The left hand as a model for the right atrium: a simple teaching tool

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Received 4 July 2005; accepted after revision 13 November 2005; online publish-ahead-of-print 21 February 2006

Aims Knowledge of the complex three-dimensional anatomy of the right atrium is mandatory for the electrophysiologist and interventional cardiologist, but its understanding remains difficult. We hypothesized that the left hand, loosely clenched, is a good three-dimensional model to understand the position of the different anatomical and electrical regions in the right atrium. For validation, we compared the hand with an endocast that had been prepared from an adult human right atrium and with a three-dimensional electro-anatomical CT image of the right atrium.

Methods and results Views of the left hand were photographed from various angles to replicate as closely as possible the standard fluoroscopic views. Using the nomenclature of the bones of the hand, we assigned the different regions of the hand to represent regions and structures of the right atrium. An endocast was prepared from an adult human right atrium. A three-dimensional electro-anatomical right atrial map with CT integration (CartoMerge) was used as the gold standard for the exact localization of electrical regions such as the sinus node (SN), bundle of His, and slow pathway region. Using the left hand, it is possible to mark the free wall, terminal crest, appendage, septal surface, oval fossa and orifices of the caval veins, tricuspid valve, and coronary sinus. We also marked the anticipated locations of the SN, His bundle, triangle of Koch, slow pathway region, inferior isthmus, and right atrial insertion of Bachmann’s bundle. When compared with an endocast and a three-dimensional electro-anatomical CT image, the position and orientation of the marked regions were deemed to be anatomically correct.

Conclusion Compared with an endocast and a CT-guided electro-anatomical reconstruction of the right atrium, the left hand is a reliable model to understand the position and orientation of the different anatomical and electrical regions in the right atrium. Although an oversimplification of the complex right atrial anatomy, this model is ‘handy’ to understand, guide, and teach electrophysiological and interventional procedures.

KEYWORDS
Atrium; Electrophysiology; Imaging; Anatomy

Introduction
Understanding the complex three-dimensional anatomy of the right atrium is mandatory for catheter ablation of right atrial arrhythmias, for guiding transseptal puncture, for coronary sinus cannulation, and for correct positioning of atrial pacing leads or atrial septal occluder devices. For the interventionist, it is the most commonly used cardiac chamber for entering the heart. The three-dimensional anatomy of the right atrium, however, is extremely complex because of its multiple orifices, arrangement of its walls, and limits of its septal component. The spatial relationships of its anatomical portions, i.e. the appendage, vestibule, septum, and venous components, are difficult to describe. The orientation of the atrial structures must be related to the orientation of the heart in the chest. This orientation is termed ‘attitudinal’ by MacAlpine. In his study on cadavers, Walmsley measured the plane of the atrial septum between 41° and 45° to the median plane. For the uninitiated, this important spatial relationship is seldom appreciated on fluoroscopy.

Several tools are available to reconstruct individual right atrial anatomy prior to, and during, interventional procedures. Nevertheless, a readily available ‘off-line’ model of the right atrium could be of value for teaching atrial arrhythmias, interpretation of fluoroscopic views, and catheter ablation. We observed that the left hand, loosely clenched, is a good and simple model to understand the position of the different regions in the right atrium and their relationship to its complex three-dimensional structure. To validate the concept, we compared the

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hand model with an endocast of a human right atrium and a three-dimensional electro-anatomical CT image (CartoMerge, Biosense Webster, Haifa, Israel) of the right atrium. CartoMerge is a new technique—currently still under development—which allows integration of a pre-acquired segmented three-dimensional CT image of the right atrium into an electro-anatomical map of the same chamber. As such, this imaging technique is the gold standard for the exact anatomical localization of electrical regions such as the sinus node (SN), bundle of His, and slow pathway region.

