

ESCOLA SUPERIOR DE TECNOLOGIA DA SAÚDE DE COIMBRA

COLLEGE OF HEALTH TECHNOLOGY OF COIMBRA

MASTER'S DEGREE IN CARDIAC PHYSIOLOGY

Specialization in Arrhythmology

INTERNSHIP IN

ARRHYTHMOLOGY

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UNITED KINGDOM, AUGUST 2014

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UNITED KINGDOM, AUGUST 2014

*"Winning is nothing if you haven't had a lot of work;
to fail is nothing if you gave your best."*

Nadia Boulanger

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List of Abbreviations and Acronyms

- AF - Atrial Fibrillation
- AMI - Acute Myocardial Infarction
- AP - accessory pathway
- ARP - Absolute Refractory Period
- ARVD - Arrhythmogenic Right Ventricular Dysplasia
- AT - Atrial Tachycardia
- AV - atrioventricular
- AVNRT - Atrioventricular Nodal Reentrant Tachycardia
- Bpm – beats per minute
- BCT - broad complex tachycardia
- CFE - complex fractionated electrogram
- CHF - Congestive Heart Failure
- CL - cycle length
- CPVT - Catecholaminergic Polymorphic Ventricular Tachycardia
- CRT – Cardiac Resynchronization Therapy
- CS – coronary sinus
- CT – Computed Tomography
- CTI - cavotricuspid isthmus
- CVD - cardiovascular disease
- ECG – electrocardiogram
- EF - ejection fraction

- EHRA - European Heart Rhythm Association
- EPS – Electrophysiology study
- ESC - European Society of Cardiology
- ETT - Exercise Tolerance Test
- HF – Heart Failure
- HOCM - hypertrophic cardiomyopathy
- HRA – high right atrium
- HRV - Heart Rate Variability
- ICD - Implantable Cardioverter Defibrillator
- IEGM – intracavitary electrogram
- IHD - Ischaemic Heart Disease
- IVCD - intraventricular conduction delay
- LAT - Local Activation Time
- LBBB - left bundle branch block
- LOC - loss of consciousness
- LQTS - Long QT Syndrome
- LVEF - left ventricular ejection fraction
- LVH - left ventricular hypertrophy
- LVSD - left ventricular systolic dysfunction
- MI - Myocardial Infarction
- mm - millimetre
- MRI - Magnetic Resonance Imaging
- ms – milliseconds
- NCT - Narrow Complex Tachycardia
- NICE - National Institute for Health and Care Excellence
- NYHA - New York Heart Association

- PM – pacemaker
- PND - paroxysmal nocturnal dyspnea
- PPM - permanent pacemaker
- PV - pulmonary veins
- PVC - premature ventricular contractions
- RAA - right atrial appendage
- RBBB - right bundle branch block
- RF – radiofrequency
- RV - right ventricle
- RVOT – Right Ventricle outflow tract
- SCD – sudden cardiac death
- SD - sudden death
- SQTS - Short QT Syndrome
- SMVT - Sustained monomorphic ventricular tachycardia
- SP - slow pathway
- SPECT - single-photon emission computed tomography
- SR – Sinus rhythm
- SSS - Sick Sinus Syndrome
- SVT - Supraventricular Tachycardia
- TAP – transmembrane action potential
- TWA - T wave alternans
- VF – ventricular fibrillation
- VT - ventricular tachycardia
- WPW - Wolff-Parkinson-White

Abstract

The arrhythmology focuses on the diagnosis and treatment of heart rhythm disorders and their complications, and has undergone a dramatic evolution over the past two decades. The widespread use of catheter ablation, the introduction of implantable cardioverter defibrillators for the prevention of sudden cardiac death and, finally, the development of cardiac resynchronization therapy led to a gradual loss of the impact of antiarrhythmic drugs as a therapeutic approach.

This report was performed as a result of an internship performed in Cardiac Physiology with the duration of 400 hours. The main goal of the internship was to strengthen theoretical knowledge and acquire practical experience in the varied fields of arrhythmology, especially in the areas of Cardiac Pacing and Electrophysiology.

During the internship were performed 41 electrophysiologic studies, where Atrioventricular Node Reentrant Tachycardia and Atrial Fibrillation were the most observed arrhythmias. New technologies such as three-dimensional mapping for electrophysiology studies are developing quickly and being use on a daily basis, as they prove to have safe and higher success rates. The proof is that in approximately half of the studies, one of the two mapping systems available, Carto or NavX, was used. In addition, were interrogated 283 pacemakers during the pacing clinics, being the dual chamber with DDD pacing mode the most encountered device. A large number of devices with Cardiac Resynchronization Therapy and/or Implantable Cardioverter Defibrillators were also observed.

This report is divided into three chapters. Chapter I is constituted by a revision of the literature and includes concepts such as definition and mechanisms of cardiac arrhythmias; a brief description of the varied diagnostic tools and its recommendations; and a presentation of the different therapeutic approaches available and its indications. The second chapter is a descriptive drawing of the activity performed in the modules of Electrophysiology and Pacing. Lastly, the chapter III presents two clinical cases in Electrophysiology considered interesting from a clinical point of view.

Introduction

Arrhythmias are defined as any cardiac rhythm other than the normal sinus rhythm and are due to several disorders that alter the rate or rhythm of the heartbeat. These can manifest itself in various ways and with a very broad spectrum of severity, ranging from asymptomatic until sudden cardiac death.

Sudden death (SD) is a major public health issue and probably the most challenging issue in modern cardiology, taking into account the remarkably high number of SD cases (accounting for approximately 100,000 adult deaths in the UK each year – Department of Health, 2005) and the important social impact of these events. The incidence of SD gradually and significantly increases after 35 - 40 years of age, and is particularly high during the acute phase of myocardial infarction (MI). It is also frequent during the chronic phase of ischaemic heart disease (IHD), as well as in subjects with any heart disease, especially when heart failure (HF) is present.

The commonest form of cardiac arrhythmia is atrial fibrillation (AF) and this affects approximately 3% of the UK population, about 2 million people, and is much more common in older subjects. AF affects approximately 4% of the population over 65 years old, and 10% of those are older than 80 years.

The selection of appropriate therapy for the management of cardiac arrhythmias necessitates an understanding of the aetiology and mechanism of the arrhythmia, an appreciation of the associated medical conditions that may contribute to and/or exacerbate the arrhythmia, the risk posed by the arrhythmia, and risk-to-benefit aspects of the selected therapy.

The most commonly therapeutic approach used in the treatment of cardiac arrhythmias continues to be held through antiarrhythmic drugs. However, there are a few advances made in this area over the past 20 years that have shown these drugs to be less effective than previously thought and sometimes pro-arrhythmic.

