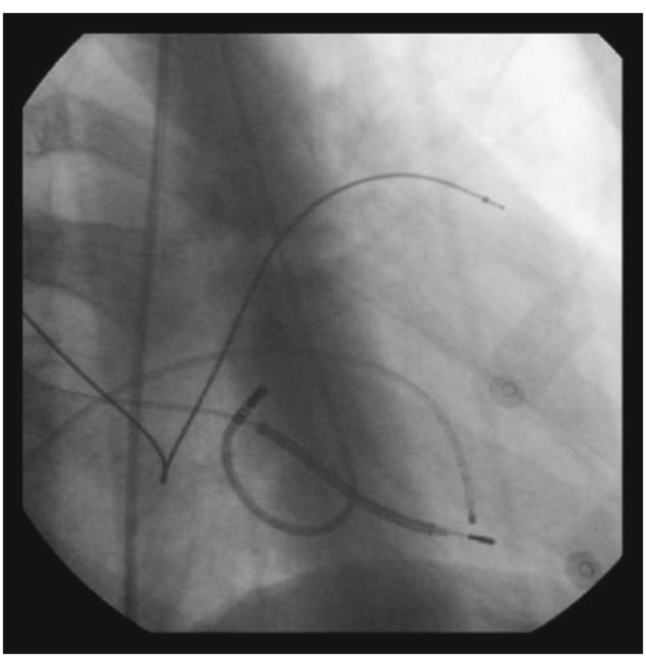


Figure 8.57 The right anterior oblique (*RAO*) view with thoroughly bent catheter to get close to the perimitral region

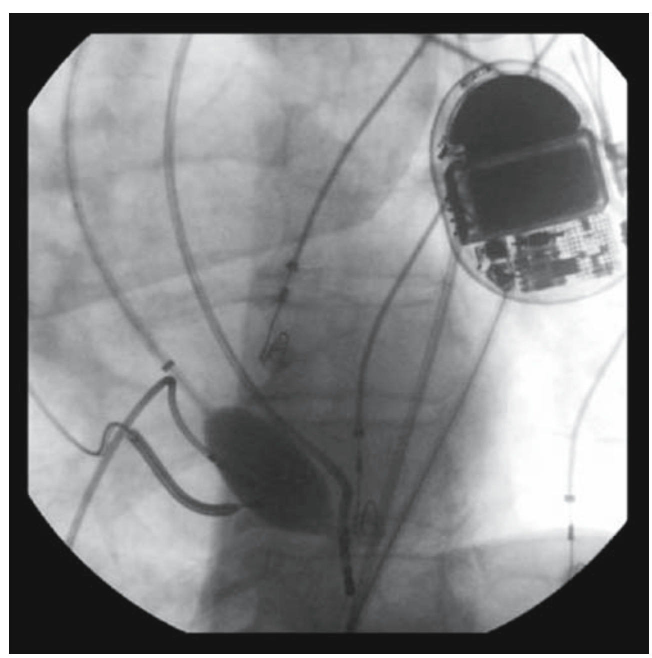


Figure 8.58 The left anterior oblique (*LAO*) view of a patient carrying dual chamber implantable cardioverter defibrillator (*ICD*). The left ventricle is mapped with a noncontact system. One can see the EnSite catheter positioned at the left ventricle septal apex. The ablation catheter has been inserted via the retrograde approach through a long braided sheath. Please notice how the catheter tip is imprisoned within the ventricular apex aneurysmal dilation

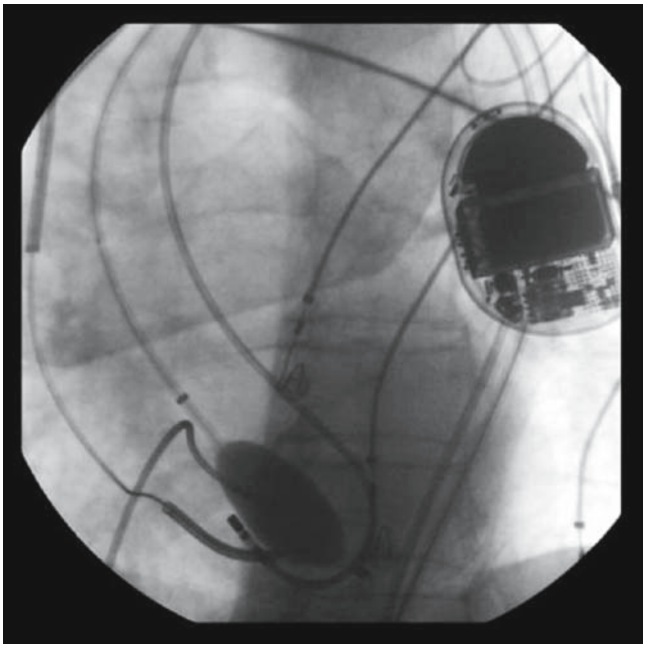


Figure 8.59 In the same patient, one can see mapping of the interventricular septum carried out using the EnSite catheter

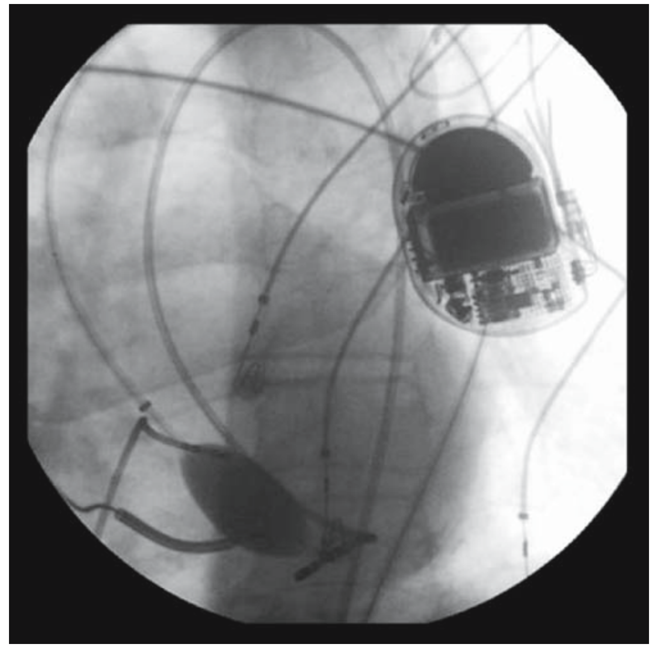


Figure 8.60 Another image showing the septal apex mapping of the same patient

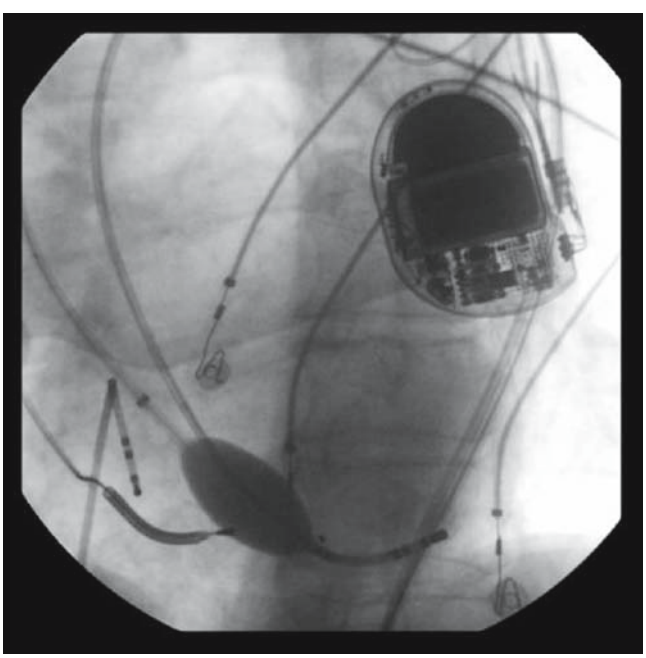


Figure 8.61 Lateral apex mapping of the same patient

8.7 Epicardial Approach

In left ventricular tachycardias, it might be necessary to map, or even to carry out radiofrequency supplies, at the epicardial level. To reach the left ventricle's epicardial surface, we can take advantage of the coronary sinus with all of its branches. Mapping can be done by inserting into the coronary sinus one or more microcatheters (2.5–3.5 Fr, 8 or 16 electrodes). Still within the coronary sinus an ablation catheter can be inserted to carry out radiofrequency application. Obviously, the limits of the cardiac veins restrict mapping to regions reached by these vessels. Moreover, because of high impedance, which is typical of small caliber vessels, it is not always possible to carry out radiofrequency ablations. Should it be necessary to ablate within the coronary sinus, it is always advisable to employ an irrigated tip ablation catheter.

The epicardial surface can also be reached directly, by positioning catheters within the pericardial space. The pericardium is a sort of fibroelastic pouch thoroughly enveloping the heart, subdivided into two layers: one internal layer adhering to the heart, that is to say the epicardium, and one more fibrous parietal layer. Between the two pericardial layers there is a virtual space filled with a small quantity of serous liquid (20–50 ml) whose function is to make reciprocal sliding of the two layers easy during the different phases of the heartbeat. Through a subxiphoid puncture one can get transcutaneous access to the pericardial space. Epicardial mapping via pericardial approach enables one to reach any point of the heart surface with the exception of areas surrounding the pulmonary veins and the large vessels, where the pericardial pouch invaginates (Figure 8.62). Just because one can

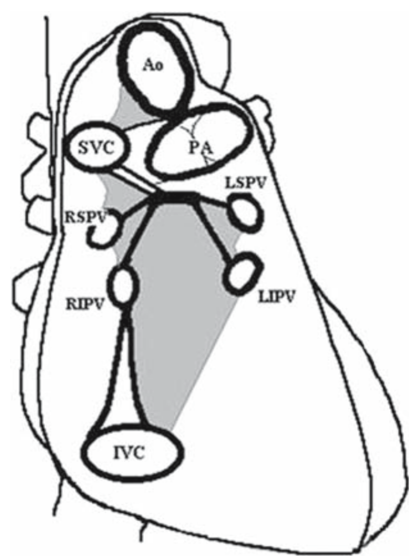


Figure 8.62 An anterior window created in the fibrous pericardium in the anteroposterior view. The heart has been removed and the serous pericardial reflections are highlighted by a dark line. The pericardial reflection may be grouped into the arterial reflection, on the top, and the lower long and continuous venous reflection. Furthermore, the pericardial reflections form some recesses, colored gray, between the parietal layer and the visceral layer of the pericardium. The arterial reflection is in proximity to the great vessels and it forms the aortocaval recess that is delimited by the superior vena cava on the right, the aorta on the left, and the left branch of the pulmonary artery on the bottom. The venous reflection form three recesses: the posterior or oblique sinus, the right lateral, and the left lateral. The oblique sinus is delimited by the pericardial reflection connecting the inferior vena cava to the right pulmonary veins, on the right; the pericardial reflection between the left pulmonary veins on the left; and the pericardial reflection joining the inferior pulmonary veins attaching to the left atrium or the right branch of the pulmonary artery, on the top. The anterior aspect of the oblique sinus mainly corresponds to the posterior wall of the left atrium. The right lateral recess includes the lateral recess, between the inferior and superior right pulmonary veins, and the retrocaval recess between the right superior pulmonary vein and the superior vena cava. The left lateral recess is found between the inferior and superior left pulmonary veins. The roof of the venous reflection extends between the pulmonary artery and the superior wall of the left atrium. *Ao* aorta, *PA* pulmonary artery, *SVC* superior vena cava, *IVC* inferior vena cava, *RSPV* right superior pulmonary vein, *RIPV* right inferior pulmonary vein, *LSPV* left superior pulmonary vein, *LIPV* left inferior pulmonary vein

reach any point of the myocardial surface, before issuing radiofrequency, it is mandatory to ascertain one is not in close proximity to structures that might also be damaged: with stimulation from ablation catheter's distal electrode, it is possible to exclude being close to the phrenic nerve. By carrying out coronary angiography, one can see the distance to the coronary branches. Besides the opportunity of unlimited mapping, this kind of approach is also characterized by excellent catheter stability; the catheter is kept in place because the space between the epicardium and the parietal layer is technically virtual.

All kinds of ablation catheters can be employed. Histological characteristics obtained with infused catheters have shown a minor carbonization degree and excellent lesion depth. Therefore, operators are employing infused catheters frequently. In the case of open-tip irrigated catheters, it is necessary to drain excess liquid every 10 min, approximately.

This kind of approach is less easily employed in patients who have previously undergone cardiac surgery, because postsurgery adherences, at the pericardial level, restrict the catheter's maneuvrability.

Some examples are shown below (Figures 8.63–8.72).

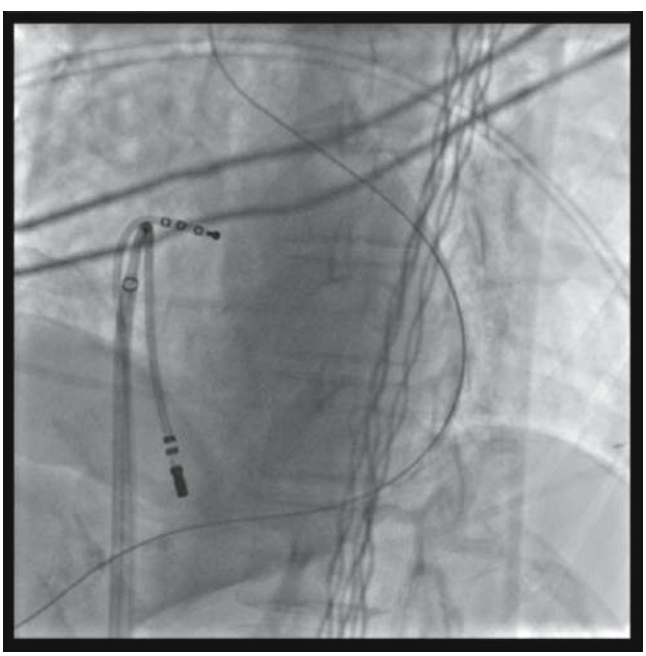


Figure 8.63 Through a subxiphoid puncture, a guidewire has been inserted into the pericardial space. The left anterior oblique (*LAO*) view is important because it enables confirmation that the guidewire is running all along the external border of the heart image without being positioned within cavity or intramyocardium

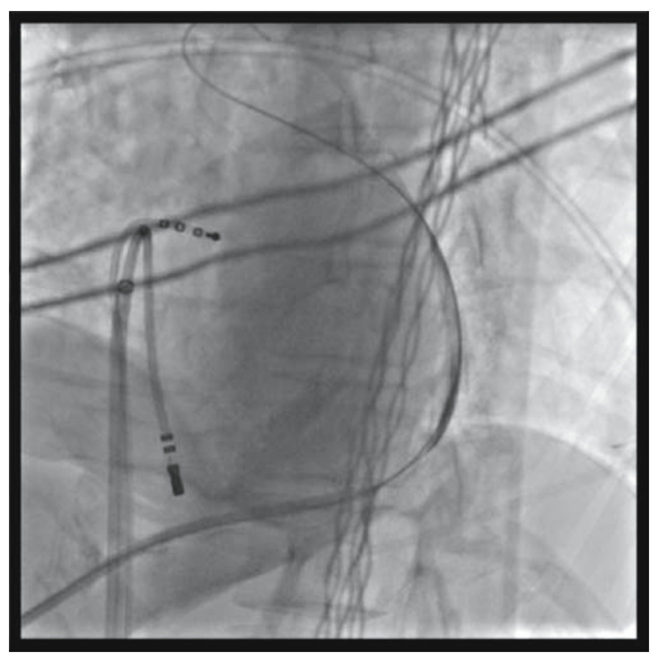


Figure 8.64 In the left anterior oblique (*LAO*) view, dye injection makes pericardial pouch opaque. The dye expands around cardiac cavities

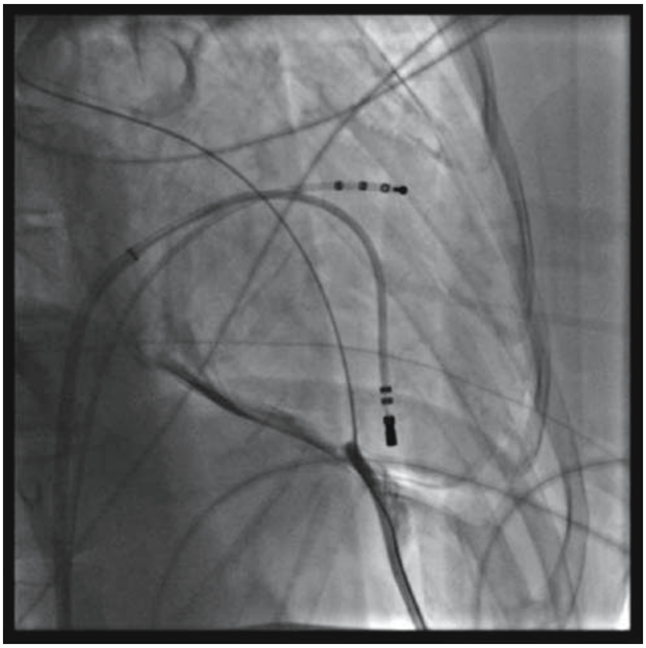


Figure 8.65 In the right anterior oblique (*RAO*) view, correct positioning of the introducer within the pericardial space is ascertained

Figure 8.66 In the left anterior oblique (*LAO*) view, the ablation catheter is advanced through the sheath into the pericardium

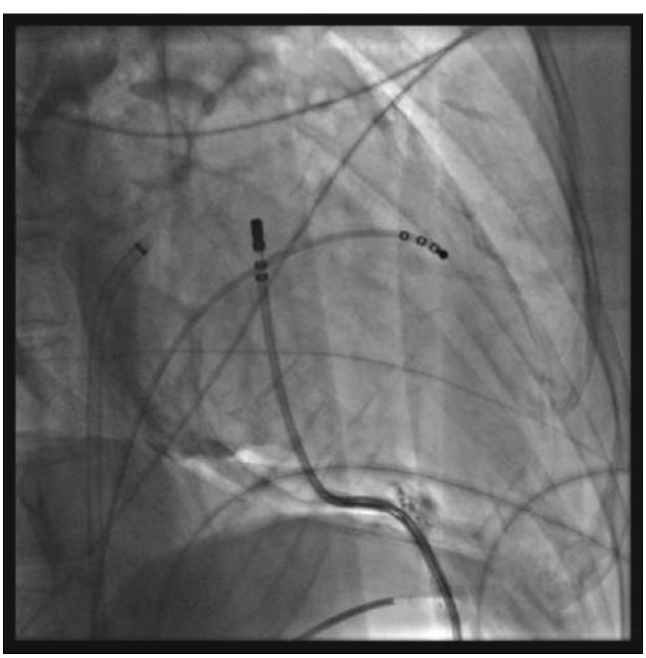


Figure 8.67 The right anterior oblique (*RAO*) view enables visualization of the catheter's position upon the long axis of the heart. In this particular case, it documents its basal position, in proximity to the atrioventricular annulus

Figure 8.68 After having positioned the ablation catheter on the target point, coronary angiography is carried out to exclude proximity of a coronary branch. According to literature, it is advisable not to apply radiofrequency at a distance less then 12 mm from a coronary branch. The posteroanterior (*PA*) view

Figure 8.69 Coronarography in the left anterior oblique (*LAO*) view

Figure 8.70 Coronarography in the right anterior oblique (*RAO*) view

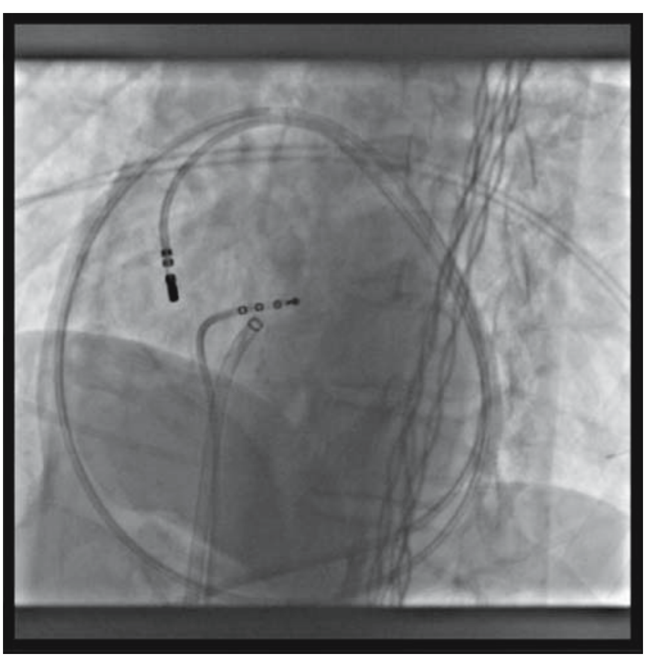


Figure 8.71 In this image, carried out in the left anterior oblique (*LAO*) view, the free catheter is evident within the pericardial pouch, and one can see also how there are no anchoring points with the exception of the access point

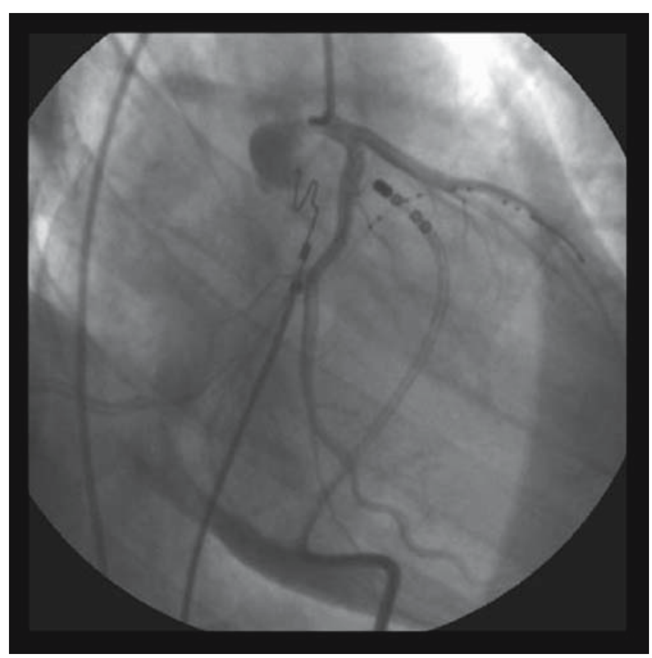


Figure 8.72 In this case, epicardial mapping is carried out in a patient with tachycardia of the left ventricular outflow tract. A microcatheter is positioned into the coronary sinus and pushed forward through the anterior cardiac vein. The ablation catheter, via a pericardial approach, is positioned on the target point. The angiographic catheter carries out a left coronary angiography. The right anterior oblique (*RAO*) view

9

Pacemaker and Implantable Cardioverter-Defibrillator Implantation

9.1 The Pacing Lead

Pacing leads, differently from electrophysiologic catheters, are permanent catheters. Once they have been inserted, they must remain within cardiac chambers for long periods of time. Pacing leads are, therefore, structurally different from electrophysiologic catheters: they are made of biocompatible insulating material and they have flexible bodies and tips provided with anchoring systems (Figure 9.1). Systems for chronic lead fixation are essentially two: passive fixation or "with tines," with hook-like protrusions in the proximity of the distal electrode (Figure 9.2), and active fixation or "screw," with a retractable or non-retractable metallic spiral that screws within the myocardium (Figure 9.3). Leads used in implantable cardioverter defibrillators are similar to those used for pacing but differ from them for the presence of metallic coils along their course (Figure 9.4).

Insertion of pacing leads is usually carried out through the subclavian vein, preferably the left one; alternatively, the cephalic vein can be used.

9.2 Atrial Lead

The atrial lead is usually positioned into the right atrial appendage. It has, in its distal portion, a preshaped J-like curve and the most frequently used fixation system is that with tines.

The catheter, with inserted stylet, is advanced into the right atrium through the superior vena cava utilizing the posteroanterior projection. When the tip of the catheter reaches the inferior third of the right atrium, the stylet is partially pulled out so that the distal segment begins to bend. By turning the lead anteriorly and making the J curve progressively narrower (by pulling out the stylet) the lead is positioned in the right atrial appendage (Figure 9.5). Correct positioning is confirmed by rhythmic movements of the catheter during the cardiac cycle (Figures. 9.6–9.8). To ascertain the catheter steadiness, a slightly withdrawing of the catheter allows the J curve to open with no tip shifting. Once the correct position has been ensured, a gentle curve within the atrium should be left (Figure 9.9). Finally, the patient is asked to take a deep breath and to cough to make sure that the catheter remains steady.

In patients who had the right atrial appendage removed, for instance during cardiosurgery, the catheter is positioned in the anterolateral region against the atrial wall (Figure 9.10): in these cases the screw fixation system is preferred. Once a steady position has been found, the catheter, with the guidewire inserted and the tip perpendicular to the wall, must be screwed by carrying out clockwise rotations (Figure 9.11). This procedure should be done under fluoros-

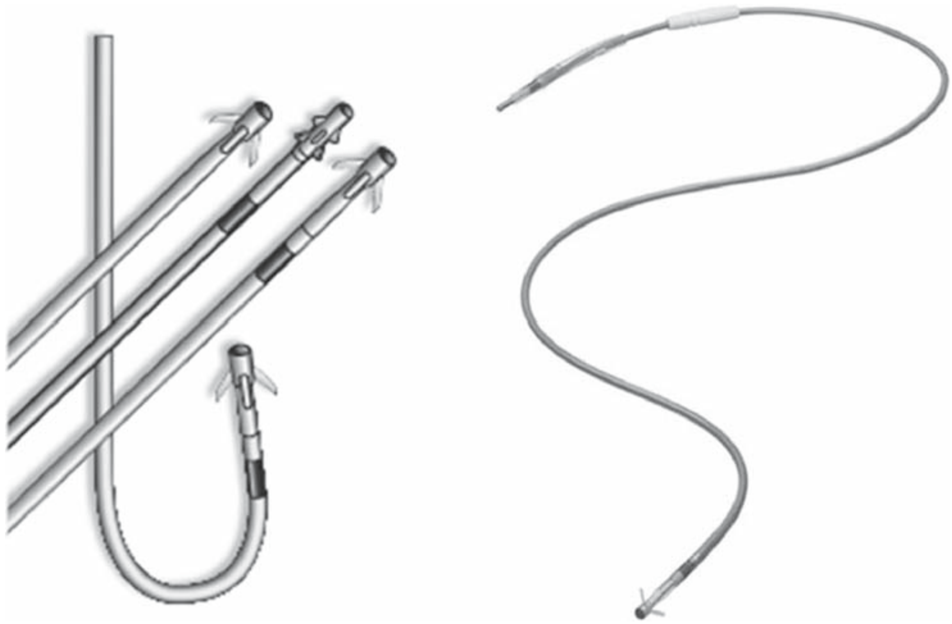


Figure 9.1 Straight and preshaped leads

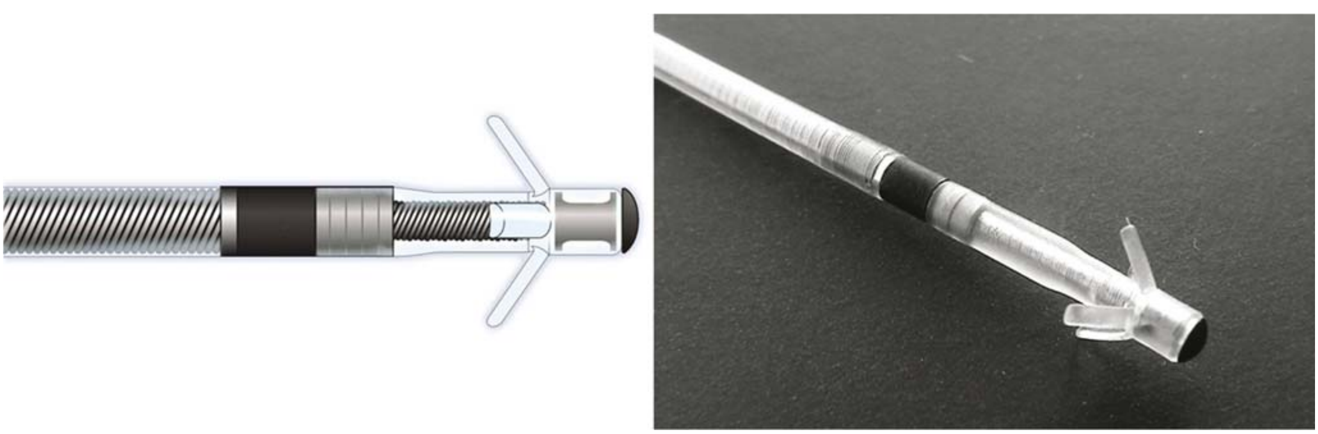


Figure 9.2 Distal end of a lead with passive fixation system

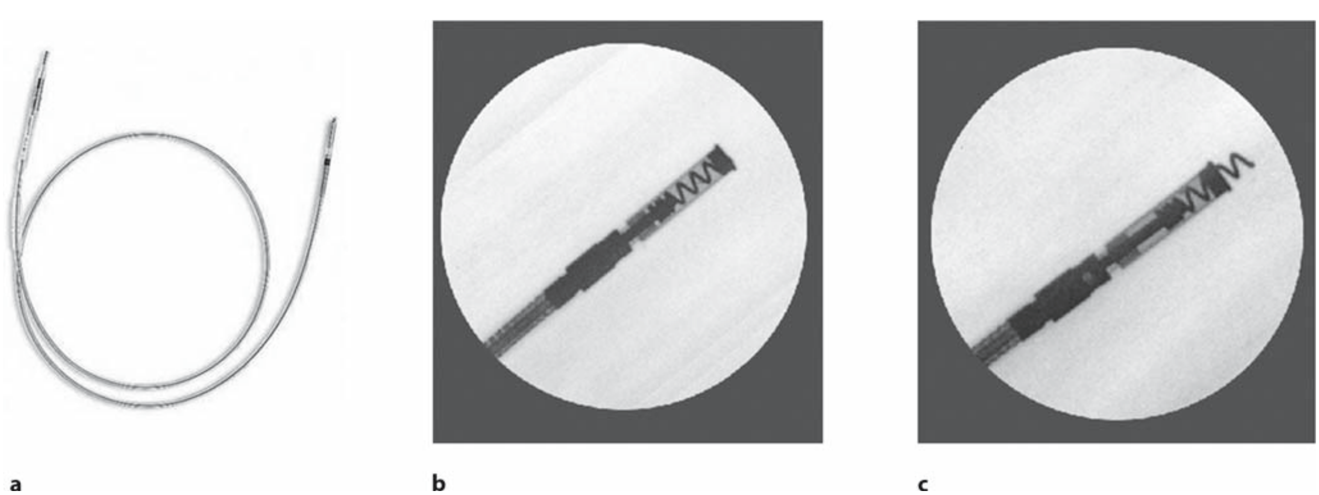


Figure 9.3 Active fixation system (panel a). Examples of catheters with screw-in (panel b) and screw-out (panel c)

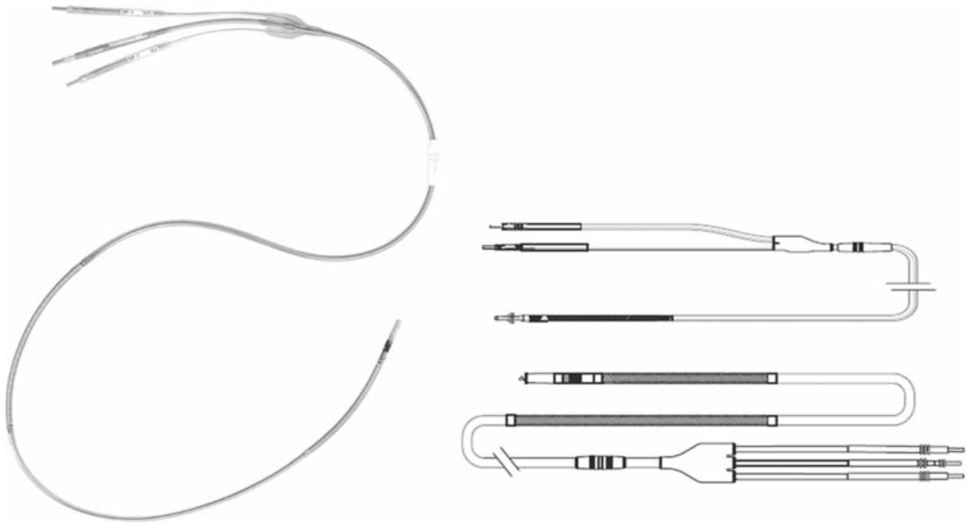


Figure 9.4 Mono- and double-coiled implantable cardioverter defibrillators (*ICDs*) leads

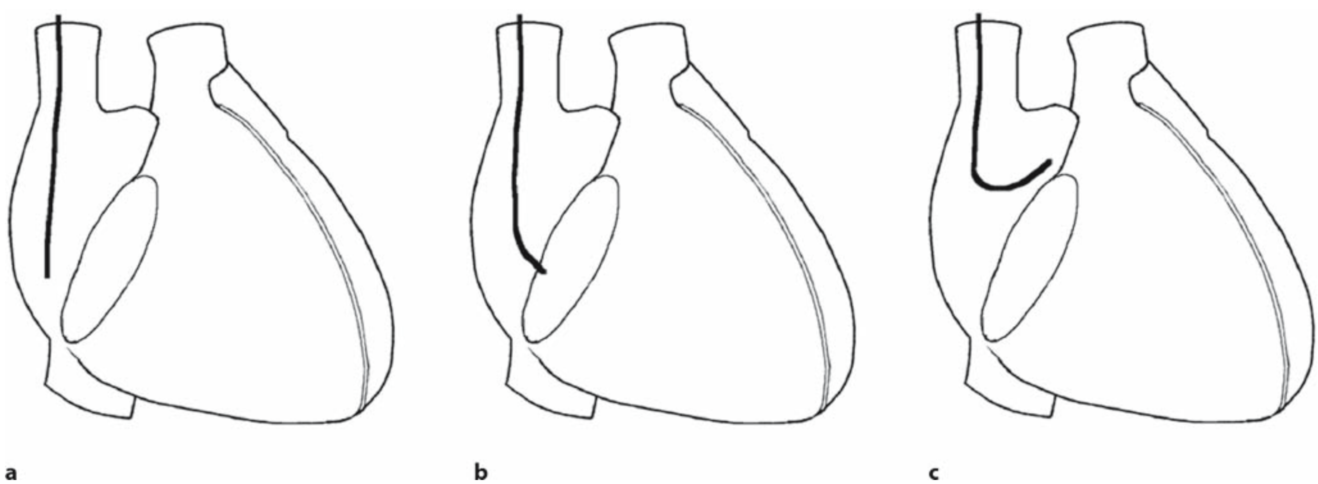


Figure 9.5 Panel a The catheter is advanced to the inferior third of the right atrium and the stylet to the distal end of the catheter. Panel b The stylet is partially pulled out and the catheter is rotated to let the J to open anteriorly. Panel c The stylet is further pulled out and, simultaneously, the catheter's distal end moves toward the right atrial appendage

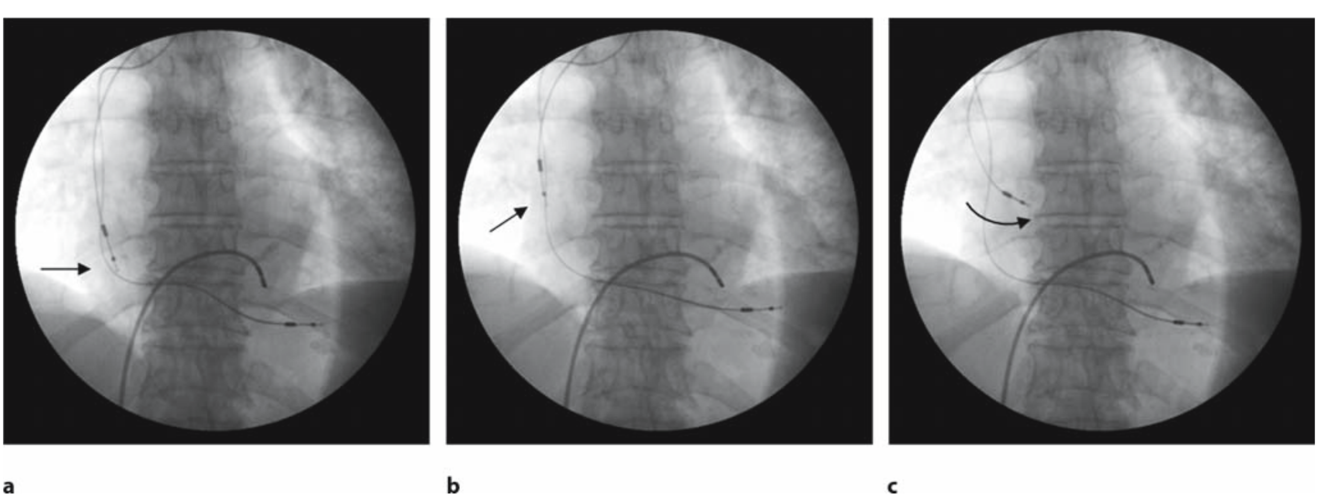
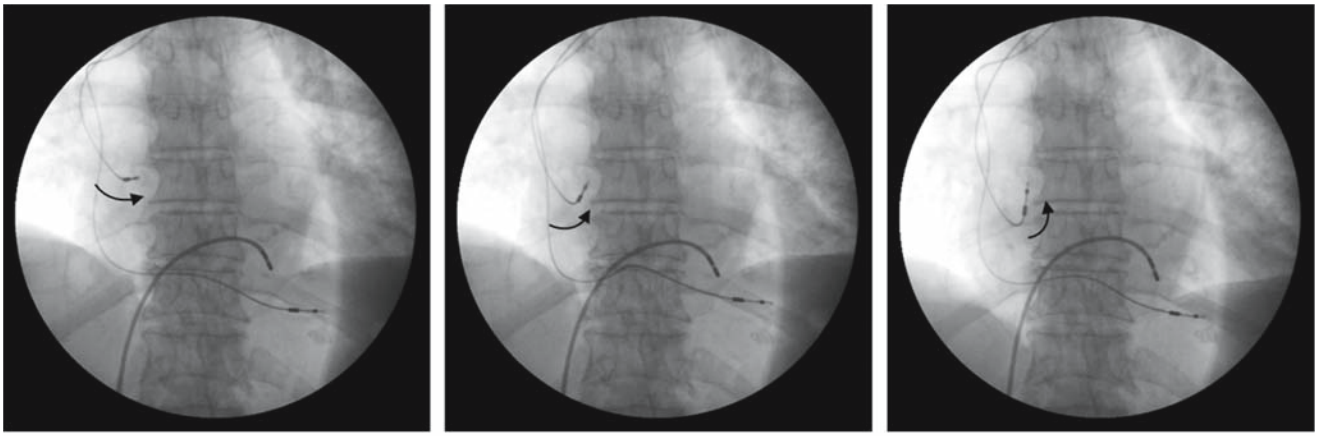
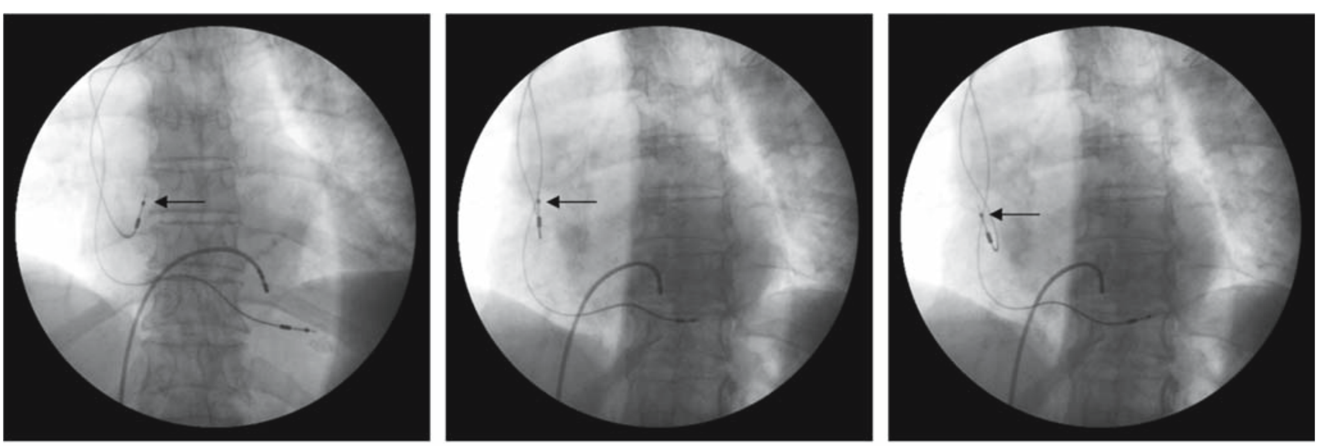


Figure 9.6 Positioning of the atrial catheter within the right atrial appendage. Arrow shows how the catheter moves from the inferior third of the right atrium (panel a) toward the superior region (panel b) to enter the right atrial appendage by stylet withdrawal (panel c)



a b c

Figure 9.7 Positioning of the atrial catheter within the right atrial appendage. Arrow shows correct positioning of the catheter within right atrial appendage, obtained by removing the stylet and simultaneously advancing the catheter (panels a–c)



a b c

Figure 9.8 In the posteroanterior (PA) projection, it is possible to visualize the atrial catheter waving (arrow) during the cardiac cycle when correctly positioned into the right atrial appendage

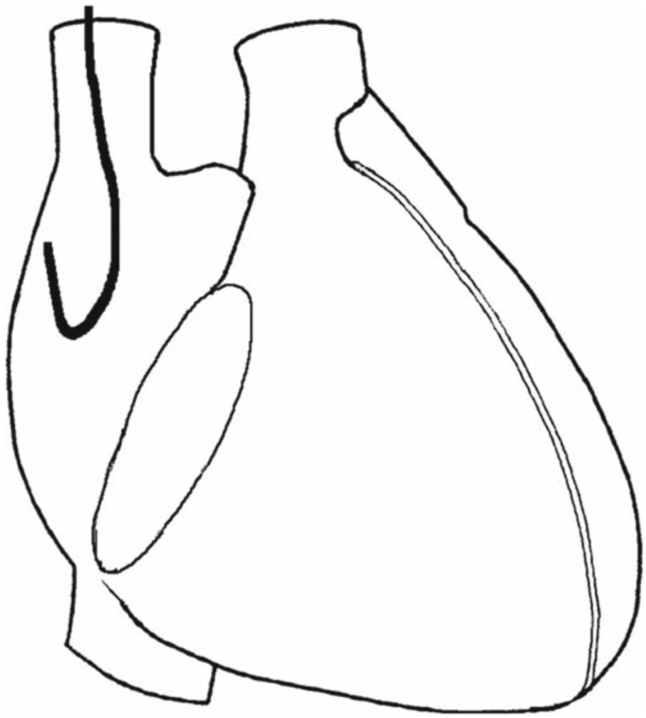


Figure 9.9 Panel a The stylet is thoroughly pulled out and the catheter tip is inserted within the right atrial appendage. During the cardiac cycle, the catheter's distal portion tends to move in an anteroposterior direction. Panel b The catheter is pulled back to make sure that the tip is stable. If so, the J-like curve tends to straighten. Panel c Withdrawal maneuver carried out in an unstable position. In this case the catheter tip comes out and the catheter moves up along the superior vena cava

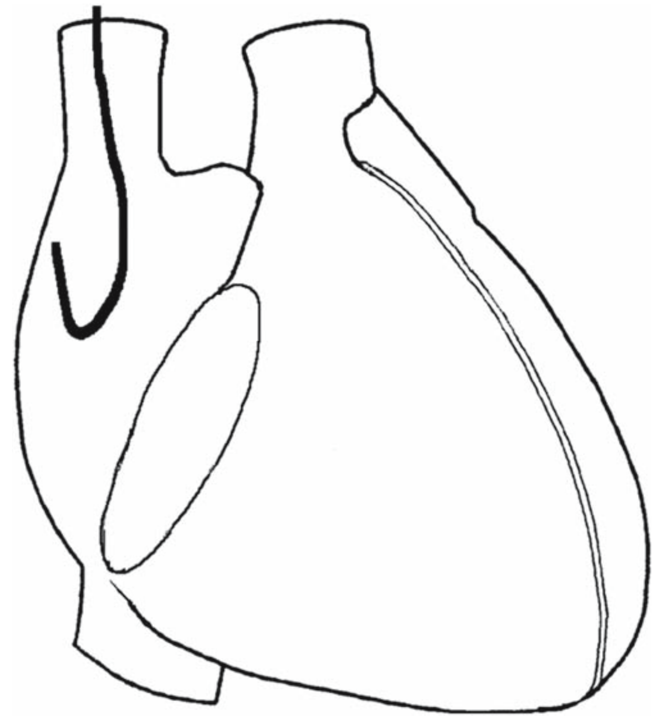
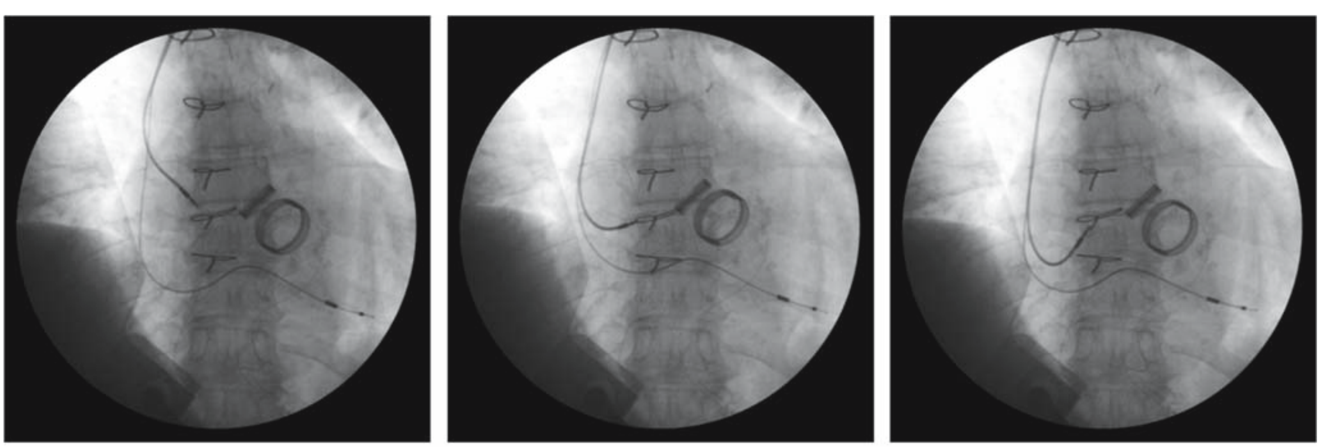
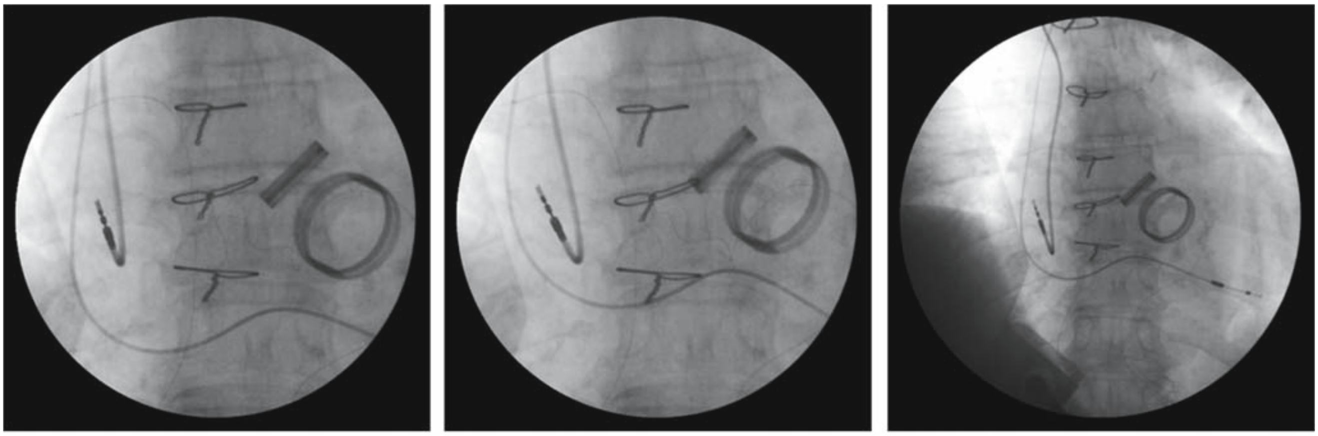


Figure 9.10 The correct position of an atrial catheter in the anterolateral wall



a b c

Figure 9.11 Positioning of an atrial screw catheter in a cardiosurgical patient

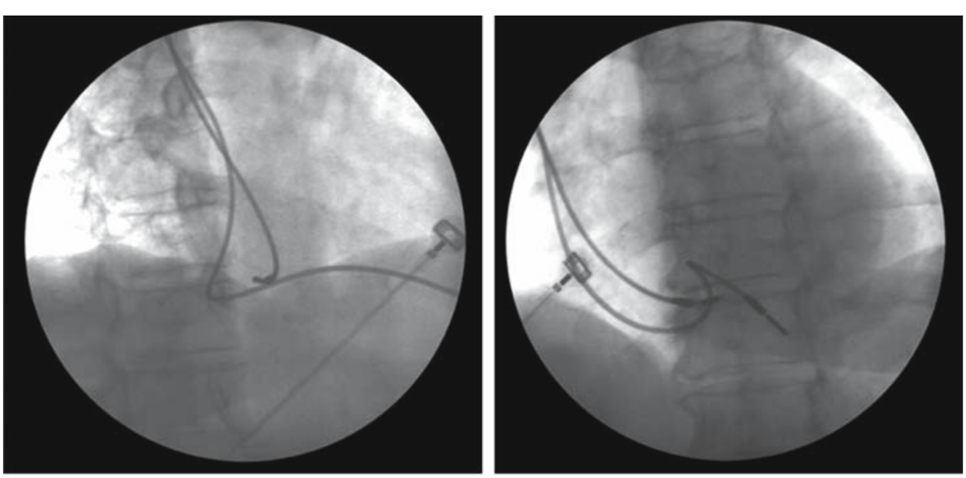


a b c

Figure 9.12 Same patient as in the previous figure. The catheter tip is definitely screwed into the right atrium's lateral wall

copy to ensure the exit of the metallic spiral into the myocardium (Figure 9.12). After a few clockwise screwing movements, a light resistance is perceived. At this point, the lead is freed and it spontaneously rotates counterclockwise over the guidewire. Actual fixation is verified by a slight pull back of the catheter with the tip that remains fixed. Once the catheter is in the correct position, a high energy threshold test must be performed to exclude phrenic nerve stimulation, which would make catheter repositioning mandatory.