Methods

Hand model

We photographed the left hand of one of the researchers to produce images that we hypothesized would correspond to standard fluoroscopic views of the right atrial chamber. We used the nomenclature of the bones on the hand for describing the locations of the atrial structures of interest (Figure 1). These included the free wall, appendage, septal surface, oval fossa, orifices of the caval veins, coronary sinus, tricuspid valve (TV), and the terminal crest. We also marked the anticipated locations of the SN, His bundle, triangle of Koch, flutter or inferior isthmus, slow pathway area or septal isthmus, and right atrial insertion of Bachmann’s bundle. To describe the anatomical position and orientation of atrial structures we used the nomenclature as proposed by the Cardiac Nomenclature Study Group.5

Endocast of an adult human right atrium

To verify that the left hand is an acceptable model for the right atrium, we compared the hand with an endocast that had been prepared from an adult human right atrium. We marked the endocast with coloured pins to represent the known anatomical sites of the penetrating bundle of His (yellow), the inferior isthmus (white), and the slow pathway area (orange dots). We then positioned the endocast in an orientation corresponding to the right atrium in the chest. To check the correct orientation, we consulted images from The Visible Human Project (www.nlm.nih.gov/research/visible/visible_human.html). The endocast was then photographed from various angles to replicate, as closely as possible, the standard views used in fluoroscopy.

Electro-anatomical mapping of the right atrium with CT integration

For further validation, we compared the left hand model with a three-dimensional electro-anatomical CT image of the right atrium (CartoMerge). Details of the CARTO navigation and mapping system have been described previously.6 Briefly, a miniature magnetic sensor is incorporated in the tip of a conventional ablation catheter. Three ultra-low magnetic field emitters—located beneath the patient—provide location and orientation of the ablation catheter. Each position of the mapping catheter, as well as the voltage or activation time, is incorporated into a three-dimensional surface reconstruction of the specific heart chamber (electro-anatomical map). The CartoMerge module allows the electrophysiologist to import a pre-acquired three-dimensional CT reconstruction of the desired chamber into this electro-anatomical surface map. For this purpose, dedicated software was developed to separate semi-automatically a conventional three-dimensional CT image into the different chambers of the heart. After segmentation, the chamber of interest is imported into the electro-anatomical surface map. Compared with other imaging tools, this method has the unique advantage of being the gold standard for correct determination of the anatomical position of electrical areas such as the SN, His bundle, or slow pathway.

Results

Hand model in the attitudinally correct position

In Figure 2A, we show the position of the hand that corresponds best with the heart in its attitudinally correct position. This view of the hand matches the classical antero-posterior (AP) view of the right atrium in fluoroscopy (inset). In Figure 2B, we illustrated the hand inside a chest X-ray to mimic its fluoroscopic position. Using nomenclature of the bones, the middle and distal phalanges II–V represent the anterior and parietal walls of the right atrium that are primarily the body of the appendage with the atrial vestibule. The thumb represents the right atrial appendage with its tip pointing anteriorly and superiorly.

Inferiorly, the inferior caval vein (ICV) (although enlarged) is given by the wrist (blue oval), whereas the orifice of the TV is given by the lower opening in the hand (black dotted line). The compact atroventricular node and penetrating bundle of His can be marked on the hand by the joint between the proximal and middle phalanx V (yellow dot). The orifice of the coronary sinus is given by the joint between metacarpal V and proximal phalanx V (orange circle). The vestibule anterior to the coronary sinus orifice, the ‘septal’ isthmus or ‘slow pathway’ area is represented by the orange dots.

Superiorly, the orifice of the superior caval vein (SCV) is represented by the upper opening in the hand (blue oval). An imaginary cranio-caudal line running from proximal phalanx I, along metacarpal I, and sweeping toward the middle of metacarpal IV represents the terminal crest. On this line, the location of the SN can be superimposed along the joint between proximal phalanx I and metacarpal I (purple oval in Figure 4A).