Consequently, the arrhythmology has undergone a dramatic evolution over the past two decades and non-pharmacological treatments have been developed very quickly. The widespread use of catheter ablation, the introduction of implantable cardioverter defibrillators for the prevention of sudden cardiac death and, finally, the development of cardiac resynchronization therapy led to a gradual loss of the impact of antiarrhythmic drugs as a therapeutic approach.

This rapid growth is a consequence of the familiarization of electrophysiological studies, which facilitated the understanding of the mechanism of clinical arrhythmias and allowed to locate, with great precision, areas within the heart considered critical for its occurrence.

The interventional laboratories for electrophysiology became important sites for therapeutic decisions, with capacity to diagnose, indicate and follow patients with arrhythmias eligible for invasive therapy (ablation, pacemaker or implantable cardioverter defibrillator).

The main goal of this internship was to apply scientific and technical knowledge acquired during the course in the daily practice and in the clinical context. Therefore, this work presents a description of the activity performed during the placement in the areas of Cardiac Pacing and Electrophysiology.

This report is divided into three chapters. Chapter I is constituted by a revision of the literature and includes concepts such as definition and mechanisms of cardiac arrhythmias; a brief description of the varied diagnostic tools and its recommendations; and also a presentation of the different therapeutic approaches available and its indications. The second chapter is a descriptive drawing of the activity performed in the modules of Electrophysiology and Pacing. Lastly, the chapter III presents two clinical cases in Electrophysiology considered interesting from a clinical point of view.

Chapter I

STATE OF THE ART

1. CARDIAC ARRHYTHMIAS

Arrhythmias are defined as any cardiac rhythm other than the normal sinus rhythm (SR). Sinus rhythm means a stimulus originates in a sinus node and subsequently occurs at appropriate rates of conduction transmitted through the atria, the atrioventricular (AV) junction and the intraventricular specific conduction system. Therefore, any changes that might occur either at the place of the origin of the stimulus or following the normal electrical activation of the heart must be considered arrhythmias.

In adults at rest, the rate of the normal sinus rhythm ranges from 60 to 80 beats per minute (bpm). Sinus rhythms over 100 bpm (sinus tachycardia) and under 60 bpm (sinus bradycardia) may be considered arrhythmias. However, it should be taken into account that sinus rhythm varies throughout a 24 hours period, either sinus tachycardia and sinus bradycardia usually are a physiologic response to certain sympathetic (exercise, stress) or vagal (rest, sleep) stimuli. Under such circumstances, the presence of these heart rates should be considered normal.

In addition, it is important to remember that:

- 1) the term arrhythmia does not specifically mean rhythm irregularity, as regular arrhythmias can occur, often with absolute stability (flutter, paroxysmal tachycardia, etc.), sometimes presenting heart rates in the normal range, as is the case of atrial flutter 4 x 1;
- 2) a diagnosis of arrhythmia in itself does not mean evident pathology. In fact, in healthy subjects, the sporadic presence of certain arrhythmias, both active (premature contractions) and passive (escape complexes, certain degree of AV block, evident sinus arrhythmia, etc.) is frequently observed (DE LUNA, 2011).

1.1. CLASSIFICATION

There are different ways to classify cardiac arrhythmias:

- **according to the site of origin** can be divided into supraventricular (including those having their origin in the sinus node, the atria, and the AV junction) and ventricular arrhythmias;

- **according to the underlying mechanism** may be explained by:

- 1) abnormal formation of impulses, which includes increased heart automaticity and triggered electrical activity;
- 2) disturbances of conduction (reentry);
- 3) combinations of both.

- **from the clinical point of view** may be paroxysmal, persistent or permanent. Regarding to tachyarrhythmias, paroxysmal tachyarrhythmias occur suddenly and usually disappear spontaneously; persistent tachyarrhythmias are characterized by short and repetitive runs of supraventricular or ventricular tachycardia; and permanent tachyarrhythmias are always present (i.e. chronic atrial fibrillation);

- **from an electrocardiographic point of view**, arrhythmias can be divided into active and passive. Active cardiac arrhythmias include isolated or repetitive impulses that command heart rhythm, instead of the basic normal sinus rhythm. They are described as isolated (premature supraventricular or ventricular complexes), repetitive (named runs), or sustained complexes (different types of tachyarrhythmias). On the other hand, passive cardiac arrhythmias show isolated or repetitive sinus or escape complexes in an abnormally slowed heart rate (bradyarrhythmias). This may be due to depression of automaticity or sinoatrial/AV block (DE LUNA, 2011).

Table 1.1 Classification of arrhythmias according to their electrocardiographic presentation

<i>Active arrhythmias</i>	<i>Passive arrhythmias</i>
Supraventricular	Escape complex
□ Premature complexes	Escape rhythm
□ Tachyarrhythmias	Sinus bradycardia
• Different types of tachycardia	Sinoatrial block
• Atrial fibrillation	Atrial block
• Atrial flutter	Atrioventricular block
Ventricular	Ventricular block
□ Premature complexes	Aberrant conduction
□ Different types of tachycardia	Cardiac arrest
□ Ventricular flutter	
□ Ventricular fibrillation	

1.2. MECHANISMS – ESSENCIAL CONCEPTS

The diagnosis of the underlying mechanism of an arrhythmia can be of great importance in guiding appropriate treatment strategies. Spontaneous behaviour of the arrhythmia, mode of initiation and termination, and response to premature stimulation and overdrive pacing are the most commonly used tools to distinguish among the different mechanisms responsible for cardiac arrhythmias. Our present diagnostic tools, however, do not always permit unequivocal determination of the electrophysiological mechanisms responsible for many clinical arrhythmias or their ionic bases. In particular, it can be difficult to distinguish among several mechanisms that appear to have a focal origin with centrifugal spread of activation (automaticity, triggered activity, microreentry). This is further complicated by the fact that some arrhythmias can be started by one mechanism and perpetuated by another (ISSA *et al.*, 2012). Additionally, we should bear in mind that there are modulating factors (unbalanced autonomic nervous system, ischemia, ionic and metabolic alterations, stress, alcohol and coffee consumption, etc.) that favour the appearance and maintenance of arrhythmias (DE LUNA, 2011).

As referred previously, the mechanisms responsible for cardiac arrhythmias are generally divided into categories of disorders of impulse formation (automaticity or triggered activity), disorders of impulse conduction (reentry), or combinations of both (PETERS *et al.*, 2000).

1.2.1. Automaticity

Automaticity is the capacity of some cardiac cells (the automatic slow response cells present in the sinus node and to a lesser degree in the atrioventricular node) to not only excite themselves but also to produce stimuli that can propagate (Figure 1). Therefore, automatic cells excite themselves and produce stimuli that may propagate, whereas contractile cells are only excited by a stimulus from a neighbouring cell, transmitting it to the nearest cell (domino effect theory). Under normal conditions, contractile cells are not automatic cells because they do not excite themselves. However, in specific situations as post myocardial infarction or in episodes of myocardial ischemia, the contractile cells may develop abnormal automaticity.