When positioning of the catheter in the interatrial septum is considered (as in patients with an interatrial conduction defect), catheters with an active fixation system should be used. The correct site is in the posteroseptal region (the triangle of Koch), in front of the coronary sinus (Figure 9.13).



a b

Figure 9.13 Panel a The right anterior oblique (*RAO*) view. The atrial catheter has its tip positioned in the posteroseptal region in front of the coronary sinus' (*CS*) ostium. Panel b The left anterior oblique (*LAO*) view. In this projection, the catheter is positioned in the basal portion of the septum. By courtesy of A.Spampinato, M.D.

9.3 Right Ventricular Lead

The ventricular lead is usually positioned in the right ventricular apex. The most utilized fixation system is the one with tines.

The catheter, with the wire inserted, is pushed forward into the right atrium via the superior vena cava, using a posteroanterior projection. Leaving the catheter in site, the stylet is taken out and bent in its distal portion. The bent stylet is inserted again so that the catheter acquires a distal curve which makes crossing the tricuspid valve easier (Figures 9.14 and 9.15). Once the tip of the catheter is within the ventricle, the curved stylet is replaced with a straight one to allow the catheter to straighten and to advance toward the apex. Sometimes

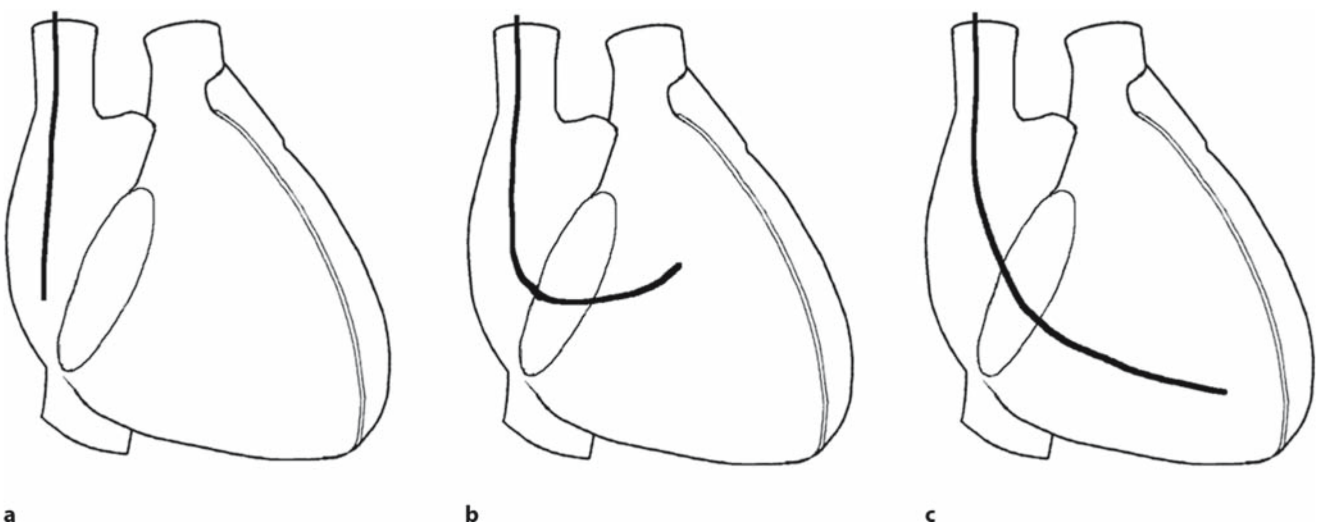


Figure 9.14 Panel a The catheter is advanced to the inferior third of the right atrium and the stylet to the catheter's distal end. Panel b The preshaped guidewire is inserted and the catheter crosses the tricuspid valve. Panel c The curved guidewire is withdrawn and the catheter spontaneously falls on the inferior wall of the right ventricle

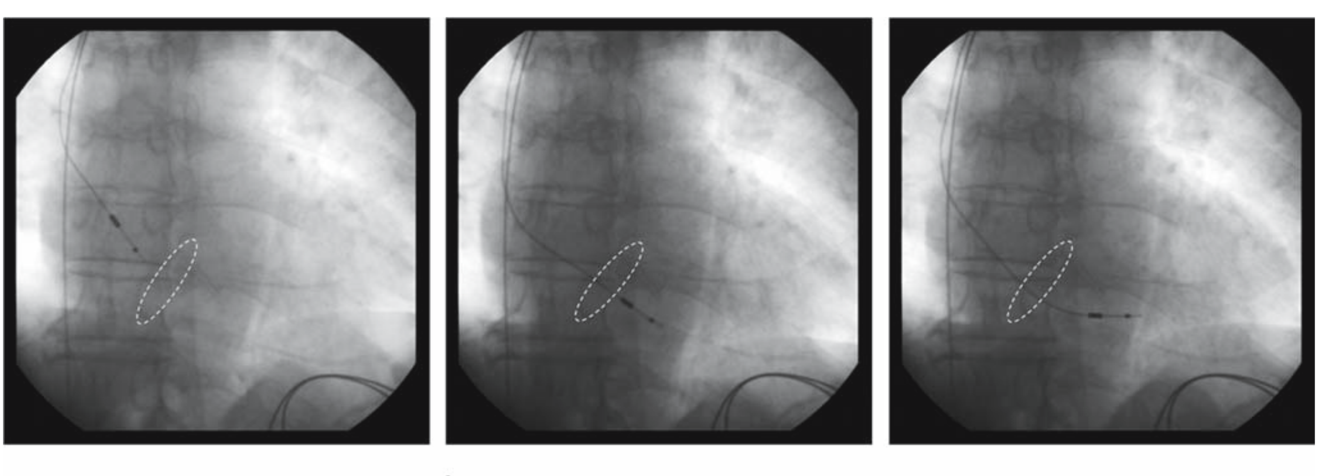
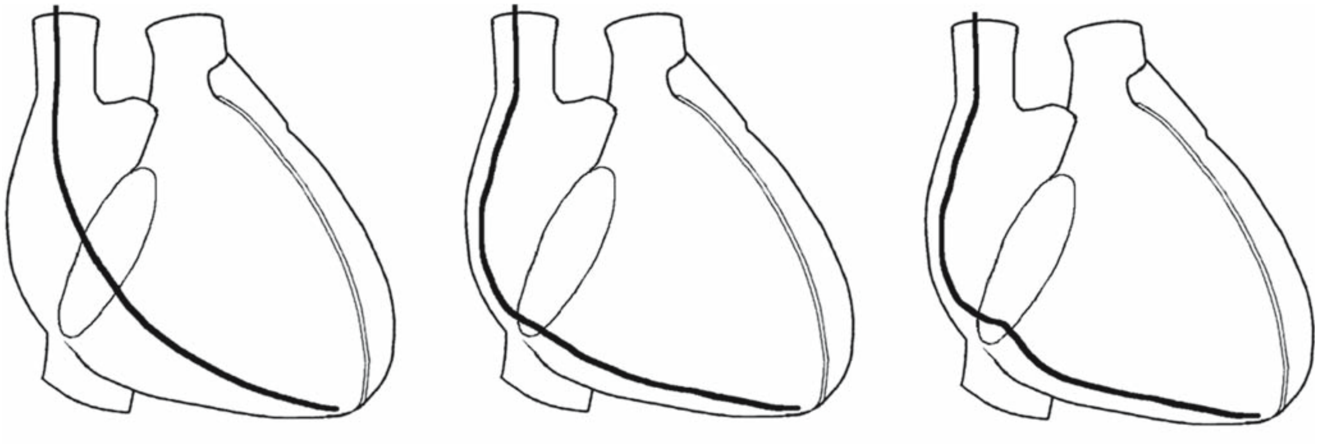


Figure 9.15 Positioning of the catheter in the right ventricular apex. The dotted line shows the tricuspid valve

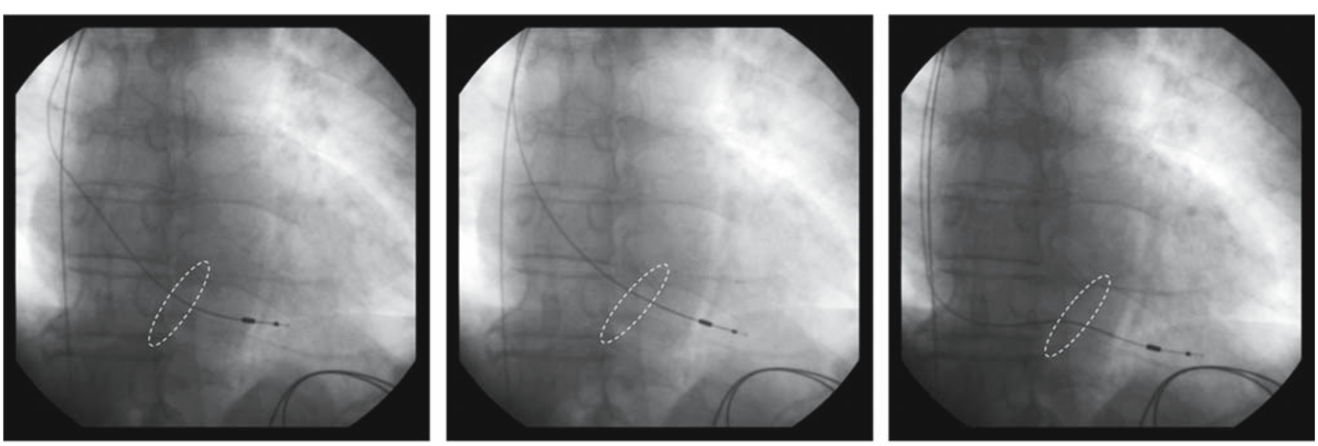


a b c

Figure 9.16 Panel a The straight guidewire moves the catheter toward the ventricular apex. Panel b The stylet is pulled back while the catheter is advanced to the ventricular apex. Panel c A soft curve within the right atrium improves lead stability

a slight withdrawing of the stylet makes the catheter tip softer for better positioning (Figures 9.16 and 9.17).

Frequently, crossing the tricuspid valve becomes difficult since the catheter tip, with its hook-like protrusions, holds on the valve cusps; in such a case, with the stylet slightly with-



a b c

Figure 9.17 The frame sequence documents the catheter's correct positioning in the right ventricular apex

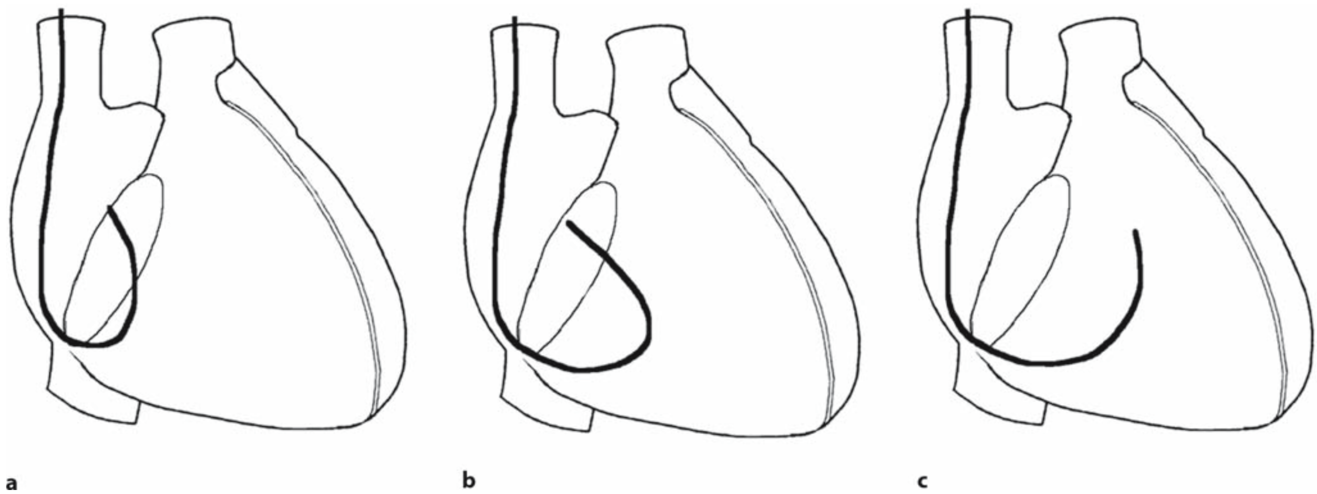


Figure 9.18 Panel a The catheter tip holds on the tricuspid cusps. Panel b After withdrawing of the guidewire to the level of the superior vena cava, the catheter is pushed to make a loop within the ventricle. Panel c The stylet is advanced and, simultaneously, the catheter is pulled back to move it out of the tricuspid cusps

drawn, a wide loop of the lead is made in the atrium and the catheter pushed in the ventricle with the loop (Figures 9.18 and 9.19). This maneuver prevents tricuspid valve from traumas, but frequently induces ventricular ectopic beats. Subsequently, by simultaneously advancing the stylet and withdrawing the catheter, the tip falls on the inferior wall of the

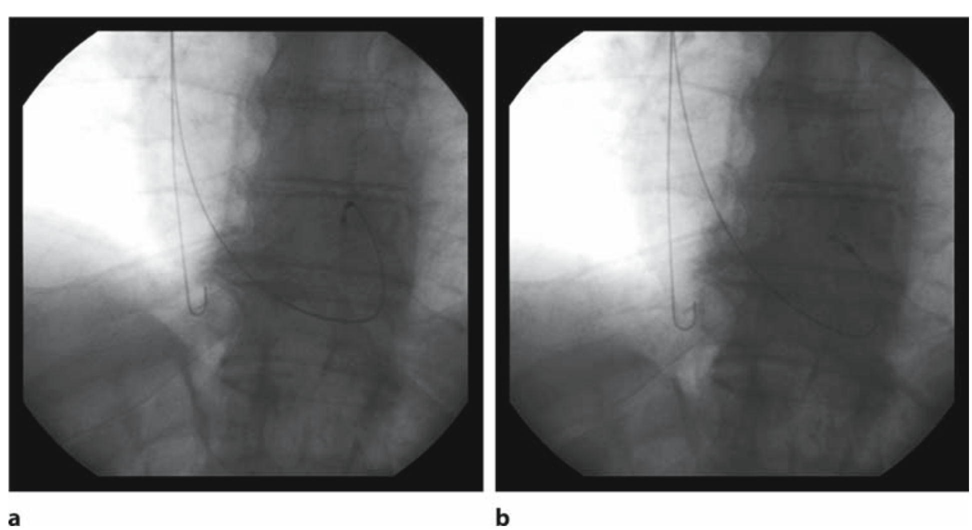
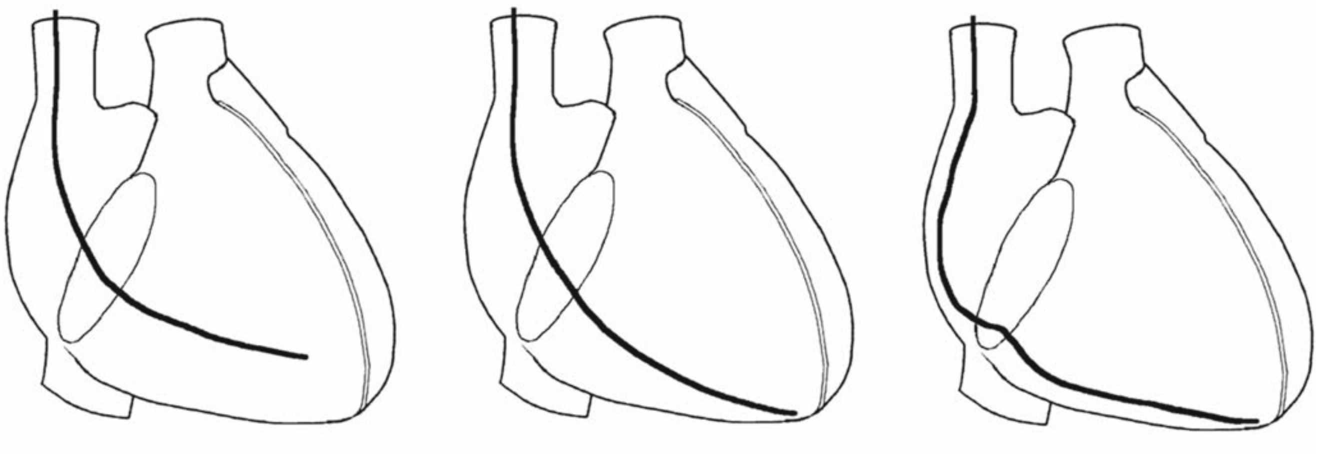


Figure 9.19 The catheter crosses the tricuspid valve with the loop

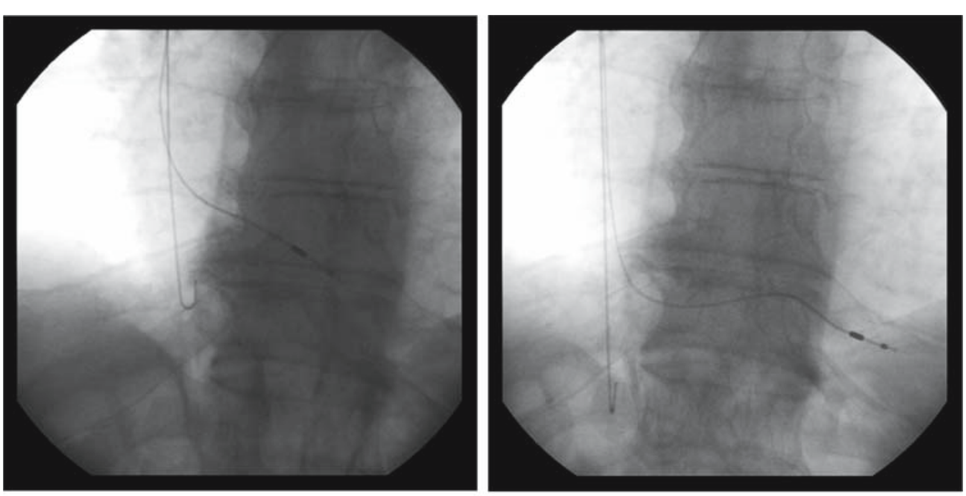


a b c

Figure 9.20 Panel a By advancing the guidewire, the catheter turns toward the ventricular apex. Panel b The straight guidewire moves the catheter toward the ventricular apex. Panel c The guidewire is taken out while slightly pushing the catheter toward the ventricular apex

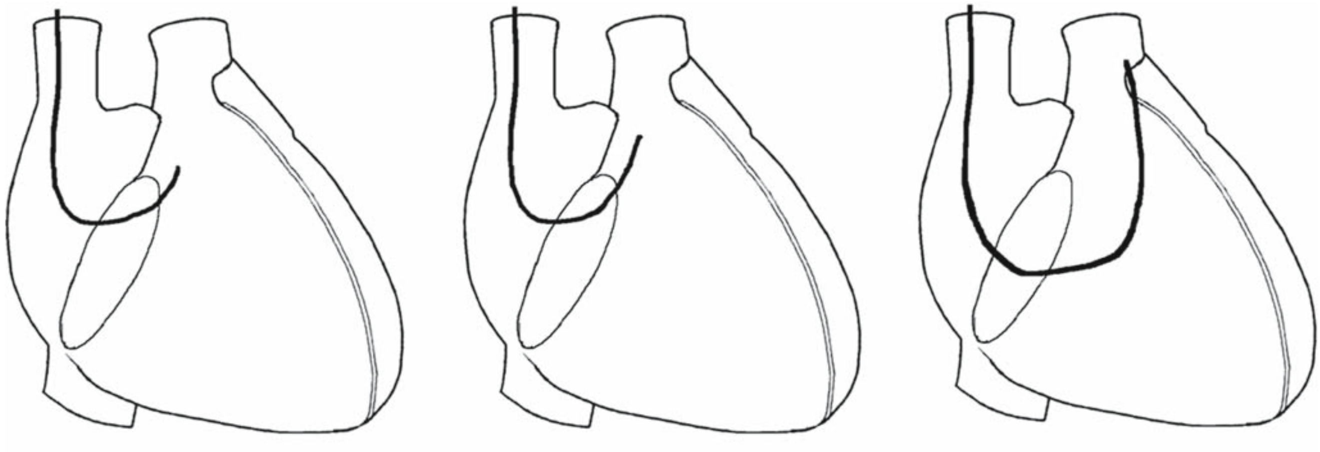
ventricle and may be positioned at the apex (Figures 9.20 and 9.21). A stable catheter position is confirmed by asking the patient to breathe deeply and cough.

Another technique to position the lead at the right ventricular apex is to move the catheter in the right outflow tract or the pulmonary artery by using a preshaped stylet with a wider curve (Figures 9.22 and 9.23). Then, by simultaneously advancing a straight stylet and withdrawing the catheter, the lead falls on the inferior ventricular wall and may be positioned at the apex (Figures 9.24 and 9.25).



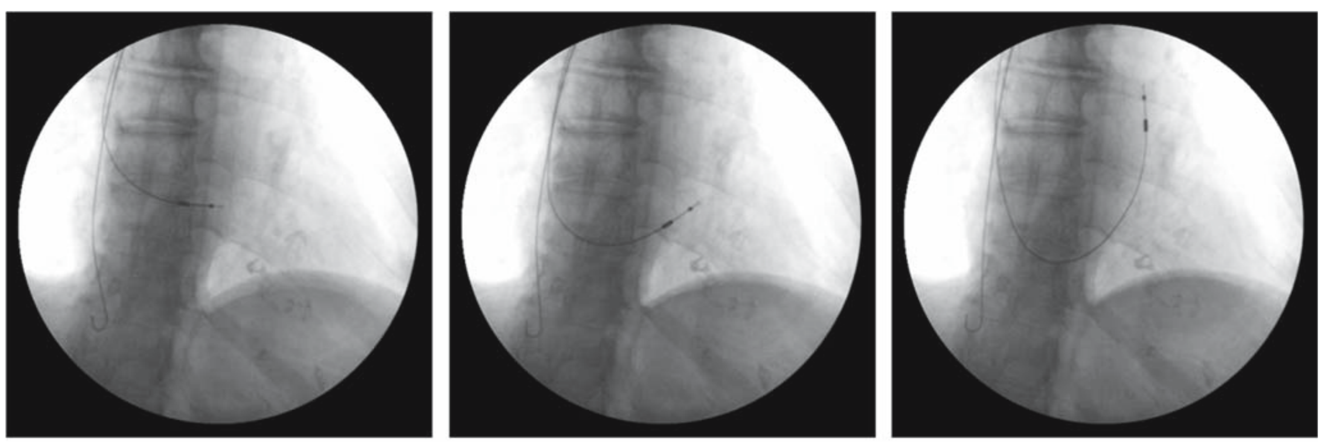
a b

Figure 9.21 The correct position of the ventricular catheter in the right ventricular apex



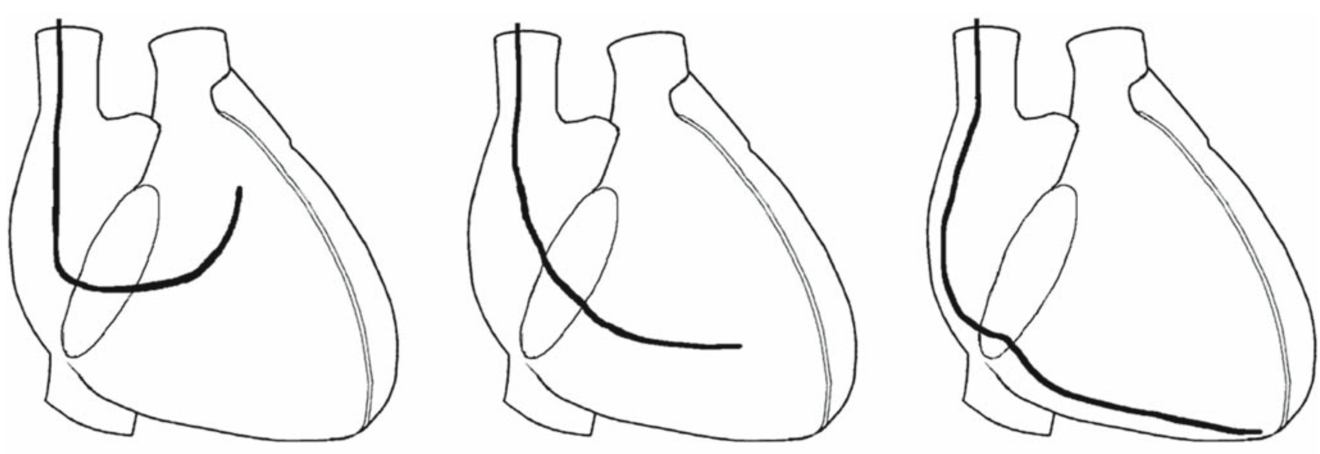
a b c

Figure 9.22 The correct positioning of the ventricular catheter in the outflow tract



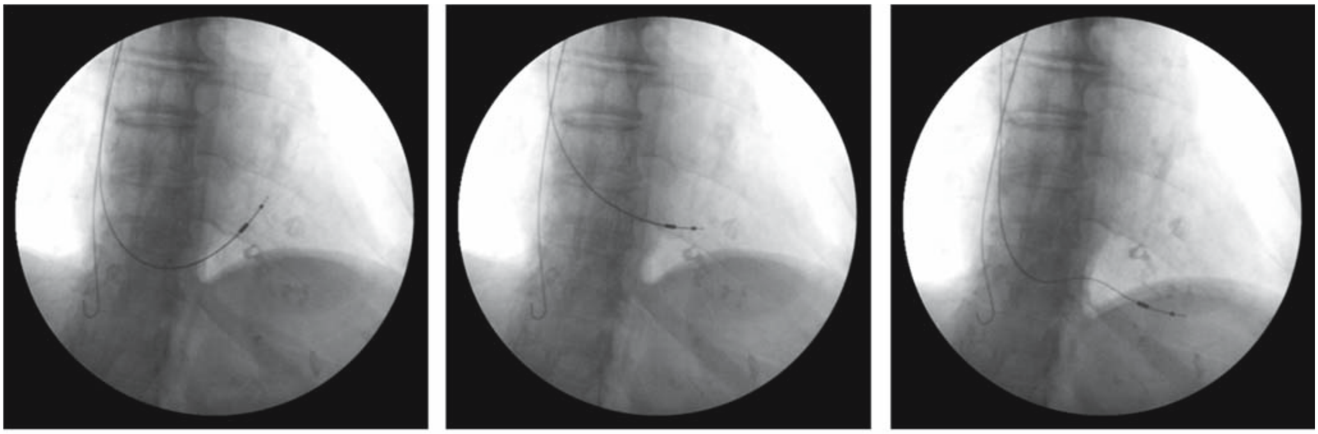
a b c

Figure 9.23 X-ray projection showing the catheter positioned in the right ventricular outflow tract as drawn in Figure 9.22



a b c

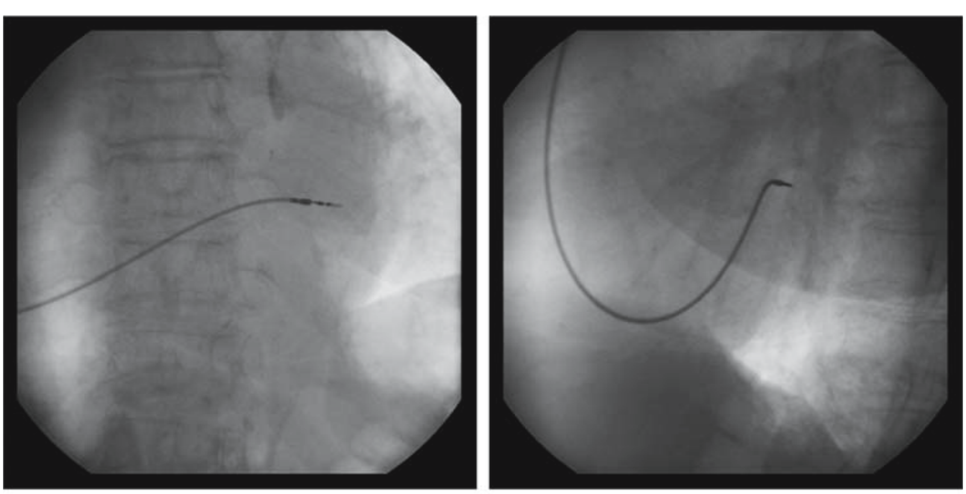
Figure 9.24 From the right ventricular outflow tract, the catheter is progressively withdrawn (panel a) and moved toward the right ventricular apical region (panel b); panel c shows the definite positioning of the catheter at the right ventricular apex



a b c

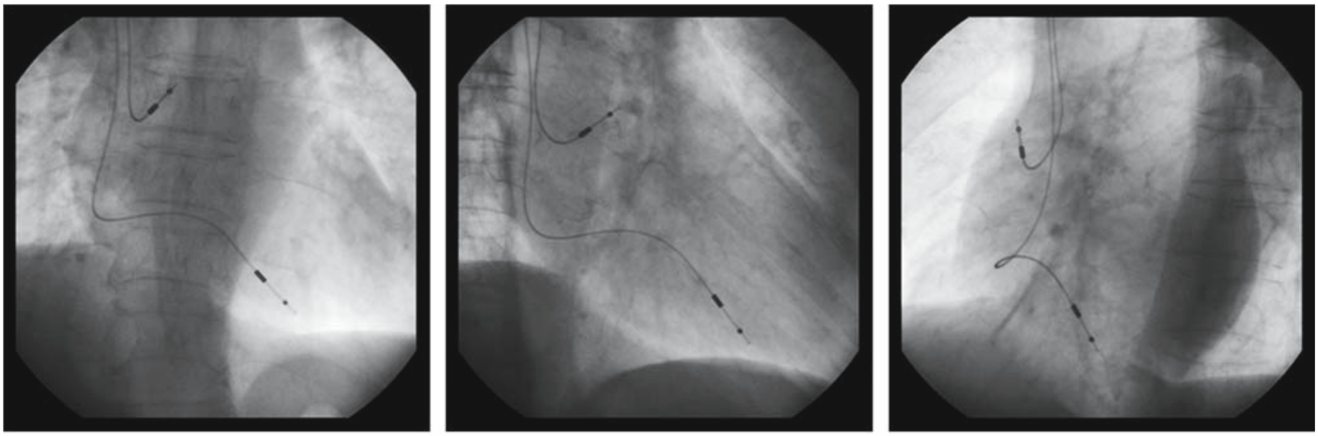
Figure 9.25 Drawn schemes showing the catheter positioned in the right ventricular outflow tract as Figure 9.24 corresponding radioscopic sequence

The right ventricular outflow tract is rarely chosen as a site of pacing. In these cases, a catheter with screw fixation system must be used. The catheter is inserted into the ventricle by means of either reported technique. With the catheter within the ventricle, a stylet with its distal portion bent in a "U-like" shape is inserted to force the catheter to bend upward. The catheter is advanced into the pulmonary artery and, then, slowly drawn back within the right ventricular outflow tract. The tip is positioned on the pulmonary infundibulum and fixed by screwing the metallic spiral into the myocardium (Figure 9.26). Lead stability is ascertained by slightly pulling the catheter in order to perceive a minimum tightening, which is rhythmic according to the cardiac contraction.



a b

Figure 9.26 Radiologic images of catheter (active fixation) positioning in the right ventricular outflow tract in the right anterior oblique (*RAO*) projection (panel a) and in the right anterior oblique (*LAO*) projection (panel b)

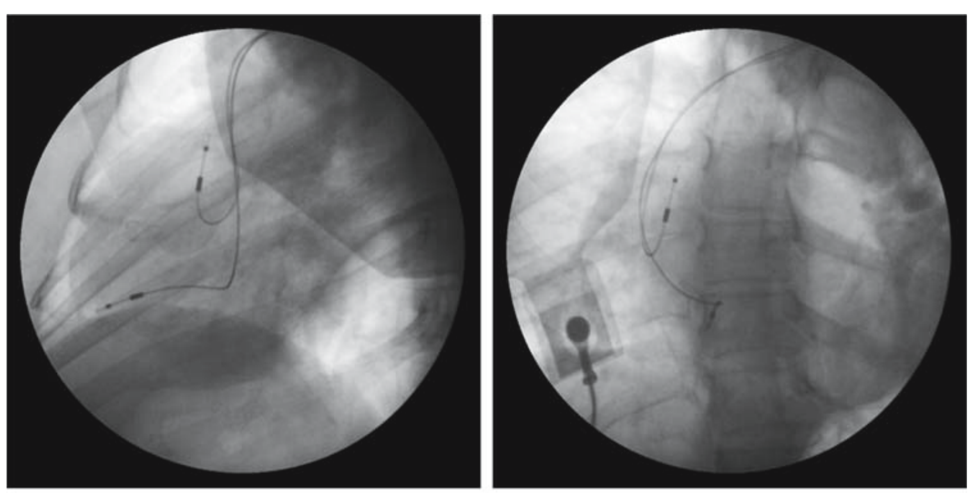


a b c

Figure 9.27 Dual-chamber pacemaker. Posteroanterior (*PA*) (panel a), right anterior oblique (*RAO*) (panel b), and left anterior oblique (*LAO*) (panel c) views of definite positioning of atrial (right atrial appendage) and of ventricular (ventricular apex) catheters (passive fixation)

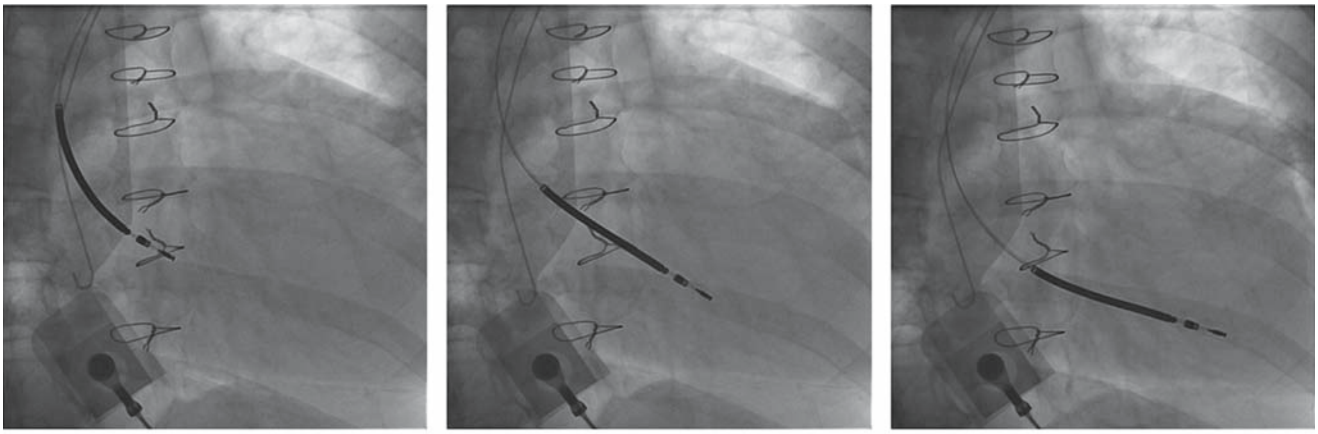
The correct and final positioning of the right atrial and ventricular catheters in different radiologic views is shown in Figures 9.27 and 9.28.

Techniques for positioning ventricular catheters of defibrillation devices are identical to those used for standard pacemakers; difference is absolutely an easier positioning, due to major stiffness of ICD catheters (Figures 9.29 and 9.30).



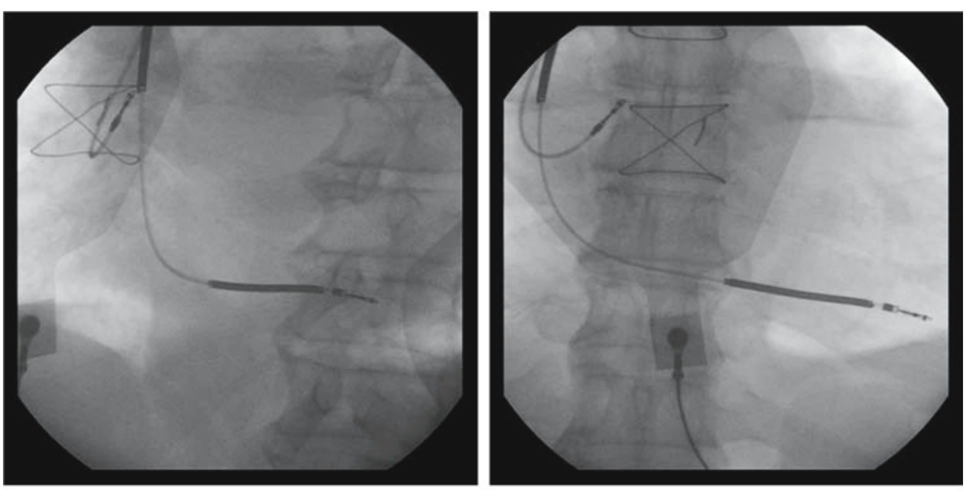
a b

Figure 9.28 Dual-chamber pacemaker in a patient with myotonic dystrophy and dextrocardia



a b c

Figure 9.29 Positioning of monocoil implantable cardioverter defibrillators (*ICDs*) lead in the right ventricle. Panel a: the catheter is in the right atrium. Panel b: the catheter has crossed the tricuspid valve. Panel c: the catheter is in the right ventricular apex



a b

Figure 9.30 Dual-chamber implantable cardioverter defibrillators (*ICDs*). The ventricular catheter is positioned with the distal coil at the right ventricular apex and the proximal coil in the superior vena cava. Posteroanterior (*PA*) (panel a) and right anterior oblique (*RAO*) projections (panel b) are shown

10

Biventricular Pacemaker and Implantable Cardioverter Defibrillator

10.1 Anatomy of the Coronary Sinus

The cardiac venous system consists of the coronary sinus (CS) and its affluent veins system (Figures 10.1–10.3). The CS is a vessel about 3–4 cm long and about 10 mm wide. It originates from the lower third segment of the septal wall of the right atrium; anteriorly, bordering on the septal cuspid of the tricuspid valve and, posteriorly, on the Eustachian valve. At the CS ostium a valvular structure may be present, the Thebesian valve; this valve, usually covering not more than one third of the ostium, extends on the inferior and posterior border of the CS ostium such that the orifice needs to be accessed from the anterosuperior direction. The CS tracks a superficial and gently curving venous channel adjoining the inferior wall of the left atrium that runs parallel to the free margin of the mitral valve annulus at a distance of about 1 cm. The venous end of the CS is marked by the junction of the tributary atrial vein of Marshall or its ligamentous remnant; in case of their absence, the CS ends at the Vieussens valve and continues as the great cardiac vein. The Vieussens valve is a very flimsy valve with one to three leaflets that sometimes offer slight resistence on probing. The site of this valve may be occasionally marked externally by a small constriction. The major tributaries of the CS are the great cardiac vein (GCV) or anterior interventricular vein; posterior, posterolateral, or lateral cardiac veins; the middle cardiac vein, also named posterior interventricular vein; and the right coronary vein. Furthermore, atrial veins also enter the CS.

Distally, the CS continues into the great cardiac vein (GCV), its most important tributary vein. The GCV begins as the anterior interventricular vein at the apex of the heart, running parallel to the anterior descending artery along the anterior interventricular septum. As the anterior interventricular vein reaches the left atrioventricular groove, it turns leftward and forms the base of the triangle of Brocq and Mouchet with the two branches of the left coronary artery, the left anterior descending coronary artery and the left circumflex coronary artery. Then, the GCV follows the left atrioventricular groove passing under the left atrial appendage. At this point, the GCV lay in close relationship to the left circumflex coronary artery, being proximally inferior, then superficial, and finally superior to the artery; the GCV may kink at the level of being crossed by the artery, resulting in a slightly luminal constriction. Finally, the GCV follows

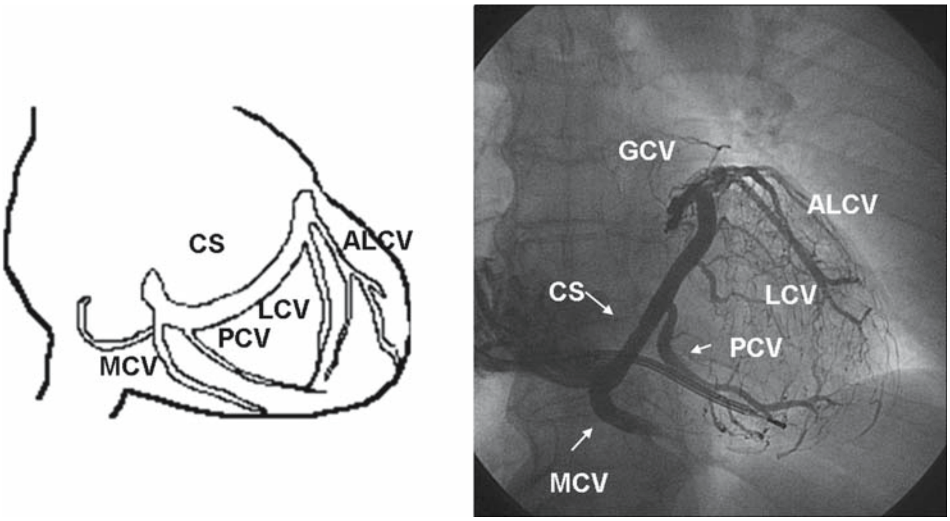


Figure 10.1 The posteroanterior (*PA*) view of the venous system of the heart. The coronary sinus (*CS*) and its branches are represented. *MCV*: middle cardiac vein. *PCV* posterior cardiac vein, *LCV* lateral cardiac vein, *GCV* great cardiac vein, *ALCV* anterolateral cardiac vein

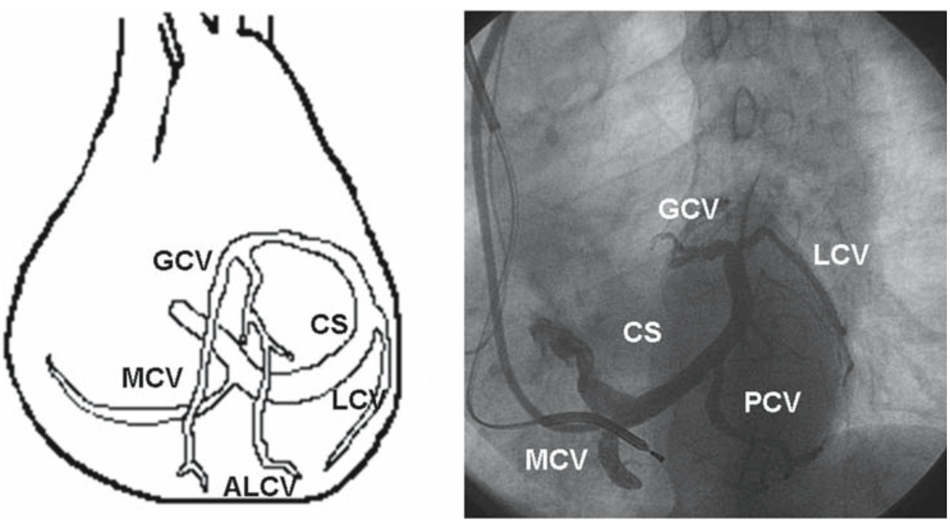


Figure 10.2 The left anterior oblique (*LAO*) view of the coronary sinus (*CS*) and its branches. This projection helps a better view of the posterior and lateral veins

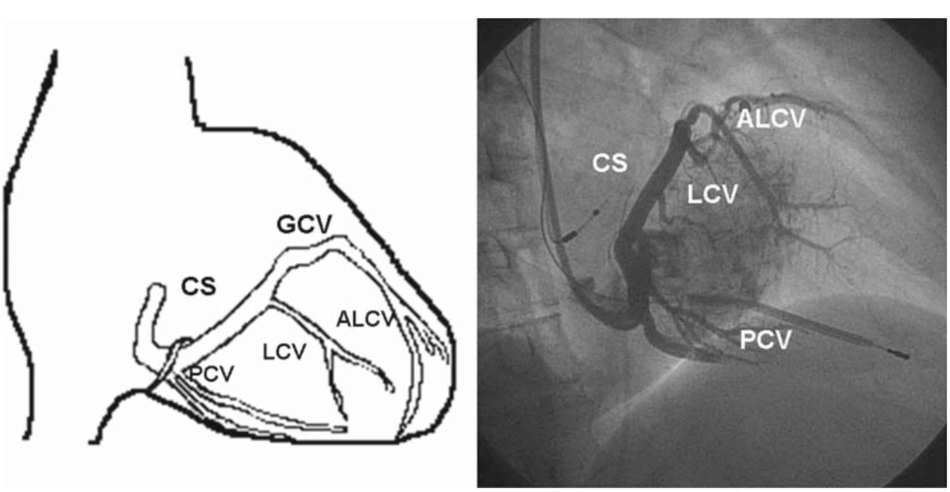
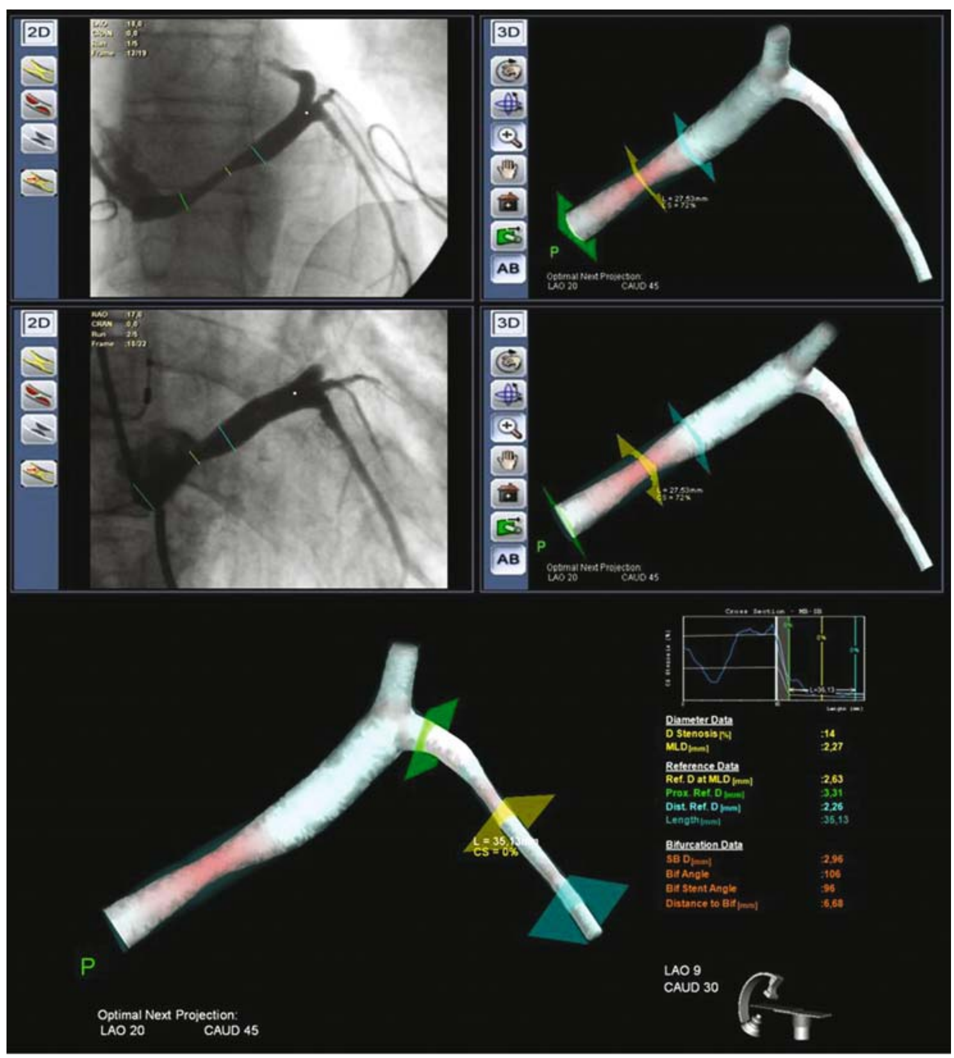


Figure 10.3 The right anterior oblique (*RAO*) view of the cardiac venous system

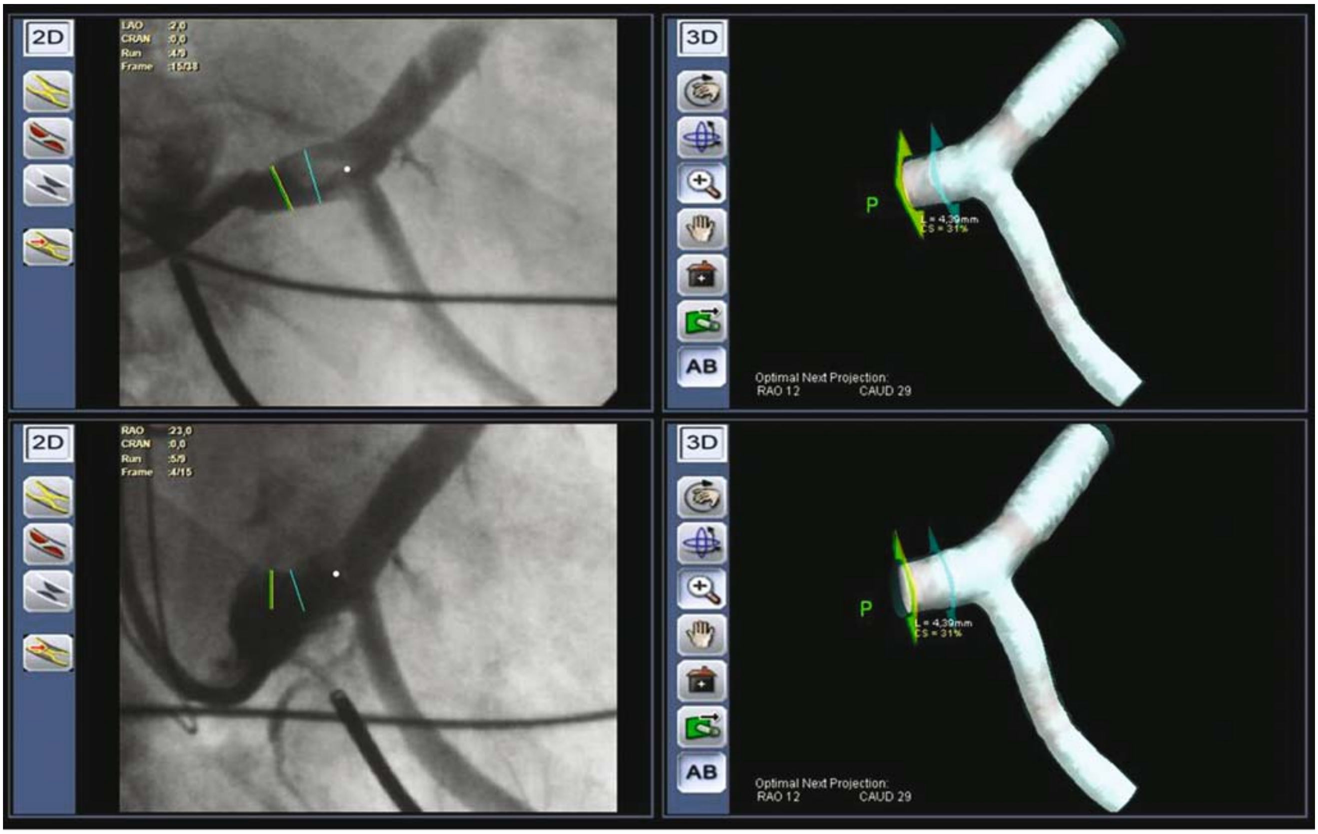
the left atrioventricular groove till the Vieussens valve. During its course, the GCV is joined by numerous venous branches from the posterior, posterolateral, or lateral cardiac veins. Usually, the proximal portion of these veins is large enough for inserting pacing leads but, in some cases, the diameter of the veins, their angulation, or tortuosity may interfere or preclude access to target areas. Furthermore, the anterior interventricular vein, the left oblique marginal vein, and the lateral veins may run in close proximity to the course of the left phrenic nerve determining nerve stimulation; in case it is impossible to stimulate the myocardium without stimulating the phrenic nerve, an alternative pacing target area needs to be found. Finally, it should be considered that the tributary veins are usually devoid of myocardial sleeves (the CS has a myocardial coat composed of sleeves from both the left and the right atrium wall), and the maneuvers for inserting pacing leads have to be very soft.