Compared with the AP view of the endocast (Figure 2C) and the three-dimensional CT reconstruction of the right atrium (Figure 2D, patient with paroxysmal atrial fibrillation), the
location and position of the ‘marked’ right atrial appendage, vestibule and orifices of the TV, caval veins, and coronary sinus were found to be anatomically correct. Also the position of the electrical regions was found to be correct. In Figure 2E, an electro-anatomical activation map of the right atrium merged with the CT image is given for a patient with atrial tachycardia. As seen in the isochronal activation map, the location of the SN (red zone is earliest activity) corresponds with the predicted position of the SN in the hand model. In this patient, we also tagged the position of the electrode when recording a His bundle electrogram (white tag) and slow pathway potential (orange tag). Clearly, the position and orientation of these electrical regions on the hand model were deemed to be anatomically correct.

Value of the hand model to understand the anatomy of the atrial septum

By rotating the fist to show the proximal phalanges II–V, we can further mark the septal structures of the right atrium on the hand model (Figure 3A). For validation, the corresponding septal aspect of the endocast is shown (Figure 3B). The proximal phalanges II–V represent the plane of the atrial septum, which runs oblique from the front and extends posteriorly and to the right. The oval fossa is expected to be approximately at the position of the wedding ring. This position was confirmed by checking with the endocast (pink dotted circle). Superiorly, Bachmann’s bundle can be marked by the joint between the proximal and middle phalanx II (green oval). Inferiorly, the location and orientation of the triangle of Koch (black dotted line) can be represented by the dorsal surface of proximal phalanx V. The inferior border of the triangle is given by the joint between metacarpal V and proximal phalanx V (orifice of the coronary sinus). The vestibule anterior to the coronary sinus orifice, the ‘septal’ isthmus or ‘slow pathway’ area is represented by the orange dots. When compared with the endocast (Figure 3B), the spatial relationship between the different components and borders of the triangle of Koch on the hand model is strikingly similar to the correct right atrial anatomy.

Use of the hand model to interpret right (RAO) and left anterior oblique (LAO) views

By turning the hand clockwise or counter clockwise around the cranio-caudal axis, approximating to the axis of the
SCV and ICV, we can obtain all possible oblique views on the right atrium to compare and validate these views with fluoroscopic imaging, endocast, schematic representations, or electro-anatomical CT images.

In Figure 4A, we show an example of the classical 30° right anterior oblique (RAO) view, which can be obtained by turning the hand approximately 30° counter clockwise. In this view of the hand, the atrial septum (and oval fossa) is
viewed en face with the right border of the silhouette being the tricuspid valve (AV plane). Compared with the endocast (Figure 4B) and a schematic RAO representation (Figure 4C) the location and orientation of the right atrial appendage, ICV and SCV, terminal crest, and atrial vestibule were anatomically correct. Moreover, the hand model also correctly projects the orientation of the target lesion needed for ablation of typical flutter (inferior isthmus, white dotted line) in an RAO view. In Figure 4D, we show the CT-integrated electro-anatomical isochronal activation map of the right atrium (30° RAO view). This CT image confirms that the hand model correctly positions the SN (purple oval) and the bundle of His (yellow dot).

In Figure 4E, we show an example of the classical fluoroscopic 30° LAO view. This image can be obtained by turning the hand approximately 30° clockwise. As in the fluoroscopic image, a view is obtained through the TV upon the posterior wall of the atrium with the right border of the silhouette being the atrial septum with the oval fossa. Clearly, the location and orientation of Bachmann’s bundle, TV orifice, and coronary sinus correspond well with the position of these regions on fluoroscopy, endocast, and scheme (Figure 4F and G). In this view of the hand, one can also appreciate the correct orientation of the ‘flutter’ isthmus running antero-posteriorly from the palmar surface of metacarpal V (TV) to the dorsal surface of metacarpal IV (ICV, white dotted line). In Figure 4H, the 30° LAO view of the CT-integrated electro-anatomical reconstruction of the right atrium with a tag on the slow pathway area is given. Moreover, by pushing the mapping catheter against the septum, we could identify the oval fossa as that part of the electro-anatomical map projecting outside the rim of the CT-image. Clearly, this position of the oval fossa corresponds with the ‘wedding ring’ sign on the hand model (Figure 4E).