1.2.2. Triggered

Another mechanism that can originate arrhythmias due to an abnormal generation of stimulus is the triggered activity, characterized as an impulse initiation in cardiac fibers caused by depolarizing oscillations in membrane voltage (known as post-potentials). This is due to the presence of early or late post-potentials significant enough that their oscillatory vibrations initiate a response that may be propagated (Figure 2). Early post-potentials originate in the beginning of Phase 3 of the transmembrane action potential (TAP) before repolarization has been completed; late post-potentials are explained by the presence of oscillatory diastolic depolarizations. These seem to be the underlying mechanism of arrhythmias such as *torsades de pointes* or certain arrhythmias caused by digitalis intoxication (DE LUNA, 2011).

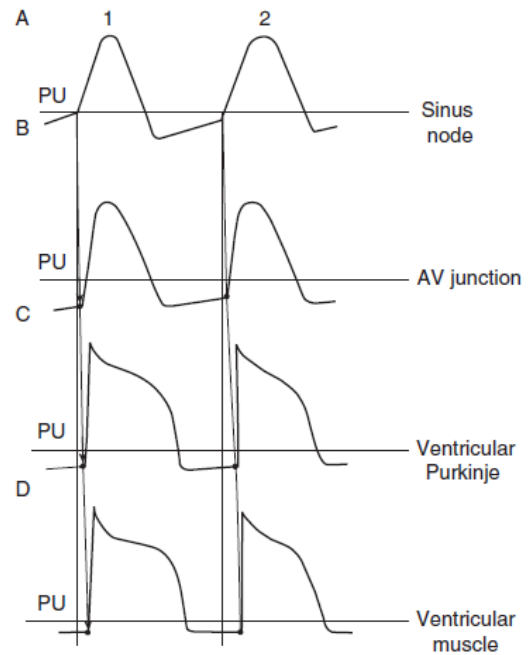


Figure 1. Sinus node transmembrane action potential (A) transmitted to the atrioventricular junction (B), the ventricular Purkinje (C) and ventricular muscle (D).

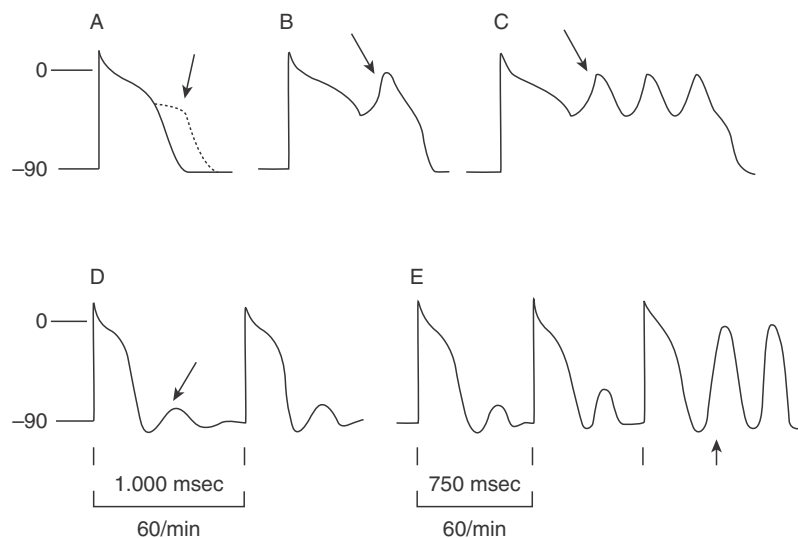


Figure 2. The presence of early (A-C) and late (D and E) post-potentials is the mechanism addressing the occurrence of early stimuli (complexes) due to triggered activity.

1.2.3. Reentry

Reentry occurs when a propagating action potential wave fails to extinguish after initial tissue activation; instead, it blocks in circumscribed areas, circulates around the zones of block, and reenters and reactivates the site of original excitation after it recovers excitability. Reentry is the likely mechanism of most recurrent clinical arrhythmias (ISSA *et al.*, 2012). For this phenomenon to exist three conditions are necessary:

- a) the presence of a circuit (through which the stimulus may circulate/reenter);
- b) an unidirectional block in part of the circuit (where the stimulus may be conducted in one direction only);
- c) an appropriate conduction velocity (the conduction velocity must be slow to improve the probability that all segments of the circuit are out of the refractory period when the reentrant stimulus reaches them).

The ectopics play an important role in the onset of reentries, once a premature impulse is much more likely to find myocardial fibers at different stages of refractory periods' recovery and therefore activate a reentrant circuit (DE LUNA, 2011).

The reentrant circuit can occur in different locations of the heart. It can be initiated in a small area (micro-reentry); be located in more extensive areas of the ventricle or through the specific intraventricular conduction system; be macro-circuits localized preferably in the right atrium causing typical or atypical flutter; and involve the AV junction.

A circuit comprising the AV junction exclusively.

It was previously believed that this circuit was functional and located within the AV node (intranodal). It was presumed that the AV node had a longitudinal dissociation, with a slow conduction tract (α) and fast conduction tract (β) (Figure 3). Now it is known (Wu and Yeh, 1994; Katritsis and Becker, 2007) that these circuits have an anatomic basis in which tissue of the lower atrium is also involved (AV junction). This results in several possible circuits accounting for the different types of reentrant tachycardias with exclusive involvement of the AV junction structures, however there are two main types:

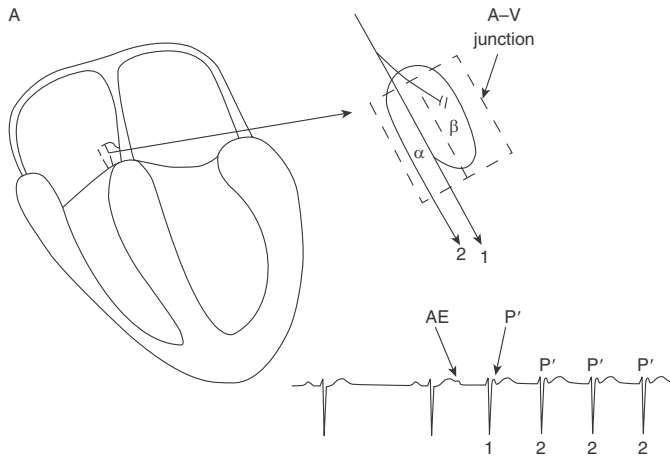


Figure 3. Example of a reentrant tachycardia involving the AV junction only. The premature atrial ectopic (AE), which does not undergo anterograde conduction on the β pathway, is conducted through the α pathway. Then, it facilitates a reentry through the β pathway, with fast atrial retrograde activation (P'), which may be concealed within or at the end of the QRS complex (it may mimic an r' or S wave).