The middle cardiac vein runs along the posterior interventricular septum, then goes inferiorly along the interventricular septum's epicardium to convey blood flowing back from the posterior septum and from the ventricles' posterior wall into the proximal portion of the CS. Its entrance into the CS is close to the CS ostium; occasionally, the venous entrance may be dilated forming a diverticulum; in rare cases, this vein enters into the right atrium directly. This vein is of adequate size to insert a pacing lead remembering the close proximity to the right coronary artery and its branches to avoid inadvertent damage (Figures 10.1–10.4).



a

Figure 10.4 Digital reconstruction of the coronary sinus (*CS*) branches with the Paeion system 3-D vessel reconstruction. With this reconstruction the angles and sizes of collateral vessels are better visualized. Panel a: the lateral cardiac vein (*LCV*) and its bifurcation from the main CS are visualized. Panel b the posterior cardiac vein (*PCV*) and its origin are reconstructed



b

Figure 10.4 (continued)

Among atrial tributary veins, a particular importance for electrophysiologists is the vein of Marshall, a little vein deriving from embryonal left superior vena cava. The vein of Marshall originates from the intermediate portion of the CS, and it directs posteriorly and obliquely through the posterior wall of the left atrium between the left pulmonary veins and the left atrium appendage.

10.2 Equipment for Coronary Sinus Cannulation: Guiding Sheaths

The equipment used to enter the CS and to reach the most appropriate vein for left ventricular (LV) pacing plays a crucial role in cardiac resynchronization therapy (CRT).

The guiding sheath (or CS sheath) is designed to give support in reaching the CS, in a continuous and steady way, as the sheath represents the channel through which we insert the lead and the guiding instruments to maneuver the lead itself and to get to the left ventricle's chosen stimulation site.

The guiding sheath is a cylindrical sheath made of a sufficiently stiff material for allowing twisting and maneuverability control, but having atraumatic characteristics, mainly in the distal section, so as to minimize risks of lesions for endocardiac and venous tissues (lesions of internal venous coat, dissections, and perforations).

Given the great variability of the CS anatomy in both normal and pathologic conditions (most usually post-CABG and valve replaced patients), guiding sheaths with different curves and lengths have been developed in order to reach the ostium of the CS and to

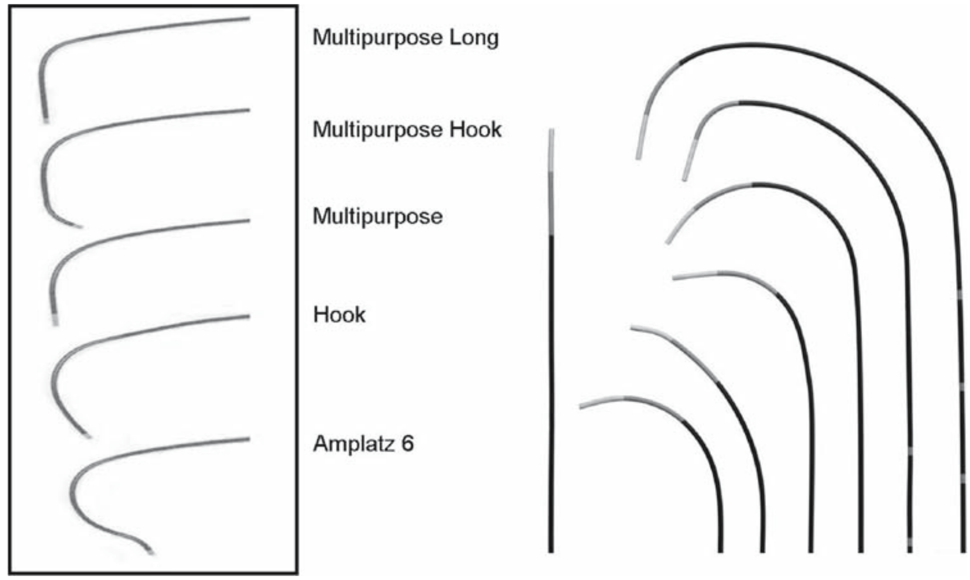


Figure 10.5 Different curves of guiding sheaths to cannulate the coronary sinus (*CS*) from the left side

ensure the best support to enter it, and with different diameters for insertion of diagnostic electrophysiologic (EP) catheters and Swan-Ganz type catheters (usually ranging between 3 Fr and 7 Fr) (Figure 10.5).

Specific guiding sheaths exist for the right subclavian vein access usually employed in exceptional cases, such as infection of implantations placed in the left pectoral site, occlusions of the left venous system, etc. (Figure 10.6). Their design is different in order to take advantage from the support offered by anatomic structures existing along the path (i.e., the superior vena cava).

Guiding sheaths' length usually ranges between 45 cm and 60 cm (the most complete systems give different sizes in order to allow employment for subjects with different heights and for hearts of various volumes).

Besides fixed curve guiding sheaths, "deflectable" sheaths are also available, whose curve can be modified according to requirements (Figure 10.7). Possible advantages to obtain are as follows:

- major flexibility and reduction of cannulation times of the CS,
- selective venograms without a Swan-Ganz catheter's aid, and
- guidewires positioning in otherwise difficult anatomic sites, so as to be able to advance, afterwards, the lead in a quick way toward the desired site.

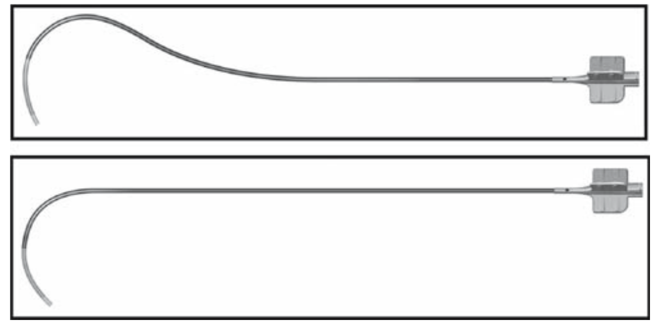


Figure 10.6 Specific preshaped guiding sheaths for the coronary sinus (*CS*) cannulation in the right side approach

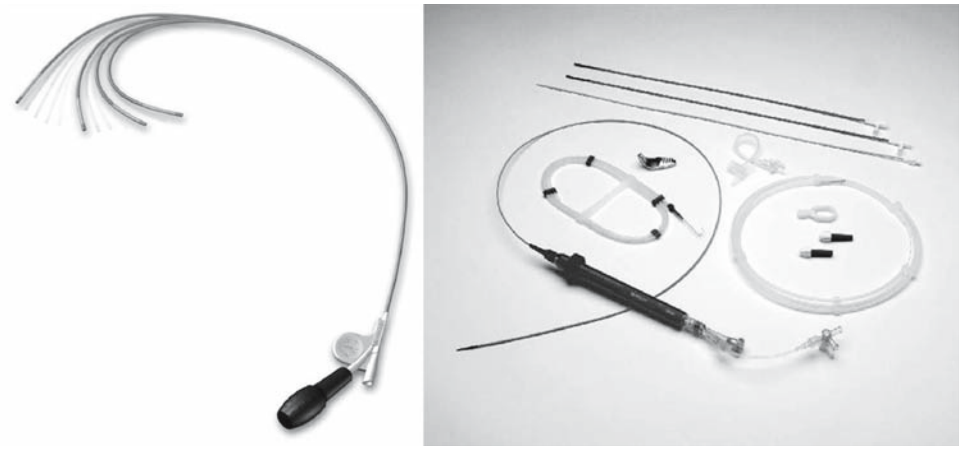


Figure 10.7 Deflectable guiding sheaths which are adaptable to different curves and different needs for the coronary sinus (*CS*)

Once the lead is positioned, guiding sheaths can be pulled out with a special "sleigh" instrument or "peel-away" (opened at the proximal end and peeled, like a "banana skin," Figure 10.8).

Besides single guiding sheath systems, there exist some with double catheter (inner or outer, Figure 10.9) telescopic systems. These catheters are made in such a way that we can insert the one within the other, thus making a guiding sheath with caliper equal to the inner catheter's one and being able to have three degrees of liberty instead of only two.. Inner catheters, straight or with distal curves having different angles, are suggested for CS cannulation and the selection of the target cardiac vein. In detail, the straight catheter, thanks to its soft and tapered tip, is thought for overcoming stenosis and vein narrowing. Catheters

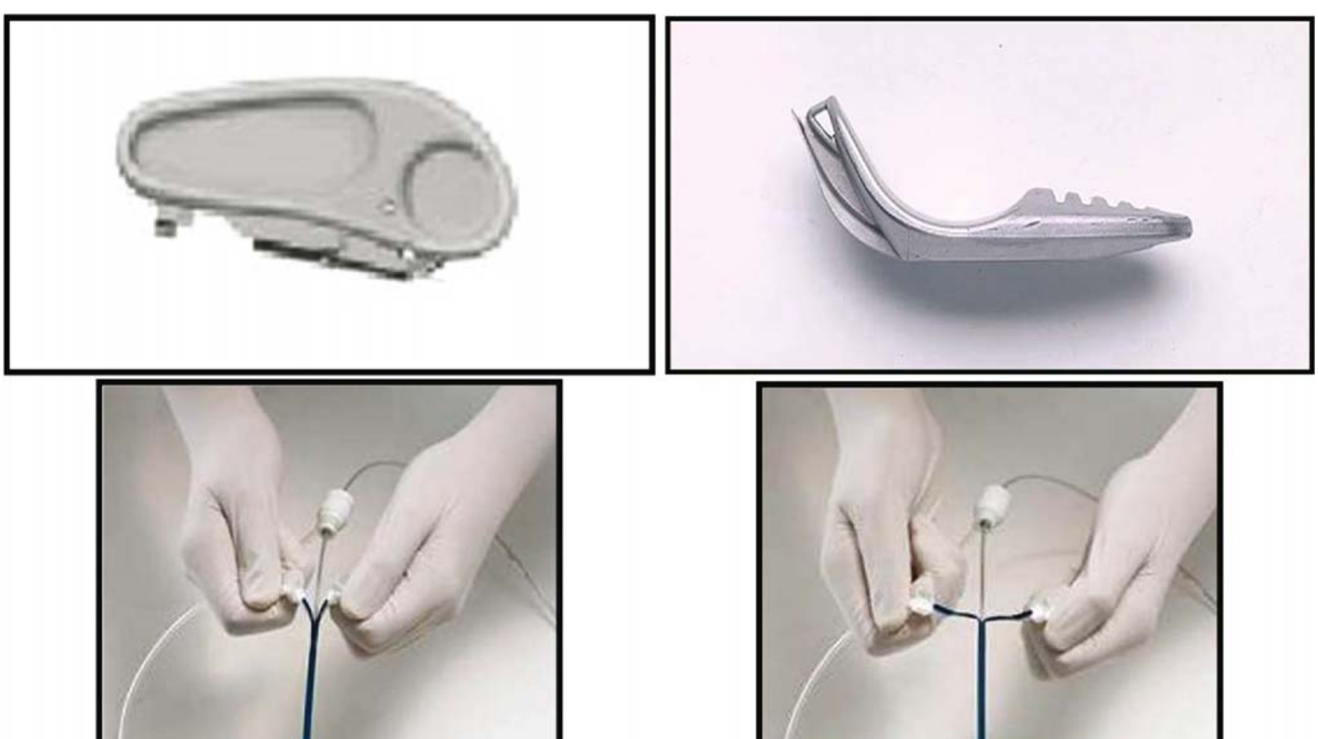


Figure 10.8 Removal of a peel-away guiding sheath. In the upper quadrant a sleigh to help cutting the sheath whenever it cannot be peeled away

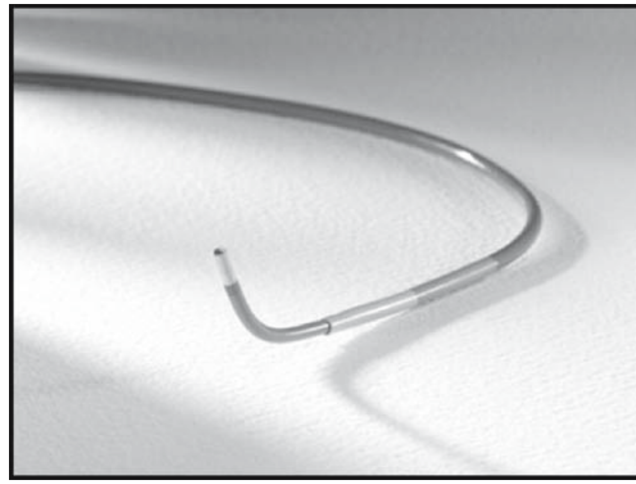


Figure 10.9 A double system of catheters sliding one over the other to help directly cannulating the target vessel

Figure 10.10 Different curves of inner catheters for different anatomical variants of the coronary sinus (*CS*) branches and angles

with curved tips are employed to cannulate those cardiac veins joining with the CS with such angles that make their selection difficult. The different curves of the inner catheter also make such maneuvers easier (Figure 10.10).

10.3 Coronary Sinus Cannulation Techniques

Coronary sinus cannulation is a crucial phase during implantation of a cardiac resynchronization device. A correct CS cannulation as well as an adequate positioning of the guiding sheath enables a better visualization of the target cardiac vein for the LV lead positioning. Two main techniques exist for such cannulation: the "electro-physiological" and the "hemo-dynamist". In the first one, an EP catheter with a suitable curve for CS anatomy (Figure 10.11) or even a deflectable catheter is used. Once the CS has been correctly cannulated (as discussed in Part II, chapter 3), it is suggested to position the EP catheter distally so as to make the guiding sheath slide on it (Figure 10.12); during this maneuver, the guiding sheath should not be removed from the CS until the EP catheter is definitely pulled back (Figure 10.13). Sometimes the CS

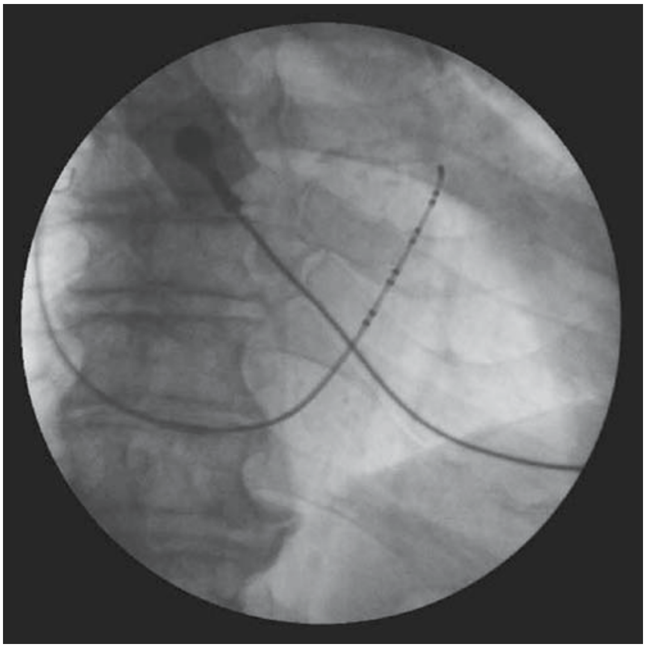


Figure 10.11 Electrophysiologic (*EP*) decapolar catheter positioned inside the coronary sinus (*CS*) through a guiding sheath

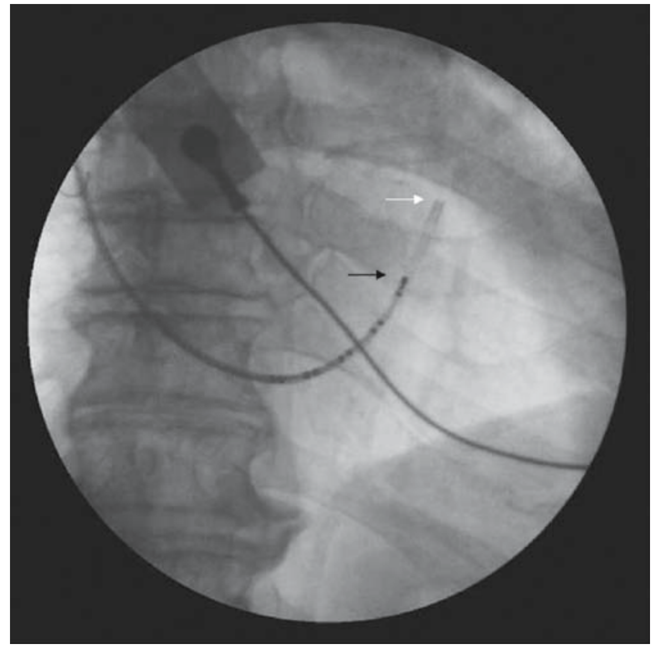


Figure 10.12 The electrophysiologic (*EP*) catheter (black arrow) is removed from the coronary sinus (*CS*) leaving the sheath (white arrow) in site

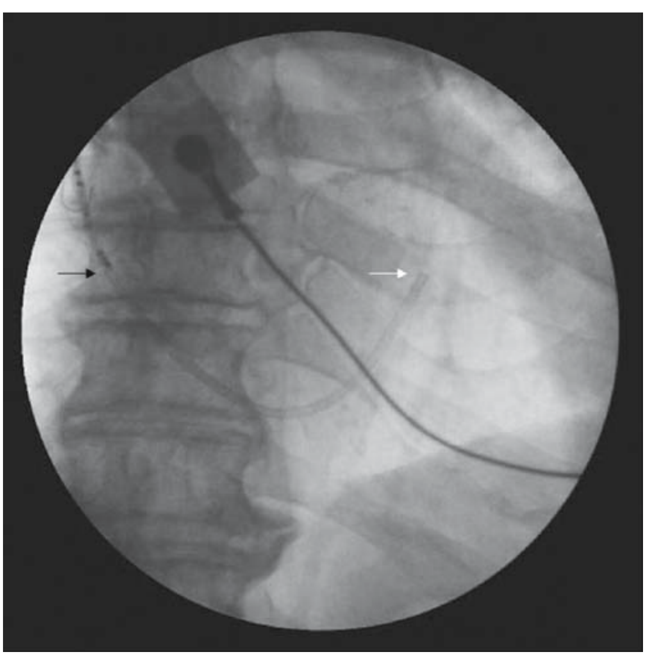


Figure 10.13 Only the sheath (white arrow) is left in place while the electrophysiologic (*EP*) catheter (black arrow) is at the level of the right atrium while being removed. The left anterior oblique (*LAO*) view

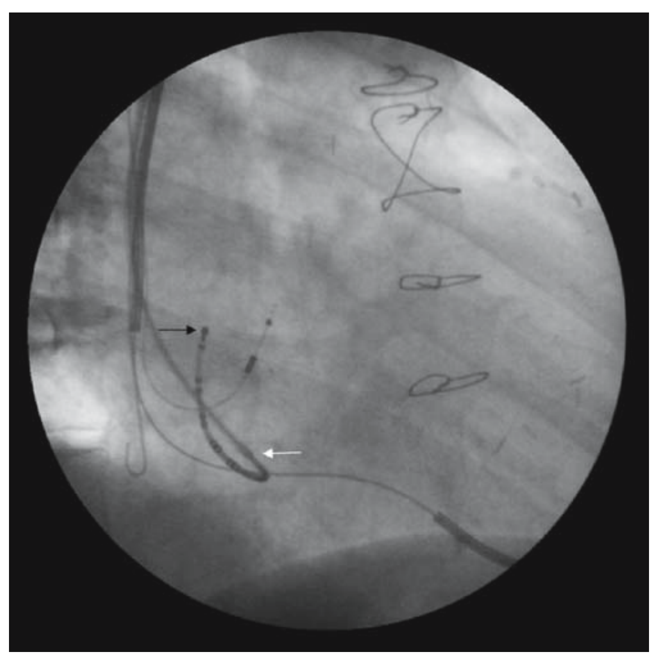


Figure 10.14 The right anterior oblique (*RAO*) view of the same previous picture. The electrophysiologic (*EP*) catheter (black arrow) helped to cannulate the coronary sinus (*CS*) and the guiding sheath (white arrow) has been advanced over it. Note how this view helps to understand the possible curves of the CS at its initial portion, which could get the maneuvre harder to perform

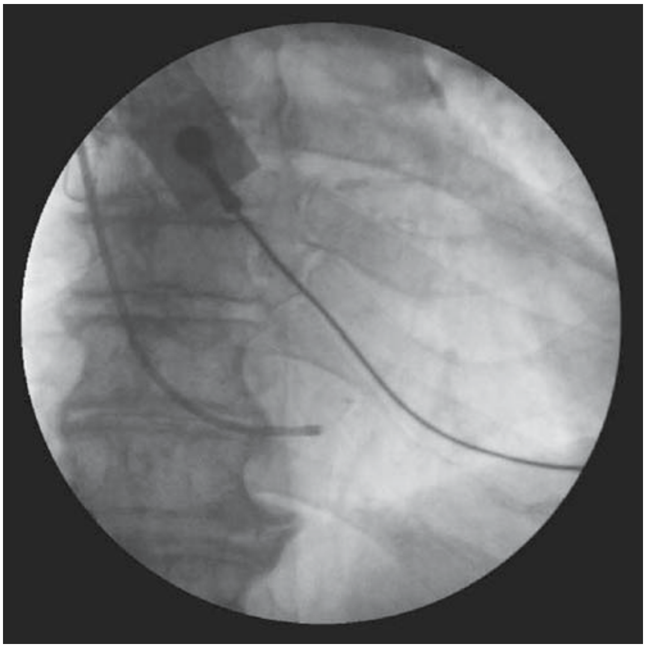


Figure 10.15 In the left anterior oblique (*LAO*) view, a different approach for the coronary sinus (*CS*): the "hemodynamist" technique

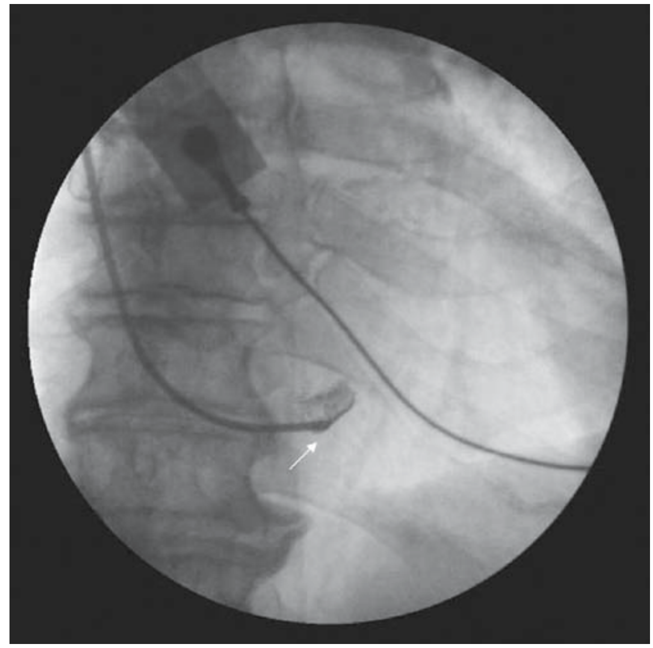
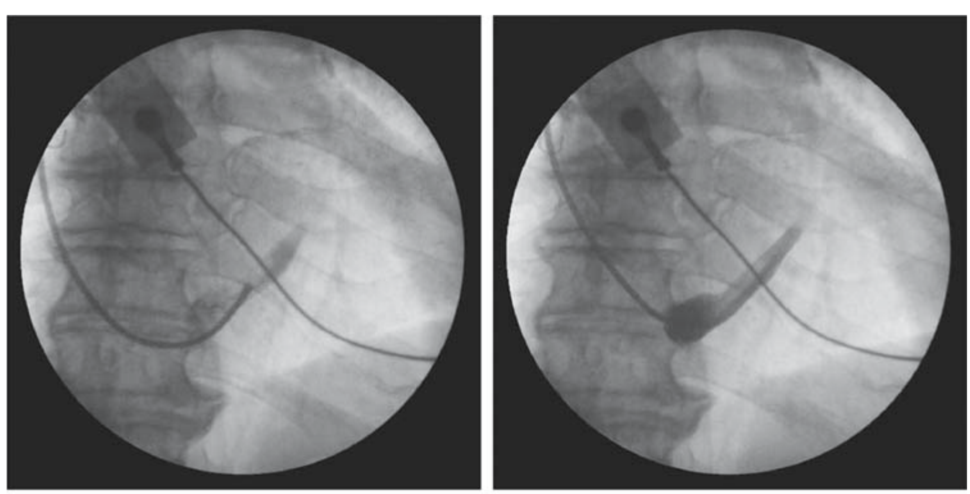


Figure 10.16 With the aid of the guiding sheath only, the operator approaches the coronary sinus (*CS*) ostium rotating the tip of the catheter and flushing dye along the sheath to help visualizing the ostium (white arrow)

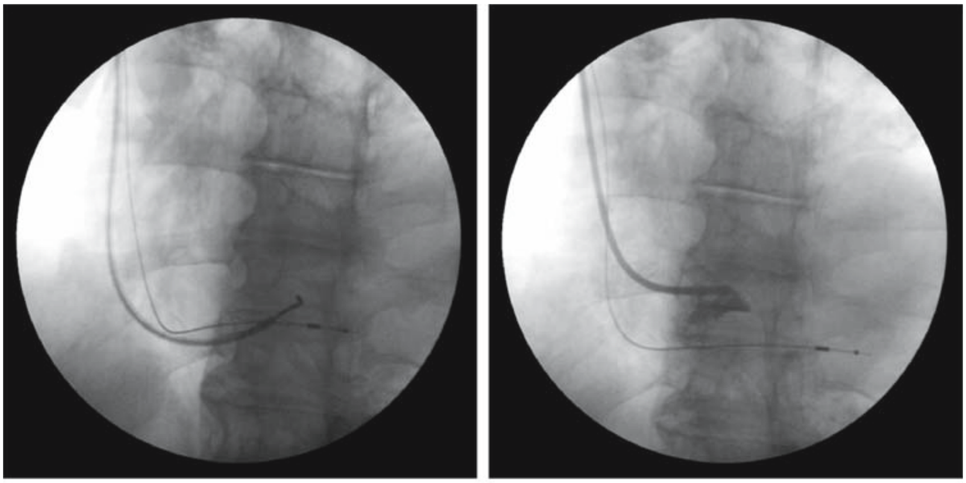
has curves hampering the crossing of a stiff catheter such as the guiding sheath. In such cases, it is advisable to position the guiding sheath using the right anterior oblique (RAO) projection (Figure 10.14); this view better visualizes the sinus curve and allows to make the guiding sheath slide over the EP catheter. Once the anatomic curve is overcome, the guiding sheath can be advanced employing the radioscopic left anterior oblique (LAO) view.

The second technique used for cannulation of the CS requires the so-called hemodynamist technique. With this approach, the guiding sheath is positioned close to the CS



a b

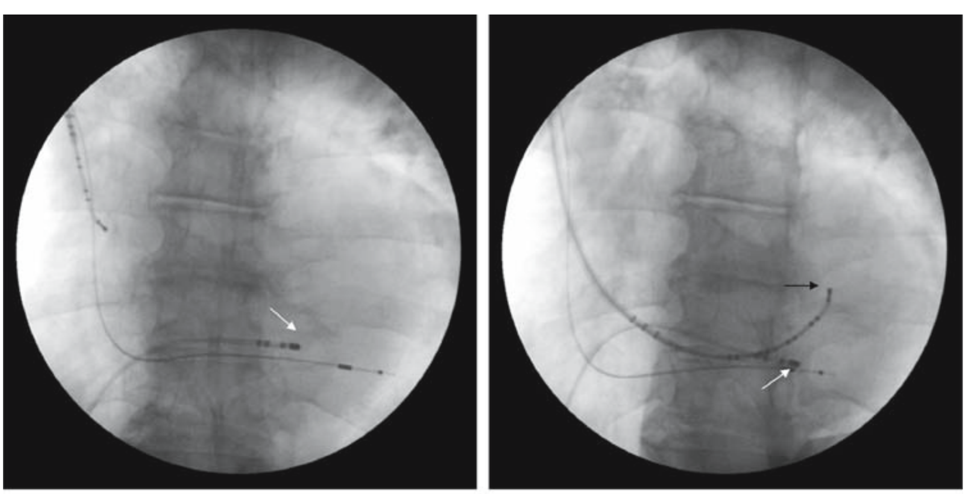
Figure 10.17 The left anterior oblique (*LAO*) view. Panel a A first dye scout is injected carefully to assess the patency of the vessel and to avoid dissection while injecting against its walls. Panel b A more powerful dye injection is made



a b

Figure 10.18 The left anterior oblique (*LAO*) view. In both panels a and b, a difficult case where none of the techniques helped to cannulate the coronary sinus (*CS*)

ostium, and when one has the feeling of being in close proximity of such a structure (Figure 10.15), it is advisable not to force but make a injection of contrast material to ascertain the existence of ostium (Figure 10.16). At this point only, it is convenient to advance the guiding sheath into the proximal CS verifying with a further minimum injection of contrast material the right positioning, being sure not to be on the wall before the final angiography (Figure 10.17).



a b

Figure 10.19 Same case as in Figure 10.18. A stiffer deflectable catheter, in this case an ablation catheter (white arrow), through a femoral approach (Panel a), is advanced in the coronary sinus (*CS*) to widen the entrance of the vessel facilitating the advancement of the electrophysiologic (*EP*) catheter (black arrow) from the subclavian vein into the *CS* (panel b)

Sometimes, in particular patients who underwent aortocoronary bypass or valve replacement, CS cannulation may be difficult with both techniques (Figure 10.18). In these cases, it is a useful suggestion to employ an approach via the right femoral vein and to insert a diagnostic deflectable EP catheter which is successful in engaging the CS by overtaking valves or curvatures caused by the previous cardiosurgical adherences (Figure 10.19).

10.4 Coronary Sinus Angiography

Once the guiding sheath is correctly positioned, it is possible to perform a CS angiography for a better view of its anatomy and to foresee the technical problems that may render positioning of the LV pacing lead difficult (small diameter of the target cardiac vein, steep angles between the CS and the target cardiac vein, presence of valves or tortuosities of the CS).

Before performing the final angiography, it is advisable to make a minimum injection of contrast material to verify the correct positioning of the guiding sheath (in order to possibly visualize all of the CS tributary cardiac veins) (Figure 10.20), or if it is necessary to position the guiding sheath more proximally (Figure 10.21). The next step is the injection of contrast

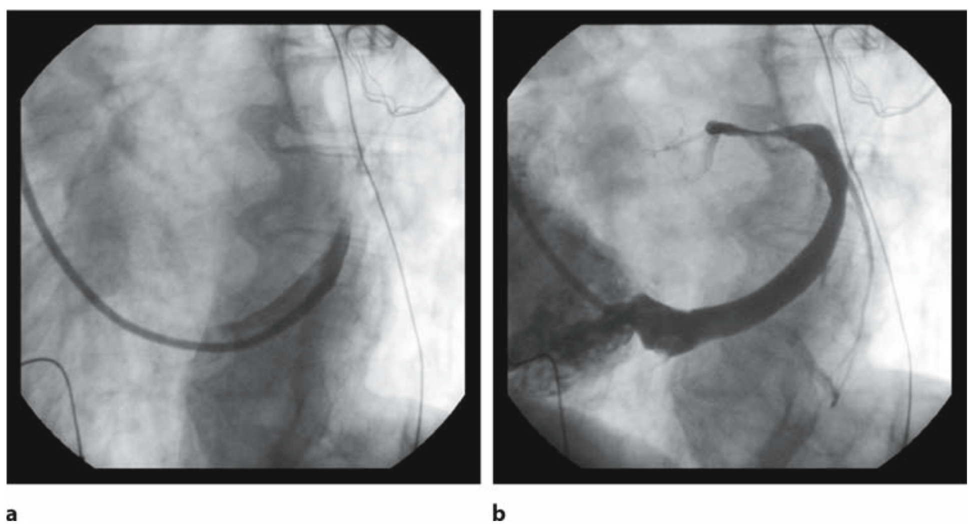


Figure 10.20 Small injections of dye (panel a are made to assess the correct position of the guiding sheath before the final angiogram (panel b)

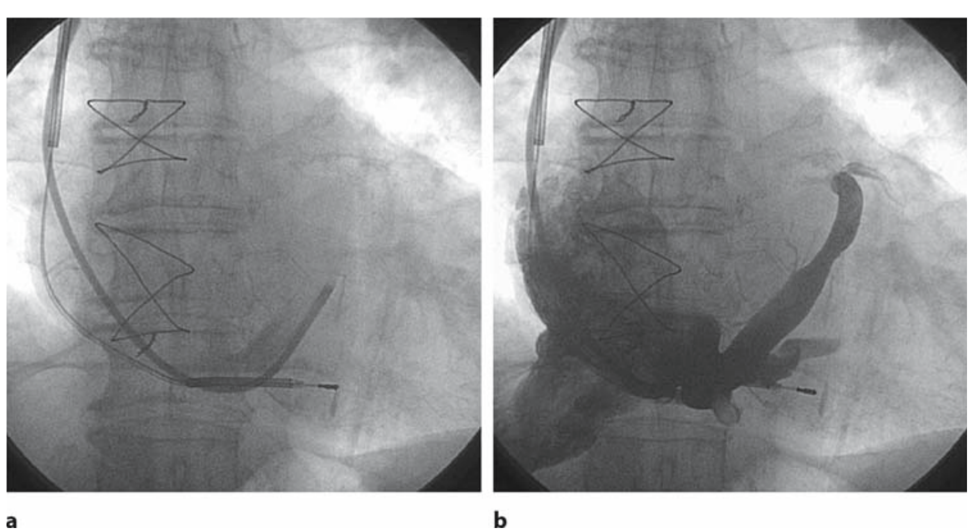
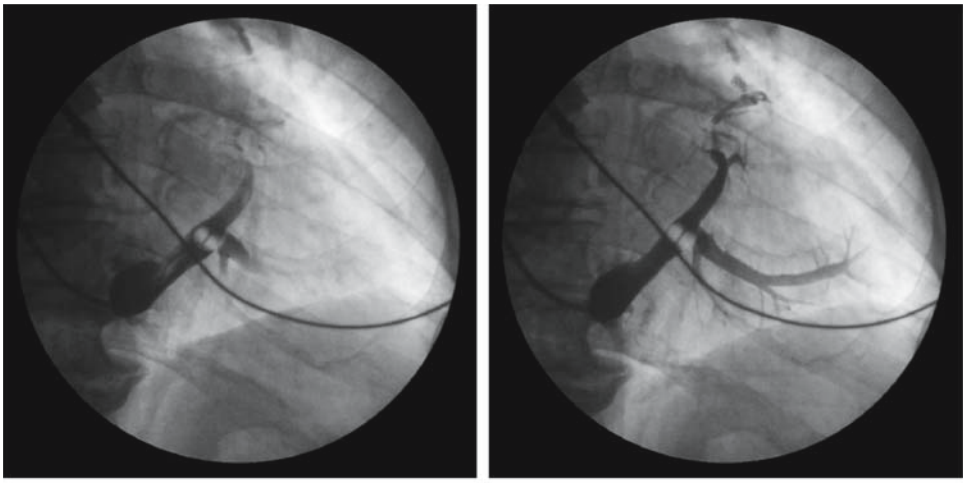


Figure 10.21 Panel a Some coronary sinus (*CS*) vessels are not visualized. Panel b Pulling back the sheath, a second injection allows better view of the posteriorlateral branches

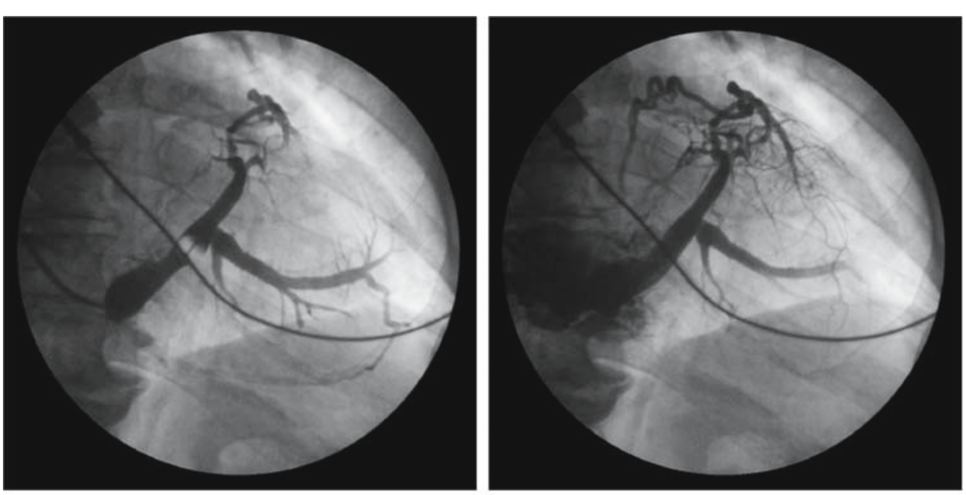


a b

Figure 10.22 The left anterior oblique (*LAO*) view. A Swann-Ganz catheter is positioned inside the lumen to obtain a better angiogram of the coronary sinus (*CS*) branches

material directly through the guiding sheath or by means of a Swann-Ganz catheter after inflation of 1–2 cc of air into a small balloon (Figure 10.22). In our experience, if one positions the guiding sheath correctly and exerts a firm pressure during the injection of the contrast material, in most cases the CS angiography is comparable to the one resulting from the Swann-Ganz catheter's aid (Figure 10.23).

A last warning to consider for a correct CS angiography is to always carry out at least two angiographic projections (30–45° LAO and 30–45° RAO) in order to better define the origin and direction of CS tributary cardiac veins (Figure 10.24).



a b

Figure 10.23 Same case as in Figure 10.22 with the coronary sinus (*CS*) angiogram performed with two different techniques, but both with the same results. In panel a with a Swann-Ganz catheter and in panel b with a powerful injection through the guiding sheath

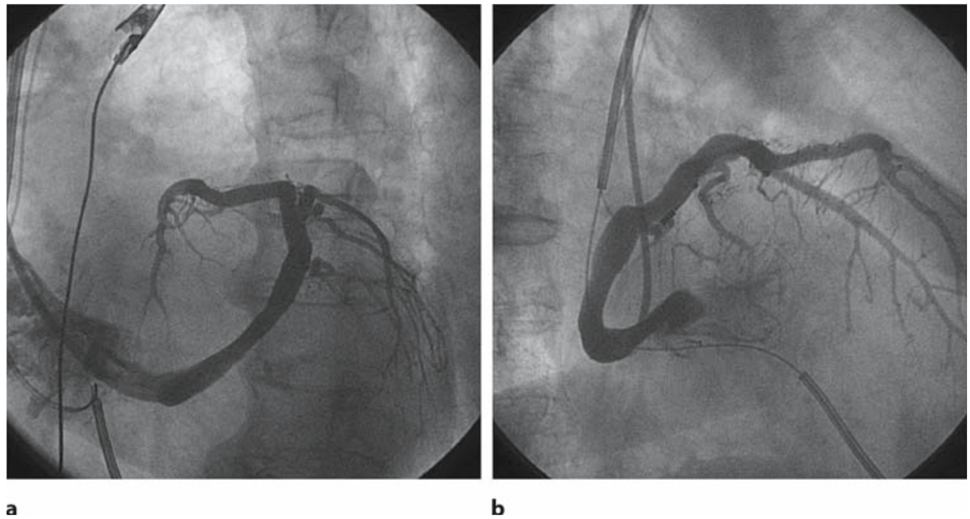


Figure 10.24 Left anterior oblique (*LAO*) (panel a) and right anterior oblique (*RAO*) (panel b) views of a coronary sinus (*CS*) angiogram

10.5 Devices for Positioning the Left Ventricular Lead

10.5.1 Guidewires and Stylets

With the guiding sheath at the CS ostium or at the entrance of the selected vessel, the LV lead can be inserted and advanced using two different approaches. The first one, also called "over the wire," requires the use of angioplasty guidewires, since the lead employs as coaxial track the angioplasty guidewire which can be pushed forward beyond the lead's tip to bring it as far as the desired position (Figure 10.25a). The second one requires the use of a stylet (or something similar). A stylet wedges itself in the distal part of the lead (in a thoroughly similar way to what occurs to conventional leads) and makes it stiff so as to be able to advance it into the venous coronary vessels easily (Figure 10.25b).

Guidewires differ in flexibility (guide tip prolapse), support (possibility to easily advance the lead over the guide), "torque" (possibility to maneuver the guide and reply from the distal part by maneuvering the proximal one), radio-opacity, material characteristics, and design (length, diameter, coating).

With regard to diameter, it is necessary that guidewires may be employed with leads with an "over the wire" design: usually, the inside caliper of leads presently on the market is such as to allow employment of 0.014 in. angioplasty guidewires. Support and flexibility of the distal part make the guidewires different and influence the success rate of the lead implantation (Figure 10.26). The coating with special materials (hydrophilic, polymeric,

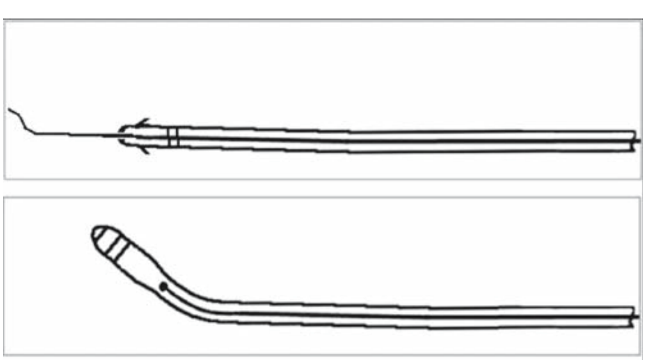


Figure 10.25 Panel a "Over the wire" left ventricular (*LV*) lead. Panel b An LV lead with stylet

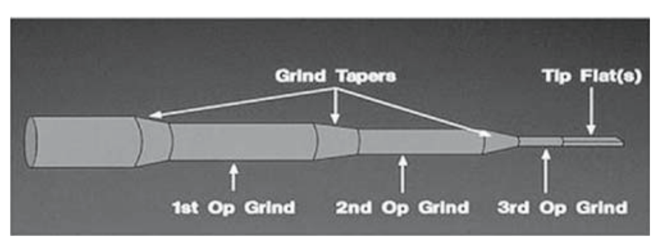


Figure 10.26 Distal portion of a guidewire, with a sequence of conical and cylindrical structures

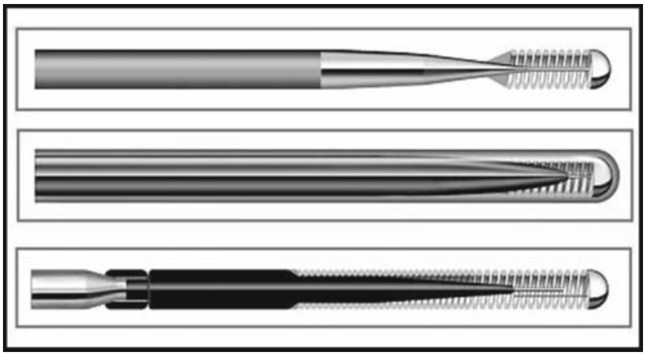


Figure 10.27 Different models of guidewires. From the bottom, guidewires with reduced support, high tip's prolapse and navigability, toward the top, the ones with higher support and torsion control, and minor tip's softness

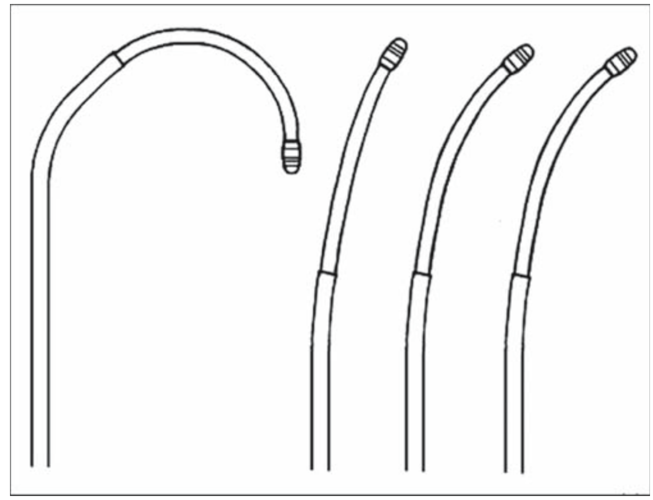


Figure 10.28 On the left, a preshaped lead appears floppy without stylet, and, moving rightward, the lead, with a guidewire of increasing stiffness, acquires different curvatures

etc.), particularly, makes the guide smooth-running. In Figure 10.27 some guidewires are presented from those with high support and torsion control and with less tip softness to those with reduced support, high tip's prolapse, and navigability.