Discussion

Main findings

(1) We observed that the left hand, loosely clenched, is a good and simple model to understand the position of the different regions in the right atrium and their relationship to its complex three-dimensional structure. (2) Compared with an endocast, fluoroscopic imaging, and schematic representations of the right atrium, the left hand is a reliable model to understand and teach the position and orientation of the different anatomical regions in the right atrium. (3) Using electro-anatomical mapping with CT integration—a new technique still under development—we showed that the hand model also correctly positions electrical regions in the right atrium.

Complexity of right atrial anatomy

Over the last decade, knowledge of right atrial anatomy—its orientation and its different structures—has become increasingly important for the cardiologist. The electrophysiologist is confronted with an increasing spectrum and complexity of ablatable arrhythmias both in the right and left atrium. Although, during ablation procedures several tools are available to reconstruct individual three-dimensional anatomy (intracardiac echocardiography, 3D-CT or MRI, electro-anatomical mapping) a correct insight in three-dimensional anatomy is mandatory for appropriate navigation of catheters, for reduction of procedural and fluoroscopic time, and for successful outcome of ablation. Also for physicians implanting pacemakers, defibrillators or cardiac resynchronization devices, knowledge of right atrial anatomy has become more and more essential. Some studies suggest that the optimal sites for atrial-based pacing are the region of Bachmann’s bundle and the ‘lower atrial septum’ rather than the conventional right atrial appendage. Especially for cardiac resynchronization therapy by biventricular pacing, knowledge of the position and orientation of the coronary sinus is mandatory to reduce fluoroscopy time and to increase implantation success. In recent years, several efforts have been made to enhance the understanding of the complex right atrial anatomy.1,2,7 In a review by Ho et al., the authors describe the orientation and the gross anatomical structures of the human right atrium. They focused on the importance of describing the heart in its attitudinally correct position as previously stressed by McAlpine.3 Also, Cosio et al. pointed to the advantages gained by the electrophysiologist when the heart is described using attitudinally appropriate nomenclature. Despite these reports and currently available correct nomenclature, for the novice cardiologist the right atrium remains ‘a muscular bag full of holes’. As a result, appropriate movement of pacing leads or catheters, correct naming of the location of accessory pathways (with understanding of the 12-lead electrocardiographic pattern), and interpretation of the different fluoroscopic views remain a stumbling block.

A ‘handy’ model of the right atrium

To facilitate the understanding of three-dimensional anatomy, we present a ‘handy’ model for the right atrium. Although oversimplifying anatomical details, the left hand, loosely clenched, is extremely useful and valid to describe and comprehend the orientation of the right atrium and septum and the spatial relationship between its different structures. For transseptal puncture, this model is useful for pointing out the limited septal area that is confined to the oval fossa and its antero-inferior muscular rim, the major part of the apparently septal wall being non-septal.1,8 For ablationists, in particular, the orientation of the different structures is attitudinally correct with the triangle of Koch depicted with its apex pointing superiorly. This model, therefore, is ‘handy’ to understand, and teach diagnostic and interventional procedures. Especially for the novice electrophysiologist, cardiologist, technician, or nursing personnel, this model is of value to understand the anatomic positions of pacing leads, sheaths, and various catheters in the different fluoroscopic views. Compared with textbooks, reviews, mapping tools, and commercially available three-dimensional models of the heart, this hand-model of the right atrium costs nothing and has the major advantage of being always to ‘hand’.

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Limitations
We were able to make comparisons with only one endocast, owing to limited availability. Furthermore the endocast was from a normal heart. We believe that the left hand model is still a fair representation of the diseased atrium, which if enlarged, will retain similar three-dimensional relationships of its structures. Besides, the variability in sizes of hands and bone structures is probably comparable to the variability in atrial structures.

References