Slow-fast type: constitute approximately 50% of paroxysmal tachycardias involving the AV junction (Atrioventricular Nodal Reentrant Tachycardia, AVNRT). In a few cases, the tachycardia is due to the abnormal generation of stimuli. In the case of an AVNRT, a premature stimulus (atrial premature contraction) is blocked in the fast pathway (β) still in the absolute refractory period (ARP). It may go through the α pathway with a shorter refractory period, albeit with a lower conduction velocity. As a result, this stimulus is conducted to the ventricles with a longer $P'R$ than the baseline PR interval. At some point as the fast pathway (β) is out of the refractory period, the premature stimulus retrogradely invades this pathway and rapidly reaches the atrium (P'), while at the same time entering again into the slow pathway (α), and is conducted to the ventricles to generate the QRS-2 complex (2 in Figure 4). Conduction to the atrium is very fast, and the ectopic P' is concealed in the QRS complex or stuck at the end of it, simulating an “S” or “r” wave.

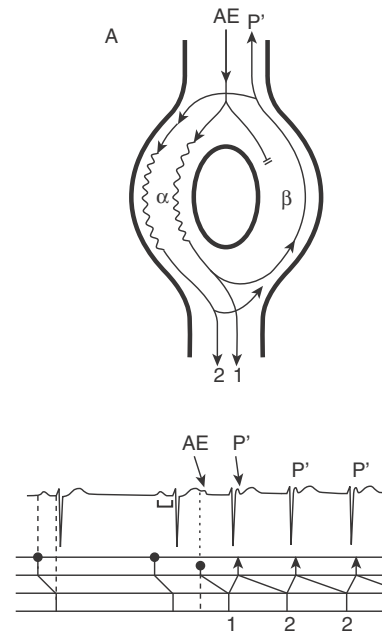


Figure 4. Example of slow-fast tachycardia with exclusive involvement of the AV junction, initiated by an atrial ectopic.

Fast-slow type: is much less frequent. The episodes are incessant and non-paroxysmal. It was thought to imply an inverted AV junctional circuit, with a stimulus going down through the fast pathway and slowly up through the slow pathway. Currently, there are some suggestions that this type of tachycardia uses a circuit in which an anomalous bundle takes part; the stimulus is anterogradely conducted through the pathway and is retrogradely conducted through an anomalous pathway with long conduction times (DE LUNA, 2011).

1.3. EPIDEMIOLOGY

Sudden death (SD) is a major public health issue and probably the most challenging issue in modern cardiology, taking into account the remarkably high number of SD cases (accounting for approximately 100,000 adult deaths in the UK each year – Department of Health, 2005) and the important social impact of these events. In addition, cardiovascular disease (CVD) is the leading cause of mortality in the UK, and was responsible for over 50,000 premature deaths in 2006.

The incidence of SD gradually and significantly increases after 35 - 40 years of age, and is particularly high during the acute phase of myocardial infarction (MI). It is also frequent during the chronic phase of ischaemic heart disease (IHD), as well as in subjects with any heart disease, especially when heart failure (HF) is present. Acute IHD is frequently associated with SD in adults. In the majority of cases of SD outside acute IHD or channelopathies, HF, or at least left ventricular systolic dysfunction (LVSD), is present. HF may be idiopathic or present in patients with chronic IHD, hypertension, cardiomyopathies, etc. (DE LUNA, 2011).

The incidence and prevalence of heart failure increase steeply with age, and the average age at first diagnosis is 76 years old. The incidence of heart failure in the UK is 140 per 100,000 men and 120 per 100,000 women. Although the incidence is higher in men, evidence suggests higher mortality in women with the condition. Around 3% of people aged 65–74 years have heart failure; this increases to about 7% of those aged 75–84 years, and to just over 14% in those aged 85 years and older. The prevalence of heart failure in the UK is 40 per 1000 in men and 30 per 1000 in women (ARONSON *et al.*, 2010).

About 1% of emergency hospital admissions amongst adults are primarily due to heart failure, which contributes to a further 4%, although these may be underestimated due to issues with diagnosis and case definition. In the EuroHeart Failure survey, 36% of those who had left ventricular function assessed, had an left ventricular ejection fraction (LVEF) $\leq 35\%$ and, of these, 41% had a QRS duration ≥ 120 ms; 7% had right bundle branch block (RBBB), 34% had left bundle branch block (LBBB) or other intraventricular conduction delay (IVCD) and 17% had RS ≥ 150 ms. In the Italian Network on CHF (IN-CHF) registry, 391 patients (25%) had complete LBBB, 336 (6%) had complete BBB and 339 (6%) had other forms of IVCD. The annual incidence of LBBB is about 10% in ambulatory patients with left ventricular systolic dysfunction and chronic HF (BRIGNOLE *et al.*, 2013).

Arrhythmias may manifest itself in various ways and in a very broad spectrum of severity. The commonest form of cardiac arrhythmia is atrial fibrillation (AF). This affects approximately 3% of the UK population, about 2 million people, and is much more common in older subjects. AF affects approximately 4% of the population over 65 years old, and 10% of those are older than 80 years. Most patients with AF are treated with tablets alone but in patients with AF who have troublesome symptoms despite medication, ablation has been recommended. Prospective and randomised studies have shown a clear reduction in symptoms from ablation therapy compared with medication alone. Furthermore, ablation therapy has been shown to be cost effective for these patients (MCKENNA *et al.*, 2009; CAMM *et al.*, 2010). Furthermore, supraventricular tachycardias (SVT) affects over 200,000 people in the UK and most commonly presents between the age of 10 and 50 years.

2. DIAGNOSTIC TOOLS

The clinical management of patients with arrhythmias or suspicion of them should begin with a history taking and a physical examination.

The history taking should include a careful examination to seek symptoms suggestive of arrhythmias, palpitations, dizziness, syncope or pre-syncope, but also angina or heart failure. Note that not all patients with arrhythmias are symptomatic and that some symptoms, such as palpitations, does not always correspond to arrhythmias.

The physical examination of patients with arrhythmias has three main goals:

- 1) Distinguish diagnostic elements of the arrhythmia itself;
- 2) Assess the hemodynamic consequences of the arrhythmia;
- 3) Diagnose a possible underlying heart disease or precipitating factors, such as hyperthyroidism, alcoholism ("Holiday Heart Syndrome", originally described by Ettinger et al, 1978), etc.

Palpitations are the most common symptom that causes the patient to seek medical help. It is defined as the perception of a heartbeat and is described by patients as an unpleasant sensation of heartbeat in chest and/or adjacent areas. The characteristics of palpitations must always be investigated: if they are associated with chest pain, either during rest or exercise; if they occur in the supine or standing position; if they occur after certain predisposing factors such as emotional stress or alcohol intake; the onset and termination of the episode (abrupt or gradual); if the beats are regular or irregular; the episode duration (short or long) and if symptoms existed prior to the episode or are associated with syncope or fainting (RAVIELE *et al.*, 2011). The presence of syncope when related with arrhythmias suggests the existence of a severe arrhythmia. This may correspond to a paroxysmal AV block or ventricular/supraventricular tachyarrhythmia.