Appropriate guidewire selection depends on the following:

- the "take off" of the target vessel,
- the anatomy of the vessel, and
- the type of the lead.

Differently from angioplasty guidewires, stylets cannot be used as a "track" to advance the lead. Stylets consist of different diameters and therefore with a different effect on the stiffening of the lead's distal part (Figures 10.28 and 10.29). The use of a guidewire and/or stylets depends on the project design of the lead. Some lead can be utilized indifferently with stylet or guidewire, with stylet only, or with angioplasty guidewire only.

10.5.2 Leads for Coronary Sinus

The leads used for pacing of the LV are similar to the conventional leads. However, some additional characteristics are required and include the following:

- better navigability,
- increased steadiness, and
- possibility of multiple configurations.

The success rate of implantation depends acutely on lead navigability (efficacy of the equipment in guiding the lead toward the target site) and strongly on mechanical and phys-

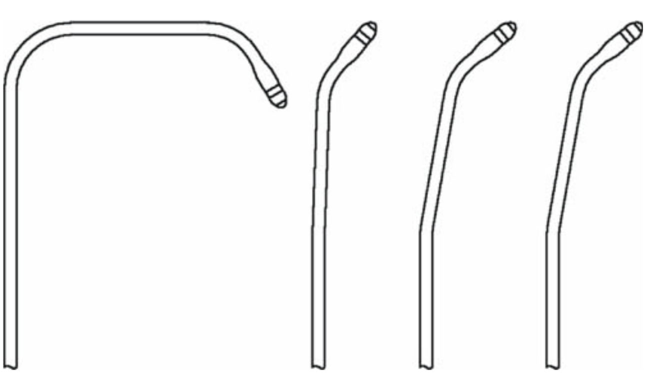


Figure 10.29 Example of catheters with stylets of different degrees of stiffness, greater than the previous ones

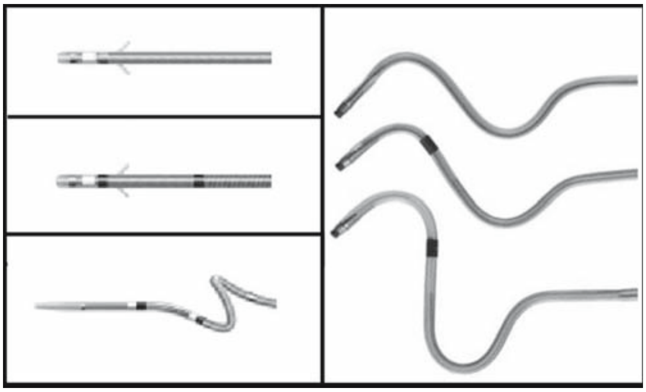


Figure 10.30 Left ventricle leads. On the left upper quadrant, two leads with tines which help to anchor the lead to the vessel. On the lower quadrant and on the right, preshaped leads that are straightened when used with a guidewire or a stylet: their curves help the lead to maintain the anchorage on the vessel by pushing against the wall

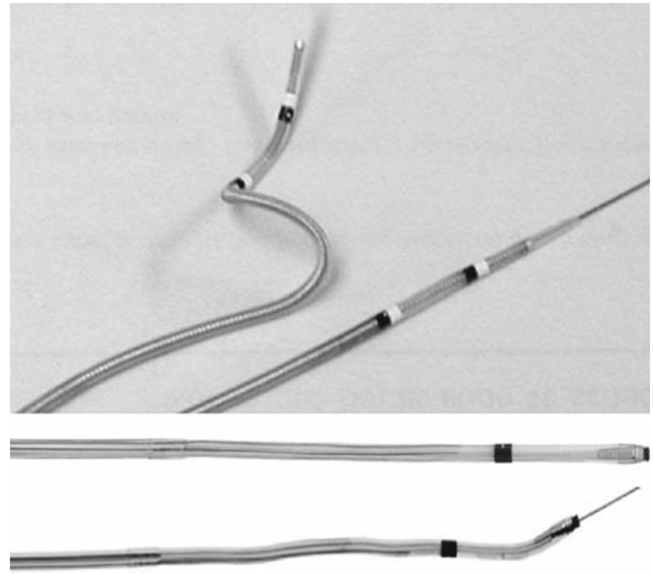


Figure 10.31 Preshaped leads that are straightened when used with a guidewire or a stylet, making them rectilinear and suitable for easy navigation

ical characteristics of the latter. The cronically success rate of implantation depends on lead steadiness (the coronary venous system lacks structures to which it is possible to adhere and the risk of dislodgement is higher than for the traditional endocardial leads).

Availability of multipolar leads and of multiprogrammable generators (pacemakers and biventricular defibrillators) adds flexibility to the entire system and makes the success rate of the implant higher. An example of this flexibility is the possibility to use one of the two electrodes of the left lead as a cathode, according to which one gives the best electric performances and no diaphragmatic and/or phrenic nerve stimulation.

Anchoring of the lead is usually "passive," since even those systems defined as "active" are furnished with a preshaped curve which can provide a better steadiness with regard to position and performances as the time goes by; the insertion of a guidewire or a stylet makes them rectilinear and suitable for easy navigation (Figures 10.30–10.32).

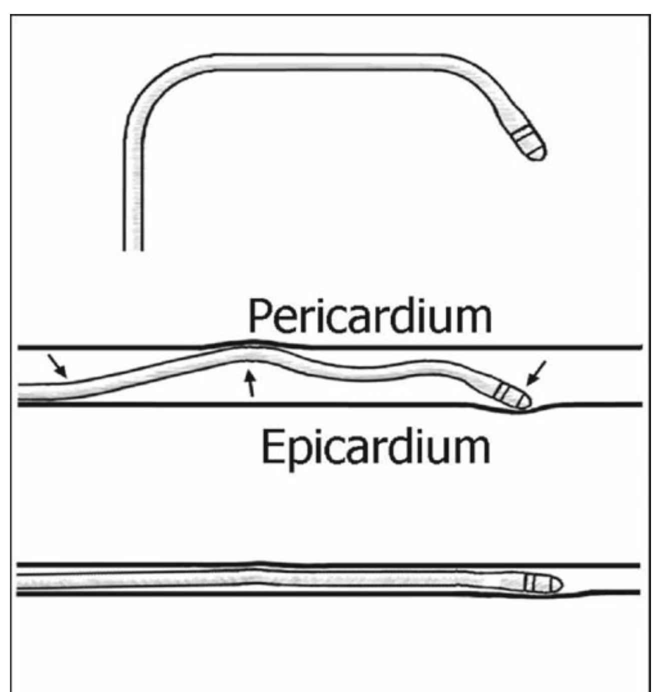
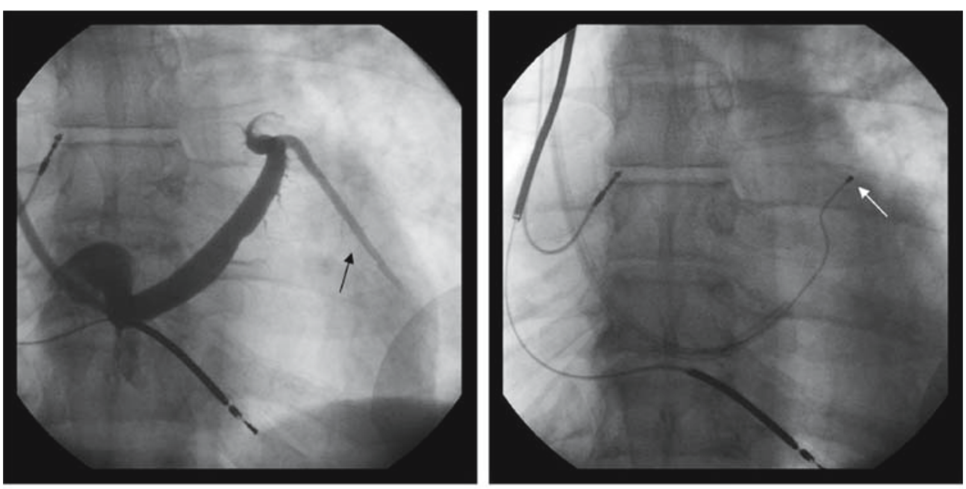


Figure 10.32 Examples of clinging to vein, obtained thanks to catheter's preforming

10.6 Positioning Techniques of the Left Ventricular Lead

Positioning of the LV lead is the fundamental part of the CRT implantation. Several multicenter studies have shown that posterolateral portion of the left ventricle represents the stimulation site with the best hemodynamic effects in the short and long run and with the best clinical results. In order to reach the optimal stimulation site, the lead should be positioned within the lateral or posterior cardiac vein or within the anterolateral cardiac vein. The great and middle cardiac veins should not be considered.

In most cases, with a favorable CS anatomy (presence of lateral, posterior, or anterolateral cardiac vein as shown in 30° LAO and RAO angiographic projections) the positioning technique includes advancing the guiding sheath 1–2 cm below the origin of the target vein; then, the lead with the stylet or with the angioplasty guidewire is pushed forward and, according to the vein angle, directly positioned by simply withdrawing the stylet (Figures 10.33–10.36) or, alternatively, by using a preshaped angioplasty guidewire (Figure 10.37). In this second instance, it is convenient to advance the guide distally and then carry out a "push and pull" maneuver to finally position the LV lead (Figures 10.38–10.44).



a b

Figure 10.33 In the left anterior oblique (*LAO*) view, a series of figures representing the sequence of a correct positioning of the left lead armed with a stylet into a lateral branch of the coronary sinus (*CS*). Panel a The CS angiogram reveals a large lateral target vessel (black arrow). Panel b The catheter (white arrow) is advanced up to the ostium of the target branch

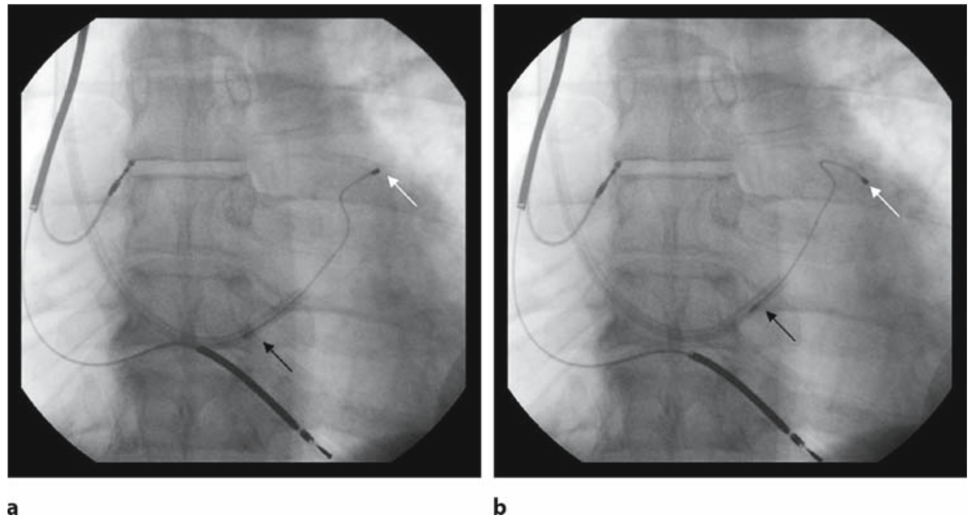


Figure 10.34 Panel a The stylet (black arrow) is lightly retracted to soften the tip (white arrow) of the lead to allow to engage the vessel. Panel b Once secured the tip in the proximal portion of the vessel, the stylet is readvanced to stiffer the tip and to allow advancing in the vein

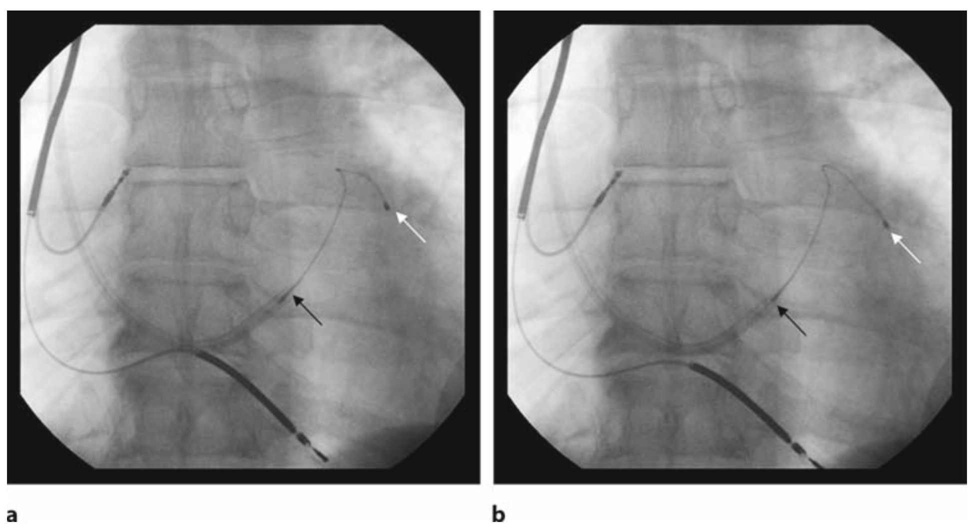


Figure 10.35 The catheter is advancing in the vein (panel a) and reaches its medial portion (panel b).

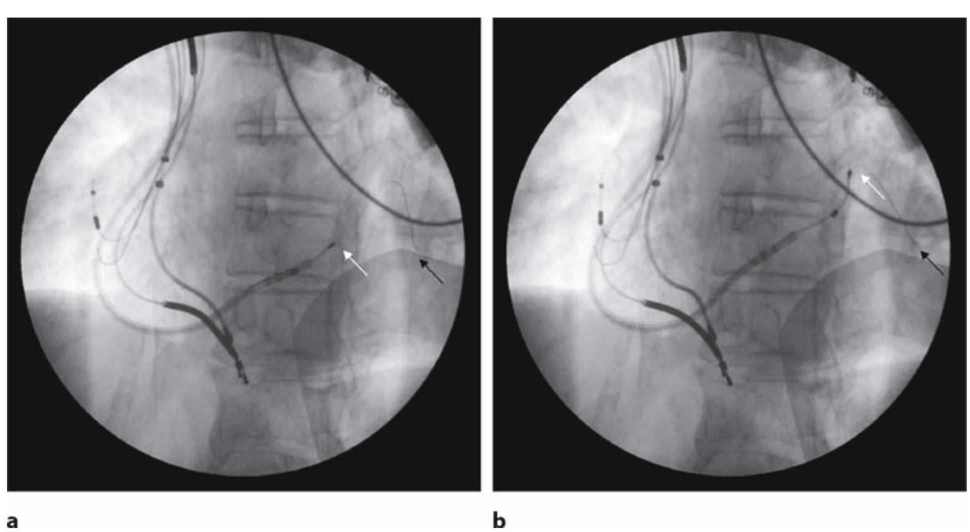
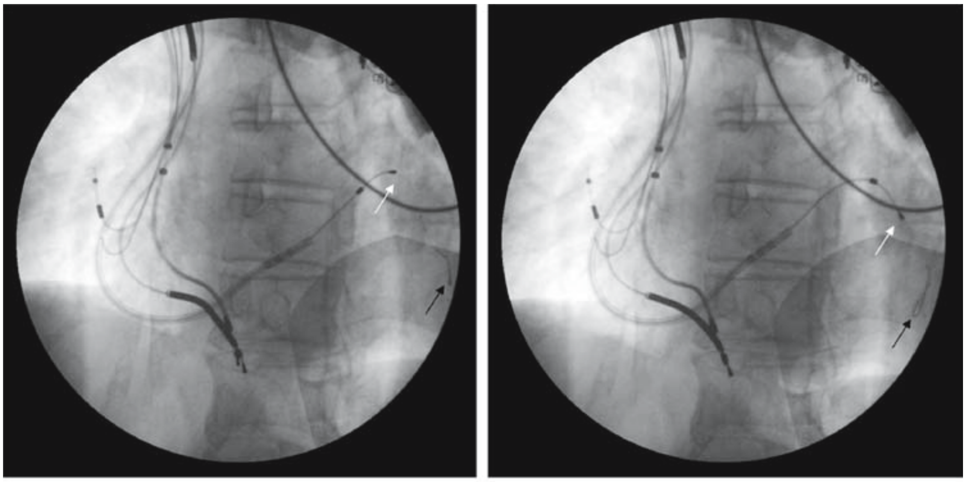
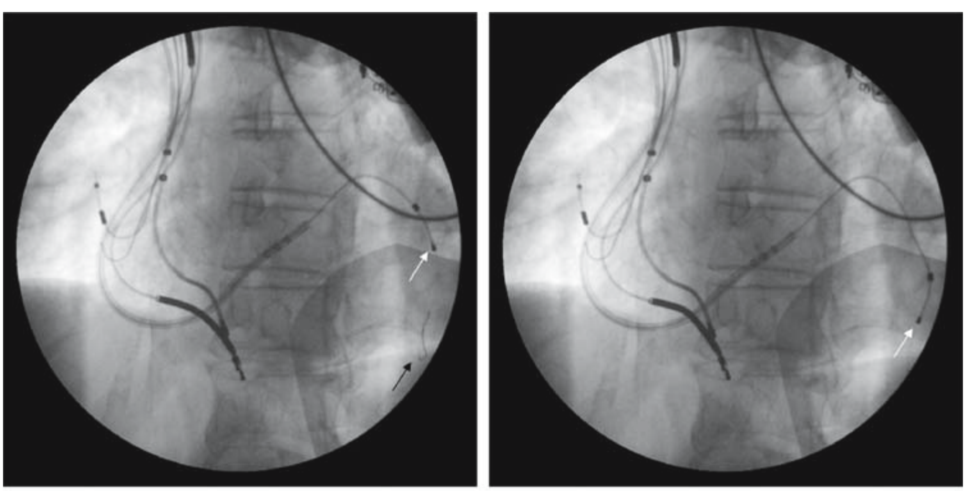


Figure 10.37 Panel a Use of a preshape guidewire (black arrow) to select the target vessel. Panel b The catheter (white arrow) is then advanced with an "over the wire" technique



a b

Figure 10.38 The left lead (white arrow) flows over the wire while the guidewire (black arrow) is pulled back ("push and pull" maneuver), advancing first proximally (panel a) then medially in the vein (panel b), ensuring the guidewire to be distally far enough to support the weight of the lead



a b

Figure 10.39 As the guidewire (black arrow) is further advanced distally (panel a), the cathetor (white arrow) slides over it till the end (panel b)

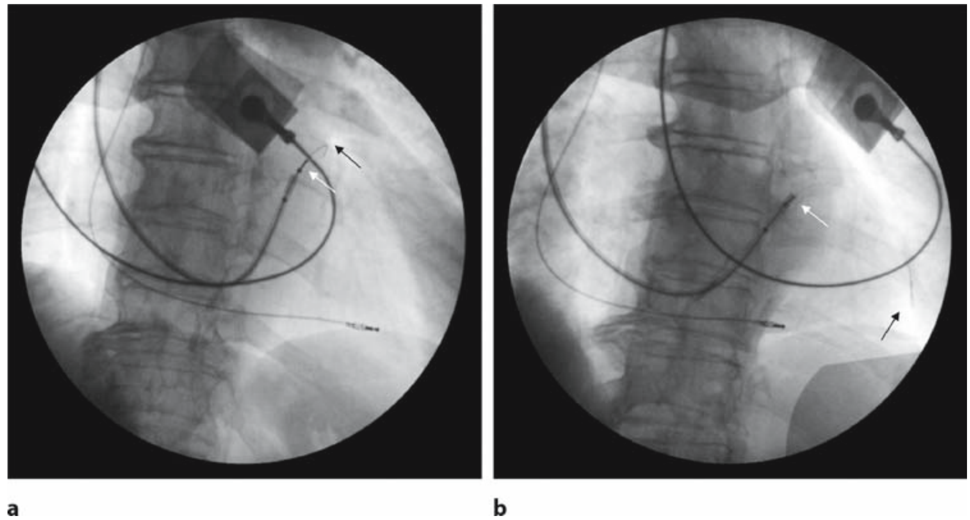


Figure 10.40 A series of images showing the correct maneuver to position the left lead (white arrow) in the target lateral vessel with an "over the wire" technique, advancing first the wire (black arrow) in the vein and securing it in its distal portion, then sliding the catheter over it using "push and pull" strategy

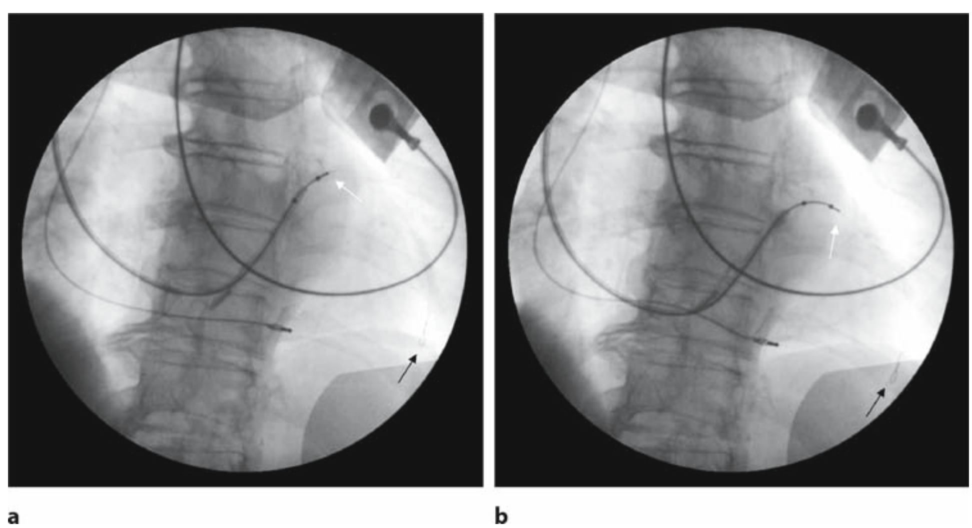
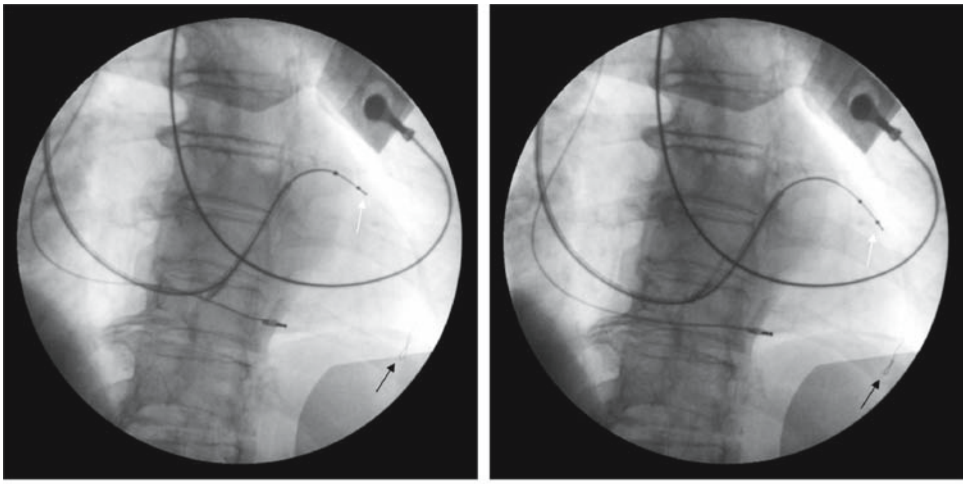
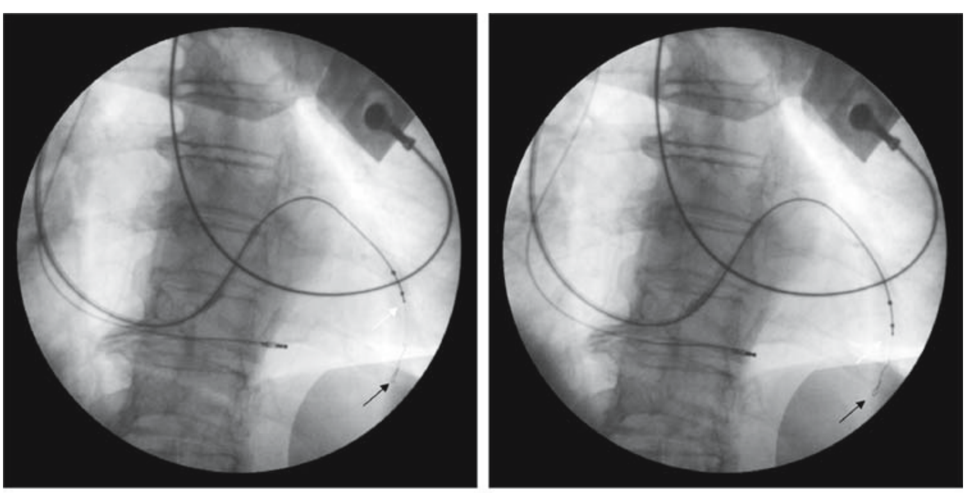


Figure 10.41 See caption Figure 10.40



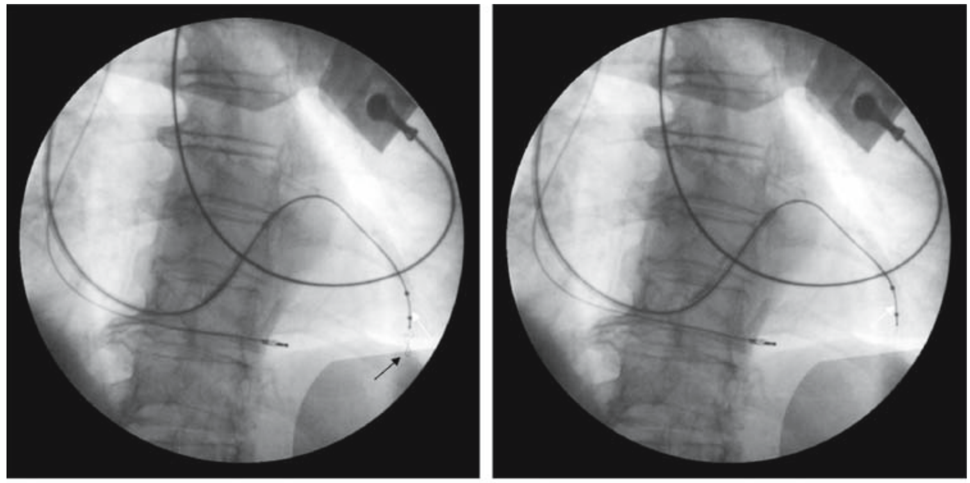
a b

Figure 10.42 See caption Figure 10.40



a b

Figure 10.43 See caption Figure 10.40

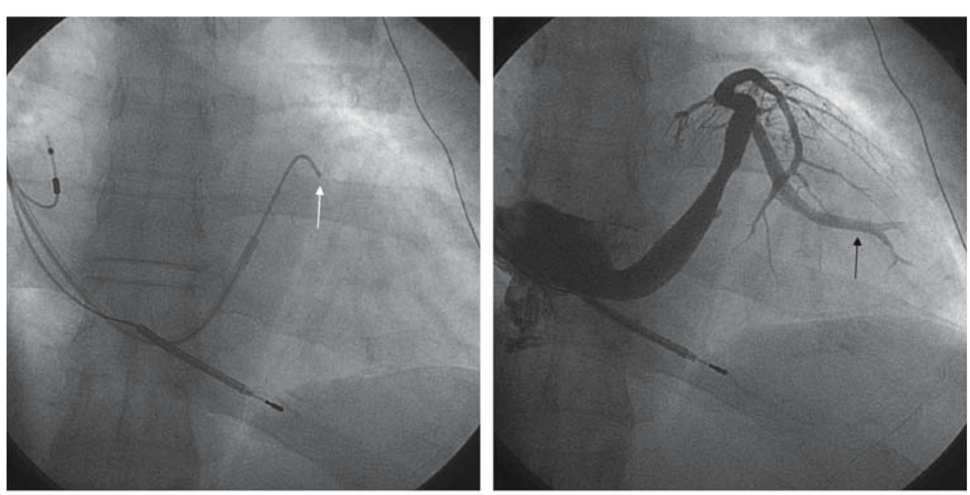


a b

Figures 10.44 See caption Figure 10.40

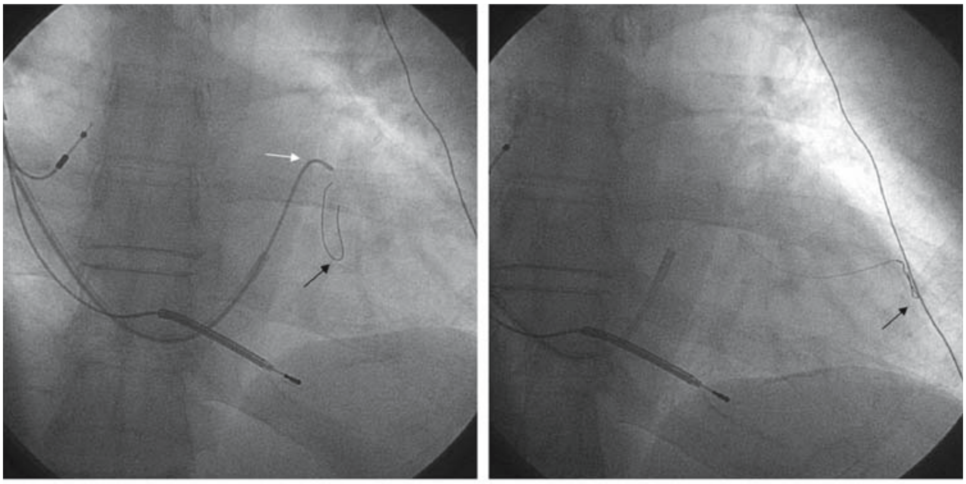
In some cases, an unfavorable anatomy (reduced CS size or absence of target cardiac veins) makes positioning of the lead extremely difficult. In these cases, it is possible to use standard angiographic catheters such as right Judkins or multipurpose catheters to directly cannulate the target cardiac vein or telescopic angiographic systems, directly furnished by the company producing CRTs (Figure 10.9).

Once the target cardiac vein has been identified, this one can be directly cannulated by a traditional angiographic catheter using a guiding sheath as support (Figure 10.45); thereafter, a soft angioplasty guidewire is advanced distally into the target cardiac vein and the angiographic catheter is removed (Figure 10.46). At last the final LV lead is positioned on the angioplasty guidewire



a b

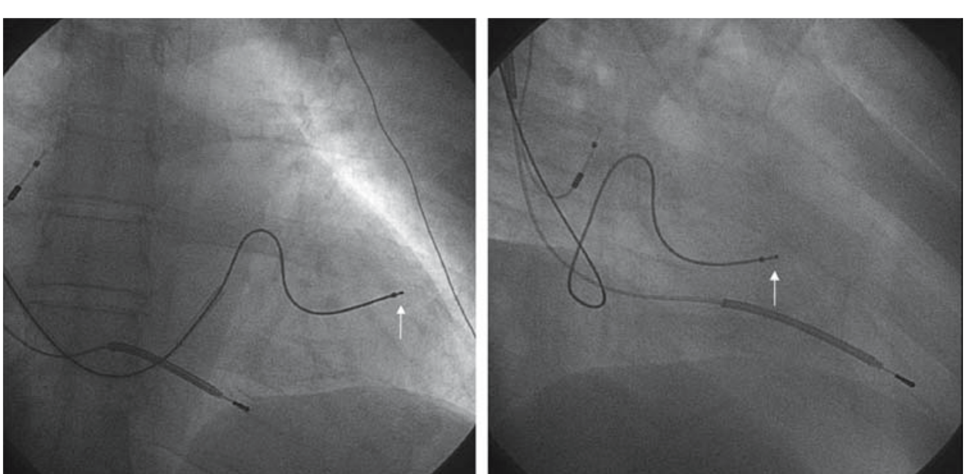
Figure 10.45 Use of a angiographic guiding catheter (panel a) to selectively cannulate the target vessel (panel b)



a b

Figure 10.46 Panel a A guidewire (black arrow) is advanced through the angiographic guiding catheter (white arrow) in the vein till its distal portion. Panel b The angiographic catheter is then removed, leaving only the wire in place

(Figure 10.47). Another strategy to cannulate a particularly difficult target cardiac vein is that of using telescopic systems made of an external guiding sheath and of an inside angiographic catheter. Once the target cardiac vein has been identified (Figure 10.48), this is selectively cannulated with the internal angiographic catheter (Figure 10.49) and, thereafter, the angioplasty guidewire is advanced to reach the distal part of the vein (Figure 10.50). Another way to position the LV



a b

Figure 10.47 With the over the wire technique, the catheter (white arrow) is safely advanced in the target vessel. Panel a The left anterior oblique (*LAO*) view. Panel b The right anterior oblique (*RAO*) view

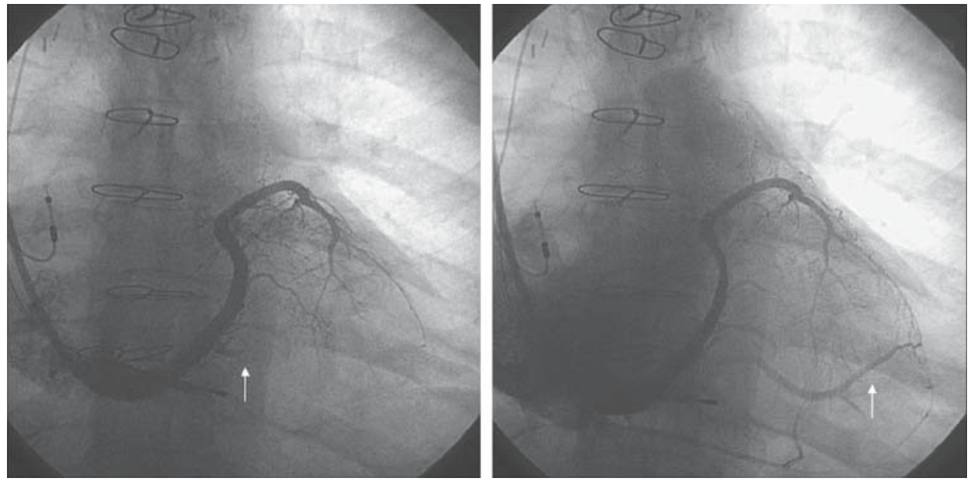


Figure 10.48 A different strategy to cannulate difficult target cardiac veins using telescopic systems made of an outer guiding sheath and of an inner angiographic catheter. The target cardiac vein is visualized. It is the posterior vein (white arrow) to be chosen this time due to the absence of lateral or anterolateral branches of good caliper

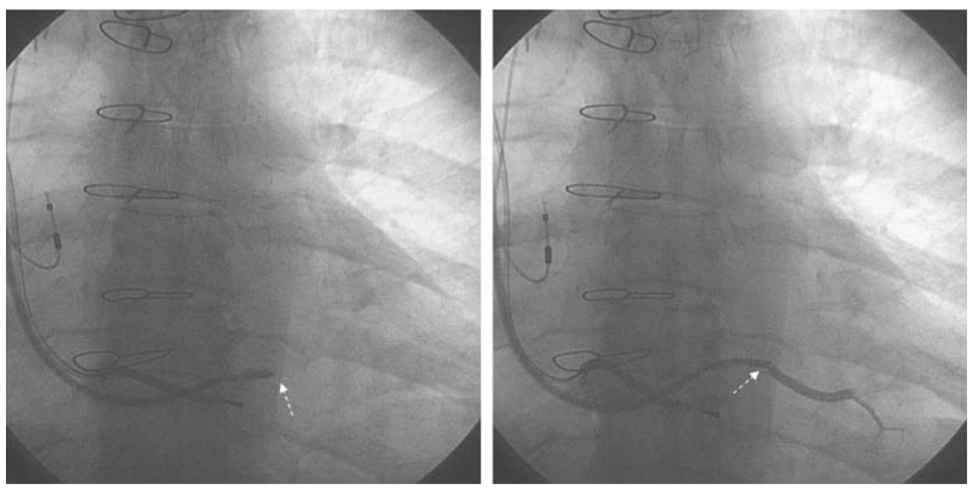


Figure 10.49 Selective cannulation of the vein with the inner angiographic catheter (dotted white arrow)

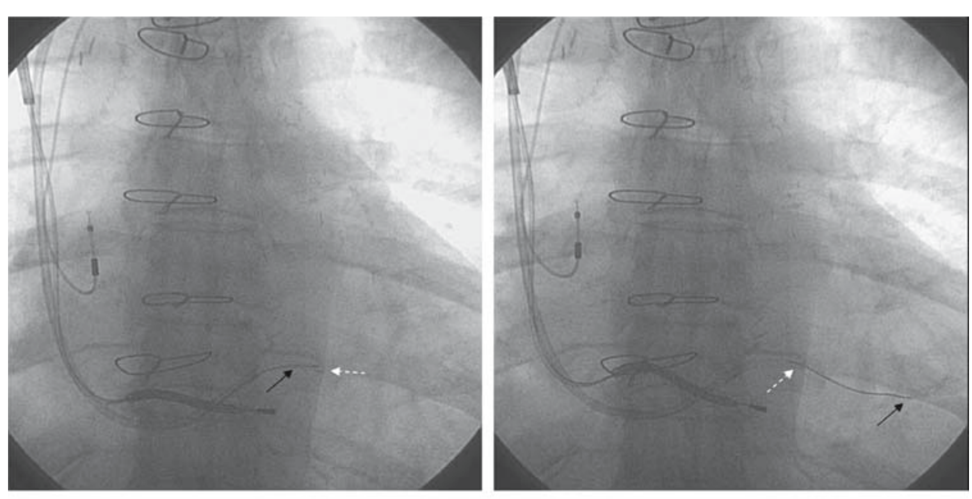


Figure 10.50 In Panel a, the guidewire (black arrow) is inserted into the inner angiographic catheter (dotted white arrow) as far as reaching the target cardiac vein's end (Panel b)

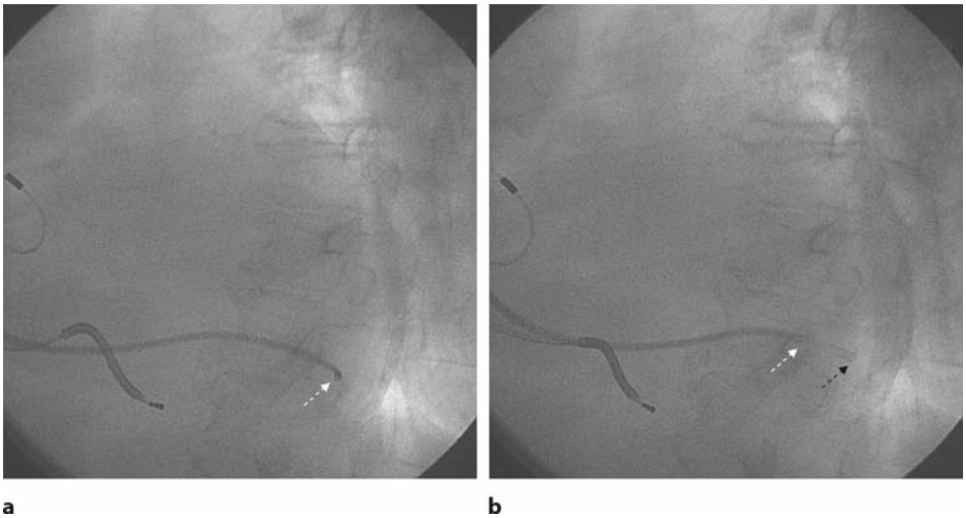


Figure 10.51 Panel a the angiographic inner catheter (dotted white arrow) is selectively advanced inside the target posterior vein. Panel b The outer guiding sheath (dotted black arrow) then slides over it as it retracts. It is like the "over the wire" maneuver using the angiographic catheter as the guiding wire

catheter is to advance an internal angiographic catheter into the target cardiac vein first and then to advance the external guiding sheath over the angiographic catheter while removing the latter (Figure 10.51). With this technique, it is also possible to perform a more selective angiography (Figure 10.52) and to position the LV catheter within the target cardiac vein (Figure 10.53) by using the over-the-wire system (Figure 10.54).