A brief description of the symptoms most of the times allow to make a preliminary diagnosis and determine the severity of the arrhythmia. However, sometimes a patient describes a change in the heart rhythm suggestive of an arrhythmia, but nothing appears on the electrocardiogram (ECG) trace, even if an arrhythmia is detected during the physical examination.

Therefore, it becomes important to integrate the family history, physical examination results and surface ECG with other special electrocardiographic techniques (Exercise Tolerance test, Holter or 24 hour tape, Electrophysiological study) and imaging techniques (Echocardiography, Cardiac MRI, Cardiac CT and Coronarography), as well as genetic tests, to reach a correct diagnosis, to determine the patient's prognosis, and to be able to take the most appropriate therapeutic decision.

It is important to emphasize the value of extensive electrocardiographic knowledge, as minor changes (i.e. of repolarization) such as the presence of negative T waves in leads V1 to V3–V4 in the case of Arrhythmogenic Right Ventricular Dysplasia (ARVD), or a slight ST segment elevation with r', usually seen in lead V1 in the case of Brugada Syndrome, may be essential to suggest a diagnosis.

2.1 . RESTING ELECTROCARDIOGRAM

The diagnosis of arrhythmias is done via additional diagnostic tests, being the ECG the first exam to take place, once is the most affordable. Identifying the presence of P waves, the QRS morphology and the relationship between both, the rate and regularity of the heart rhythm, may be the only information needed to accurately diagnose the arrhythmia (O'ROURKE *et al.*, 2002).

Furthermore, a standard resting 12 lead ECG also allows the identification of various congenital abnormalities associated with ventricular arrhythmias and sudden cardiac death (SCD) {e.g., Long QT Syndrome (LQTS), Short QT Syndrome (SQTS), Brugada Syndrome, ARVD}; the identification of many other parameters, such as those due to electrolyte disturbances; or evidence suggesting underlying structural disease, such as bundle branch block, AV block, left ventricular hypertrophy (LVH) and Q waves indicative of ischemic heart disease or infiltrative cardiomyopathy. QRS duration and repolarization abnormalities are both independent predictors of SCD. A prolonged QRS duration greater

than 120 to 130 ms has been shown in a number of studies to be associated with increased mortality in patients with a reduced LVEF (equal to or less than 30%). Prospective studies have also reported an association between ST segment depression or T wave abnormalities and increased risk of cardiovascular death and SCD in particular (ZIPES *et al.*, 2006).

Carotid sinus massage with electrocardiographic recording may also help us in the differential diagnosis of the different types of tachyarrhythmias, according to the results of this manoeuvre.

On some occasions, however, conventional surface electrocardiography cannot confirm an arrhythmia suggested by history taking or physical examination, or it cannot confirm the correct diagnosis (DE LUNA, 2011).

2.2. AMBULATORY ECG

The use of continuous or intermittent ambulatory recording techniques can be very helpful in diagnosing a suspected arrhythmia, establishing its frequency, and relating symptoms to the presence of the arrhythmia. Silent myocardial ischemic episodes may also be detected (ZIPES *et al.*, 2006).

The 24 hour tape recording for prolonged periods of daily living was introduced in cardiology in 1961 by Norman J. Holter. Its introduction allowed to make the diagnosis and characterization of cardiac arrhythmias; to obtain an objective correlation between symptoms and the presence or absence of arrhythmias; quantify and classify the severity, identify the mechanisms and conditions; and also assess the therapeutic efficacy of antiarrhythmic drugs.

The devices for ambulatory ECG monitoring may be divided into two main categories: external and implanted. External devices include Holter recorder - indicated for review of arrhythmias and symptoms with a daily frequency; and cardiac loops – for recording of events triggered by the patient or self-activated for a period of more than two weeks in situations where the frequency of symptoms occurs weekly. On the other hand, implantable loop recorders, a subcutaneous implantable device, are suitable for situations where the frequency of symptoms is monthly or more. These devices are capable of monitoring the rhythm and logging events triggered by the patient and self-activated events

and although it requires surgical implantation, they have been shown to be extremely useful in diagnosing serious tachyarrhythmias and bradyarrhythmias in patients with life-threatening symptoms such as syncope (ZIPES *et al.*, 2006). Pacemakers and Implantable Cardioverter Defibrillators (ICD) are also included in the category of implantable devices and provide important information through the diagnostic functions and intracavitary electrograms (IEGM) that are stored in the internal memory (RAVIELE *et al.*, 2011).

Nowadays, due to the high technological evolution established either regarding the recorders or the analysis systems, 24 hour tapes provide even additional information such as: ST segment analysis, Heart Rate Variability (HRV), QT interval dispersion and late potentials, which provides prognostic information for the respective arrhythmia.

Recommendations of Class I (ZIPES *et al.*, 2006):

- 1) Ambulatory ECG is indicated when there is a need to clarify the diagnosis by detecting arrhythmias, QT interval changes, T-wave alternans (TWA), or ST changes; to evaluate risk, or to judge therapy (Level of Evidence A);
- 2) Event monitors are indicated when symptoms are sporadic, to establish whether or not they are caused by transient arrhythmias (Level of Evidence B);
- 3) Implantable recorders are useful in patients with sporadic symptoms suspected to be related to arrhythmias such as syncope when a symptom-rhythm correlation cannot be established by conventional diagnostic techniques (Level of Evidence B).

2.3. EXERCISE TOLERANCE TEST

The exercise tolerance test (ETT) is useful for the evaluation of exercise-induced arrhythmias, particularly ventricular ectopy and tachyarrhythmias; to evaluate ischemic heart disease, sinus or AV node dysfunction and also to assess the proarrhythmic effects (heart rate dependent) of antiarrhythmic drugs. The exercise tolerance test can also be used to estimate the refractory period of the accessory pathway (AP) in patients with Wolff-Parkinson-White (WPW) syndrome: its disappearance with effort can be a benign sign as may be indicative of a refractory period higher than 250 ms and therefore, with low risk. In patients with IHD, myocardial ischemia induced by exercise can precipitate the onset of

monomorphic ventricular tachycardia (VT), polymorphic or even ventricular fibrillation (VF).

The ETT is also valuable for evaluating patients with symptoms suggestive of arrhythmias triggered by exercise such as idiopathic ventricular tachycardia in patients with Arrhythmogenic Right Ventricular Dysplasia, *Torsades de Pointes* secondary to long QT syndrome, or Catecholaminergic Polymorphic ventricular tachycardia (CPVT) (O'ROURKE *et al.*, 2002).