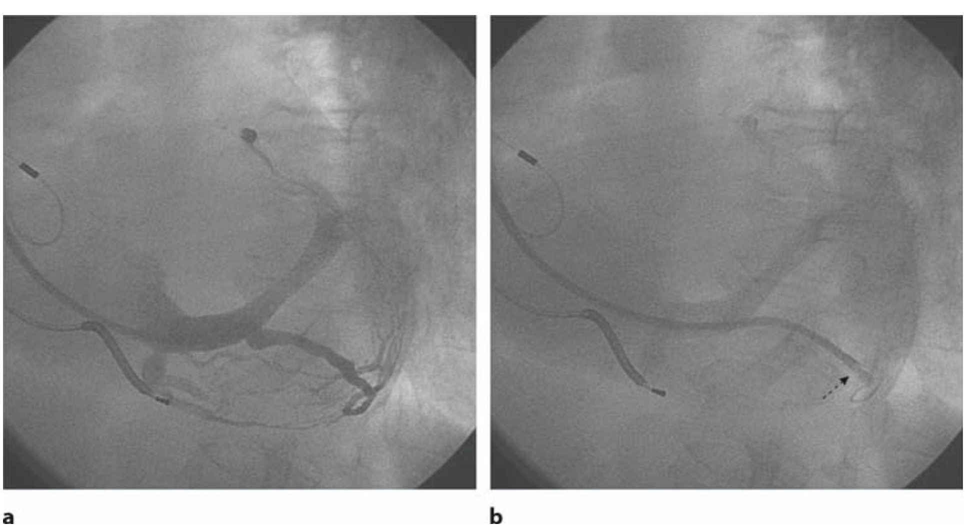
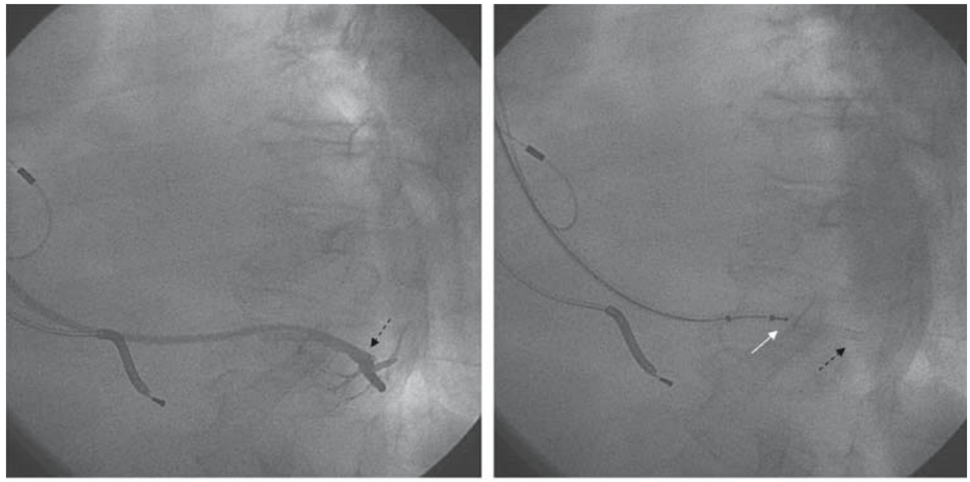
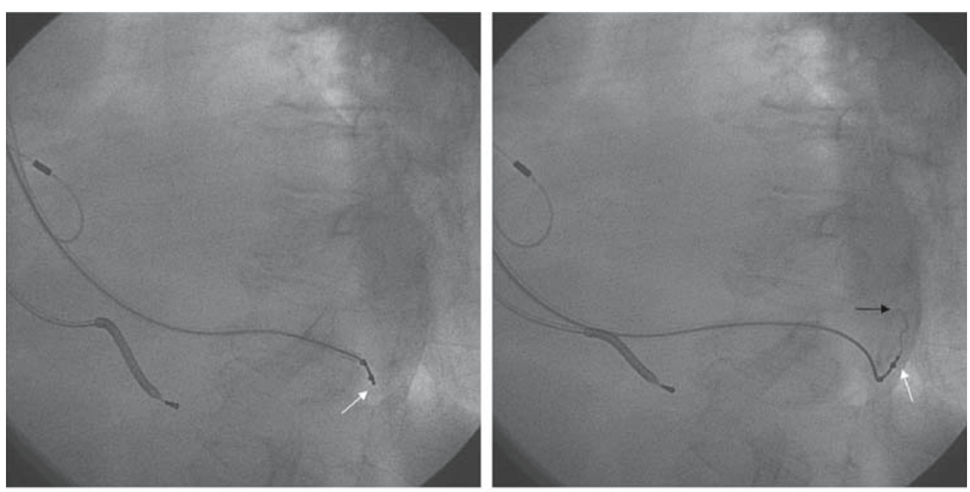


Figure 10.52 Panel a Coronary sinus (*CS*) angiogram showing a large posterior vein. Panel b The outer guiding sheath (dotted black arrow) cannulates selectively the target vessel



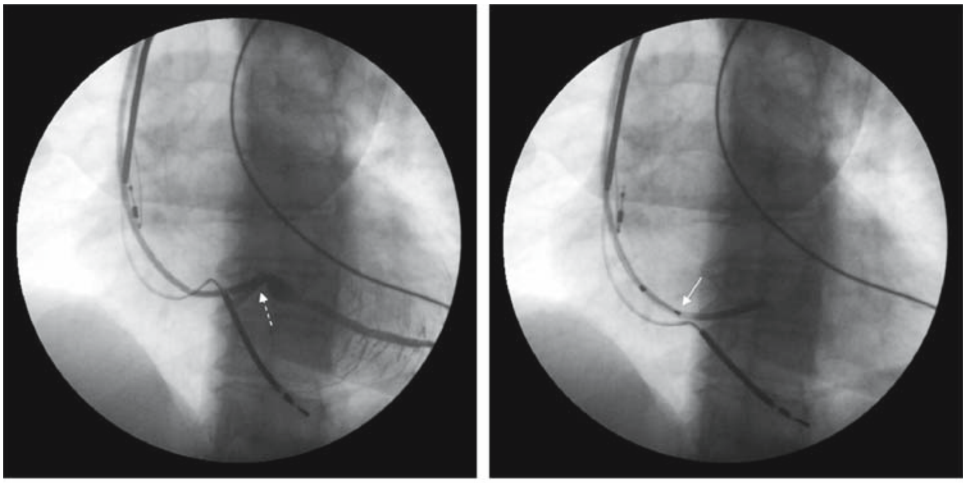
a b

Figure 10.53 Panel a Selective angiogram of the target vessel through the outer guiding sheath (black arrow). Panel b The left lead (white arrow) is advanced directly inside the target vein



a b

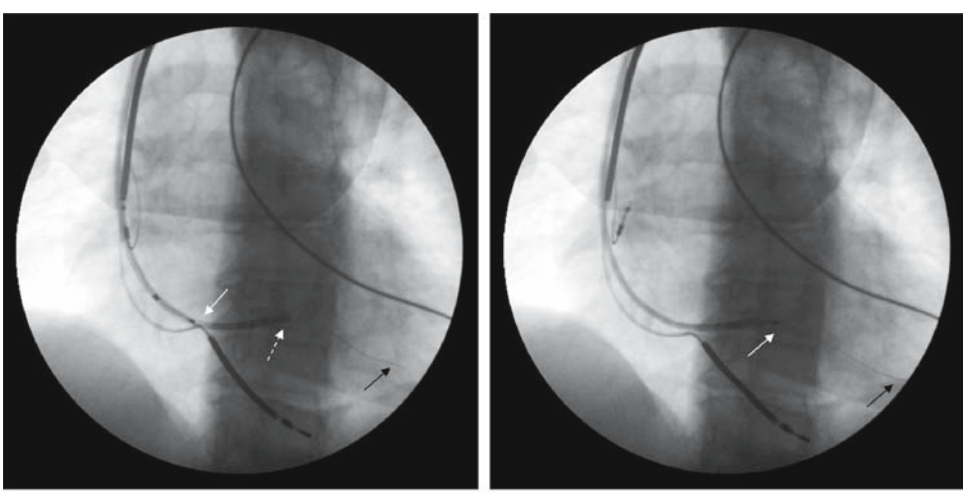
Figure 10.54 Panel a Further advancing the lead (white arrow) up to a small branch where it stops (Panel b); black arrow shows the guidewire.



a b

Figure 10.55 Sequence of an attempt to position the lead (white arrow) over the wire (black arrow) in an angulated posterior vein through direct cannulation with the guiding sheath (dotted white arrow)

If, once the target cardiac vein is cannulated, steep vein angles make further advancement of the LV catheter impossible, no matter one uses very supportive angioplasty guidewires (Figures 10.55–10.57), two other techniques can be considered: using an EP catheter on which the guiding sheath first and then the left lead slide (Figures 10.58–10.60); or using a



a b

Figure 10.56 Despite the correct maneuver, the lead fails to advance because narrow angles do not allow the guiding sheath to straighten the vein enough

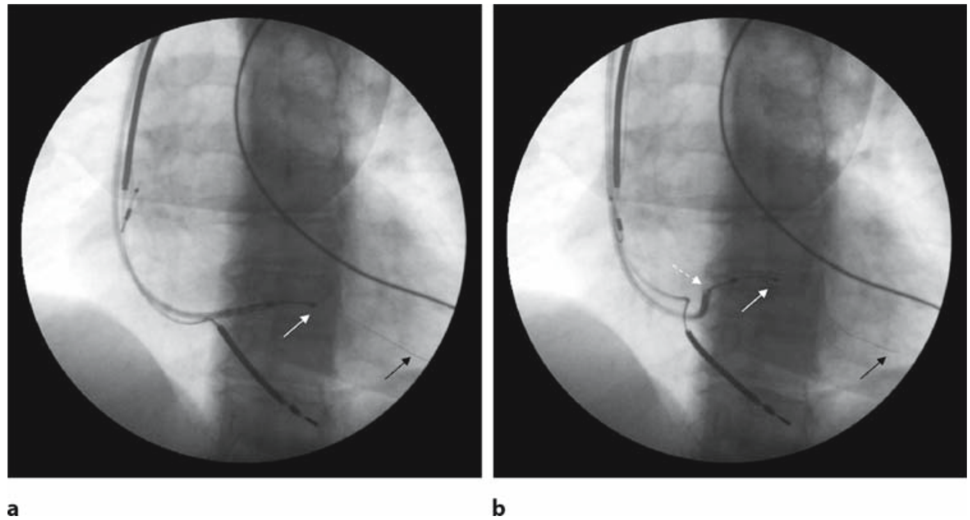


Figure 10.57 The catheter bends instead of advancing and forces the proximal part of the guiding sheath, which makes it lose the engagement at the coronary sinus (*CS*) ostium, removing all the system

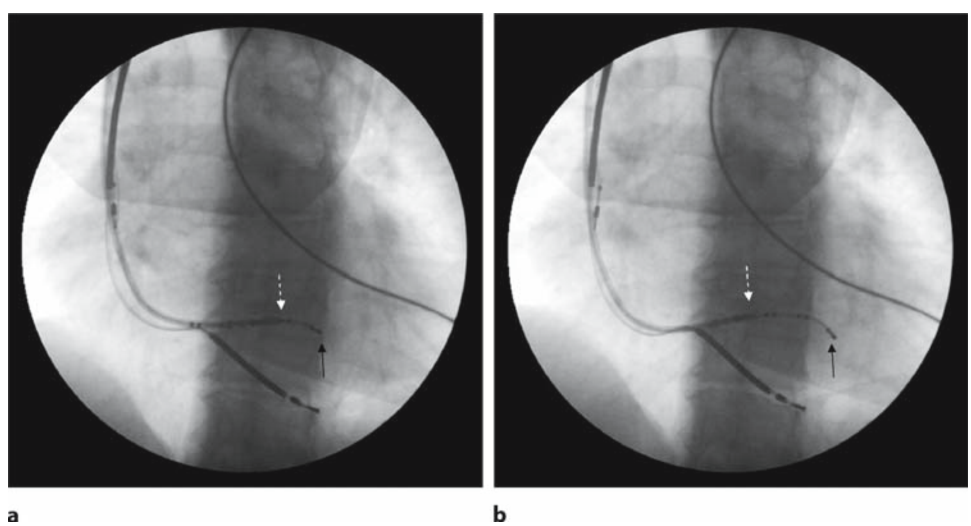
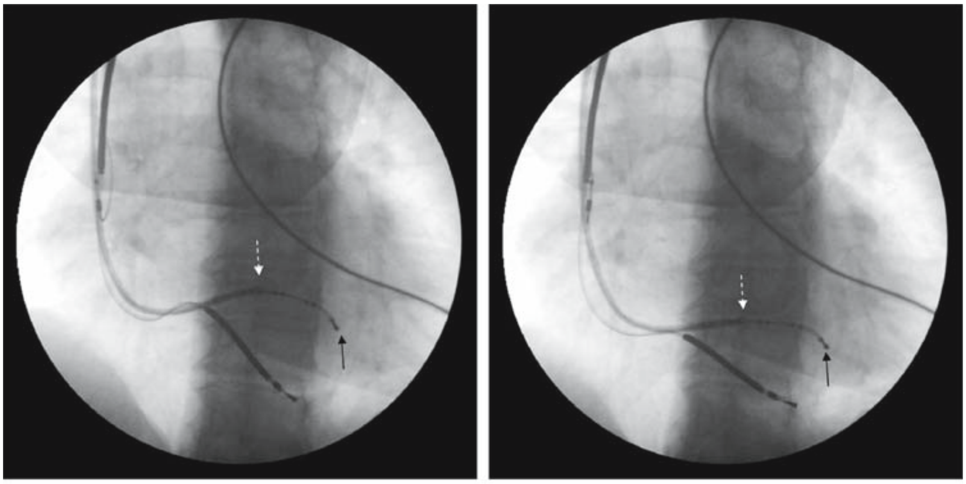
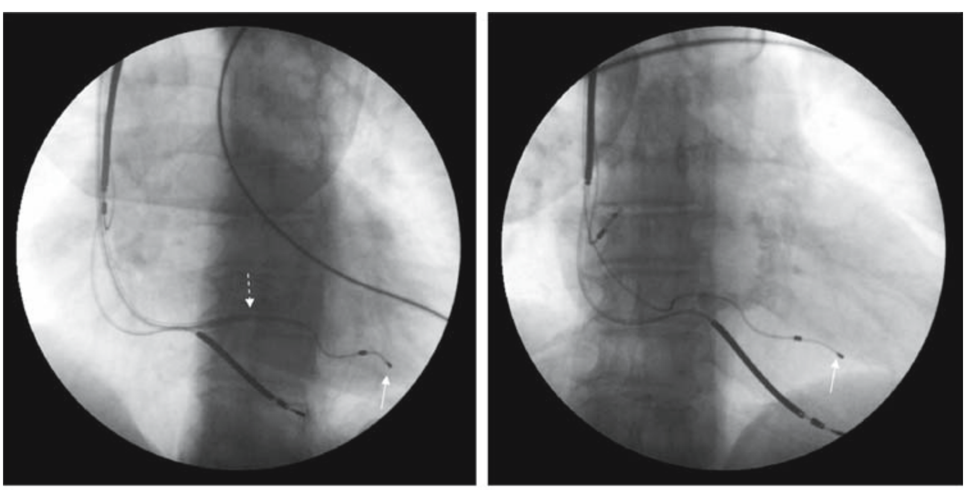


Figure 10.58 This time, the posterior vein is cannulated with an electrophysiologic (*EP*) catheter (black arrow)



a b

Figure 10.59 The electrophysiologic (*EP*) catheter straightens its angles so as to allow the guiding sheath (dotted white arrow) to slide over it and go further inside the vein



a b

Figure 10.60 Once there, the lead (white arrow) can easily be advanced, and the sheath retracted

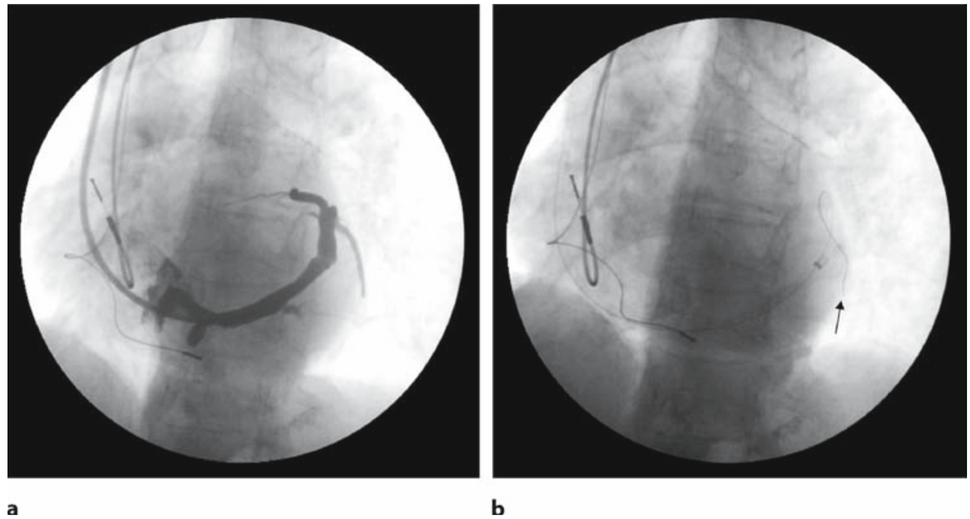


Figure 10.61 "Buddy wire technique." The target vein originates with a very narrow angle

double angioplasty guidewire or "buddy-wire" technique. By this technique, a supportive angioplasty guidewire (buddy) is positioned within the CS or at the end of the angulated target cardiac vein and the LV lead is placed utilizing a softer angioplasty guidewire, which uses the buddy guide as a track (Figures 10.61–10.63).

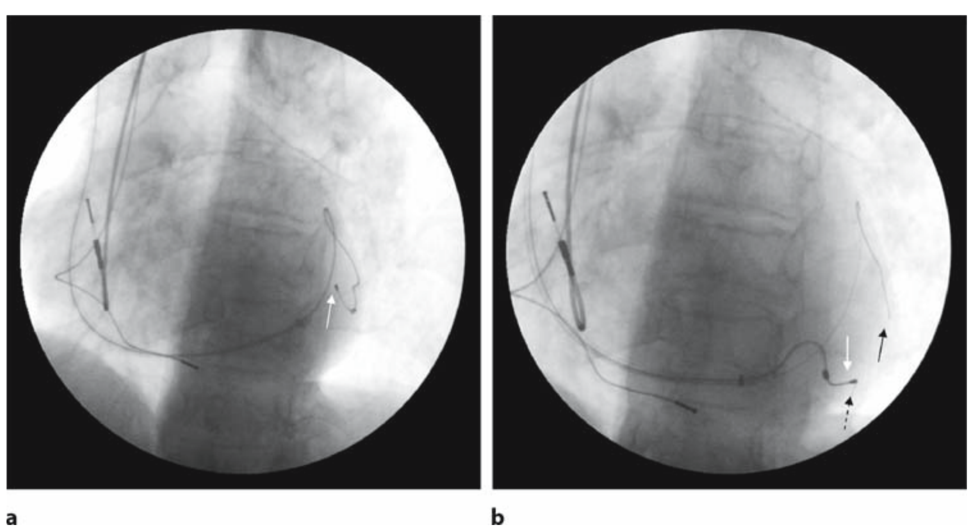


Figure 10.62 A supportive angioplasty guide wire (black arrow) is advanced within the coronary sinus (*CS*) up to the end of the angulated target cardiac vein

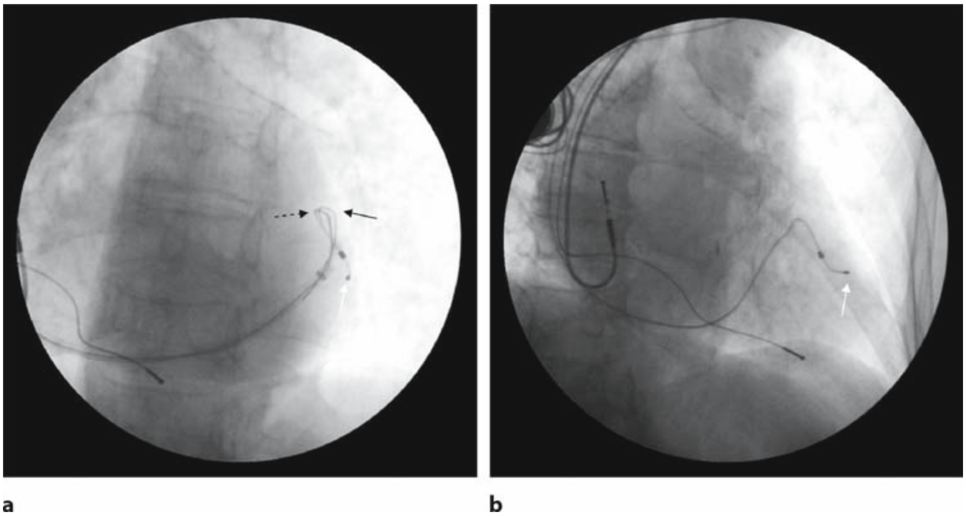


Figure 10.63 Panel a A softer angioplasty guidewire (dotted black arrow), placed close to it, uses the "buddy" guide, the more supportive one, as a track to overtake the obstacle represented by the target cardiac vessel's angle. Panel b Now that the angle has been straightened a bit, the left ventricular (*LV*) lead (white arrow) can be placed sliding over it

11

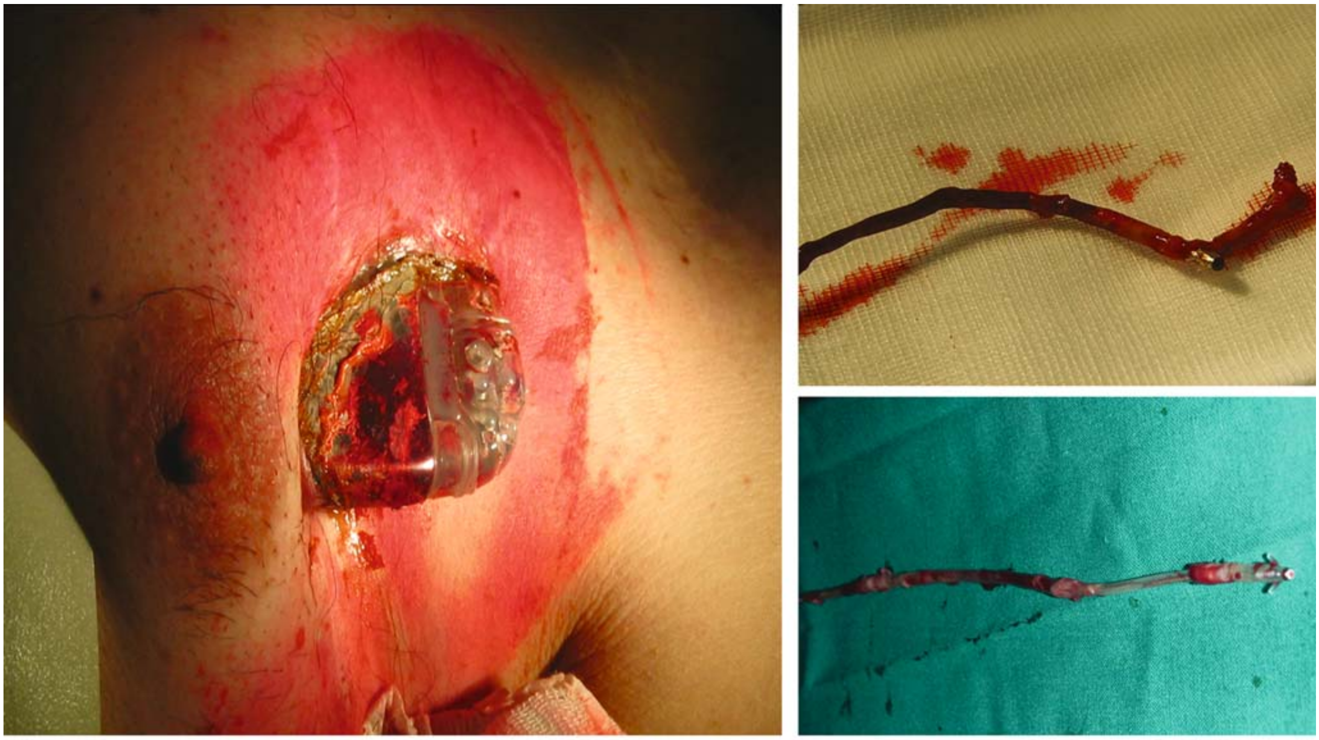
Pacemaker and Implantable Cardioverter Defibrillator Lead Extraction

11.1 Introduction

Occurrence of infections connected with implantations and replacements of pacemaker (PM), cardioverter defibrillator (ICD), and biventricular devices (Figure 11.1) varies in literature between 0.5% and 4%. Conservative treatment (antibiotic therapy, pocket's review as well as device and catheters' repositioning) has got the purpose of saving implantation; however, it is often not definitive, mainly in case of systemic infections. Therefore, much more frequently removal of infected catheters and extraction of devices is the treatment of choice. Other indications for lead extraction are the development of superior vena cava syndrome due to the presence of an excessive number of catheters and the existence of catheters' fractures with protrusion of the internal cores.

Recently implanted leads are free within the veins and myocardium as they are gradually covered by endothelial and endocardiac cells. With time, a fibrous capsule develops around the catheter with consequent adhesion not only in its distal end but also at the height of its body, mainly in those regions of different diameter such as electrodes or ICD coils.

Recently implanted catheters can be removed relatively easy as the fibrous capsule has not been thoroughly formed. With regard to chronically implanted catheters, in the past, surgical removal was the only resolutive technique with a perioperative mortality rate up to 15%. Presently, the endovascular approach, through various techniques, has reduced perioperative mortality and the total rate of complications is about 2.5%.



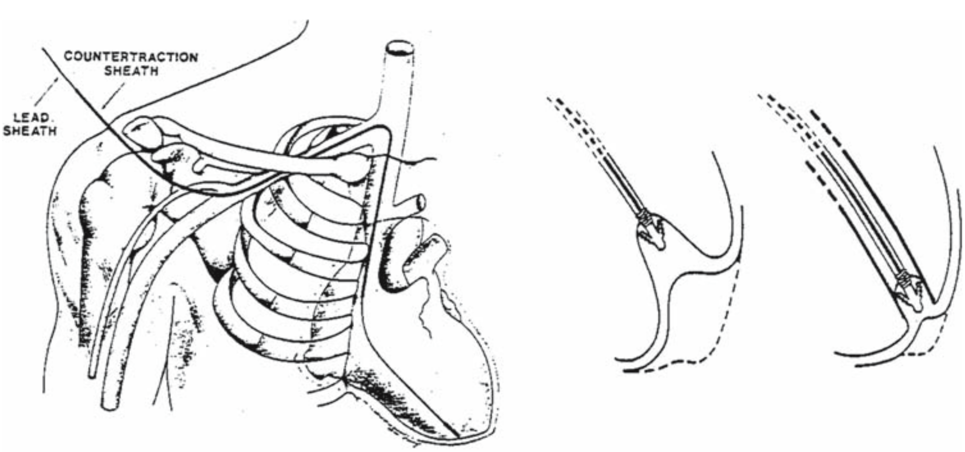
a b

Figure 11.1 Infection in patient with biventricular implantable cardioverter defibrillator (*ICD*). Panel a shows the device thoroughly removed from its original pocket. Panel b shows double-coil right ventricular lead extracted with significant fibrous envelope at level of distal coil, and the atrial lead with tines surrounded with adhered fibrous capsule

11.2 Extraction Techniques

11.2.1 Traction

Direct traction, or by means of additional weights, has been the traditional mechanism used since 1950 for endovascular removal of infected catheters. This method, once the catheter is freed from device's pocket adhesions, lies on applying a direct traction force and a countertraction in order to free the catheter's distal end from the myocardium (Figure 11.2). Such mechanism is invalidated



a b

Figure 11.2 Panel a Technique of direct lead traction. Panel b Traction and countertraction mechanisms to remove the distal tip of the lead from the myocardium

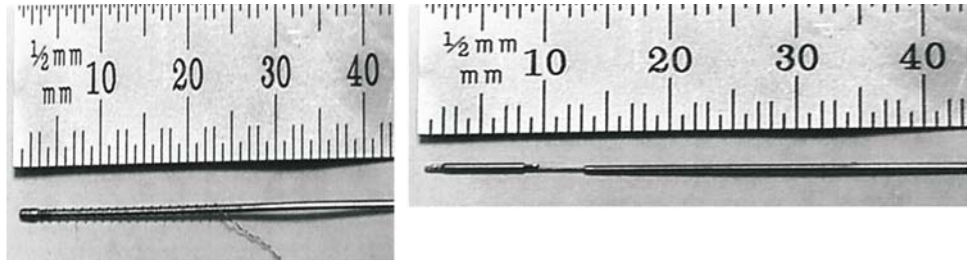


Figure 11.3 Locking stylet Wilkoff of various sizes (Cook Vascular, Inc.)

by a high percentage of failures connected with catheter ruptures because traction force is not uniformly distributed because of the existence of anatomic angles along the catheters' path. Furthermore, the rate of complications, such as rupture of the myocardium, arrhythmias, ruptures of tricuspid flaps, and thromboembolic complications, is significant.

11.2.2 Traction and Countertraction with Locking Stylets and Telescoping Synthetic Sheaths

In order to avoid catheters' ruptures with consequent partial extractions or other more serious complications, locking stylets have been produced which, once they are inserted within catheter, make a part of it or the whole body stiffen (Figures 11.3–11.5). Locking stylets have different characteristics and sizes according to the various manufacturing companies. Some of them, moreover, once they have been inserted, cannot be removed from catheters

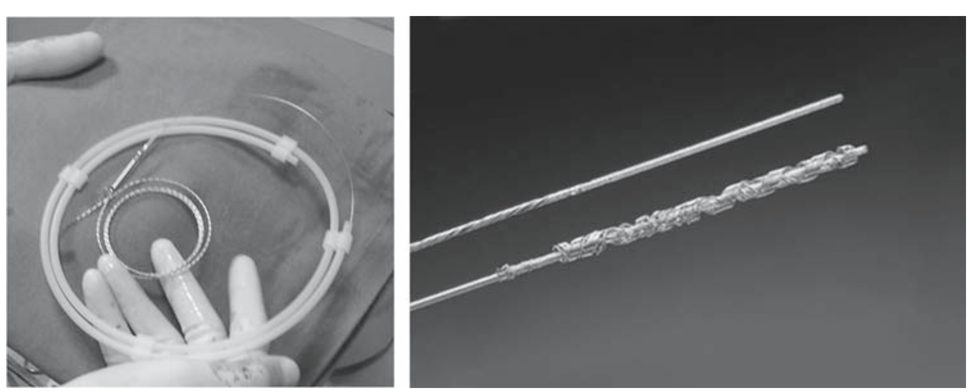


Figure 11.4 Locking stylet Liberator (Cook Vascular, Inc.). Such a stylet is of one single size. The locking mechanism is made of a mesh positioned at a distal end of a guiding sheath which is expanded and stops at the level of the lead tip. This sort of mechanism does not allow any more the removal of the locking sheath after the mesh has been expanded

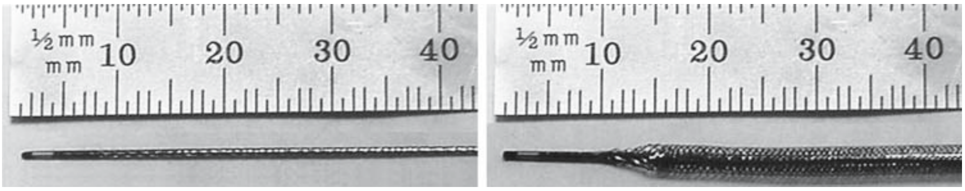


Figure 11.5 LLD locking stylet (Lead Locking Device, Spectranetic Co.). This stylet has a braid extending all along its length. When the stylet is inserted within lead, it expands by means of a special mechanism and after a short traction it stops further within the lead, making it thoroughly stiffened. This stylet is available in three sizes and can be removed from the lead by withdrawing the expansion mechanism from its original position

any more, differently from others. Before inserting the locking stylet, it is necessary to test the catheter's perviousness using a traditional stylet.

The second step calls for accurately preparing the catheter by cutting the outer silicon sheath. At last, one inserts the locking stylet and activates the locking mechanism (Figures 11.6 and 11.7). During the positioning of the locking stylet within the catheter, it is important to make sure that it has been inserted as far as the distal lead's end (Figures 11.8 and 11.9) and it is also important to measure the exact size of the stylet with regard to the lead's diameter so that, during traction, the stylet stays firm without withdrawing.

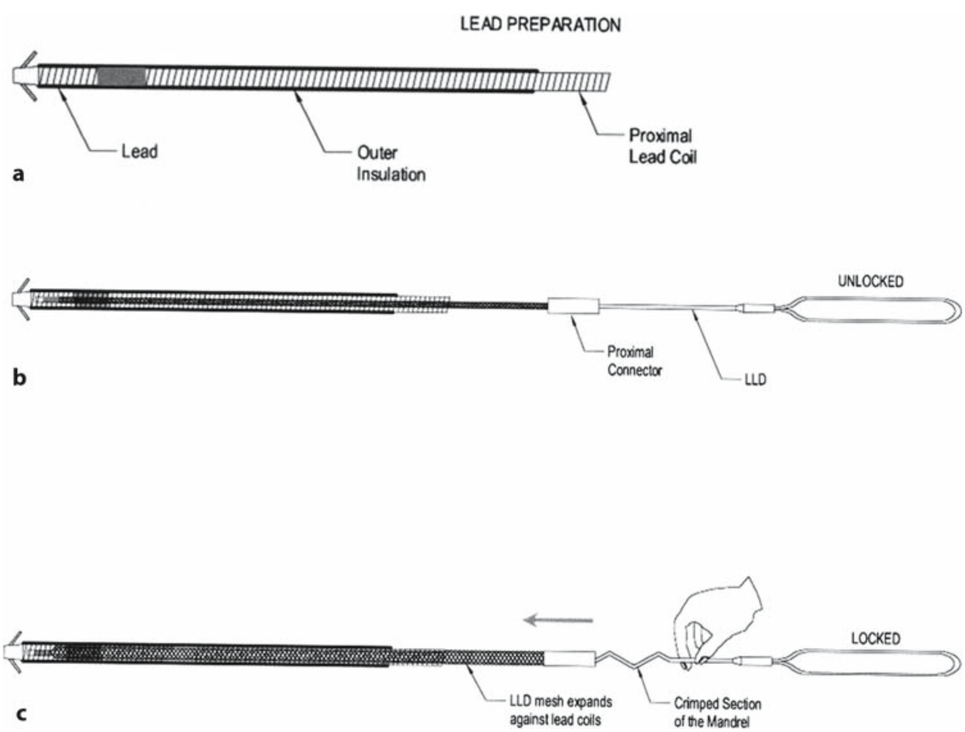


Figure 11.6 Panel a Preparation of lead during the extraction procedure. Panel b Insertion of LLD locking stylet within lead. Panel c Locking mechanism of stylet within lead. To activate locking, it is necessary to release the proximal connector from the crimped section of the mandrel. To unlock it is necessary to reconnect the proximal connector to the crimped section of the mandrel

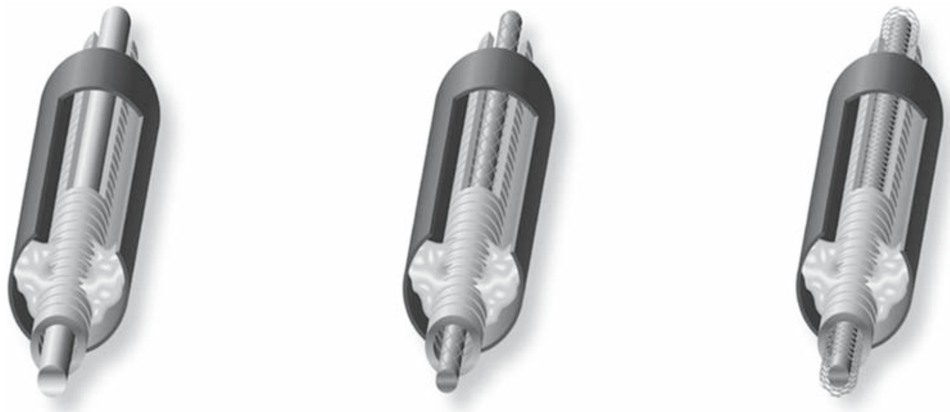


Figure 11.7 Section of a lead (from the left) before extraction, during insertion of locking stylet, and after locking of stylet within lead

Unfortunately, there are limitations, even using these stylets. As a matter of fact, if the lead is obstructed, it is not possible to insert the stylet; at times, the existence of significant fibrous adhesions on catheters does not allow extraction with consequent uncoiling of the lead or rupture of distal electrodes. Other times, direct lead extraction, stiffened by locking stylet, causes an excessive invagination of the myocardium with risk of cardiac rupture.

In order to overcome all of these restrictions, telescoping synthetic sheaths can be used, made of two dilators (internal and external, Figure 11.10) which are advanced along the lead-locking stylet apparatus, thus mechanically removing fibrous adhesions and creating within the vessels' lumen the necessary room for lead removal. During this

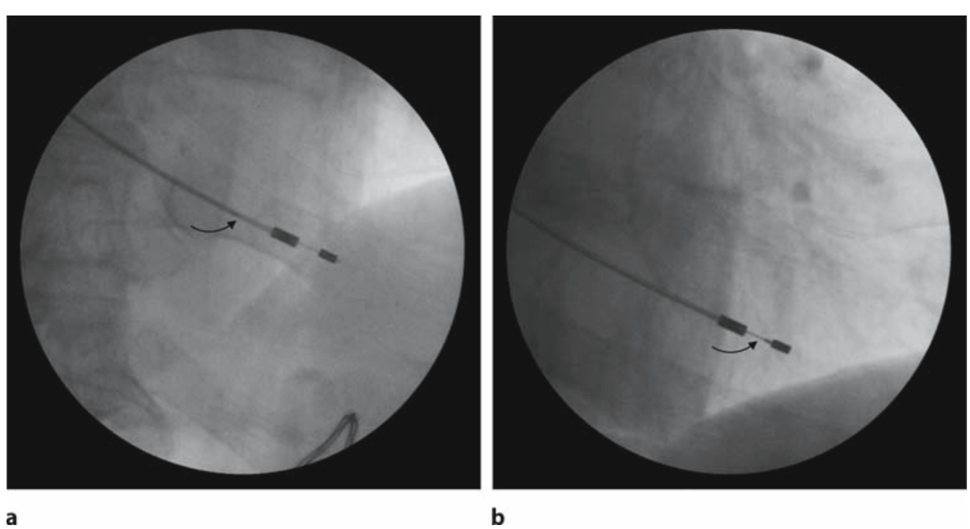


Figure 11.8 Panel a Insertion of locking stylet of the LLD-2 type, within ventricular bipolar lead with tines. Arrow indicates that the stylet has not yet reached the lead's distal tip. In panel b one can see that the stylet is at the level of the lead's distal electrode (arrow); in this position, the lead's locking mechanism can be activated

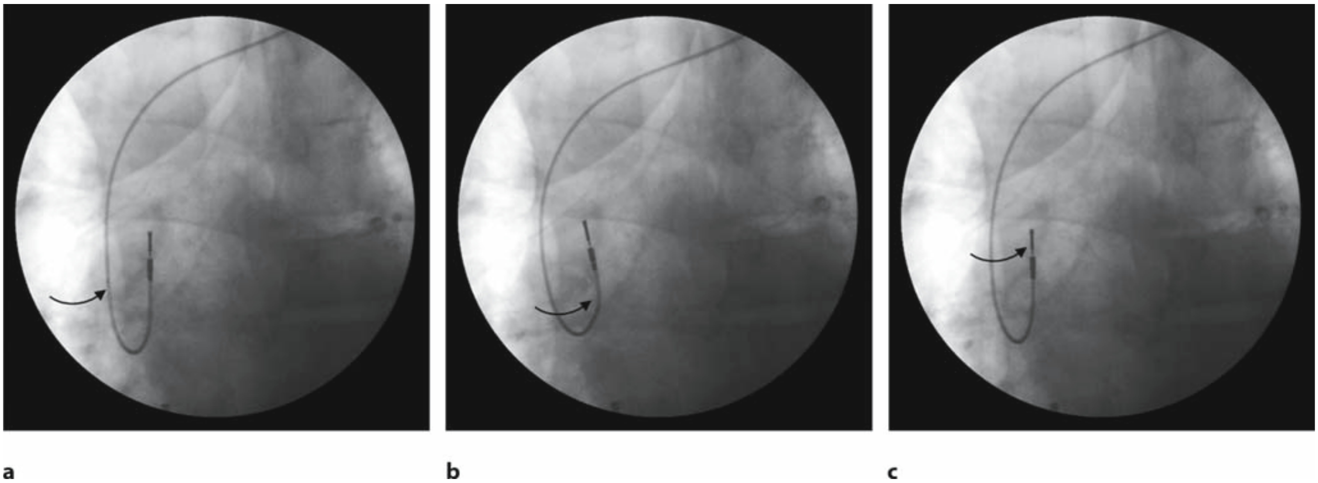


Figure 11.9 Insertion of locking stylet, of the LLD-2 type, within atrial bipolar lead with tines; arrow shows the stylet advancing into the lead's body at the level of superior vena cava (panel a); after curvature at the level of the right atrium appendage (panel b) and at the lead's distal tip (panel c)

Figure 11.10 Telescoping synthetic sheaths of different size and material to manually detach fibrous adhesions of leads. Panel a shows five internal and external types of mechanical propylene sheaths (different colors for different sizes). Panel b shows telescoping synthetic teflon sheaths, which are more flexible compared with the propylene made ones. Panel c shows stiffer sheaths that are used when subclavian approach is difficult

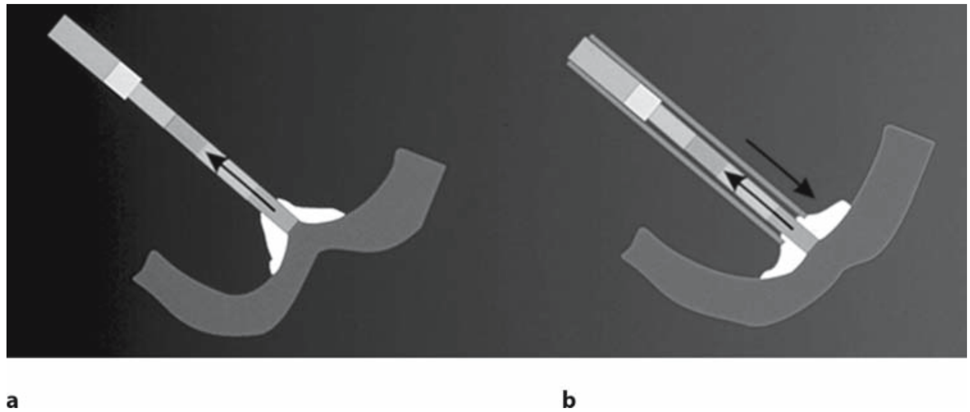


Figure 11.11 Panel a Direct traction of lead causes invagination of the myocardium with risk of tissue damage and possible cardiac tamponade. Panel b Countertraction carried out by pushing the external sheath against the myocardium counterbalances the traction on lead exerted by the locking stylet, thus limiting the risk of cardiac rupture

maneuver, it is important to align the telescoping synthetic sheath and the lead. Once the distal electrode of lead is reached, it is advisable to exert a countertraction with the external sheath against the myocardium, so as to prevent its invagination during the mechanical lead traction. (Figure 11.11).

11.2.3 Electrosurgical Dissection System

Another extraction technique which is progressively developing is the one that requires an electrosurgical dissection sheath (EDS) (Figure 11.12). These sheaths are equipped with two electrodes at the tip (Figure 11.13). Radiofrequency (RF) delivered from these electrodes causes dissection of the scar tissue. It is important to direct the sheath tip aligning it and the lead, thus avoiding angles with the vein dangerous for possible vascular ruptures. This device too is equipped with an external sheath enabling a countertraction for lead's tip removal (Figures 11.14 and 11.15).

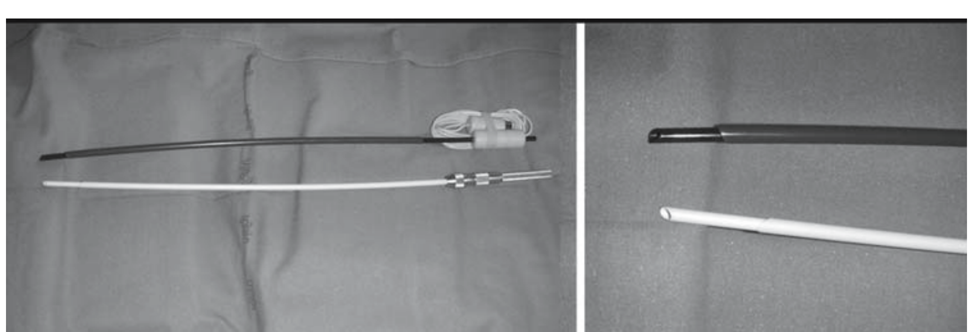


Figure 11.12 Electrosurgical sheath for radiofrequency (*RF*) bipolar dissection of scar tissue and propylene sheath

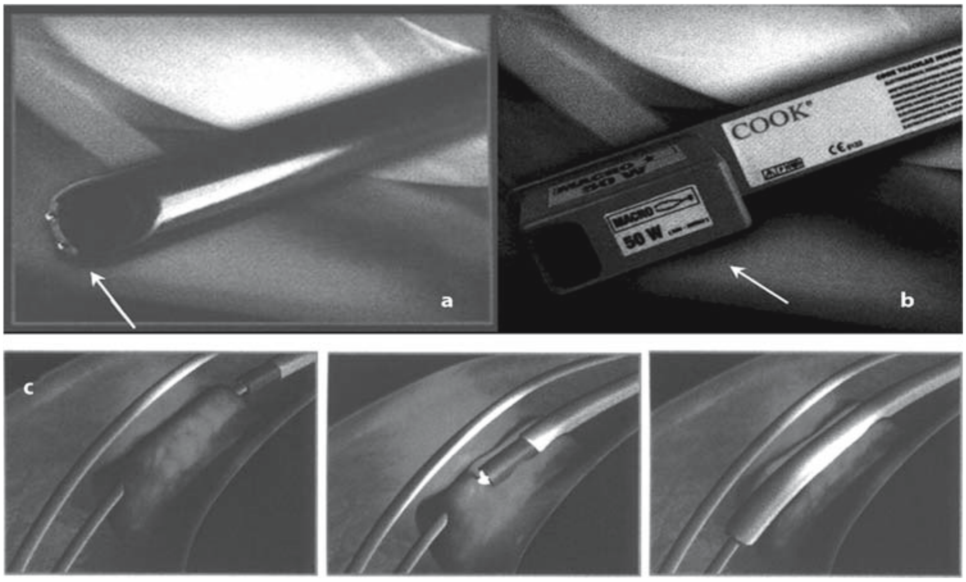


Figure 11.13 Panel a The tip of the electrosurgical dissection sheath (*EDS*) has two active electrodes (arrow) for dissection of scar tissue. Panel b Electrosurgical dissection system interface adapter (arrow). Panel c Electrosurgical dissection system mechanism: *EDS* advanced, activated and fibrous sheath, split and external sheath advanced

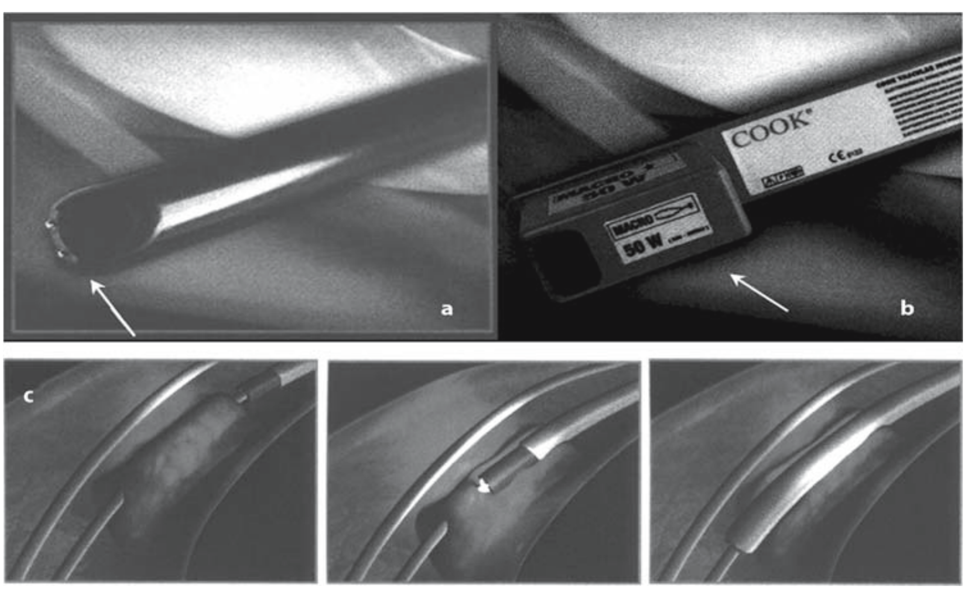


Figure 11.14 Panel a Patient with infected VDD pacemaker (*PM*) implanted via right subclavian vein approach. Panel b Electrosurgical dissection sheath (*EDS*). Black arrow indicates internal sheath; white arrow the external sheath

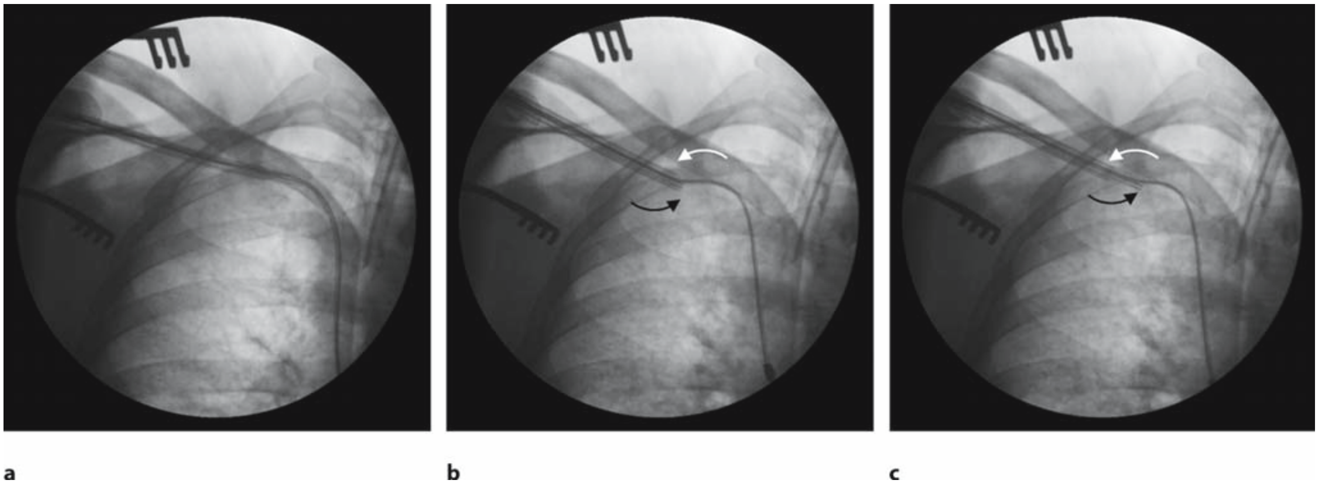


Figure 11.15 Panel a Electrosurgical dissection sheath (*EDS*) in the same patient as in Figure 11.14. Panel b The external sheath (white arrow) thoroughly covers the internal sheath with visible two active electrodes (black arrow). Panel c Internal sheath is advanced with the two active electrodes (black arrow) turned downward and perfectly lined up with lead; the external sheath (white arrow) is kept proximally to give support during the radiofrequency (*RF*) issue

11.2.4 Laser Lead Extraction

The laser sheath (Spectranectic Laser Sheath, SLS, SLS II), in three sizes 12, 14, 16 Fr, is made of coiled optical fibers between the inside and the outside of the structure's body. At its tip the fibers are arranged in a ring-like shape from which a laser source is delivered (Figure 11.16.) The laser energy is issued with a 308 nm XeCl system (Spectranetic

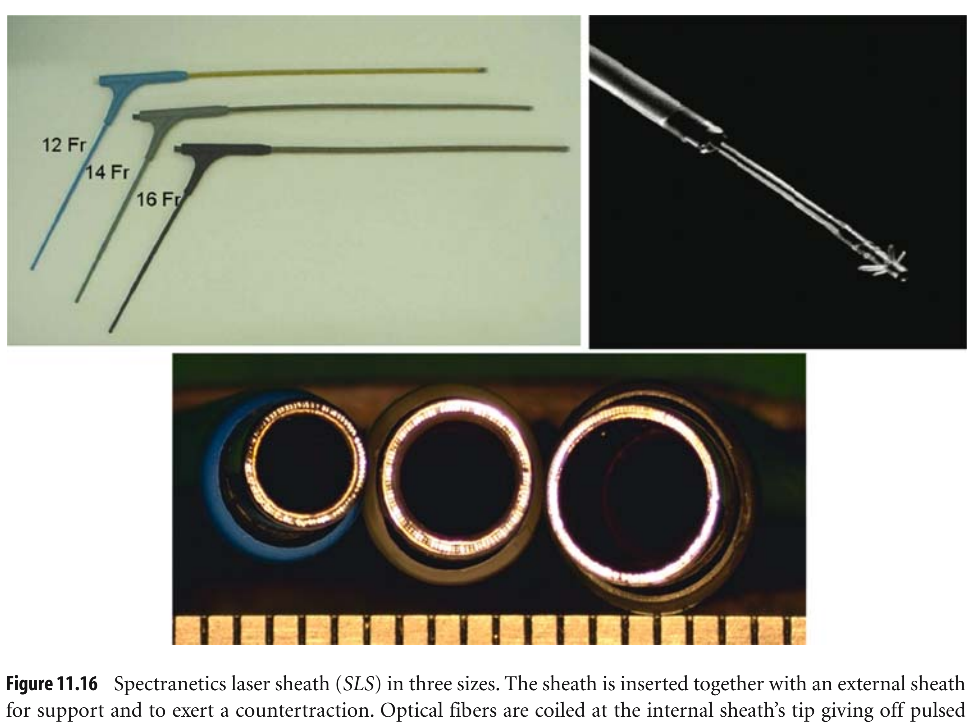


Figure 11.16 Spectranetics laser sheath (*SLS*) in three sizes. The sheath is inserted together with an external sheath for support and to exert a countertraction. Optical fibers are coiled at the internal sheath's tip giving off pulsed laser light

Figure 11.17 Panel a Spectranetics CVX-300 Excimer XeCl laser system. Panelb Laser consol. The arrows indicate fluence set and repetition rate set

CVX-300) which gives off pulsed light at 40–80 Hz repetition rate (Figure 11.17). Rupture of fibrous adhesions around the leads is caused by a combination of mechanisms such as a photochemical destruction of tissue material and a liquid vaporization, thus creating photoablation of the fibrous adhesions. With regard to the extraction method, as for other extraction techniques, the accurate preparation of lead is crucial. As a matter of fact, the first step is freeing the lead from fibrous adhesions and isolating the internal proximal coil. One must evaluate the lead's perviousness and its integrity by inserting a conventional stylet. Afterwards, specific gauges are employed to measure the internal lumen of each lead to be extracted (Figure 11.18). It is important not to fail this operation; otherwise the chosen lead locking device (LLD) locking stylet will risk to withdraw from the lead's distal tip during the traction maneuver.

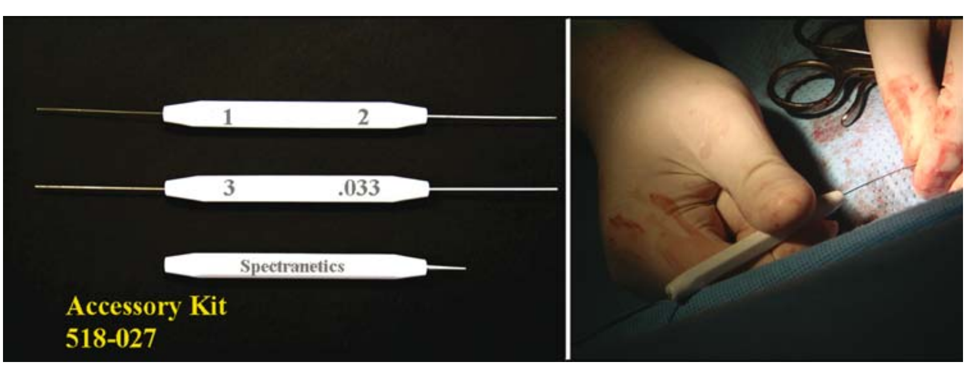
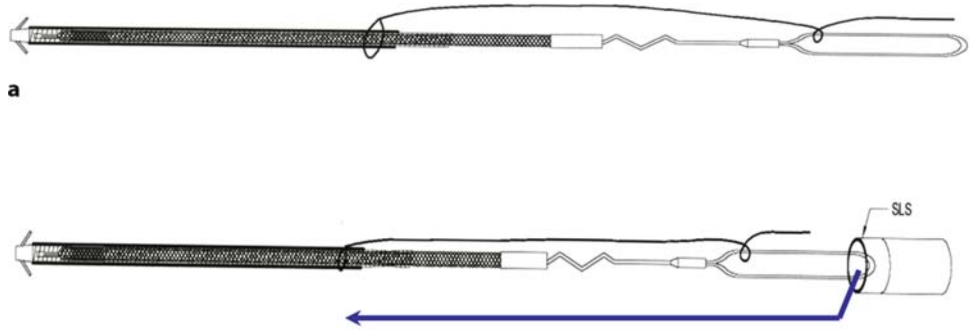


Figure 11.18 Panel a Accessory Kit Spectranetics to measure internal lead caliper. Panel b One defines the maximum internal lead size



a

b

Figure 11.19 Panel a A suture material is secured in place around distal lead insulation. Panel b Load the Spectranetic laser sheath (*SLS*) over the lead locking device (*LLD*) or the locking stylet

Then one thoroughly inserts the LLD locking stylet within the lead to extract and when the tip has been reached the locking mechanism is activated (Figures 11.6–11.9). In order to be sure of having chosen the correct size of the LLD, one exerts traction on the lead-LLD system, being ascertained by fluoroscopy that LLD does not withdraw.

Once the target lead has a Locking Stylet or a LLD in place, a length of suture material is secured in place around distal lead insulation. The suture is used as an additional traction device during the lead removal procedure (Figure 11.19). Then one loads the lead with SLS and proceeds to activate the laser train using only steady forward finger pressure on the SLS assembly (Figure 11.20). The pressure exerted on the sheath increases the mechanical effect of microbubbles. It does not pay to use the laser's blunted tip mechanically, as we would not accomplish the desired effect; on the contrary, we would only increase the risk of complications. As for conventional sheaths, the aid of the external sheath, even by means of this

a b c

Figure 11.20 Panel a Spectranetic laser sheath (*SLS*) advanced. Panel b *SLS* activated. Panel c Binding site ablated

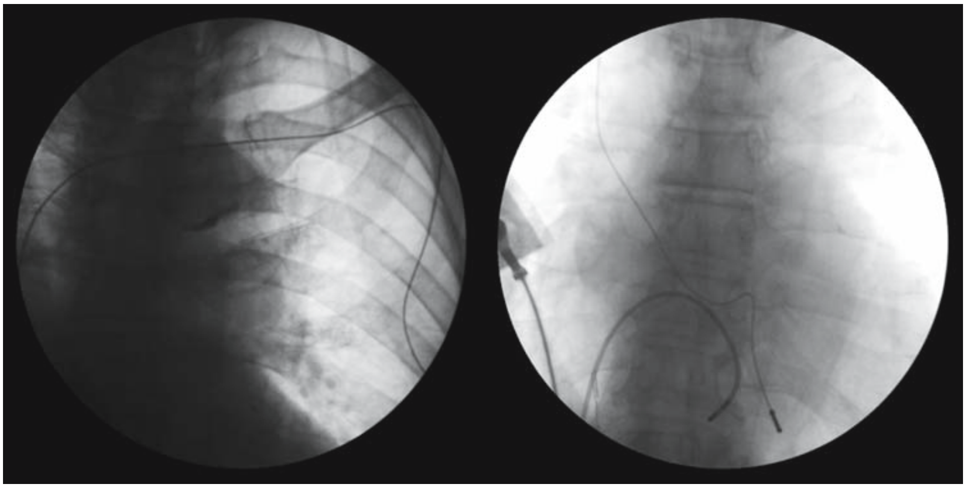
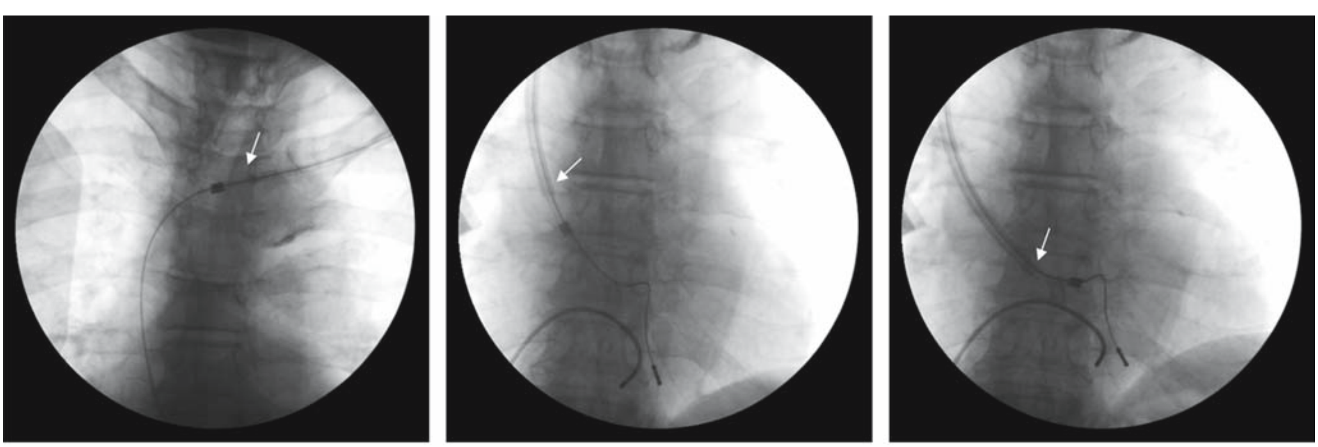


Figure 11.21 Fluoroscopic projections of infected ventricular lead with tines

extraction technique, is crucial as it enables to align the SLS and the lead, thus increasing maneuverability and reducing obstacles during its progression (Figures 11.21 and 11.22). By using this technique one can reach the lead's distal tip (Figure 11.23). It is advisable to stop delivering laser energy when about 1 cm from myocardium tissue and to remove the lead's tip by advancing the external sheath and utilizing the countertraction technique. (Figures 11.24 and 11.25). It is advisable to use the laser technique as soon as one perceives, with the traction technique, resistance on lead, in order to avoid uncoiling or ruptures of lead (Figure 11.26). Frequently, the commonest resistance sites to manual traction, where



a **b** **c**

Figure 11.22 Panel a Spectranetic laser sheath (*SLS*) II loaded over lead at the level of the left subclavian vein. The *SLS* II tip is turned downward while the external sheath is kept more proximally. Panel b After laser energy emission, the *SLS* II-external sheath system (arrow) is advanced within the right atrium, freeing lead from fibrous adhesions as far as reaching the tricuspid valve (panel c)

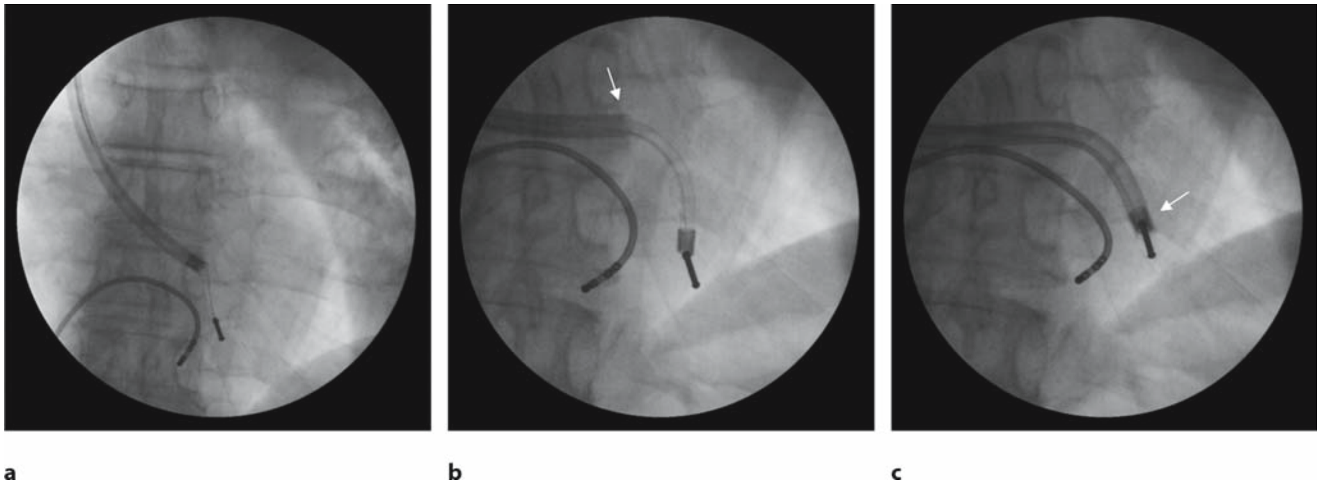


Figure 11.23 Panel a The Spectranetic laser sheath (*SLS*) II-external sheath system is advanced beyond the tricuspid valve. Panel b One keeps advancing *SLS* II using laser energy up to nearly 1 cm from the myocardial wall, keeping more at back the external sheath (arrow). Panel c Afterwards, one advances the external sheath (arrow) over the *SLS* II to carry out the countertraction

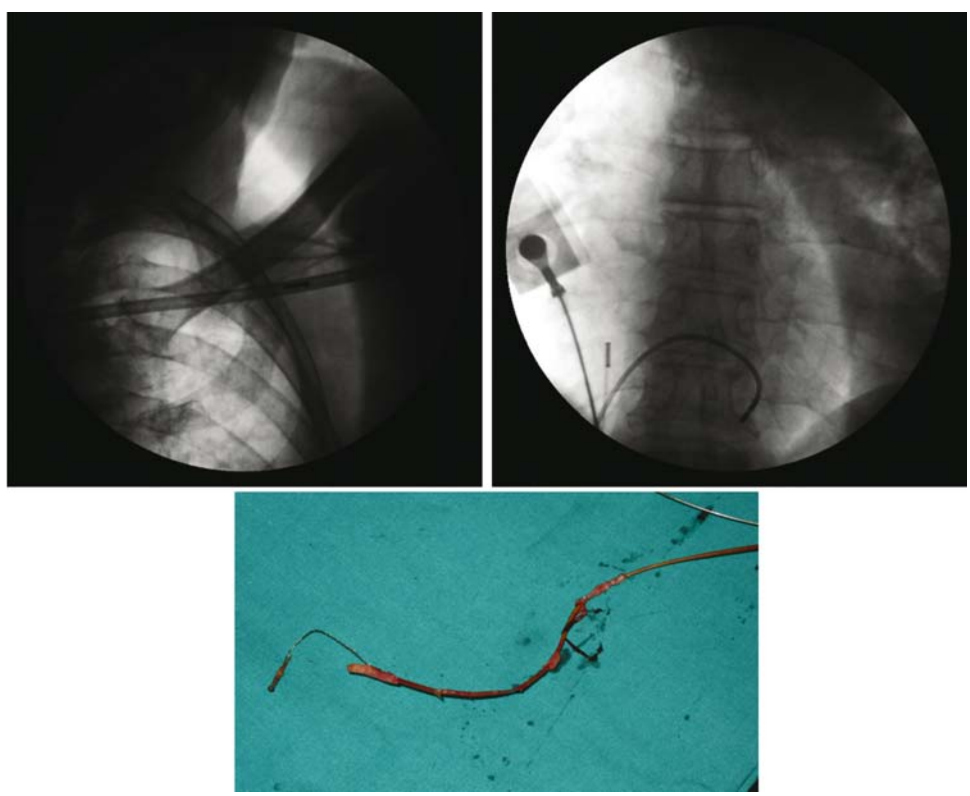


Figure 11.24 Panel a Countertraction technique. Arrow indicates the external sheath which is advanced as far as reaching the lead tip. Panel b One exerts traction on lead and a countertraction of the external sheath. Panel c The curved arrow shows detachment of the lead tip from the myocardial wall; straight arrow shows countertraction carried out by the external sheath in order to minimize the risk of perforation

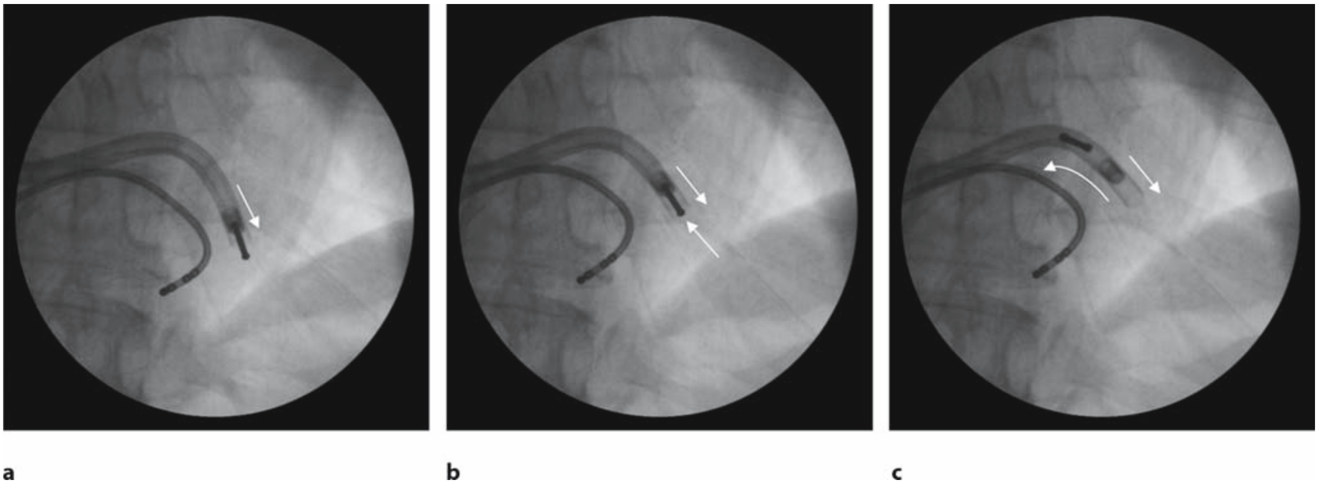


Figure 11.25 Definitive removal of ventricular lead which is covered with a significant fibrous muff

fibrous adhesions take place, are the subclavian region, superior vena cava region (often where superior ICD lead coils are localized), tricuspid valve region, and regions for anchoring leads (Figures 11.27 and 11.28). At times, we have to deal with patients who have already undergone an extraction procedure with the traction technique and partial lead removal. In this case, one must consider the opportunity of utilizing extraction of lead left in site with the laser technique. As a matter of fact, the difficulty of the previous procedure suggests the existence of strong fibrous adhesions (Figures 11.29 and 11.30).

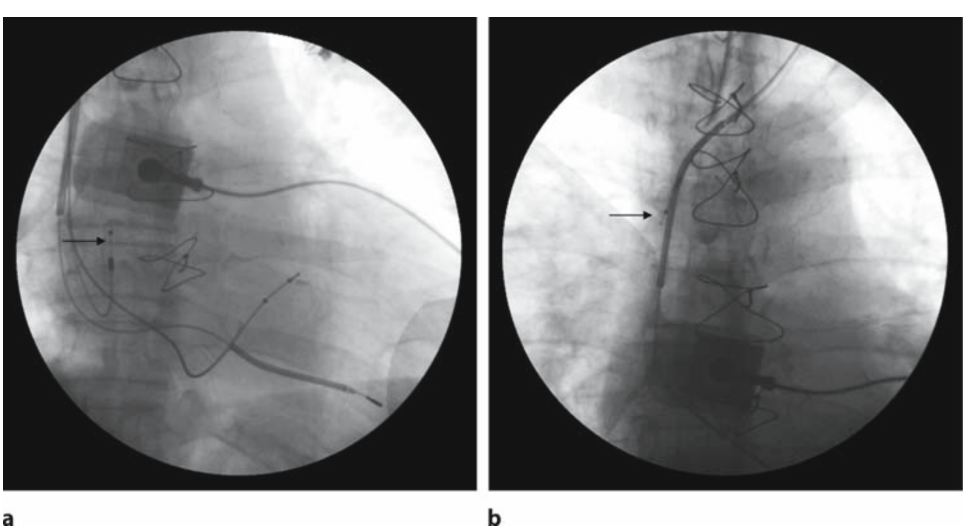


Figure 11.26 Panel a Patient with biventricular implantable cardioverter defibrillator (*ICD*). Traction maneuvers have already positioned left ventricular lead at the coronary sinus target branch; arrow indicates atrial lead within the right atrium appendage. Panel b With direct traction the left ventricular lead is definitively removed while the atrial lead stops at the level of the right ventricular lead's proximal coil

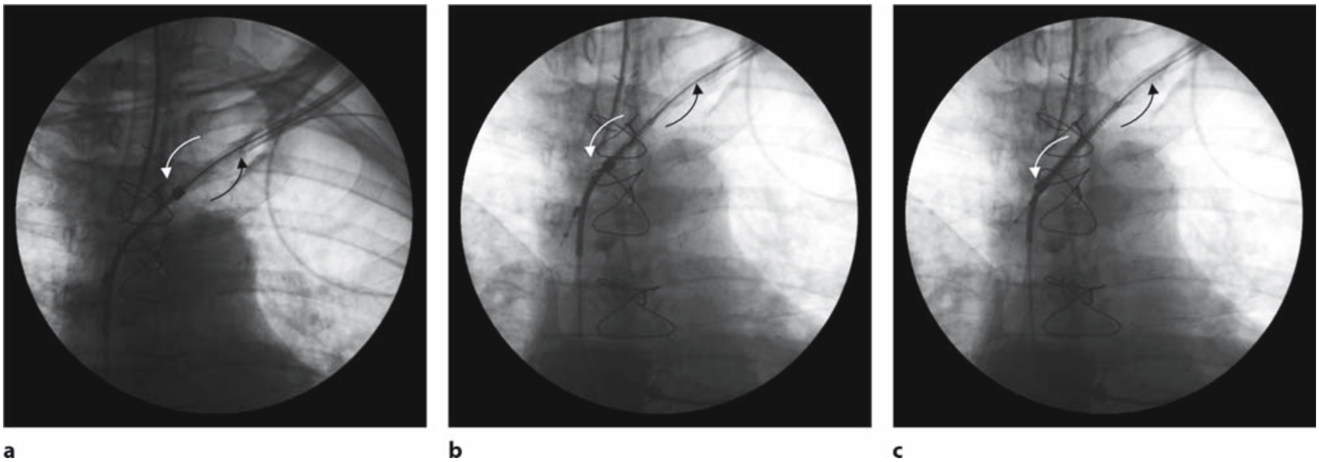


Figure 11.27 Panel a In order to free the atrial lead from fibrous adhesion at the level of the proximal coil, one inserts over the right ventricular lead, the Spectranetic laser sheath (*SLS*) II (white arrow) with the external sheath (black arrow) kept more proximally. Panel b The *SLS* II with its tip turned downward advances toward the superior vena cava freeing the right ventricular lead's proximal coil from the fibrous capsule. Panel c One loads *SLS* II-external sheath system over the atrial lead and then proceeds as far as its end up to freeing it from the fibrous muff

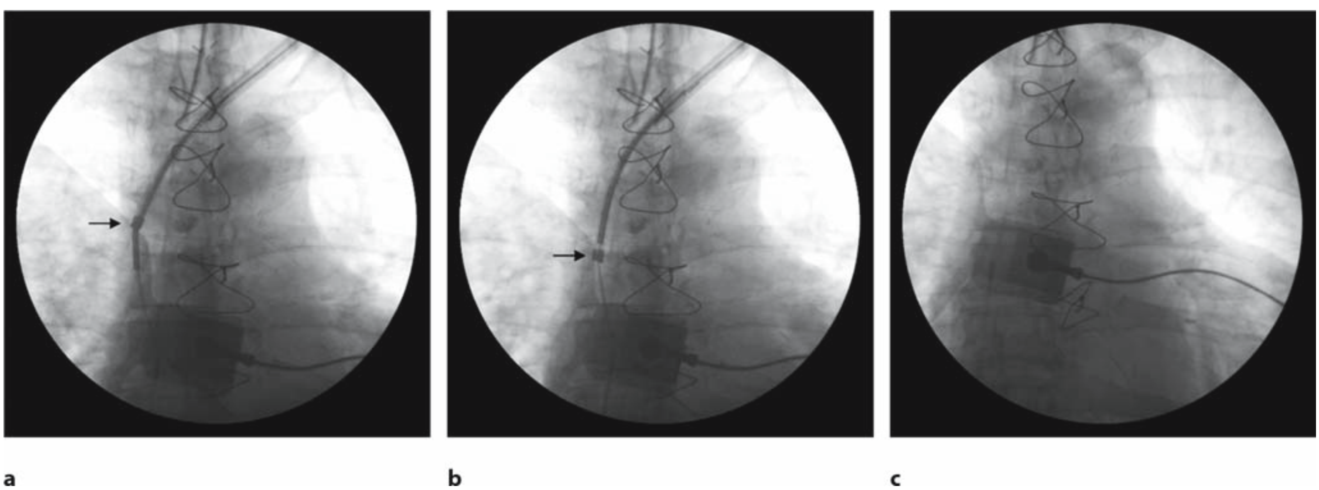


Figure 11.28 Panel a Same patient as in Figures 11.26 and 11.27. Once the atrial lead has been removed, one advances the Spectranetic laser sheath (*SLS*) II over the proximal coil (black arrow). Panel b Once the distal end of the laser sheath has passed beyond the right ventricular lead's coil, the rupture of fibrous adhesions occurs and the lead is easily removed (panel c)

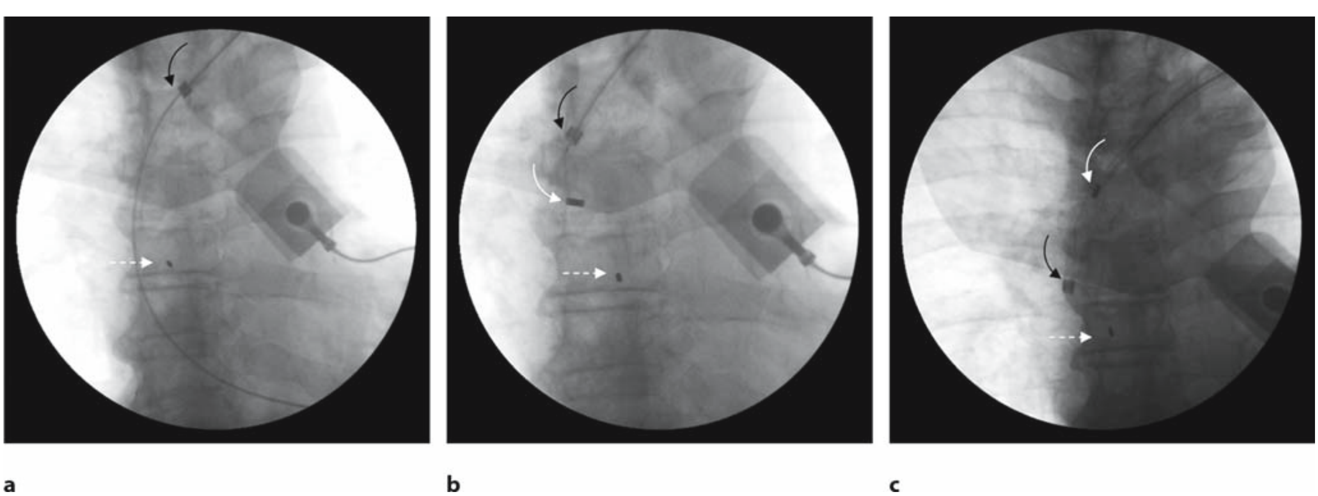


Figure 11.29 Panel a Patient with previous partial removing procedure of the atrial lead and existence of lead's distal end in the right atrium appendage (dotted white arrow). To remove the ventricular lead, the laser-assisted extraction has been utilized by positioning the Spectranetic laser sheath (*SLS*) II within the left subclavian vein (black arrow). Panel b The *SLS* II distal end (black arrow) is directed downward to minimize the risk of perforation; it is advanced up to cover the ventricular lead's uncoiled distal end (white arrow). Panel C. Advancing *SLS* II (black arrow) and exerting traction on lead, its distal end (white arrow) is removed from fibrous adhesion

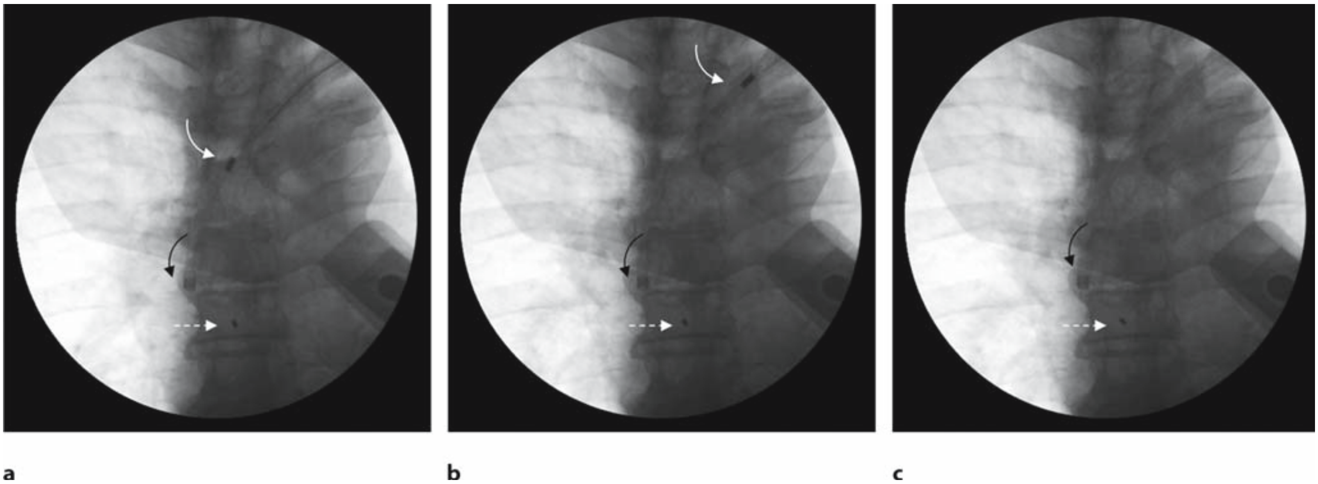


Figure 11.30 Panel a–c The white arrow shows definitive removal of the right ventricular lead; black arrow shows the Spectranetic laser sheath (*SLS*) II within the superior vena cava; dotted white arrow indicates the previously extracted lead's tip

11.2.5 Transfemoral or Transjugular Approach

Transfemoral approach is a technique for recovering leads or their parts entirely different from other techniques. It is a matter of inserting within a femoral vein a sheath of large size (it is advisable to use a 16 Fr sheath) to recover still bent leads. Tools employed in this approach are of various kinds (Figure 11.31) but they have got the aim to hook up a lead or part of it. This approach is usually utilized when one of the previous techniques has failed (Figure 11.32) or when it is necessary to remove fractured or interrupted leads because it is impossible to provide lead with locking stylets (Figures 11.33–11.36). At times with this approach, it is difficult to disengage leads' tips from fibrous sheath. Therefore, similarly to other techniques, one can use an external sheath which is advanced over the retriever system, when this one exerts traction on lead downward, to carry out the countertraction maneuver. This technique is also employed to recover venous central leads Port or parts of stents peripherally stationed (Figures 11.37–11.39). If the leads' distal tips cannot be recovered through the sheath within femoral vein, this can be done through the right jugular vein. As a matter of fact, at times, one uses the femoral approach in order to be able to make the lead slide through the fibrous sheath and, thereafter, through the right jugular vein, one can utilize the above-mentioned extraction techniques for lead removal.

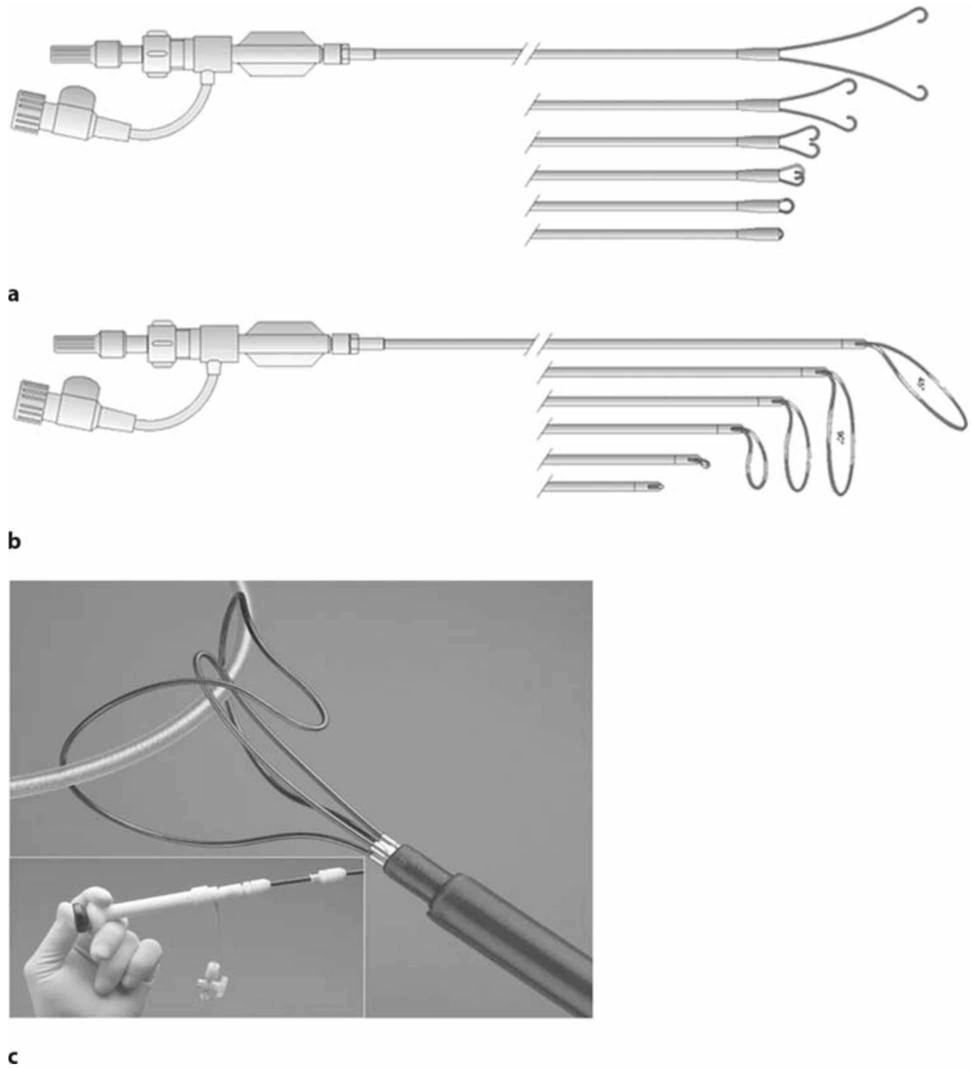


Figure 11.31 Transfemoral approach lead extraction. Panels a and b Catcher and Lassos Retriever (Osypka): Panel c Needle Eye Retriever (Cook Vascular, Inc)

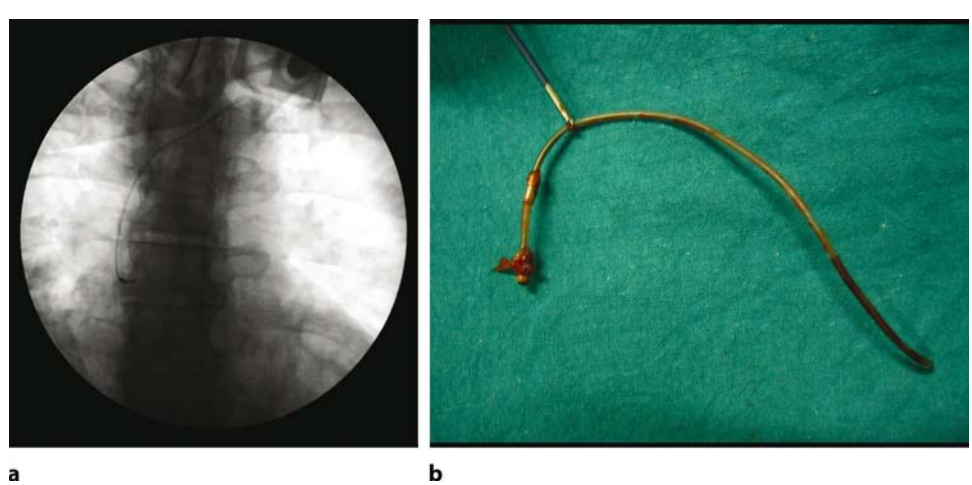
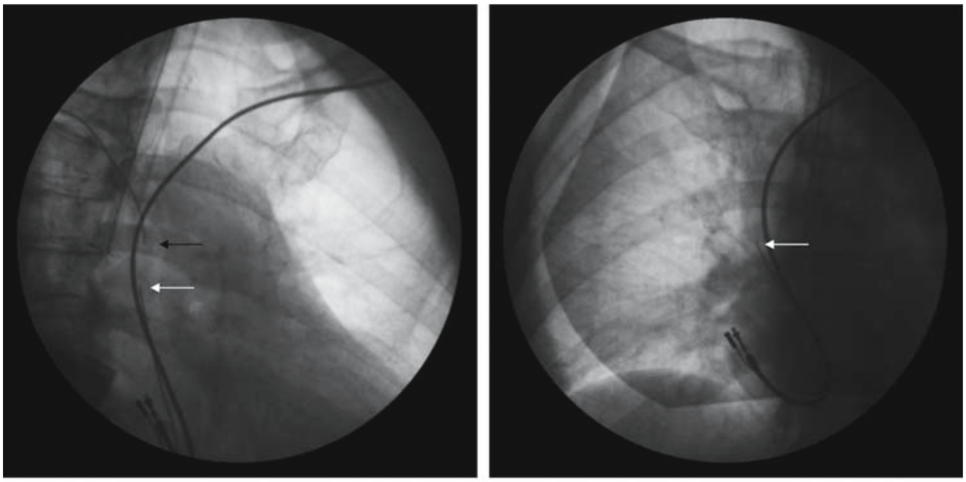
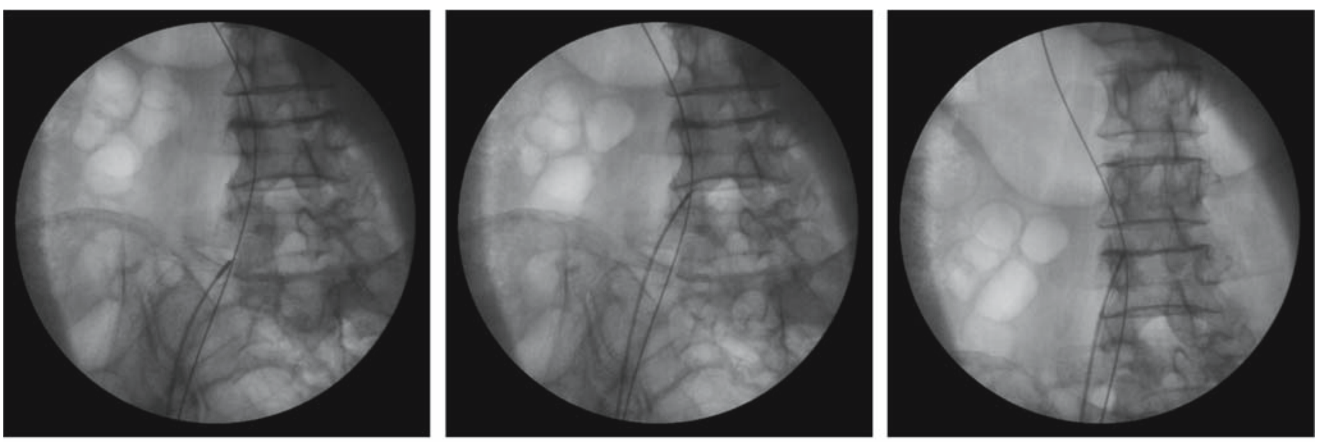


Figure 11.32 Panel a Posteroanterior projection showing the atrial lead with tines broken during extraction with laser technique. Panel b Recovering lead by the Catcher transfemoral approach



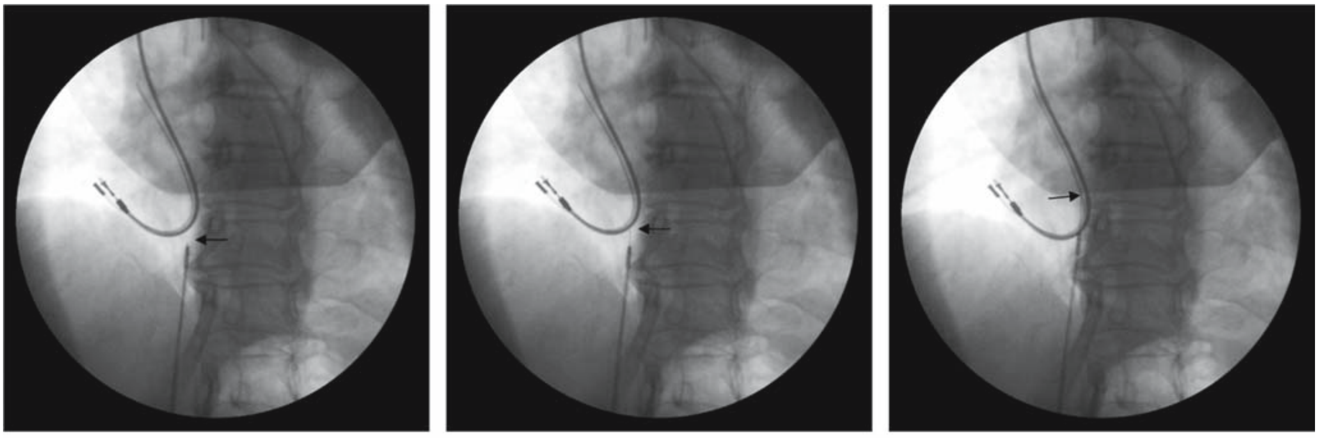
a b

Figure 11.33 Panel a Atrial lead implanted via the right cephalic vein broken into a proximal stump (black arrow) and a distal stump (white arrow) at the level of the superior vena cava. Panel b Once the proximal stump has been removed, stiffening lead with conventional stylet and using traction, in order to recover distal stump (white arrow) transfemoral approach has been used



a b c

Figure 11.34 Same patient as in Figure 11.33. Panel a A catcher (Osypka) is inserted through the right femoral vein by means of a 16 Fr sheath. Panels b–c In order to advance the catcher into the right femoral vein, one hooks it up to a 0.32 J guide wire, so as to go beyond vein's valves and bifurcations



a b c

Figure 11.35 Panel a Once the right atrium has been reached, the catcher is freed from the 0.32 guidewire. Panel b One advances the catcher toward the atrial lead's loop, activating the recovering mechanism (arrow). Panel c One tries unsuccessfully to catch the atrial stump

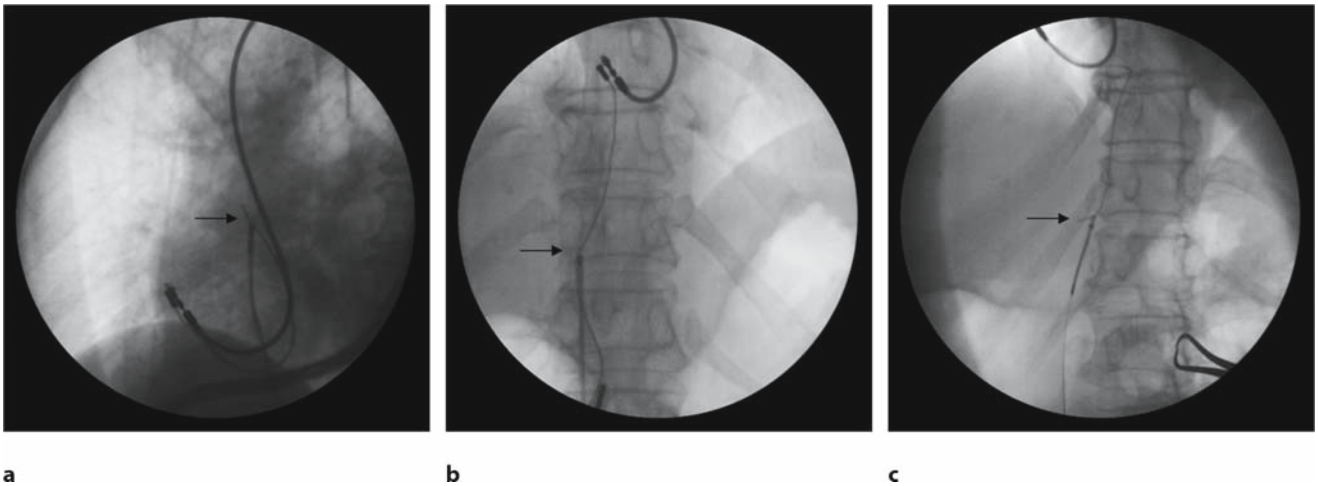


Figure 11.36 Panel a The catcher is directed toward the lead's stump (arrow), succeeding in hooking it up steadily. Panel b One exerts continuous traction of the catcher downward, thus straightening the lead. Panel c Definitive removal of the atrial stump, which is taken back within the femoral sheath

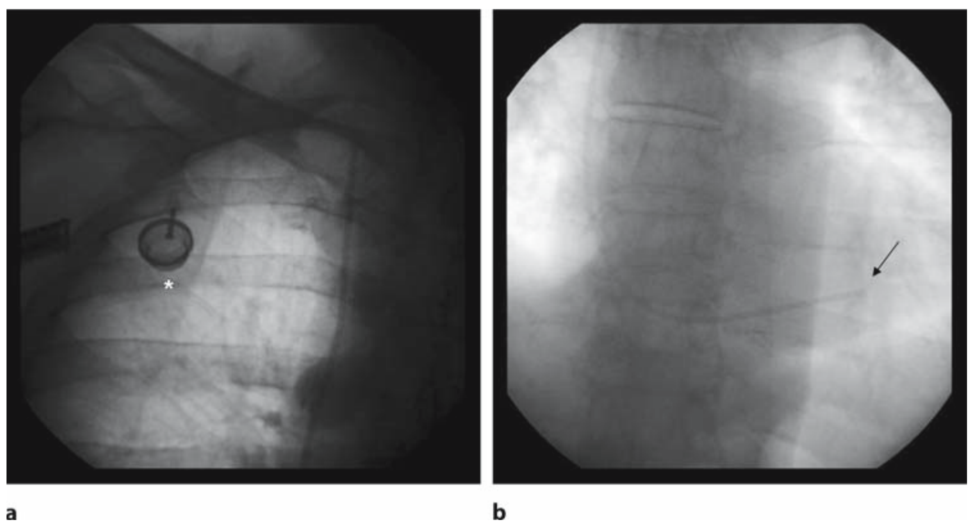


Figure 11.37 Panel a Port device (asterisk) visible in the PA projection. Panel b The arrow indicates the central venous lead within the right ventricle

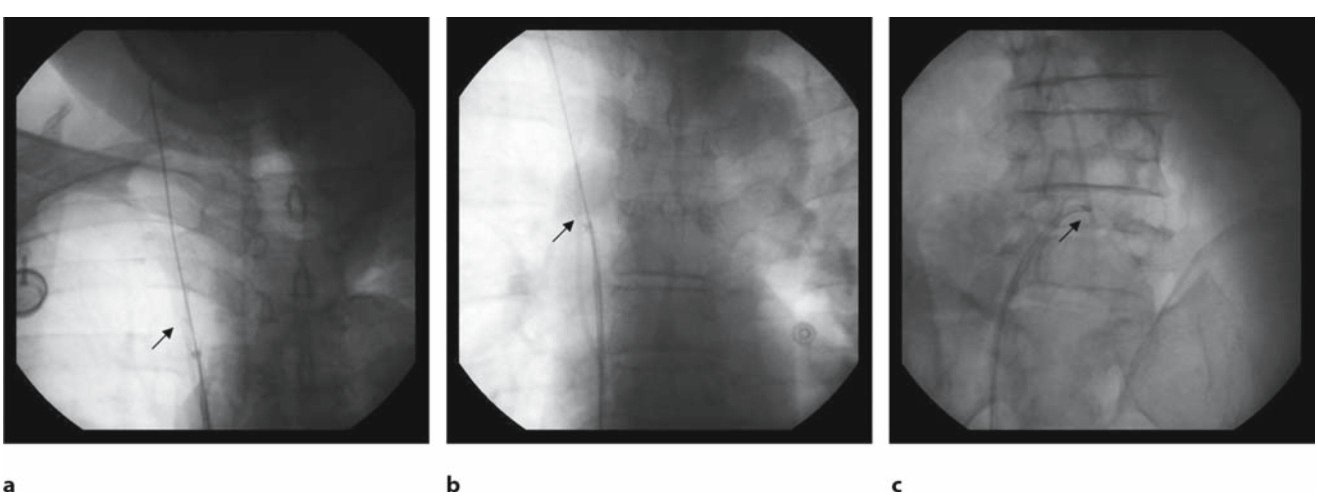
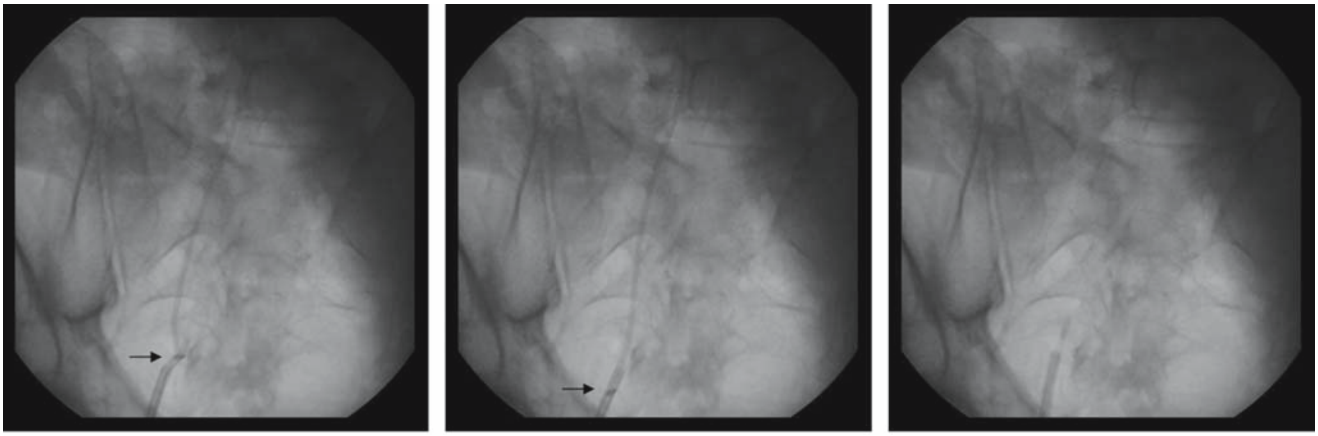


Figure 11.38 Panel a Slip-knot shaped device (arrow), inserted through the right femoral vein, reaching the right atrium near the free tip of the central venous lead. Panel b Slip-knot (arrow) hooks up the lead within the right atrium. Panel c Slip-knot with lead (arrow) is taken at the level of the right femoral sheath



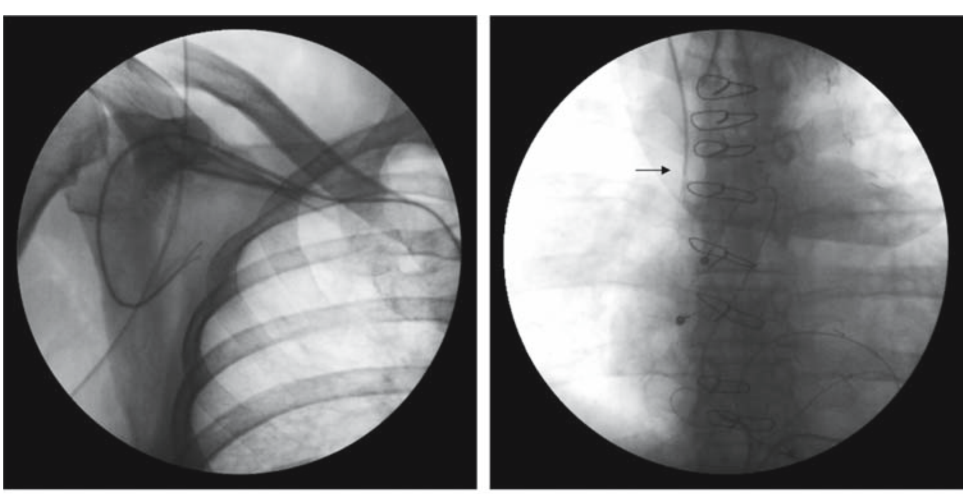
a b c

Figure 11.39 Panel a Slip-knot with hooked up lead (arrow) reaches the sheath's tip within the right femoral vein. Panel b The slip-knot is inserted within the sheath (arrow) pulling the lead with itself too. Panel c Lead has been definitively removed through the transfemoral recovering system

11.3 Conclusions

At the present time, endovascular extraction of leads provides a good definitive solution for PM/ICD postimplantations infections, which is an increasingly frequent complication relative to the increase of indications for ICD implantations and biventricular devices. Furthermore, not always surgery is successful in thoroughly removing leads, mainly in the venous subclavian district.