Recommendations of Class I (ZIPES *et al.*, 2006):

- 1) Exercise testing is recommended in adult patients with ventricular arrhythmias who have an intermediate or greater probability of having CHD by age, gender, and symptoms to provoke ischemic changes or ventricular arrhythmias (Level of Evidence B);
- (2) Exercise testing, regardless of age, is useful in patients with known or suspected exercise-induced ventricular arrhythmias, including catecholaminergic VT, to provoke the arrhythmia, achieve a diagnosis, and determine the patient's response to tachycardia (Level of Evidence B).

2.4. IMAGING TECHNIQUES

2.4.1. Transthoracic Echocardiogram

Echocardiography is the imaging technique that is most commonly used because it is inexpensive in comparison with other techniques such as Magnetic Resonance Imaging (MRI) and Cardiac Computed Tomography (CT), it is readily available, and it provides accurate diagnosis of myocardial, valvular, and congenital heart disorders associated with ventricular arrhythmias and SCD (Table 2). In addition, LV systolic function and regional wall motion can be evaluated and, in a majority of patients, ejection fraction (EF) can be determined. The combination of echocardiography with exercise or pharmacological stress (commonly known as 'stress echo') is applicable to a selected group of patients who are

suspected of having ventricular arrhythmias triggered by ischemia and who are unable to exercise or have resting ECG abnormalities that limit the accuracy of ECG for ischemia detection. Anomalous origin of coronary arteries can be detected by echocardiography or other imaging techniques (ZIPES *et al.*, 2006).

Disease entity	Diagnostic accuracy
Dilated cardiomyopathy	High
Ischemic cardiomyopathy	High
Hypertension with moderate to severe LVH	High
Hypertrophic cardiomyopathy	High
Valvular heart disease	High
ARVC	Moderate
Brugada syndrome	Poor

Table 2. Conditions associated with ventricular arrhythmias that can be diagnosed with echocardiography.

Recommendations of Class I (ZIPES *et al.*, 2006):

- 1) Echocardiography is recommended in patients with ventricular arrhythmias who are suspected of having structural heart disease. It is also recommended for the subset of patients at high risk for the development of serious ventricular arrhythmias or SCD, such as those with dilated, hypertrophic, or right ventricle (RV) cardiomyopathies, acute myocardial infarction (AMI) survivors, or relatives of patients with inherited disorders associated with SCD (Level of Evidence B);
- 2) Exercise testing with an imaging modality (echocardiography or myocardial perfusion [single-photon emission computed tomography (SPECT)]) is recommended to detect silent ischemia in patients with ventricular arrhythmias who have an intermediate probability of having IHD by age, symptoms, and gender and in whom ECG assessment is less reliable because of digoxin use, LVH, greater than 1mm ST segment depression at rest, WPW syndrome and LBBB; or are physically unable to perform a symptom limited exercise test (Level of Evidence B).

2.4.2. Magnetic Resonance Imaging

Advances in cardiac MRI have made possible the use of this imaging technique to evaluate both the structure and function of the beating heart. The excellent image resolution obtained with current techniques is suitable for an accurate quantification of chamber volumes, LV mass, and ventricular function. This is of particular value to patients with

suspected arrhythmogenic RV dysplasia, in whom MRI provides excellent assessment of RV size, function, and regional wall motion and, importantly, may allow the detection of fatty infiltration within the RV myocardium (RV angiography may also be useful in these cases). Cardiac MRI is increasingly being applied and validated for the detection of ischemia (adenosine stress perfusion and dobutamine stress wall motion studies) and for the detection and quantification of infarction/fibrosis, a substrate for VT. The cost and availability of cardiac MRI are becoming more competitive. Cardiac MRI can provide a comprehensive cardiac evaluation in a single study.

Recommendation of Class IIa (ZIPES *et al.*, 2006):

- 1) Magnetic Resonance Imaging can be useful in patients with ventricular arrhythmias when echocardiography does not provide accurate assessment of LV and RV function and/or evaluation of structural changes (Level of Evidence B).

2.4.3. Cardiac Computed Tomography

The same way as MRI, the field of CT has advanced greatly with the development of fast scanners with better resolution that allow tomographic imaging of the heart and coronary arteries. These systems allow precise quantification of LV volumes, EF, and LV mass with results comparable to MRI but, in addition, provide segmental images of the coronary arteries from which the extent of calcification can be quantified. Cardiac CT can also be used in selected patients in whom evaluation of cardiac structures is not feasible with echocardiography and when MRI is not available. Currently, there is no incremental clinical benefit derived from imaging the coronary arteries by cardiac CT in patients with ventricular arrhythmias.

Recommendation of Class IIa (ZIPES *et al.*, 2006):

- 1) Cardiac Computed Tomography can be useful in patients with ventricular arrhythmias when echocardiography does not provide accurate assessment of LV and RV function and/or evaluation of structural changes (Level of Evidence B).

2.5. ELECTROPHYSIOLOGY STUDY

Electrophysiology studies (EPS) for the evaluation of VT were introduced in 1972 by Wellens *et al.* In the recent years though, has been converted into an important clinical tool for the diagnosis and treatment of many arrhythmias, especially when information provided by electrocardiography and other non-invasive diagnostic tests are not enough.

The placement of electrocatheters in many and varied intracardiac points allows you to map the sequence of activation in the atria, AV junction and ventricles; locate the crossing points of the accessory pathways; situate the place of origin of arrhythmias; understand the mechanisms of supraventricular and ventricular tachyarrhythmias as well as evaluate the efficiency of the antiarrhythmic therapy. In summary, the indications for EP studies are: document the inducibility of VT; guide ablation; evaluate drug effects; assess the risks of recurrent VT or SCD; evaluate loss of consciousness (LOC) in selected patients with arrhythmias suspected as a cause; assess the indications for ICD therapy.

The yield of EP varies fundamentally with the kind and severity of the underlying heart disease, the presence or absence of spontaneous VT, concomitant drug therapy, the stimulation protocol, and the site of stimulation. Highest induction rates and reproducibility are observed in patients after MI. To evaluate patients with ventricular arrhythmias, most centres use 6 to 8 ventricular stimuli at drive cycle lengths (CL) between 600 and 400 ms at the RV apex, at twice diastolic threshold and the pulse duration of 0.5 to 2.0 ms, delivering 1 to 3 ventricular extrastimuli at baseline. This test may be repeated during isoprenaline infusion. The prematurity of extrastimuli is increased until refractoriness or induction of sustained ventricular tachyarrhythmia is achieved. Long-short cycle sequences may be tested. Because premature ventricular stimulation with a very short coupling interval is more likely to induce VF as opposed to monomorphic VT, it may be reasonable to limit the prematurity of the extrastimuli to a minimum of 180 ms when studying patients for whom only inducible sustained monomorphic VT would be considered a positive endpoint. EP testing may be repeated at the RV outflow tract (RVOT) or LV. In some patients with rate-dependent induction of VT, rapid atrial or ventricular stimulation may induce VT (ZIPES *et al.*, 2006).