Various available techniques can help even in the case of partial removals of postsurgical leads (Figures 11.40–11.44). In the future, one might also think of a reverse stand by offered by endovascular lead extraction in case heart surgery fails.



a b

Figure 11.40 Panel a Stump of the right ventricular lead after partial surgical removal. Panel b Arrow indicates lead's tip cut by surgeon with no more electrode

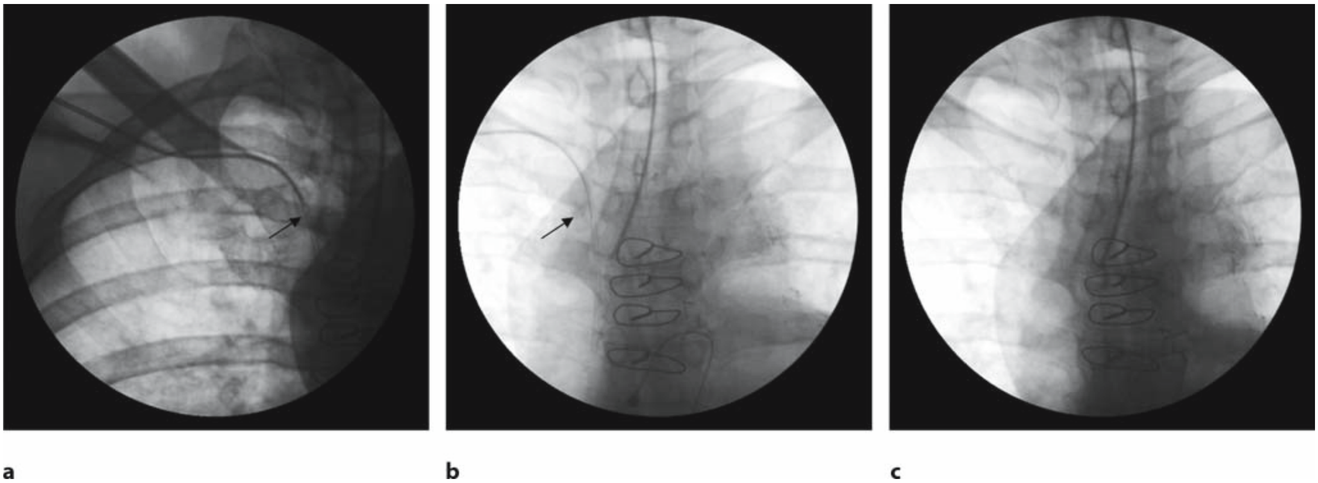


Figure 11.41 Same patient as in Figure 11.40. Panels a–b Arrow indicates stiffening of lead's stump with locking stylet. Panel c Thorough removal of the ventricular stump using traction after having activated the locking mechanism

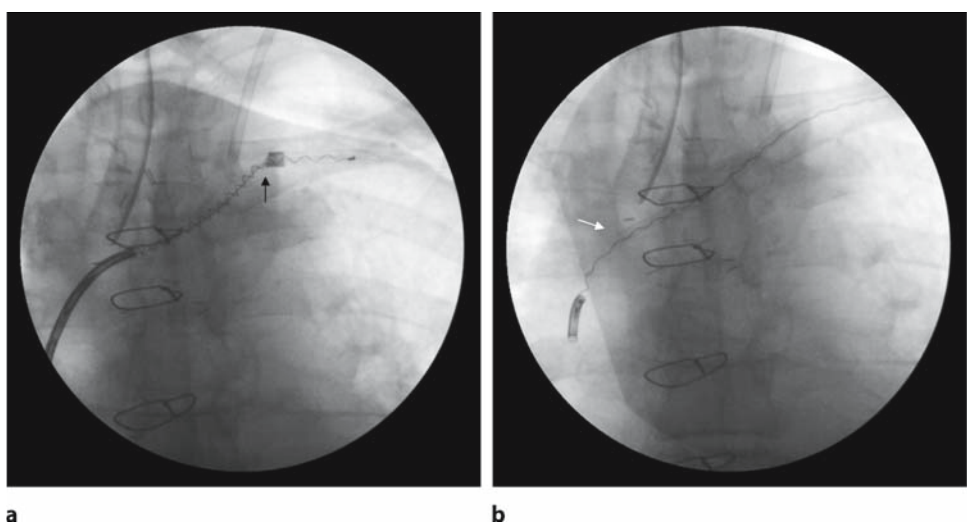


Figure 11.42 Panel a Partial removal after surgery for infective endocarditis and vegetations on leads in patient with biventricular implantable cardioverter defibrillator (*ICD*) and double valve prosthesis. Panel b White asterisk indicates atrial lead's stump without distal electrode; black asterisk indicates ventricular lead's proximal coil's stump with no more distal coil and electrode

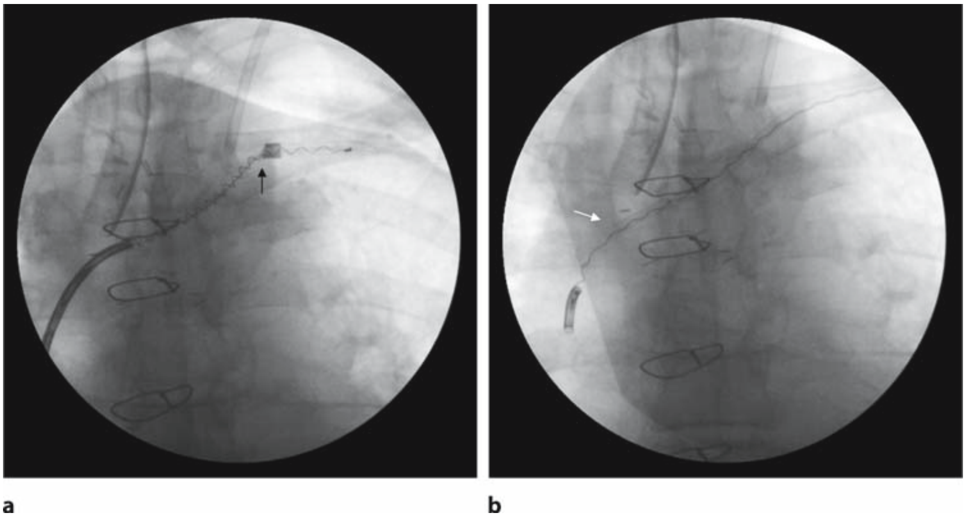


Figure 11.43 Same patient as in Figure 11.42. Panel a Atrial lead has been removed with traction technique, using a locking stylet. The arrow indicates that the laser sheath's distal end cannot advance over uncoiled ventricular lead. Panel b One inserts a long sheath which is successful in thoroughly covering the coil while exerting a manual traction, thus minimizing the risk of perforation

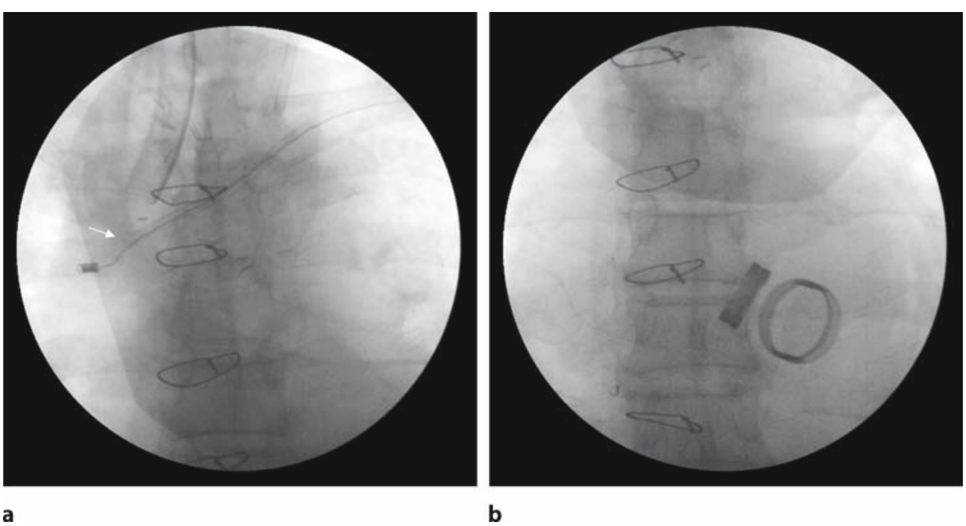


Figure 11.44 Same patient as in Figures 11.42–11.43. Panel a Arrow indicates sheath that has almost entirely covered the lead's coil, by now completely uncoiled by traction. Panel b Thorough removal of the right ventricular lead's part

12

Endomyocardial Biopsy

The technique of percutaneous endomyocardial biopsy was introduced in the last decades to complete and improve the study of heart muscle diseases. There is growing evidence that the analysis of endomyocardial biopsies may contribute to define not only the diagnosis but also the prognosis and treatment of patients with myocardial disorders and also with apparently idiopathic ventricular arrhythmias.

The first cardiac biopsies were performed in the first sixties with a transthoracic approach, using biopsy needles inserted under fluoroscopy and electrocardiographic guide in the left ventricular apex: this approach, although providing diagnostic material in a high percentage of cases, was characterized by a high rate of complications including pneumothorax, hemopericardium, and postpericardioectomy syndrome.

Sakakibara and Konno first introduced a bioptome for percutaneous endomyocardial biopsy, characterized by a distal end with two cups, opened and closed through a wire activated by a sliding assembly at the proximal end. The bioptome, due to its size, was inserted in large veins or arteries by a cutdown technique.

This new concept of bioptome was improved in the following years by Caves and Richardson that introduced more flexible and smaller bioptomes that could be inserted percutaneously in smaller veins and arteries.

At variance with earlier reusable devices, modern biopsy forceps are all single-use and disposable, thus eliminating the risk of patient-to-patient disease transmission, pyrogen reaction, and mechanical malfunction.

There are two different types of bioptomes currently available: preshaped bioptomes, stiffer, introduced through a short sheath, and maneuvered as independent catheters, and flexible bioptomes, inserted through a preformed long sheath that is positioned inside the ventricular cavity and directs the head of the bioptome toward the ventricular wall.

Preshaped bioptomes allow a better control, and their curvature can be modified by the operator to better traverse the tricuspid valve or reach an optimal site to perform biopsies. However, the relative stiffness of preshaped bioptome may increases the risk of perforation of the vena cava, right atrium, or right ventricular free wall, during the maneuvers to reach the right ventricular septum. In addition, in the presence of significant trabeculation of the right ventricle, tricuspid valve regurgitation, and significant enlargement of the right ventricle, it can be difficult to enter the right ventricle. Moreover, preshaped bioptomes are not suitable for left ventricular endomyocardial biopsy.

Flexible bioptomes are inserted through a preformed long sheath, usually advanced over an angled pigtail or balloon flotation catheter and maintained in the ventricular cavity throughout the biopsy procedure. The long sheath partially reduces the operator control of the site of biopsy and its persistence inside the ventricle may increase the risk of ventricular arrhythmias, conduction disturbances and, rarely, free wall perforation.

Actually there are several disposable sheaths and bioptomes for use from jugular, and subclavian veins, and femoral veins and arteries; currently available devices vary in terms of length, flexibility, mechanism of jaws opening and closing, jaw size, and diameter.

12.1 Biopsy Technique

Right ventricular endomyocardial biopsy can be performed from the jugular, subclavian, brachial, and femoral veins, while left ventricular endomyocardial biopsy is generally performed from the right or left femoral artery, although a brachial approach can be adopted in particular patients.

Endomyocardial biopsy is generally performed under fluoroscopic guidance. Echocardiography has been suggested as a better tool to guide biopsy execution, leading to a lower rate of perforation, but a correct visualization of the forceps inside the right ventricle is provided only by very expert operators. On the contrary, echocardiographic guidance can provide an adjunctive value in the biopsy of atrial and ventricular masses. We usually perform endomyocardial biopsy under fluoroscopy, although in the recent years we are testing a combined fluoroscopic and electroanatomical guidance in patients with ventricular arrhythmias (see further sections).

With regard to the kind of vascular approach, we usually perform endomyocardial biopsy from the femoral vein and artery using preformed long sheaths. The femoral approach is preferred in diagnostic (nonheart transplant monitoring) procedures, when endomyocardial biopsy is performed in concomitance with coronary angiography, and right and left catheterization. In addition, mostly in patients with heart failure of unknown cause, we generally perform biventricular endomyocardial biopsies to increase the diagnostic sensitivity of the procedure by reducing the sampling error. Similarly in patients with idiopathic ventricular arrhythmias undergoing electroanatomical mapping and programmed stimulation, the femoral approach is generally more suitable.

The jugular approach, although the jugular vein access is technically more difficult than the femoral one, is widely adopted as the execution of endomyocardial biopsy, particularly with preshaped bioptome, is generally considered more easy. The jugular approach is preferred in patients with heart transplantation, undergoing multiple biopsies.

The right subclavian vein is usually approached when the internal jugular and femoral veins are not suitable for access. The only recommendation concerning this access regards the site of entry into the subclavian vein, which must be more lateral than usual to avoid a subclavian vein/superior vena cava angle too acute making it difficult to advance the stiff preshaped bioptome into the heart.

As preshaped bioptomes are maneuvered as conventional catheters, while flexible bioptomes require a more complex preparation, according to our experience, we will describe in detail and with pictures the femoral approach with preformed sheath for both right and left endomyocardial biopsy, and we will briefly summarize how to maneuver preshaped bioptomes.

12.1.1 Femoral Approach with Preformed Sheath and Flexible Bioptome

Right Ventricular Endomyocardial Biopsy

In-hospital patients undergoing right or left ventricular endomyocardial biopsy via the femoral vein or artery must be in fasting state since at least 12 h, and a bland sedative premedication is usually administered before the procedure.

The femoral vein is approached by Amplatz, Seldinger, or micropuncture approach. A short 7 Fr sheath is inserted in the femoral vein before the long preformed sheath is placed. If necessary, right cardiac catheterization can be performed using the short sheath;

with regard to right ventricular angiography we prefer to perform it using the pigtail inside the long preformed sheath before it is removed (see further).

All preformed sheaths for right ventricular endomyocardial biopsy present an angulated distal end with an angle of curvature varying from 135° to 180°. Sheaths for left ventricular endomyocardial biopsy present a straight distal end (Figure 12.1).

The guiding sheath is mounted over a 7 Fr angulated pigtail catheter as shown in Figure 12.2: the pigtail is used as a support during the positioning of the sheath. Some authors use to insert a 9 Fr self-sealing sheath through which the 7 Fr guiding sheath is advanced to reduce the risk of kinking and to increase maneuverability of the sheath. We suggest to perform this maneuver in the anterior view.

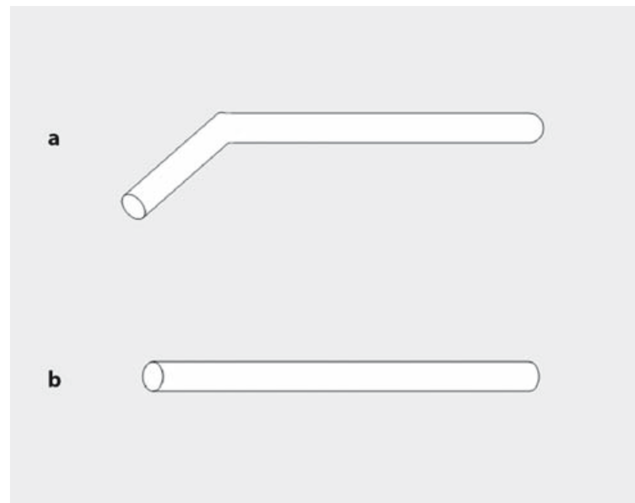


Figure 12.1 Distal ends of preformed long sheath for right and left ventricular endomyocardial biopsy (*EMB*). The preshaped long sheath for right ventricular endomyocardial biopsy (**a**) is generally angulated with different angles of curvature: the most common present an angle of about 135°. This curvature allows to direct the bioptome toward the interventricular septum avoiding the free wall. The long preformed sheath used for left ventricular endomyocardial biopsy is usually a straight one (**b**), allowing to perform biopsies in the apical portion of the ventricle

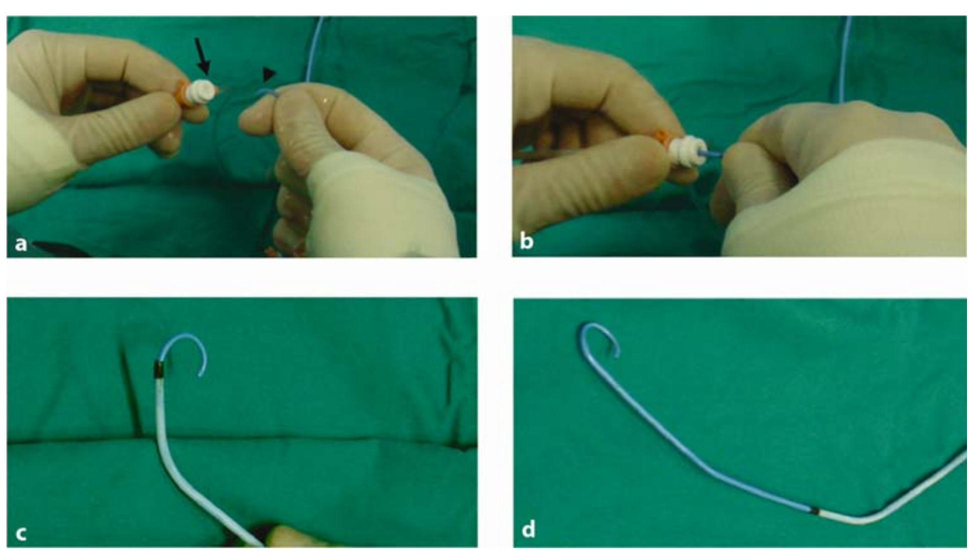


Figure 12.2 Assembly of preformed sheath and pigtail catheter for sheath positioning in ventricular chambers. An angulated pigtail catheter is generally used to introduce the long sheath inside the ventricles. The pigtail tip is gently straightened (arrowhead) and inserted in the valve of the sheath (arrow) (panel a). The pigtail is advanced inside the sheath (panel b) until it exits the sheath (panel c). The pigtail must be advanced until all the exceeding length exits the sheath (panel d) to have a relatively floppy distal end when entering the ventricles

The guidewire is inserted in the short sheath and advanced to the inferior vena cava; the short sheath is then removed and the proximal end of the wire is inserted in the proximal end of the pigtail (inside the preformed long sheath); the pigtail and the preshaped sheath are then inserted in the femoral vein.

The pigtail catheter is advanced in the inferior vena cava and in the lower portion of the right atrium. The pigtail is then introduced in the right ventricle with either a conventional or a modified approach. In the conventional approach, the pigtail is advanced to the right atrium roof and gently forced to obtain a curve of the catheter, allowing to advance it through the tricuspid valve. This approach, generally used for all flexible catheters such as pigtail alone and multipurpose catheter, may become more difficult when handling the long sheath over the pigtail, as the presence of the sheath makes the pigtail itself more stiff: in particular, this approach may become difficult when the right atrium is significantly enlarged or tricuspidal regurgitation is present. In the alternative approach (that we generally use), once the pigtail is positioned in the lower right atrium, a J flexible guidewire is advanced out of the pigtail through the tricuspid valve (Figure 12.3), taking care to not induce sustained ventricular arrhythmias if the guidewire hurts the right ventricular outflow tract or the free wall. Once the guidewire reaches the right ventricular apex, the pigtail is advanced over the guidewire to the septal–apical region and the guidewire is rapidly removed. This position of the pigtail can be used, if required, to perform right ventricular angiography with the sheath still mounted over the pigtail to reduce the time of the procedure. We always perform right ventricular angiography before the execution of right ventricular endomyocardial biopsy, to obtain further details of right ventricular structure and contractility, identifying akinetic and diskinetic segments that may result more affected by the underlying disease: this approach may increase the diagnostic sensitivity of endomyocardial biopsy. The preformed sheath is then advanced over the pigtail, keeping this one firm in the right ventricular apex: the sheath must be advanced gently, to avoid excessive pressure of the pigtail against the apical wall, but firmly, to maintain the apical positioning of the pigtail. Once the sheath reaches the interventricular septum, the pigtail is removed keeping the sheath in the obtained position.

The correct position is also confirmed by ventricular ectopic beats: it is possible to slightly modify the position of the sheath to avoid premature contractions during the execution of biopsy. To further verify a correct positioning of the long sheath against the right ventricular septum and away from the free wall, we suggest to perform contrast medium flushes in both right (30°) and left (60°) anterior oblique views to visualize the interventricular septum. It must be noticed that once we remove the pigtail, the sheath reacquires its original angulated shape and therefore a minimal retraction of the tip from the original position may occur: this retraction is compensated by the extension of distal portion of the sheath, occurring when the bioptome (straighter and stiffer than sheath) enters the distal end (Figure 12.4). The guiding sheath must always be flushed with saline during all its permanence in the right ventricle and during the insertion of the bioptome to avoid air embolization and clotting.

The bioptome is inserted in the sheath and rapidly advanced: once it reaches its distal end, the bioptome is slowly advanced outside the sheath and jaws are immediately open. Many operators while advancing the bioptome slowly withdraw the sheath to facilitate jaws opening and to reduce the risk of piercing the cardiac wall. The bioptome with opened jaws is advanced against the cardiac wall (with the contact being confirmed by fluoroscopy and occurrence of ectopic beats) and jaws are slowly but firmly closed to enucleate the specimen. Once the sample has been retrieved, it is gently removed from the bioptome cups with a fine needle and immediately placed in the adequate preservative.

During biopsy execution some patients may experience a tugging sensation and occasionally chest pain, mostly when a left ventricular biopsy is performed.

Chest pain during or immediately after biopsy may represent the sign of cardiac perforation: fluoroscopy of the heart must be immediately checked to detect signs of cardiac tamponade; if a long sheath has been used, minimal flushes of contrast medium inside the ventricular cavity can be performed to visualize eventual leakage of medium in the pericardial space. Blood pressure decrease and swollen jugular veins are the first signs of cardiac tamponade and should prompt for pericardial drainage. A kit for pericardiocentess should always be available in the catheterization or electrophysiology lab, when performing

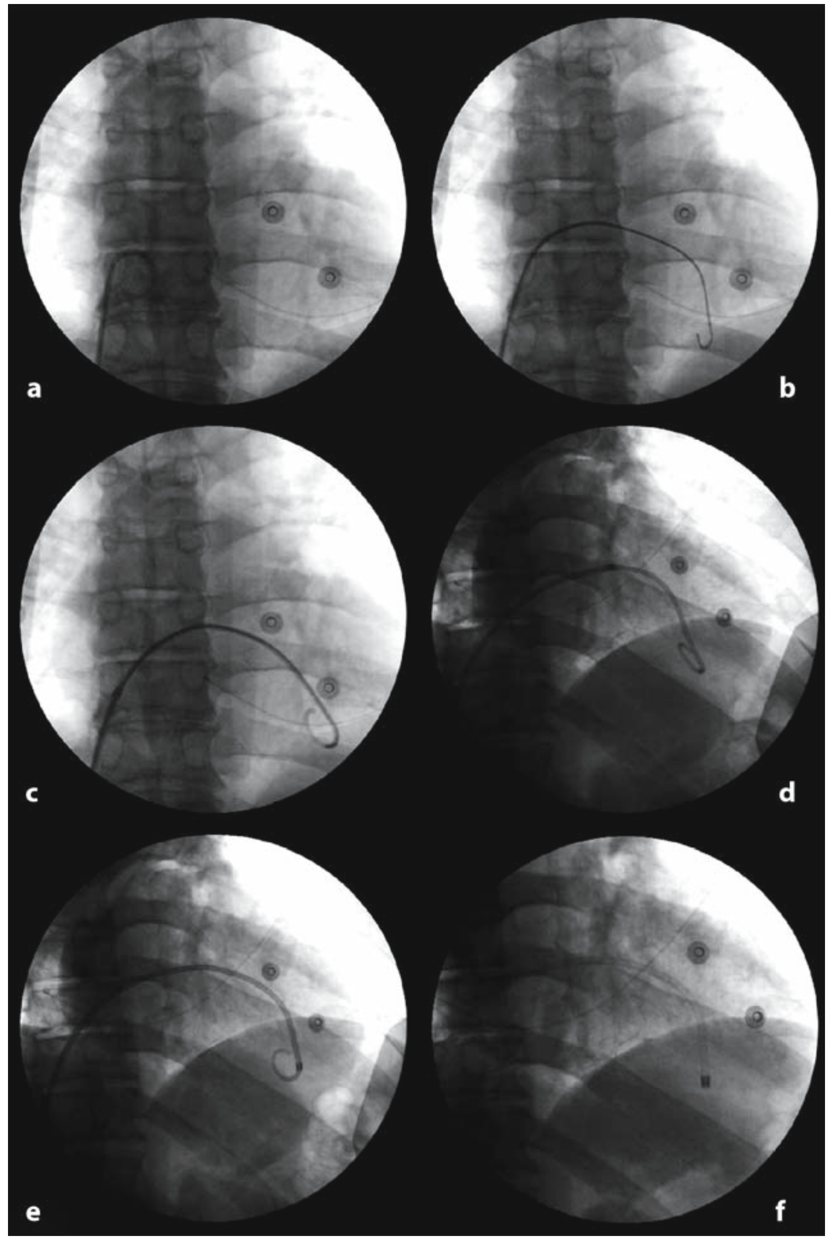


Figure 12.3 Positioning of preformed long sheath for right ventricular endomyocardial biopsy. The right ventricular preformed sheath (angulated distal end) is mounted over a 7 Fr pigtail catheter as previously described: the pigtail is used as a guide for the positioning of the sheath. We suggest to perform this maneuver in the anterior view. The pigtail end is advanced in the inferior vena cava and in the lower portion of the right atrium (panel a). The pigtail is then introduced in the right ventricle with either a conventional or a modified approach. In the conventional approach, the pigtail is advanced to the right atrium roof and gently forced to obtain a curve of the catheter allowing it to advance it through the tricuspid valve. This approach, generally used for all flexible catheters such as pigtail alone and multipurpose catheter, may become more difficult when handling the long sheath over the pigtail as the presence of the sheath makes the pigtail end more stiff: in particular, this approach may become difficult when the right atrium is significantly enlarged or tricuspidal regurgitation is present. In the alternative approach (that we generally use) once the pigtail is positioned in the lower right atrium, a J flexible guidewire is advanced out of the pigtail through the tricuspid valve (panel b), taking care to not induce sustained ventricular arrhythmias if the guidewire hurts the right ventricular outflow tract or the free wall. Once the guidewire reaches the right ventricular apex, the pigtail is advanced over the wire to the apex and the guidewire is rapidly removed (panel c). This position of the pigtail can be used, if required, to perform right ventricular angiography. We always perform right ventricular angiography before the execution of right ventricular endomyocardial biopsy (*EMB*) to obtain further details of right ventricular structure and contractility, identifying akinetic and diskinetic segments that may result more affected by the underlying disease: this approach may increase diagnostic sensitivity of the EMB. The preformed sheath is then advanced over the pigtail, keeping this one firm in the right ventricular apex: the sheath must be advanced gently, to avoid excessive pressure of the pigtail against the apical wall, but firmly, to maintain the apical positioning of the pigtail (panels d and e). Once the sheath reaches the apex, the pigtail is removed keeping the sheath in the obtained position (panel f). To further verify a correct positioning of the long sheath against the right ventricular septum and away from the free wall, we suggest to perform contrast medium flushes in the left anterior oblique view to visualize the interventricular septum. It must be noticed that once the pigtail is removed, the sheath reacquires its original shape and therefore a minimal retraction of distal end from the original position may occur: this retraction is compensated by the extension of distal end, occurring when the bioptome (straighter and stiffer than sheath) enters the distal end repositioning it in the desired position (see 12.4)

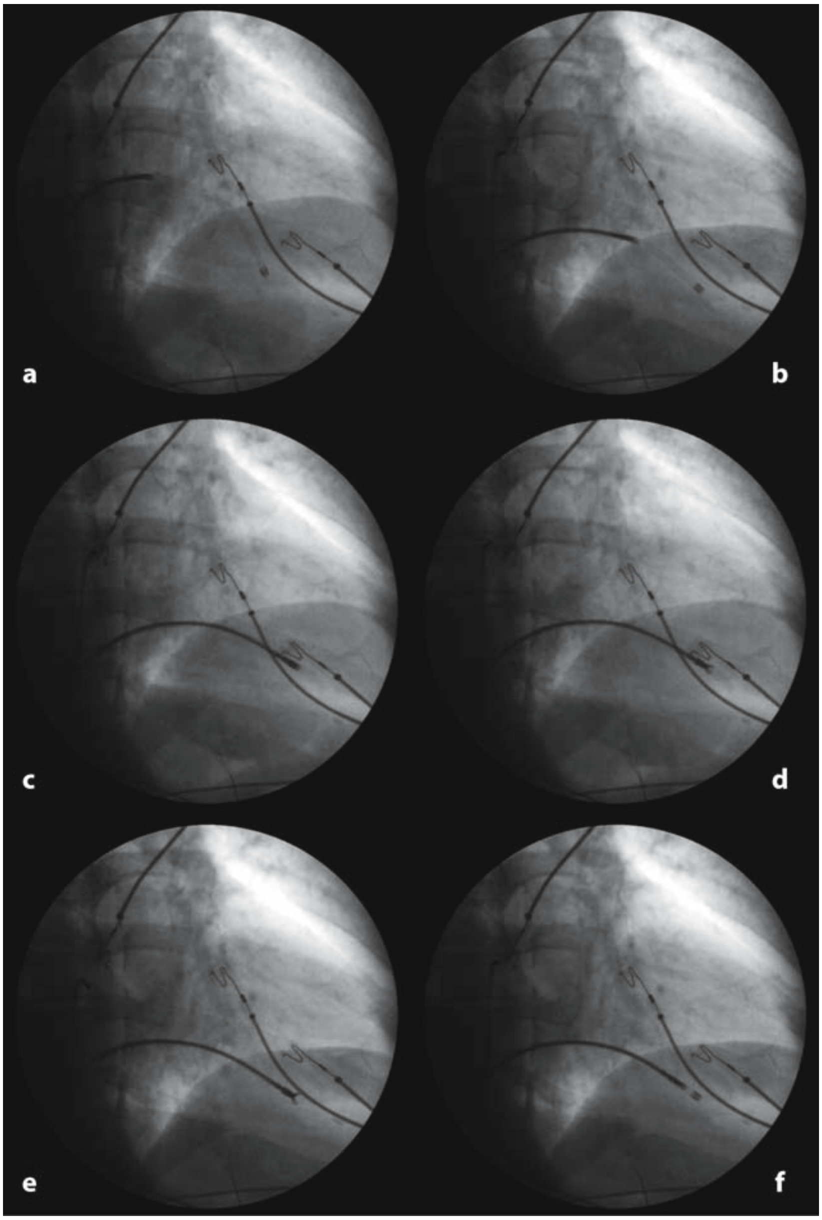


Figure 12.4 Execution of right ventricular endomyocardial biopsy. Once the preformed sheath has been positioned in the right ventricle (panel a), the bioptome is introduced in the sheath and advanced to its distal end (panel b). The presence of the bioptome inside may slightly straighten the distal end of the preformed sheath (panels b and c), possibly changing its original position: this displacement may be a desirable one if the positioning of the sheath in the optimal position has been made difficult by prominent ventricular trabeculation; on the contrary, if this displacement must be avoided, it is possible to gently curve the distal end of the bioptome according to the sheath curve, paying attention not to damage the mechanism of opening and closing of the bioptome. In the case illustrated, the bioptome straightens the distal end of the sheath, leading to a better positioning against the interventricular septum. Once the bioptome has reached the distal end, it must slightly advance outside the sheath and immediately opene on exiting the sheath, reducing as much as possible the time close cusps are outside the sheath (panel d) and therefore the risk of perforation. The bioptome with opened cusps is then advanced against the ventricular wall and slowly closed and withdrawn inside the sheath (panels e and f)

endomyocardial biopsies. An additional sign suggesting cardiac perforation is floating of the specimen in formalin, indicating a significant fat content and therefore an epicardial sampling (although in patients with arrhythmogenic right ventricular cardiomyopathy, endomyocardial biopsies can almost completely contain adipose tissue).

The risk of perforation is lowest in patients with prior cardiac surgery (in particular patients submitted to heart transplant) and greatest in patients with preserved cardiac function and dimensions, or clinical suspicion of arrhythmogenic right ventricular cardiomyopathy.

Left Ventricular Endomyocardial Biopsy

Patients undergoing left ventricular endomyocardial biopsy are premedicated with antithrombotic drugs to reduce the risk of systemic embolization during the procedure. We usually administer high-dose aspirin (800 mg bid the day before the procedure plus 800 mg the morning before the procedure) or loading dose of clopidogrel (600 mg) the day before the procedure.

Once the femoral artery is accessed, a short 7 Fr sheath is inserted before the long preformed sheath is placed. As mentioned regarding the right ventricle, we usually perform left ventricular angiography using the pigtail inside the long preformed sheath before its removal. A still end-diastolic frame of ventricular angiography can be maintained in the monitor as an adjunctive guide during biopsy execution.

The guiding sheath for left ventricular endomyocardial biopsy is not angulated, and it is prepared as described for right ventricular endomyocardial biopsy. Once inside the left ventricle, the pigtail must be advanced in the left ventricular apex where endomyocardial biopsy is generally performed. The preformed sheath is then advanced over the pigtail, keeping this one firm in the left ventricular apex: the sheath must be advanced gently to avoid excessive pressure of the pigtail against the apical wall and induction of sustained ventricular arrhythmias. When the sheath reaches the apex, the pigtail is removed keeping the sheath in the obtained position. The stiff sheath tip may cause ventricular arrhythmias by a traumatic effect against the ventricular wall: if this is the case, the sheath must be gently and slowly withdrawn until arrhythmias disappear. Withdrawal of the sheath may cause its displacement and then the pigtail catheter must be reinserted in the sheath to reposition it: sometimes it can be necessary to withdraw the sheath outside the left ventricle and repeat the complete maneuver.

During the positioning of the guiding sheath in the left ventricle, before the execution of biopsy, it is important to always confirm free motion of the sheath to avoid perforation of the wall when the close bioptome exits the sheath. Flushes of contrast medium may help to assess the distance from the sheath tip to the cardiac wall. The guiding sheath must always be flushed with saline during all its permanence in the left ventricle and during the insertion of the bioptome to avoid air embolization and clotting.

The bioptome is inserted in the sheath and rapidly advanced: once it reaches its distal end the bioptome is slowly advanced outside the sheath and jaws are immediately open (Figure 12.5). Many operators while advancing the bioptome slowly withdraw the sheath to facilitate jaws opening and to reduce the risk of piercing the cardiac wall.

If any resistance is encountered opening the jaws, mostly if they remain close, contact of the sheath with the cardiac wall must be suspected and the bioptome must be immediately withdrawn outside the sheath to avoid cardiac perforation.

The bioptome with opened jaws is advanced against the cardiac wall (with the contact being confirmed by fluoroscopy and occurrence of ectopic beats) and jaws are slowly but firmly closed to enucleate the specimen. Left ventricular myocardium requires a little more pressure against the wall and a complete closure of jaws, as the endocardium and the myocardium are generally stiffer than the right ventricle (Figure 12.6).

After the first biopsy, the sheath can be slightly moved to change the site of further biopsies and sample different areas of the ventricle.

12.1.2 Preshaped Bioptome

Right ventricular endomyocardial biopsy via the jugular vein is generally an outpatient procedure requiring fasting state since at least 8 h with sedative premedication.

Preshaped bioptomes are inserted through a short sheath inside jugular, femoral, brachial, and subclavian veins. The preshaped bioptome is advanced in the right atrium with its distal end pointing toward its lateral wall; to cross the tricuspid valve, the bioptome is turned counterclockwise and slowly advanced under fluoroscopy to avoid entrapment in the tricuspid valve apparatus or the coronary sinus. The entrance in the right ventricle is also confirmed by the induction of ventricular ectopic beats. Once in the right ventricle,

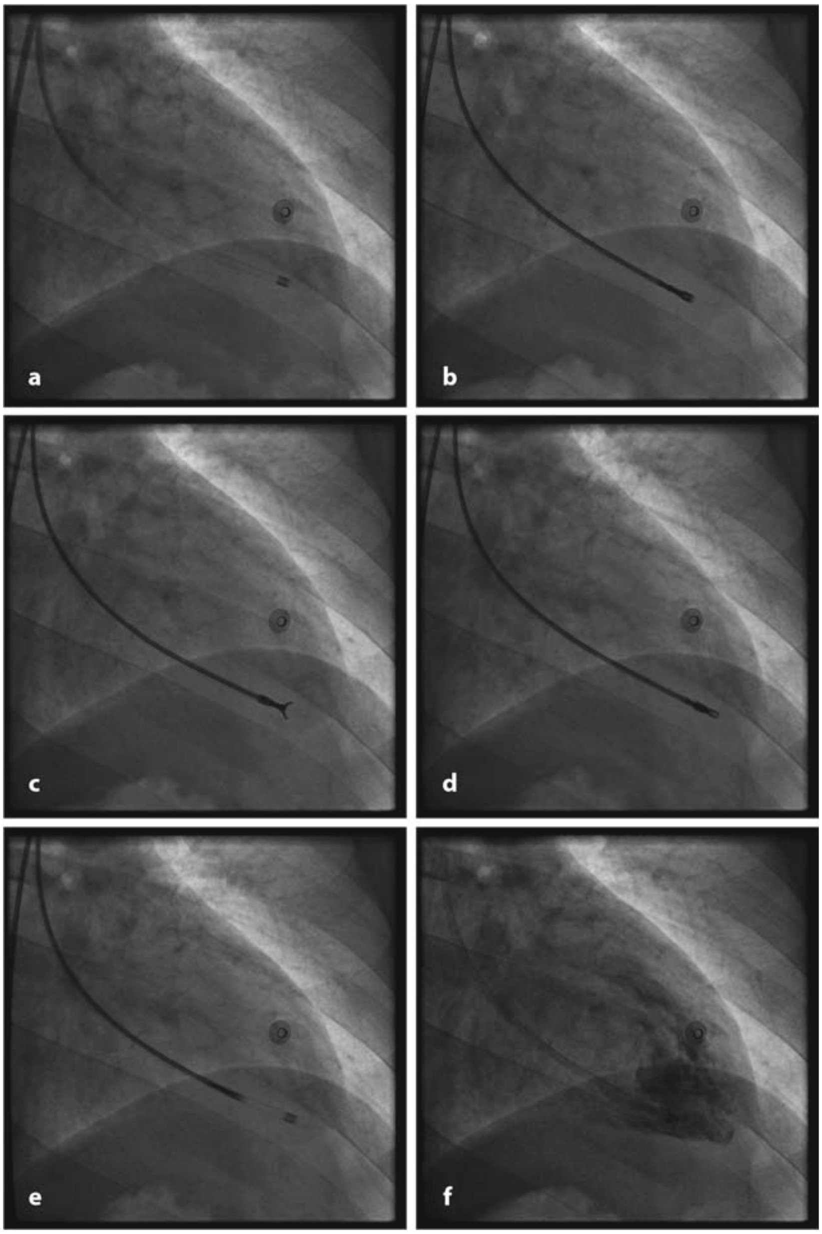


Figure 12.5 Execution of left ventricular endomyocardial biopsy. The long sheath has been positioned in the left ventricle with the tip directed toward the ventricular apex (panel a). The bioptome is advanced to the tip of the sheath without exiting it (panel b). The bioptome is slowly advanced outside the sheath and jaws are immediately opened and pressed against the ventricular wall (panel c). Bioptome jaws are slowly but firmly closed (panel d) and the bioptome withdrawn inside the sheath (panel e). At the end of the endomyocardial biopsy procedure, flushes of contrast medium are performed to demonstrate the absence of medium leakage in the pericardial space and therefore the integrity of the cardiac wall

further advancement and counterclockwise rotation allow to orient the bioptome toward the septum. During these maneuvers, it is important to pull back and never force the bioptome if resistance is encountered, as the stiff bioptome may cause perforation of the vena cava, right atrium, or right ventricular free wall. Optimal position of the bioptome for right ventricular biopsy is against the midportion of the interventricular septum; it is important to avoid the thin free right ventricular wall to reduce the risk of perforation. As previously mentioned, bioptome's position must be checked in both right (30°) and left (60°) anterior oblique views.

Once in contact with the septum, the bioptome is withdrawn 1–2 cm, opened, advanced slowly against the wall, and then closed to cut away the myocardial specimen.

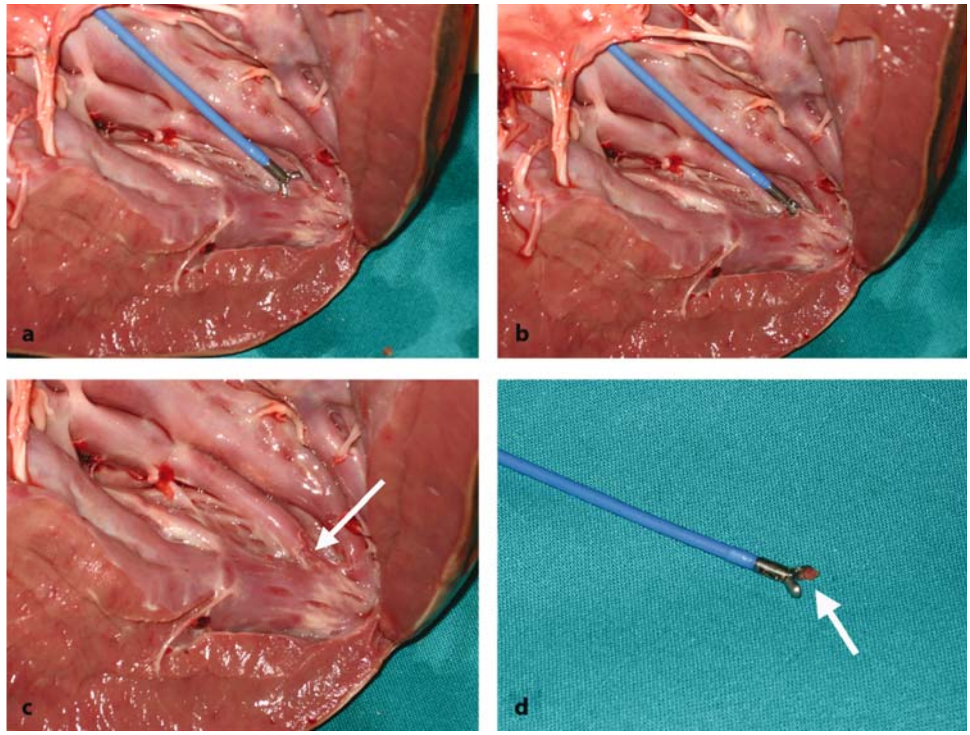


Figure 12.6 Inside view of left ventricular endomyocardial biopsy on pig heart. The bioptome with opened jaws is pressed against the septal–apical segment of the left ventricle (panel a). The jaws are closed and the bioptome is withdrawn (panel b). A little "bite" is present in myocardial tissue where biopsy has been performed (arrow) (panel c). The myocardial sample inside the bioptome cup (panel d)

12.2 Indications to Endomyocardial Biopsy

The indications to endomyocardial biopsy remain a controversial issue. The improvement of the technique and the development of new tools to analyze myocardial samples obtained have significantly increased the impact of the procedure on the diagnostic approach to heart muscle diseases. As a result, although several concerns regarding the risks of the procedure and the poor diagnostic utility are still occasionally raised, there is growing evidence that in expert and trained hands, the procedure is safe and may influence both prognosis and treatment in several clinical conditions. There is general agreement on endomyocardial biopsy classical indications, such as monitoring of cardiac allograft transplant rejection and drug toxicity. Similarly endomyocardial biopsy is generally considered useful in differential diagnosis between constrictive pericarditis and restrictive cardiomyopathies: many disorders (e.g., amyloidosis, hemochromatosis, sarcoidosis, Fabry disease) frequently presenting as restrictive cardiomyopathy are easily recognizable at conventional histology with specific stainings (Table 12.1).

More challenging is to define clinical indications to endomyocardial biopsy in patients with heart failure symptoms and evidence of cardiac dysfunction and/or dilation.

In the recent years, many studies have emphasized the relevance of identifying the underlying pathological process in patients with heart failure and normal coronary arteries.

There is general agreement that endomyocardial biopsy should be regularly included in the diagnostic approach to patients with cardiac systolic dysfunction and normal coronary arteries and valvular function. In these patients, endomyocardial biopsy may be crucial to identify an inflammatory cardiomyopathy or secondary forms, potentially treatable, of dilated cardiomyopathy. More recently, endomyocardial biopsy has been included among the studies possibly contributing to identify the cause of heart failure in patients with preserved systolic function, such as infiltrative cardiomyopathies.

Table 12.1 Indications to endomyocardial biopsy

Cardiac allograft rejection monitoring
Drug-induced cardiomyopathy (anthracycline)
Restrictive cardiomyopathy
Heart failure
Impaired systolic function with normal coronary arteries*
Preserved systolic function with normal coronary arteries**
Noninvasive diagnosis of ARVC
Idiopathic ventricular arrhythmias†

ARVC arrhythmogenic right ventricular cardiomyopathy

*With or without left ventricular enlargement

**To rule out an infiltrative process or inflammatory heart disease

†Including Brugada syndrome

Inflammatory cardiomyopathy, defined as the association of myocarditis and cardiac dysfunction, is emerging as the leading cause of nonischemic nonvalvular heart failure. Myocarditis is an inflammatory process of myocardial tissue with infective and autoimmune etiologies. Viral infection is the most common cause of myocarditis, and specific cardiotropic viruses, including enterovirus, adenovirus, and parvovirus B19, have been identified in endomyocardial biopsies of patients. Clinical presentation of myocarditis includes heart failure, ventricular arrhythmias, and even sudden death; in addition, acute myocarditis may resemble clinical and electrocardiographic features of acute coronary syndromes. The diagnosis of myocarditis, although cardiac magnetic resonance may provide a noninvasive identification of myocardial inflammatory process, is made by histological examination of endomyocardial biopsies. Specific criteria at both histochemistry and immunohistochemistry have been defined to establish the diagnosis. Immunohistochemistry and molecular biology studies may further define this diagnosis, suggesting an autoimmune rather than viral etiology.

Myocarditis present a spontaneous healing in about 50% of cases, while in the remaining 50% present a progression to chronic myocarditis and even dilated cardiomyopathy. The identification of myocarditis as the cause of heart failure symptoms and cardiac dysfunction as well as ventricular arrhythmias has important therapeutic implications.

In fact, it has been recently demonstrated that immunosuppressive treatment is effective in autoimmune myocarditis with regression of cardiac dysfunction and disappearance of ventricular arrhythmias. In contrast, in patients with chronic viral myocarditis, treatment with β-interferon may lead to viral genome elimination from the myocardium and recovery of cardiac function.

12.3 Endomyocardial Biopsy in Patients with Arrhythmias

There is growing evidence that endomyocardial biopsy may contribute to the diagnostic and therapeutic approach in patients with arrhythmias.

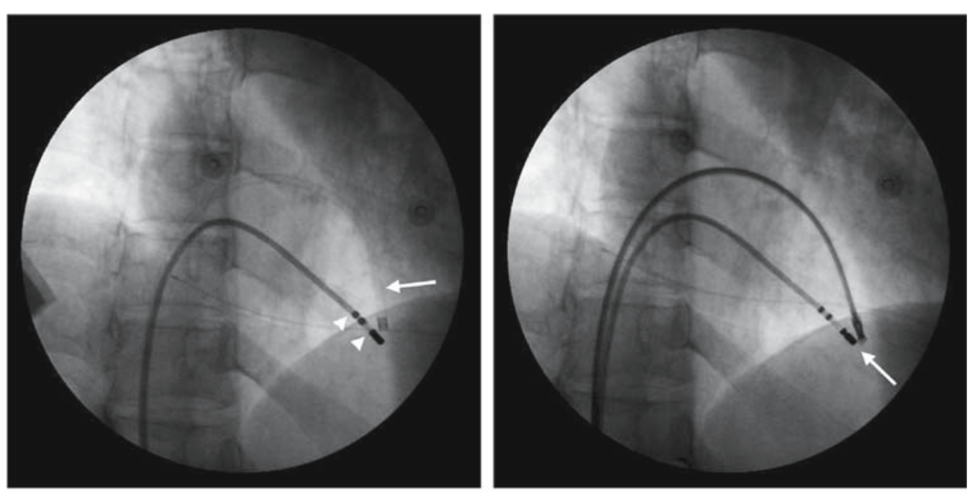
Both supraventricular and ventricular arrhythmias are frequently the clinical manifestation of underlying cardiomyopathies and myocardial diseases that may result making it difficult to diagnose and completely assess on the basis of noninvasive studies.

In the settings of malignant ventricular arrhythmias, despite the technological improvement of imaging tools such as cardiac magnetic resonance, endomyocardial biopsy still represents the gold standard for the diagnosis of arrhythmogenic right ventricular cardiomyopathy, particularly in sporadic cases, as myocarditis of the right ventricle may mimic clinical and imaging features of this cardiomyopathy.

Myocarditis represents a frequent cause of ventricular arrhythmias and sudden death even in the presence of apparently normal heart. The diagnosis of myocarditis in subjects with sustained ventricular arrhythmias and no evidence of structural heart disease may considerably affect both treatment and prognosis. Frequently myocarditis may cause ventricular microaneurysms representing the substrate of ventricular arrhythmias. Interestingly, myocarditis has been also detected in a significant percentage of patients with ventricular arrhythmias and electrocardiographic type I Brugada pattern at rest or after flecainide challenge, in the absence of sodium channel gene mutations: these patients, as myocarditis was the substrate for electrocardiographic and arrhythmic presentation, showed no recurrence of arrhythmias and an implantable cardioverter defibrillator was not considered.

As previously mentioned, myocarditis is often a self-limiting disease, frequently presenting a spontaneous resolution of the inflammatory process with disappearance of arrhythmias. With regard to arrhythmias in the context of a persisting myocardial inflammation, specific therapies have been proven effective in viral and nonviral myocarditis, leading to resolution of myocardial inflammation and clinical manifestations. It is therefore clear that treatment and prognosis of myocarditis may significantly differ from other cardiomyopathies and syndromes with arrhythmic presentation, often requiring long-term antiarrhythmic therapies, radiofrequency ablation, and even the implantation of an implantable cardioverter defibrillator.

The main limitation of endomyocardial biopsy to provide a specific diagnosis in patients with ventricular arrhythmias caused by focal myocardial diseases (i.e., myocarditis or initial forms of arrhythmogenic right ventricular cardiomyopathy) is represented by the sampling error due to the lack of an effective guide in selecting ventricular areas where to perform biopsies. In the last years, after the development of 3-D electroanatomical mapping systems, we introduced a new technique for the execution of endomyocardial biopsies in patients with ventricular arrhythmias. The new approach is aimed at performing endomyocardial biopsies in the ventricular segments presenting electrical abnormalities at electroanatomical mapping. Once the electroanatomical map is completed, the mapping catheter is placed in a region of interest of the ventricular wall and the preformed sheath is positioned close to the catheter tip (Figure 12.7). Endomyocardial biopsy is then performed in the area with abnormal electrical properties as shown by the map. Another approach requires the electrical connection of the bioptome to the mapping system: the presence of the metallic jaws makes the bioptome similar to a mapping catheter and it is therefore visualized in the 3-D electroanatomical map of the ventricle. In this case, the site of biopsy can be chosen "live," directly mapping the ventricular wall with the bioptome (Figure 12.8).



a b

Figure 12.7 Endomyocardial biopsy guided by electroanatomical mapping. A 35-year-old male patient was admitted for repetitive sustained ventricular arrhythmias originating from the right ventricle. The optimal site to perform endomyocardial biopsies in abnormal voltages area is detected with 3-D electroanatomical mapping (panel a, arrow). Panel b shows the mapping catheter (arrowheads) maintained against the ventricular wall segment with abnormal voltages and the long sheath (arrow) positioned close to its tip. Endomyocardial biopsies are then performed close to the mapping catheter tip (panel c, arrow). Histology showed the presence of a focally active myocarditis (panel d)

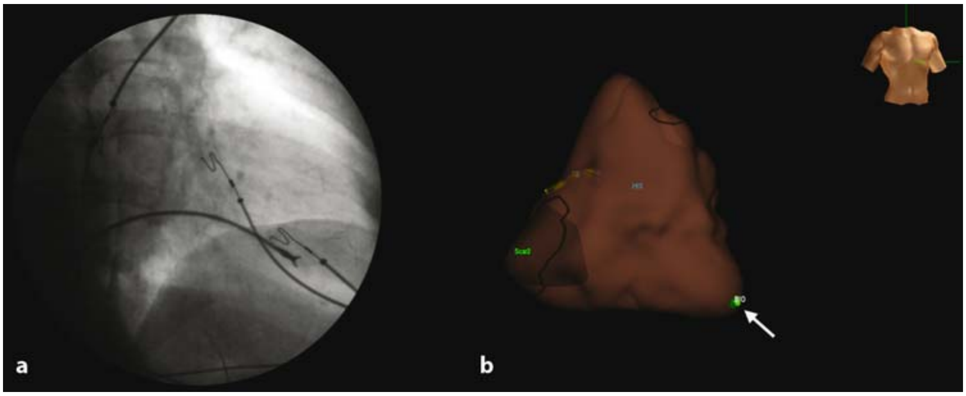


Figure 12.8 Endomyocardial biopsy guided by electroanatomical mapping. A 47-year-old female was admitted for sustained ventricular tachycardia originating from the right ventricle. The bioptome was connected to the mapping system and the metallic jaws are visualized in the map and register electrograms when they are opened and are in contact with the cardiac wall (panel a and panel b)Endomyocardial biopsies were performed in ventricular segment presenting abnormal voltages and the site of biopsy was marked on the map (panel b, green point and arrow). Histology showed the presence of fibro-fatty replacement consistent with the diagnosis of arrhythmogenic right ventricular cardiomyopathy

12.4 Tissue Processing and Analysis

Diagnostic and prognostic contribution yielded by endomyocardial biopsy significantly relies on the number of samples available for analysis and the kind of studies applied to the myocardial tissue provided. Accordingly, it is important to obtain an adequate number of samples and mostly to preserve myocardial tissue to perform all the studies necessary for its diagnostic interpretation. In fact, different studies require different preservation of myocardial samples: for instance, frozen biopsies are necessary to extract nucleic acids and perform polymerase chain reaction. With this regard, the clinical evaluation of the patient is fundamental to suggest the possible underlying disorders and therefore the kind of studies that would be important to perform on biopsies.

In our experience, to reduce the sampling error, we recommend to obtain at least five biopsies from the most affected ventricular chamber or the ventricle from which arrhythmias seem to originate.

Specimens must be removed from the jaws of the bioptome and immediately placed in the appropriate preservative. At least three good-sized specimens must be preserved in buffered formalin (Figure 12.9A) and paraffin embedded (Figure 12.10) for histology and immunohistochemistry, as these studies are crucial to formulate the diagnosis and to address further analyses. Three specimens are generally sufficient to detect focal pathology that might not be evident in a single sample.

Two samples must be placed in dedicated vials (Figure 12.9B) and shock frozen in liquid nitrogen for molecular biology studies; if specific immunohistochemistry on frozen sections is to be performed, specimens should be placed in a fluid-embedding medium, immersed in isopentane and frozen in liquid nitrogen. It is important to remark that all the freezing procedures must be performed as soon as the specimens are taken from the bioptome, and therefore all the necessary material must be available in the catheterization lab. Molecular biology studies are particularly important when a myocarditis is clinically suspected, as the detection of viral genome in myocardial tissue significantly affects the specific treatment: in these cases, at least two frozen specimens must be collected. Once nucleic acids (DNA and RNA) have been extracted from myocardial tissue, they can be used also to evaluate the expression of specific genes, such as connexins, ion channels, and other ones possibly involved in arrhythmia's pathogenesis.

Electron microscopy requires small samples preserved in glutaraldheyde and is usually reserved to specific cardiomyopathies in which ultrastructural analysis is required to formulate the diagnosis: these include Fabry disease, some cases of amyloidosis, and mitochondrial disorders.

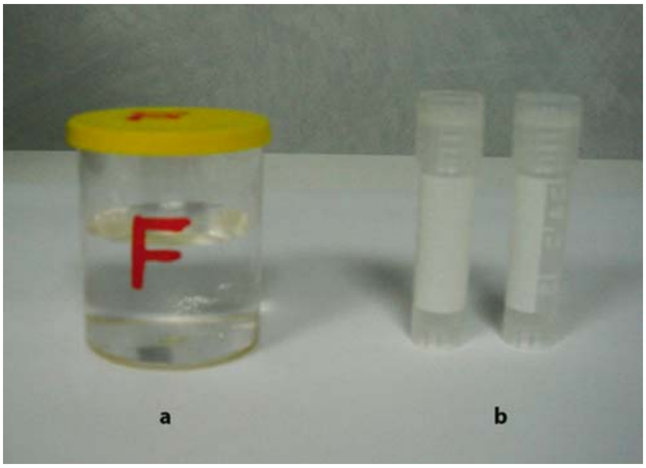


Figure 12.9 Vials for endomyocardial biopsies preservation. At least three myocardial samples are to be preserved in 10% buffered formalin and then embedded in paraffin wax for histology and immunohistochemistry (panel a). Cryovials resistant to liquid nitrogen freezing and to storage at –80 °C (panel b) are used to preserve frozen samples destined to molecular biology studies

Figure 12.10 Paraffin-embedded endomyocardial biopsies. Example of three large paraffin-embedded endomyocardial biopsies. Five micrometer sections are cut from the paraffin block and stained with conventional and specific stainings. Routine stainings for endomyocardial biopsies include hematoxylin and eosin, Miller's elastic van Gieson, and Masson's thrichrome. Immunohistochemistry may help to characterize eventual inflammatory infiltrates and to detect immune activation of the myocardial tissue

Bibliography

Cardiac Anatomy

1. McAlpine WA. Heart and Coronary Arteries. Berlin: Springer, 1975.
2. Left atrial isthmus: anatomic aspects relevant for linear catheter ablation procedures in humans. Becker AE. J Cardiovasc Electrophysiol. 2004; 15: 809-812
3. Chiang SJ, Tsao HM, Wu MH, et al. Anatomic Characteristics of the Left Atrial Isthmus in Patients with Atrial Fibrillation: Lessons from Computed Tomographic Images. J Cardiovasc Electrophysiol 2006; 17: 1-5
4. Cabrera JA, Sanchez-Quintana D, Ho SY, et al. Angiographic Anatomy of the Inferior Right Atrial Isthmus in Patients With and Without History of Common Atrial Flutter. Circulation. 1999;99:3017-3023
5. Ho SY, Cabrera JA, Sanchez-Quintana D. Vagaries of the vagus nerve: relevance to ablationists. J Cardiovasc Electrophysiol. 2006;17(3):330-1
6. Lunkenheimer PP, Redmann K, Kling N, et al. Three-dimensional architecture of the left ventricular myocardium. Anat Rec A Discov Mol Cell Evol Biol. 2006;288(6):565-78
7. Ho SY, Nihoyannopoulos P. Anatomy, echocardiography, and normal right ventricular dimensions. Heart. 2006;92 Suppl 1:i2-13
8. Duytschaever M, Ho SY, Devos D, Tavernier R. The left hand as a model for the right atrium: a simple teaching tool. Europace. 2006;8(4):245-50
9. Sanchez-Quintana D, Cabrera JA, Climent V, et al. Anatomic relations between the esophagus and left atrium and relevance for ablation of atrial fibrillation. Circulation. 2005;112(10):1400-5
10. Ho SY, Sanchez-Quintana D, Becker AE. A review of the coronary venous system: a road less travelled. Heart Rhythm. 2004;1(1):107-12Cabrera JA, Sanchez-Quintana D, Farre J, et al. The inferior right atrial isthmus: further architectural insights for current and coming ablation technologies. J Cardiovasc Electrophysiol. 2005;16(4):402-8Sanchez-Quintana D, Cabrera JA, Climent V, et al. How close are the phrenic nerves to cardiac structures? Implications for cardiac interventionalists. J Cardiovasc Electrophysiol. 2005;16(3):309-13Sanchez-Quintana D, Cabrera JA, Farre J, et al. Sinus node revisited in the era of electroanatomical mapping and catheter ablation. Heart. 2005;91(2):189-94
11. Wittkampf FH, van Oosterhout MF, Loh P, et al. Where to draw the mitral isthmus line in catheter ablation of atrial fibrillation: histological analysis. Eur Heart J. 2005;26(7):689-95
12. Ho SY. Pulmonary vein ablation in atrial fibrillation: does anatomy matter? J Cardiovasc Electrophysiol. 2003;14(2):156-7
13. Ho SY. Anatomy of the mitral valve. Heart. 2002;88 Suppl 4:iv5-10
14. Anderson RH, Ho SY. The morphology of the specialized atrioventricular junctional area: the evolution of understanding. Pacing Clin Electrophysiol. 2002;25(6):957-66
15. de Bakker JM, Ho SY, Hocini M. Basic and clinical electrophysiology of pulmonary vein ectopy. Cardiovasc Res. 2002;54(2):287-94
16. Ho SY, Cabrera JA, Tran VH, et al. Architecture of the pulmonary veins: relevance to radiofrequency ablation. Heart. 2001 Sep;86(3):265-70Sanchez-Quintana D, Ho SY, Cabrera JA, et al. Topographic anatomy of the inferior pyramidal space: relevance to radiofrequency catheter ablation. J Cardiovasc Electrophysiol. 2001;12(2):210-7
17. Anderson RH, Ho SY, Becker AE. Anatomy of the human atrioventricular junctions revisited. Anat Rec. 2000;260(1):81-91
18. Ho SY, Sanchez-Quintana D, Cabrera JA, Anderson RH. Anatomy of the left atrium: implications for radiofrequency ablation of atrial fibrillation. J Cardiovasc Electrophysiol. 1999;10(11):1525-33
19. Anderson RH, Ho SY. The architecture of the sinus node, the atrioventricular conduction axis, and the internodal atrial myocardium. J Cardiovasc Electrophysiol. 1998;9(11):1233-48

20. Cabrera JA, Sanchez-Quintana D, Ho SY, et al. The architecture of the atrial musculature between the orifice of the inferior caval vein and the tricuspid valve: the anatomy of the isthmus. J Cardiovasc Electrophysiol. 1998;9(11):1186-95
21. Anderson RH, Ho SY. Anatomy of the atrioventricular junctions with regard to ventricular preexcitation. Pacing Clin Electrophysiol. 1997;20(8 Pt 2):2072-6

Part 1

1. Kannel WB, Wolf PA, Benjamin EJ. Prevalence, incidence, prognosis and predisposing conditions for atrial fibrillation: population-based estimates. Am J Cardiol 1998; 82:2N-9N.
2. Kannel WB, Abbot RD, Savage DD, et al. Epidemiologic features of chronic atrial fibrillation: the Framingham Study. N Engl J Med 1982; 306:1018-1022.
3. Gallagher MM, Camm AJ. Classification of atrial fibrillation. PACE 1997; 20: 1603-5.
4. Moe GK. On the multiple wavelet hypothesis of atrial fibrillation. Arch Int Pharmacodyn Ther 1962; 140: 183-8.
5. Konings KTS, Kirchhof CJ, Smeets JR, et al. High density mapping of electrically induced atrial fibrillation in man. Circulation 1994; 89:1665-80.
6. Coumel P. Paroxysmal atrial fibrillation: role of autonomic nervous system. Arch Mal Coeur Vaiss. 1994; 87 (3): 55-62.
7. Wolff PA, Abbott RD, Kannel WR. Atrial fibrillation as a independent risk factor for stroke: the Framingham Study. Stroke 1991; 22: 983-8.
8. Haissaguerre M, Jais P, Shah DC, et al. Electrophysiolocical end point for catheter ablation of atrial fibrillation initiated from multiple pulmonary venous foci. Circulation 2000; 101: 1409-1417.
9. Haissaguerre M, Jais P, Shah DC, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med 1998: 339; 659-66.
10. Haissaguerre M, Jais P, Shah DC et al. Right and left atrial radiofrequency catheter therapy of paroxysmal atrial fibrillation. JCE 1996; 12: 1132-1144.
11. Kato R, Lickfett L, Meininger G, et al. Pulmonary vein anatomy in patients undergoing catheter ablation of atrial fibrillation. Lessons learned by use of magnetic resonance imaging. Circulation 2003, 107:2004–2010.
12. Tsao HM, Wu MH, Yu WC, et al. Role of right middle pulmonary vein in patients with paroxysmal atrial fibrillation. J Cardiovasc Electrophysiol 2001, 12:1353–1357.
13. Lickfett L, Kato R, Tandri H, et al. Characterization of a new pulmonary vein variant using magnetic resonance angiography: incidence, imaging and interventional implications of the "right top pulmonary vein". J Cardiovasc Electrophysiol 2004, 15:538–543.
14. Mansour M, Holmvang G, Sosnovik D, et al. Assessment of pulmonary vein anatomic variability by magnetic resonance imaging: implications for catheter ablation techniques for atrial fibrillation. J Cardiovasc Electrophysiol 2004, 15:387–393.
15. Wittkampf FH, Vonken EJ, Derksen R, et al. Pulmonary vein ostium geometry: analysis by magnetic resonance angiography. Circulation 2003, 107:21–23.
16. Jongbloed MR, Bax JJ, Lamb HJ, et al. Multislice computed tomography versus intracardiac echocardiography to evaluate the pulmonary veins before radiofrequency catheter ablation of atrial fibrillation: a head-to-head comparison. J Am Coll Cardiol 2005; 45 (3):343–350.
17. Takahashi Y, Jais P, Hocini M, et al. Acute occlusion of the left circumflex coronary artery during mitral isthmus linear ablation. J Cardiovasc Electrophysiol 2005;16:1104-1107.
18. Tanabe Y, Deguchi Y, Handa S, et al. Longer longitudinal atrial dimension in patients with idiopathic paroxysmal atrial fibrillation: a possibile cause of atrial fibrillation. Am Heart J 2001, 142:669–678.
19. Berkowitsch A, Neumann T, Ekinci O, et al. A decrease in pulmonary vein diameter after radiofrequency ablation predicts the development of severe stenosis. Pacing Clin Electrophysiol 2005, 28(Suppl 1):S83–85.
20. Purerfellner H, Cihal R, Aichinger J, et al. Pulmonary vein stenosis by ostial irrigated-tip ablation: incidence, time course, and prediction. J Cardiovasc Electrophysiol 2003, 14:158–164.
21. Arentz T, Weber R, Jander N, et al. Pulmonary haemodynamics at rest and during exercise in patients with significant pulmonary vein stenosis after radiofrequency catheter ablation for drug resistant atrial fibrillation. Eur Heart J, 2005, 26(14):1410–1414.
22. Kluge A, Dill A, Ekinci O, et al. Decreased pulmonary perfusion in pulmonary vein stenosis after radiofrequency ablation - assessment with dynamic magnetic resonance perfusion imaging. Chest 2004, 126:428–437.
23. Nilsson B, Chen X, Pehrson S et al. Acute fatal pulmonary vein occlusion after catheter ablation of atrial fibrillation. J Interv Card Electrophysiol 2004, 11(2):127–130.
24. Pappone C, Oral H, Santinelli V, et al. Atrio-esophageal fistula as a complication of percutaneous transcatheter ablation of atrial fibrillation. Circulation. 2004;109:2724–2726.
25. Lacomis JM, Goitein O, Deible C, Schwartzman D. CT of the Pulmonary Veins. J Thorac Imaging, 2007 22, 1: 63-76.
26. Dong J, Dickfeld T, Dalal D et al. Initial Experience in the Use of Integrated Electroanatomic Mapping with Three-Dimensional MR/CT Images to Guide Catheter Ablation of Atrial Fibrillation. J Cardiovasc Electrophysiol, 2006; 17(5): 459-66.

Part 2

1. Jackman WM, Beckman KJ, McClelland JH, et al. Treatment of supraventricular tachycardia due to atrioventricular nodal reentry by radiofrequency catheter ablation of slow-pathway conduction. N Engl J Med 1992; 327: 313-316.
2. Haissaguerre M, Gaita F, Fischer B, et al. Elimination of atrioventricular nodal reentrant tachycardia using discrete slow potentials to guide application of radiofrequency energy. Circulation 1992; 85: 2162-75.
3. Wu D, Yeh SJ, Wang CC, et al. A simple technique for selective radiofrequency ablation of the slow pathway in atrioventricular node reentrant tachycardia. J Am Coll Cardiol 1993; 21: 1612-1621.
4. Proclemer A, Della Bella P, Tondo C, et al. Radiofrequency ablation of atrioventricular junction and pacemaker implantation versus modulation of atrioventricular conduction in drug refractory atrial fibrillation. Am J Cardiol. 1999 May 15;83(10):1437-42
5. Carbucicchio C, Tondo C, Fassini G, et al. Modulation of the atrioventricular node conduction to achieve rate control in patients with atrial fibrillation: long-term results. Pacing Clin Electrophysiol. 1999 Mar;22(3.:442-52
6. Della Bella P, Carbucicchio C, Tondo C, Riva S. Modulation of atrioventricular conduction by ablation of the "slow" atrioventricular node pathway in patients with drug-refractory atrial fibrillation or flutter. J Am Coll Cardiol. 1995 Jan;25(1):39-46
7. Chen J, de Chillou C, Basiouny T, et al. Cavotricuspid Isthmus Mapping to Assess Bidirectional Block During Common Atrial Flutter Radiofrequency Ablation. Circulation. 1999;100:2507-2513.
8. Melo SL, Scanavacca MI, Darrieux FC, et al. Ablation of typical atrial flutter: a prospective randomized study of cooled-tip versus 8-mm-tip catheters. Arq Bras Cardiol. 2007 Mar;88(3):273-8
9. Da Costa A, Jamon Y, Romeyer-Bouchard C, et al. Catheter selection for ablation of the cavotricuspid isthmus for treatment of typical atrial flutter. J Interv Card Electrophysiol. 2006 Nov;17(2):93-101
10. Okumura Y, Watanabe I, Ashino S, et al. Anatomical characteristics of the cavotricuspid isthmus in patients with and without typical atrial flutter: Analysis with two- and three-dimensional intracardiac echocardiography. J Interv Card Electrophysiol. 2006 Oct;17(1)11-9.
11. Chang SL, Tai CT, Lin YJ, et al. The electroanatomic characteristics of the cavotricuspid isthmus: implications for the catheter ablation of atrial flutter. J Cardiovasc Electrophysiol. 2007 Jan;18(1):18-22.
12. Sugimura H, Watanabe I, Okumura Y, et al. Differential pacing for distinguishing slow conduction from complete conduction block of the tricuspid-inferior vena cava isthmus after radiofrequency ablation for atrial flutter--role of transverse conduction through the crista terminalis. J Interv Card Electrophysiol. 2005 Jul;13(2):125-34.
13. Cosio FG, Awamleh P, Pastor A, Nunez A. Determining inferior vena cava-tricuspid isthmus block after typical atrial flutter ablation. Heart Rhythm. 2005 Mar;2(3):328-32
14. Calkins H, Canby R, Weiss R, et al. Results of catheter ablation of typical atrial flutter. Am J Cardiol. 2004 Aug 15;94(4):437-42
15. Morton JB, Sanders P, Davidson NC, et al. Phased-array intracardiac echocardiography for defining cavotricuspid isthmus anatomy during radiofrequency ablation of typical atrial flutter. J Cardiovasc Electrophysiol. 2003 Jun;14(6):591-7.
16. Marrouche NF, Schweikert R, Saliba W, et al. Use of different catheter ablation technologies for treatment of typical atrial flutter: acute results and long-term follow-up. Pacing Clin Electrophysiol. 2003 Mar;26(3):743-6.
17. Cheng A, Calkins H. A Conservative Approach to Performing Transseptal Punctures Without the Use of Intracardiac Echocardiography: Stepwise Approach with Real-Time Video Clips. J Cardiovasc Electrophysiol, Vol. 18, pp. 1-4, February 2007
18. De Ponti R, Cappato R, Curnis A, et al. Trans-Septal Catheterization in the Electrophysiology Laboratori. Data From a Multicenter Survey Spanning 12 Years. J Am Coll Cardiol 2006;47:1037– 42
19. Colombo A, Iakovou I. Another trick to improbe the safety of transseptal puncture. J Invasiv Cardiol 2005; 17 (2): 71-72
20. Verma A, Marrouche NF, Natale A. Pulmonary vein antrum isolation: intracardiac echocardiography-guided technique. J Cardiovasc Electrophysiol. 2004 Nov;15(11):1335-40.
21. Cope C. Technique for trans-septal catheterization of the left atrium: preliminary report. J Thorac Surg 1959;37:482– 6.
22. Ross J, Braunwald E, Morrow AG. Trans-septal left atrial puncture: new technique for the measurement of left atrial pressure in man. Am J Cardiol 1959;3:653–5.
23. Vranckx P, Foley DP, de Feijter PJ, et al. Clinical introduction of the Tandemheart, a percutaneous left ventricular assist device, for circulatory support during high-risk percutaneous coronary intervention. Int J Cardiovasc Intervent 2003;5:35–9.
24. Brockenbrough EC, Braunwald E, Ross J. Trans-septal left heart catheterization: a review of 450 studies and description of an improved technique. Circulation 1962;25:15–21.
25. De Ponti R, Zardini M, Storti C, et al. Trans-septal catheterization for radiofrequency catheter ablation of cardiac arrhythmias: results and safety of a simplified method. Eur Heart J 1998;19:943–50.
26. Gonzales MD, Otomo K, Shah N, et al. Trans-septal left heart catheterization for cardiac ablation procedures. J Interv Card Electrophysiol 2001;5:89 –95.
27. Hildick-Smith D. McCready J, de Giovanni J. Transseptal Puncture: Use of an Angioplasty for Enhanced Safety. Catheterization and Cardiovascular Interventions 2007; 69:519–521

28. Sherman W, Lee P, Hartley A, Love B. Transatrial Septal Catheterization Using a New Radiofrequency Probe Catheterization and Cardiovascular Interventions 2005; 66:14–17
29. Johnson SB, Seward JB, Packer DL. Phased-array intracardiac echocardiography for guiding transseptal catheter placement: utility and learning curve. Pacing Clin Electrophysiol. 2002; 25(4 Pt 1):402-7.
30. Pappone C, Santinelli V, Manguso F, et al. A Randomized Study of Prophylactic Catheter Ablation in Asymptomatic Patients with the Wolff–Parkinson–White Syndrome. N Engl J Med 2003;349:1803-11
31. Della Bella P, Brugada P, Talajic M, et al. Atrial fibrillation in patients with an accessory pathway: importance of the conduction properties of the accessory pathway. J Am Coll Cardiol. 1991 May;17(6):1352-6
32. Natale A, Wathen M, Yee R, et al. Atrial and ventricular approaches for radiofrequency catheter ablation of leftsided accessory pathways. Am J Cardiol 1992;70:114–6.
33. Swartz JF, Tracy CM, Fletcher RD. Radiofrequency endocardial catheter ablation of accessory atrioventricular pathways at atrial insertion sites. Circulation 1993;87:487–99.
34. Saul JP, Hulse JE, De W, et al. Catheter ablation of accessory atrioventricular pathways in young patients: use of long vascular sheaths, the trans-septal approach and a retrograde left posterior parallel approach. J Am Coll Cardiol 1993;21:571– 83.
35. Collins KK, Rhee EK, Kirsh JA, et al. Cryoablation of accessory pathways in the coronary sinus in young patients: a multicenter study from the Pediatric and Congenital Electrophysiology Society's Working Group on Cryoablation. J Cardiovasc Electrophysiol. 2007 Jun;18(6):592-7
36. De Ponti R. Cryothermal energy ablation of cardiac arrhythmias 2005: state of the art. Indian Pacing Electrophysiol J. 2005 Jan 1;5(1):12-24.
37. Ong MG, Lee PC, Tai CT, et al. Coronary sinus morphology in different types of supraventricular tachycardias. J Interv Card Electrophysiol. 2006 Jan;15(1):21-6.
38. Bar-Cohen Y, Cecchin F, Alexander ME, et al. Cryoablation for accessory pathways located near normal conduction tissues or within the coronary venous system in children and young adults. Heart Rhythm. 2006 Mar;3(3):253-8.
39. Chang SL, Lee SH, Tai CT, et al. Electrocardiographic and electrophysiologic characteristics of midseptal accessory pathways. J Cardiovasc Electrophysiol. 2005 Mar;16(3):237-43
40. Takenaka S, Yeh SJ, Wen MS, et al. Characteristics and radiofrequency ablation in posteroseptal and left freewall subepicardial accessory pathways. J Electrocardiol. 2005 Jan;38(1):69-76.
41. Gatzoulis K, Apostolopoulos T, Costeas X, et al. Paraseptal accessory connections in the proximity of the atrioventricular node and the His bundle. Additional observations in relation to the ablation technique in a high risk area. Europace. 2004 Jan;6(1):1-9.
42. Pappone C, Manguso F, Santinelli R, et al. Radiofrequency ablation in children with asymptomatic Wolff-Parkinson-White syndrome. N Engl J Med. 2004 Sep 16;351(12):1197-205.
43. Katritsis D, Giazitzoglou E, Korovesis S, Zambartas C. Comparison of the transseptal approach to the transaortic approach for ablation of left-sided accessory pathways in patients with Wolff-Parkinson-White syndrome. Am J Cardiol. 2003 Mar 1;91(5):610-3.
44. Haissaguerre M, Jais P, Shah DC, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med. 1998 Sep 3;339(10):659-66.
45. Haissaguerre M, Jais P, Shah DC, et al. Electrophysiological end point for catheter ablation of atrial fibrillation initiated from multiple pulmonary venous foci. Circulation. 2000 Mar 28;101(12):1409-17.
46. Jais P, Hocini M, Hsu LF, et al. Technique and results of linear ablation at the mitral isthmus. Circulation. 2004 Nov 9;110(19):2996-3002.
47. Hsu LF, Jaïs P, Sanders P, et al. Catheter Ablation for Atrial Fibrillation in Congestive Heart Failure. N Engl J Med 2004;351:2373-83
48. Oral H, Pappone C, Chugh A, et al. Circumferential pulmonary-vein ablation for chronic atrial fibrillation. N Engl J Med. 2006 Mar 2;354(9):934-41
49. Pappone C, Santinelli V, Manguso F, et al. Pulmonary vein denervation enhances long-term benefit after circumferential ablation for paroxysmal atrial fibrillation. Circulation. 2004 Jan 27;109(3):327-34.
50. Pappone C, Rosanio S, Oreto G, et al. Circumferential radiofrequency ablation of pulmonary vein ostia: A new anatomic approach for curing atrial fibrillation. Circulation. 2000 Nov 21;102(21):2619-28.
51. Pappone C, Rosanio S, Augello G, et al. Mortality, morbidity, and quality of life after circumferential pulmonary vein ablation for atrial fibrillation: outcomes from a controlled nonrandomized long-term study. J Am Coll Cardiol. 2003 Jul 16;42(2):185-97.
52. Kanj MH, Wazni OM, Natale A. How to do circular mapping catheter-guided pulmonary vein antrum isolation: the Cleveland Clinic approach. Heart Rhythm. 2006 Jul;3(7):866-9
53. Verma A, Natale A.Should atrial fibrillation ablation be considered first-line therapy for some patients? Why atrial fibrillation ablation should be considered first-line therapy for some patients. Circulation. 2005 Aug 23;112(8):1214-22.
54. Haissaguerre M, Sanders P, Hocini M, et al. Catheter Ablation of Long-Lasting Persistent Atrial Fibrillation: Critical Structures for Termination. J Cardiovasc Electrophysiol 2005; 16: 1125-1137
55. Wazni OM, Tsao HM, Chen SA, et al. Cardiovascular Imaging in the Management of Atrial Fibrillation. J Am Coll Cardiol 2006;48:2077-84
56. Fassini G, Riva S, Chiodelli R, et al. Left mitral isthmus ablation associated with PV Isolation: long-term results of a prospective randomized study. J Cardiovasc Electrophysiol. 2005 Nov;16(11):1150-6.
57. Casella M, Dello Russo A, Lombardo A, et al. High-density mapping at pulmonary veins antrum: a new tool for atrial fibrillation ablation. Europace. 2007 Jul;9(7):496-7

58. Tondo C, Mantica M, Russo G, et al. Pulmonary vein vestibule ablation for the control of atrial fibrillation in patients with impaired left ventricular function. Pacing Clin Electrophysiol. 2006 Sep;29(9):962-70
59. Elayi CS, Fahmy TS, Wazni OM, et al. Left superior vena cava isolation in patients undergoing pulmonary vein antrum isolation: impact on atrial fibrillation recurrence. Heart Rhythm. 2006 Sep;3(9):1019-23.
60. Kanj MH, Wazni OM, Natale A. How to do circular mapping catheter-guided pulmonary vein antrum isolation: the Cleveland Clinic approach. Heart Rhythm. 2006 Jul;3(7):866-9.
61. Bai R, Patel D, Di Biase L, et al. Phrenic nerve injury after catheter ablation: should we worry about this complication? J Cardiovasc Electrophysiol. 2006 Sep;17(9):944-8.
62. Wazni OM, Fahmy TS, Natale A. Circumferential pulmonary-vein ablation for atrial fibrillation. N Engl J Med. 2006 May 25;354(21):2289-91.
63. Kilicaslan F, Verma A, Saad E, et al. Transcranial Doppler detection of microembolic signals during pulmonary vein antrum isolation: implications for titration of radiofrequency energy. J Cardiovasc Electrophysiol. 2006 May;17(5):495-501
64. Cummings JE, Schweikert RA, Saliba WI, et al. Assessment of temperature, proximity, and course of the esophagus during radiofrequency ablation within the left atrium. Circulation. 2005 Jul 26;112(4):459-64.
65. Wazni OM, Rossillo A, Marrouche NF, et al A. Embolic events and char formation during pulmonary vein isolation in patients with atrial fibrillation: impact of different anticoagulation regimens and importance of intracardiac echo imaging. J Cardiovasc Electrophysiol. 2005 Jun;16(6):576-81.
66. Zei PC, Stevenson WG. Epicardial catheter mapping and ablation of ventricular Tachicardia Heart Rhythm 2006;3:360 –363
67. Natterson Horowitz B, Vaseghi M, Mahajan A, et al. Percutaneous intrapericardial echocardiography during catheter ablation: a feasibility study. Heart Rhythm 2006;3:1275–1282
68. Arenal A, del Castello S, Gonzalez-Torrecilla E, et al. Tachycardia-Related Channel in the Scar Tissue in Patients With Sustained Monomorphic Ventricular Tachycardias. Influence of the Voltage Scar Definition. Circulation. 2004;110:2568-2574
69. Chow AWC, Schilling RJ, Davies DW, Peters NS. Characteristics of Wavefront Propagation in Reentrant Circuits Causing Human Ventricular Tachycardia. Circulation. 2002;105:2172-2178
70. Dixit S, Gerstenfeld EP, Lin D, et al. Identification of distinct electrocardiographic patterns from the basal left ventricle: Distinguishing medial and lateral sites of origin in patients with idiopathic ventricular tachycardia. Heart Rhythm 2005;2:485-491
71. Hsia HH, Callans DJ, Marchlinski FE. Characterization of Endocardial Electrophysiological Substrate in Patients With Nonischemic Cardiomyopathy and Monomorphic Ventricular Tachycardia. Circulation. 2003;108:704-710
72. Ouyang F, Cappato R, Ernst S, et al. Electroanatomic Substrate of Idiopathic Left Ventricular Tachycardia Unidirectional Block and Macroreentry Within the Purkinje Network. Circulation. 2002;105:462-469
73. Josephson ME, Callans DJ. Using the twelve-lead electrocardiogram to localize the site of origin of ventricular tachicardia. Heart Rhythm 2005, 2: 443-446
74. Zeppenfeld K, Kiès P, Wijffels M, et al. Identification of successful catheter ablation sites in patients with ventricular tachycardia based on electrogram characteristics during sinus rhythm. Heart Rhythm 2005;2:940-950
75. Della Bella P, Pappalardo A, Riva S, et al. Non-contact mapping to guide catheter ablation of untolerated ventricular tachycardia. European Heart Journal (2002) 23, 742–752
76. Strickberger SA, Knight BP, Michaud GF, et al. Mapping and Ablation of Ventricular Tachycardia Guided by Virtual Electrograms Using a Noncontact, Computerized Mapping System. J Am Coll Cardiol 2000;35:414-21
77. Segal OR, Chow AW, Wong T, et al. A novel algorithm for determining endocardial VT exit site from 12-lead surface ECG characteristics in human, infarct-related ventricular tachycardia. J Cardiovasc Electrophysiol. 2007 Feb;18(2):161-8
78. Della Bella P, Riva S, Fassini G, et al. Incidence and significance of pleomorphism in patients with postmyocardial infarction ventricular tachycardia. Acute and long-term outcome of radiofrequency catheter ablation. Eur Heart J. 2004 Jul;25(13):1127-38
79. Della Bella P, Carbucicchio C. Non-contact left ventricular endocardial mapping for cardiac resynchronisation therapy: a "slow conduction" towards the fast solution. Heart. 2004 May;90(5):483-4

Part 3

1. Ong LS, Barold SS, Lederman M, et al. Cephalic vein guide wire technique for implantation of permanent pacemakers.Am Heart J. 1987 Oct;114(4 Pt 1):753-6.
2. Gillette PC, Wampler DG, Shannon C, et al. Use of atrial pacing in a young population.Pacing Clin Electrophysiol. 1985 Jan;8(1):94-100.
3. Liu KS, Liu C, Xia Y, et al. Permanent cardiac pacing through the right supraclavicular subclavian vein approach.Can J Cardiol. 2003 Aug;19(9):1005-8.
4. De Voogt WG, Van Mechelen R, Van Den Bos A, et al. A technique of lead insertion for low atrial septal pacing.Pacing Clin Electrophysiol. 2005 Jul;28(7):639-46.
5. Daubert J. et al. Long term stability of a left ventricular over the wire pacing lead. Pacing Clin Electrophysiol 2003; 26(4):329.

6. De Martino G., Sanna T., Dello Russo A., et al. A randomized comparison of alternative techniques to achieve coronary sinus cannulation during biventricular implantation procedures.J Interv Card Electrophysiol. 2004 Jun;10(3):227-30.
7. De Martino G., Messano L., Santamaria M., et al. A randomized evaluation of different approaches to coronary sinus venography during biventricular pacemaker implants. Europace (2005) 7, 73-76.
8. Purerfellner H, Nesser HJ, Winter S, et al.Transvenous left ventricular lead implantation with the EASYTRAK lead system: The European experience. Am J Cardiol (suppl) 2000;86:K157–K164.
9. Sayad DE, Sawar A, Curkovic V, et al. Simple access to the coronary venous system for left ventricular pacing. PACE 2003;26:1856–1858.
10. Walker S, Levy T, Rex S, et al.. Initial United Kingdom experience with the use of permanent biventricular pacemakers: Implantation procedure and technical considerations. Europace 2000;2:233–239.
11. Walker S, Levy T, Rex S, et al. Initial results with left ventricular pacemaker lead implantation using preformedm"peel-away" guiding-sheat and "side-wire" left ventricular pacing lead. PACE 2000;23:985–990.
12. Sack S, Heinzel F, Dagres N, et al. Stimulation of the left ventricle through the coronary sinus with a newly developed "over the wire" lead system: Early experiences with lead handling and positioning. Europace 2001;3:317–323.
13. Proclemer A, Zanon F, Facchin D, et al. Can a comprehensive family of catheters be helpful in achieving implant success. PACE 2002;25(4), Part II:690.
14. Butter C, Gras D, Ritter P, et al. Comparative prospective randomized efficacy testing of different guiding catheters for coronary sinus cannulation in heart failure patients. J of Interv Card Electrophys 2003:9,343–351.
15. Gould L, Maghazeh P, Giovanniello J. Successful removal of a severed transevenous pacemaker electrode. Pacing Clin. Electrophysiol.1981;4: 713-5.
16. Krupienicz A, Janczak J. Two cases of successful percutaneous chronic pacemaker lead extraction using a long vascular sheat. Pacing. Clin. Electrophysiol. 1995;18:1081.
17. De Martino G, Orazi S, Bisignani G, et al..Safety and feasibility of coronary sinus left ventricular leads extraction: a preliminary report.J Interv Card Electrophysiol. 2005 Jun;13(1):35-8.
18. Molina JE. Undertreatment and overtreatment of patients with infected antiarrhythmic implantable devices. Ann.Thorac. Surg.1997;63:504-9.
19. Madigan NP, Curtis JJ, Sanfelippo JF, et al. Difficulty of extraction of chronically implanted tined ventricular endocardial leads. J. Am. Coll. Cardiol. 1984;3:724-31.
20. Bilgutay AM, Jensen NK, Schmidt WR, et al. Incarceration of transvenous pacemaker electrode. Removal by traction. Am. Heart J. 1969; 77:377-9.
21. Brodel GK, Castle LW, Maloney JD, et al. Chronic transvenous pacemaker lead removal using a unique, sequential transvenous system. Am. J. Cardiol. 1990;66:964-6.
22. Smith HJ, Fearnot NE, Byrd CL, et al. Five-years experience with intravascular lead extraction. U.S. Lead Extraction Database. Pacing. Clin. Electrophysiol. 1994;17:2016-20.
23. Alt E, Neuzner J, Binner L, et al. Three-year experience with a stylet for lead extraction: a multicenter study. Pacing Clin. Electrophysiol. 1996;19:18-25.
24. Bracke FA, Meijer A, van Gelder B. Learning curve characteristics of pacing leads extraction with a laser sheat. Pacing Clin Electrophysiol 1998;21:2309-13.
25. Wilkoff BL, Byrd CL, Love CJ, et al. Pacemaker lead extraction with the laser sheat.:results of the pacing lead extraction with the excimer sheat (PLEXES) trial. J.Am. Coll. Cardiol. 1999;33:1671-6.
26. Byrd CL, Love CJ, Wilkoff BL, et al. A bipolar electrosurgical dissection sheat for lead extraction: result of the EXCL multicenter clinical study. Pacing Clin. Electrophysiol. 2002;24:560.
27. Byrd CL, Wilkoff BL, Love CJ, et al. Clinical study of the laser sheat for lead extraction: the total experience in the United States. Pacing Clin. Electrophysiol 2002;24:560.
28. Moak JP, Freedenberg V, Ramwell C, et al. Effectiveness of excimer laser-assisted pacing and ICD lead extraction in children and young adults.Pacing Clin Electrophysiol. 2006 May;29(5):461-6.
29. Kennergren C, Bucknall CA, Butter C, et al. PLESSE investigators group. Laser-assisted lead extraction: the European experience.Europace. 2007 Aug;9(8):651-6.
30. Rizzello V, Dello Russo A, Casella M, et al. Residual fibrous tissue floating in the right atrium after percutaneous pacemaker lead extraction: An unusual complication early detected by intracardiac echocardiography. Int. J. Cardiol. 2007 doi: 10.1016/j.ijcard.2007.04.07

Part 4

1. Sutton DC, Sutton GC. Needle biopsy of the human ventricular myocardium: review of 54 consecutive cases. Am Heart J. 1960;60:364-70.
2. Sakakibara S, Konno S. Endomyocardial biopsy. Jpn Heart J. 1962;3:537-43.
3. Richardson PJ. King's endomyocardial bioptome. Lancet. 1974;1:660-1.
4. Braunwald's heart disease 7th Edition. Part III Heart Failure. Saunders Editions.
5. Frustaci A, Chimenti C, Calabrese F, et al. Immunosuppressive therapy for active lymphocytic myocarditis: virologic and immunologic profile of responders versus nonresponder. Circulation. 2003; 107: 857.
6. Chimenti C, Calabrese F, Thiene G, et al. Inflammatory left ventricular microaneurysms as a cause of apparently idiopathic ventricular tachyarrhythmias. Circulation. 2001;104:168.

7. Kühl U, Pauschinger M, Bock T, et al. Parvovirus B19 infection mimicking acute myocardial infarction. Circulation. 2003; 108: 945–950.
8. Mahrholdt H, Goedecke C, Wagner A, et al. Cardiovascular magnetic resonance assessment of human myocarditis: a comparison to histology and molecular pathology. Circulation. 2004;109:1250.
9. De Cobelli F, Pieroni M, Esposito A, et al. Delayed gadolinium-enhanced cardiac magnetic resonance in patients with chronic myocarditis presenting with heart failure or recurrent arrhythmias. J Am Coll Cardiol. 2006;47:1649.
10. Wojnicz R, Nowalany-Kozielska E, Wojciechowska C, et al. Randomized, placebo-controlled study for immunosuppressive treatment of inflammatory dilated cardiomyopathy: two-year follow-up results. Circulation. 2001;104:39.
11. Kühl U, Pauschinger M, Schwimmbeck PL, et al. Interferon-ß treatment eliminates cardiotropic viruses and improves left ventricular function in patients with myocardial persistence of viral genomes and left ventricular dysfunction. Circulation. 2003; 107: 2793.
12. Chimenti C, Pieroni M, Maseri A, et al. Histologic findings in patients with clinical and instrumental diagnosis of sporadic arrhythmogenic right ventricular dysplasia. J Am Coll Cardiol. 2004;43:2305.
13. No authors listed. Survivors of out-of-hospital cardiac arrest with apparently normal heart. Need for definition and standardized clinical evaluation. Consensus Statement of the Joint Steering Committees of the Unexplained Cardiac Arrest Registry of Europe and of the Idiopathic Ventricular Fibrillation Registry of the United States. Circulation. 1997;95:265.
14. Ouyang F, Antz M, Deger FT, et al. An underrecognized subepicardial reentrant ventricular tachycardia attributable to left ventricular aneurysm in patients with normal coronary arteriograms. Circulation. 2003;107:2702.
15. Frustaci A, Priori S, Pieroni, M, et al. Cardiac histological substrate in patients with clinical phenotype of Brugada syndrome. Circulation. 2005;112:3680.

Index