Recent advances in technology have enabled mapping systems to:

- a) display three-dimensional representation of cardiac chambers;
- b) provide a visual display of the arrhythmia activation sequence;
- c) display the arrhythmia substrate, e.g. scars, areas of conduction block;
- d) non-fluoroscopically navigate catheters in real-time;
- e) annotate sites of ablation lesions.

Three-dimensional mapping also provides an opportunity to elucidate the substrate of an arrhythmia. Mapping of electrogram voltage and local excitability helps to delineate areas of interest including potential scar or channels of conduction in reentry circuits. The systems that are most commonly used in clinical practice include sequential site mapping using magnetic field (Carto) or electrical field (NavX) guidance.

CARTO (BIOSENSE WEBSTER, INC) ELECTROANATOMICAL MAPPING SYSTEM

The Carto system uses ultra-low magnetic fields to localize a specialized ablation catheter (Navistar) that contains a magnetic sensor at the distal electrode (Figure 5). These magnetic fields are generated by three coils mounted under the examination table (Figure 6). The three-dimensional position and orientation (pitch, roll and yaw) of the catheter tip can be determined.

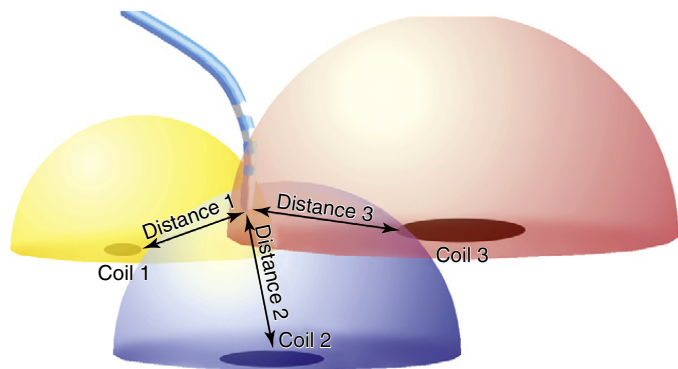


Figure 5. CARTO electroanatomical map setup. The three hemispheres represent fields from the three different electromagnets situated beneath the patient. The catheter tip contains an element that is sensed by these fields, and this triangulating information is used to monitor the location and orientation of the catheter tip in the heart.

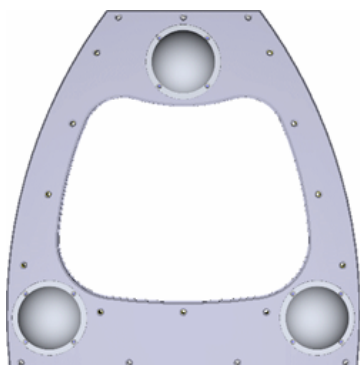


Figure 6. Illustration of the three coils mounted under the examination table.

The Navistar catheter then collects electrical data sequentially from one or more cardiac chambers of interest. The system constructs a 3D geometric “shell” representing the shape and size of the chamber. Electroanatomic data can be shown in a number of ways: Local activation time (LAT) map (Figure 7); Isochronal map; Propagation map; Voltage map; Mesh map and Complex fractionated atrial electrograms.

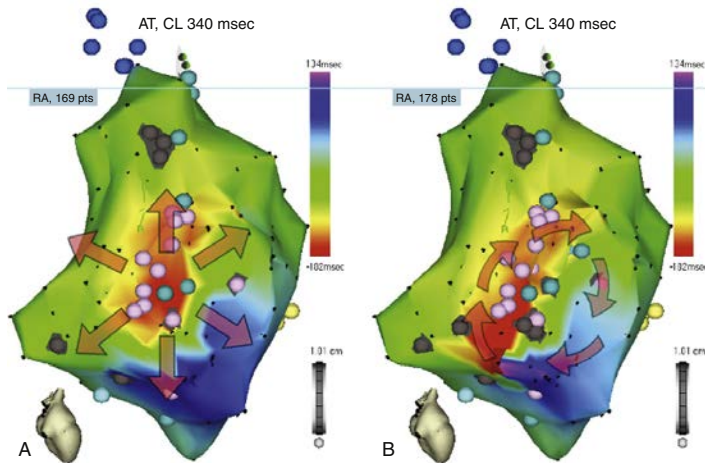


Figure 7. Right atrial electro-anatomical activation map in a patient with prior atrial tachycardia following atrial septal defect repair years before. The view is from the aspect of the right rib margin (upward toward the lateral right atrium). A, The activation pattern suggests a focal process with centrifugal spread of activation from the central red area. B, With additional detailed mapping below the red area, a return path for a reentrant circuit is evident.

Advantages of this system:

- Geometry construction and annotation of sites of interest are accurate and intuitive;
- Electrical data and anatomic locations are collected and displayed by the system simultaneously during construction of the chamber geometry;
- Respiratory motion artefacts are relatively limited;
- LAT maps can be superimposed on a substrate map (e.g. scar);
- The algorithm is suitable for generating endocardial and epicardial anatomic maps.

Like any other imaging technique, this system also carries some limitations:

- Sequential site mapping can be time-consuming;
- Mapping of non-sustained tachycardia may be very difficult;
- Arrhythmias that are not well tolerated hemodynamically are usually not mappable;
- A change in tachycardia cycle length or morphology requires new mapping of the chamber (BASHIR *et al.*, 2010).

ENSITE NAVX (ST. JUDE MEDICAL) NAVIGATION SYSTEM

The Ensite NavX system (Figure 8) generates a transthoracic electrical field by three pairs of orthogonal cutaneous patches. Catheter location can be determined by measuring the local voltage gradient along each axis with respect to a reference electrode. Sequential positioning of a conventional catheter along the endocardial surface defines the geometry of a cardiac chamber. Separate geometries can be constructed for vessels attached to the chamber. The mapping catheter then collects electrical data and the system sequentially displays the information onto the geometry. Electroanatomic data can be shown in many ways: diagnostic landmarking tool; voltage mapping and Complex fractionated atrial electrograms mapping (as in Carto system).

Advantages:

- Multi-polar catheters may be used to simultaneously collect electroanatomical data from multiple sites at the same time;
- Catheter navigation is fast and responsive;
- Any conventional mapping catheter may be used, thus reducing costs;
- Any energy source may be used for ablation;
- Multiple chamber mapping can be performed.

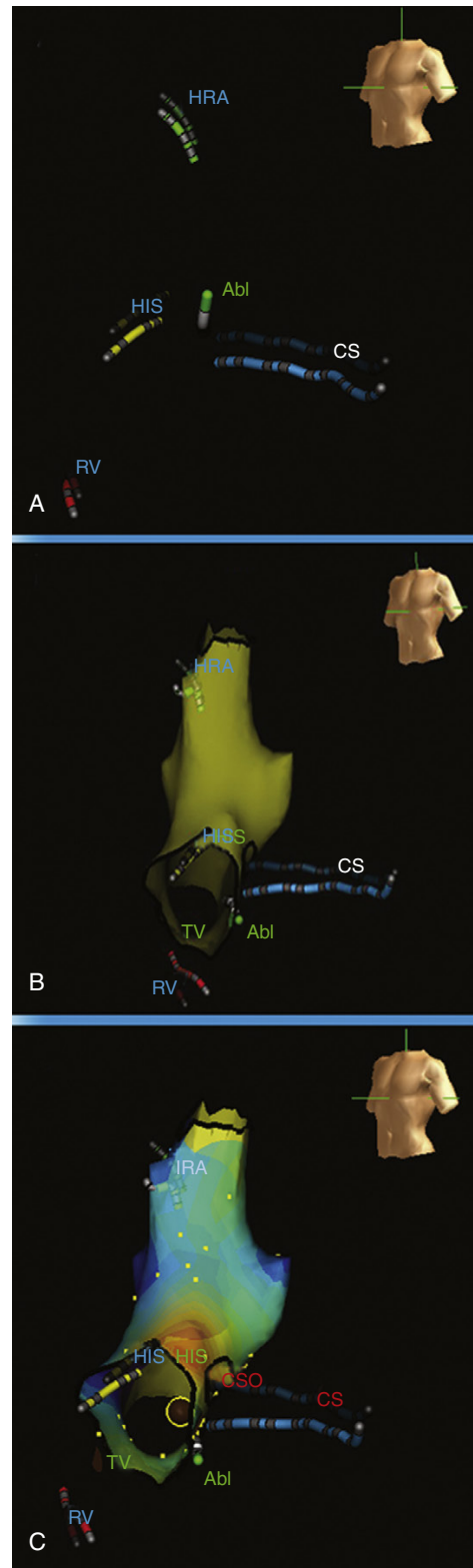


Figure 8. The NavX system. A, Left anterior oblique view of four standard diagnostic catheters (positioned in the high right atrium [HRA], His bundle [HIS], right ventricular [RV] apex, and coronary sinus [CS]) and a standard ablation catheter (Abl). B, Virtual anatomical geometry of the RA is acquired by moving the catheter in all directions throughout the chamber of interest. C, Color-coded activation map superimposed on the RA 3D geometry localizing the origin of the atrial tachycardia to the triangle of Koch between the His bundle, coronary sinus ostium (CSO) and tricuspid valve (TV).

Limitations:

- Chamber surface interpolations (“false space” without collected points) can occur in complex geometries;
- Catheter navigation accuracy can be affected by changes in respiratory patterns in a conscious patient;
- Mapping of non-sustained or poorly tolerated tachycardia may be difficult;
- Changes in tachycardia cycle length or morphology requires repeat sequential mapping of the tachycardia circuit (BASHIR *et al.*, 2010).

Recommendations of Class I (ZIPES *et al.*, 2006):

- 1) EP is recommended for diagnostic evaluation of patients with remote MI with symptoms suggestive of ventricular tachyarrhythmias, including palpitations, presyncope, and syncope (Level of Evidence B);
- 2) EP is recommended in patients with CHD to guide and assess the efficacy of VT ablation (Level of Evidence B);
- 3) EP is useful in patients with CHD for the diagnostic evaluation of wide QRS complex tachycardias of unclear mechanism (Level of Evidence C);
- 4) EP is recommended in patients with syncope of unknown cause with impaired LV function or structural heart disease (Level of Evidence B).

Recommendation of Class IIa (ZIPES *et al.*, 2006):

- 5) EP can be useful in patients with syncope when bradyarrhythmias or tachyarrhythmias are suspected and in whom non-invasive diagnostic studies are not conclusive (Level of Evidence B).

3. THERAPEUTIC APPROACH

The selection of appropriate therapy for the management of cardiac arrhythmias necessitates an understanding of the aetiology and mechanism of the arrhythmia, an appreciation of the associated medical conditions that may contribute to and/or exacerbate the arrhythmia, the risk posed by the arrhythmia, and risk-to-benefit aspects of the selected therapy. Management of the manifest arrhythmia may involve discontinuation of offending proarrhythmic drugs, specific antiarrhythmic therapy with drugs, implantable devices, ablation or surgery (ZIPES *et al.*, 2006).

The most commonly therapeutic approach used in the treatment of cardiac arrhythmias continues to be held through antiarrhythmic drugs. However, there are a few advances made in this area over the past 20 years that have shown these drugs to be less effective than previously thought and sometimes pro-arrhythmic. Thereafter, non-pharmacological treatments have been developed very quickly and there are many centres where this form of therapy is already being used on a daily basis, especially in patients with tachycardic syndromes. This rapid growth is a consequence of the familiarization of electrophysiological studies, which facilitated the understanding of the mechanism of clinical arrhythmias and allowed to locate, with great precision, areas within the heart considered critical for its occurrence.

At the moment there are three main types of therapeutic available: surgical ablation, catheter ablation and implantable devices (PM, ICD and CRT). Its applications as well as the results obtained depend primarily on the type of the arrhythmia.

It is also important to mention that procedures with ablation (surgical and via catheter) were designed to be "curative", while implantable devices were not designed to prevent the occurrence of tachycardia but to stop it quickly (when able to). For this reason, the patient needs to continue on antiarrhythmic drug therapy and often feel the onset of seizures.

These implantable devices are therefore "palliative" procedures rather than "curative", however depending on each case, it might be the best treatment option.

In order to obtain a successful outcome in the treatment of arrhythmias, it is important to treat the underlying pathology with optimal therapy for heart failure, correction of hemodynamic and electrolyte disturbances and optimized treatment of ischemic heart disease. There is also a reasonable likelihood of coronary revascularization reducing the frequency and complexity of arrhythmias, and in some patients even eliminates these arrhythmias. These options can reduce the symptoms of arrhythmias and specially reduce total and arrhythmic mortality (ZIPES *et al.*, 2006).

We will now present a brief description of the different non-pharmacological therapeutic approaches available: Cardiac Pacing, Implantable Cardioverter Defibrillator, Cardiac Resynchronization Therapy (CRT) and Radiofrequency Ablation.

3.1. CARDIAC PACING

The earliest demonstration of temporary pacing of the heart was provided by Mark C. Lidwill in the 1920s. Dr. Lidwill developed a portable piece of electrical equipment that was meant to provide temporary pacing in the event of an emergency during a surgical procedure. There was little further progress in development of pacing until the 1950s. Shortly thereafter, in 1954, *Electrodyn*e came out with a commercial version of an external pacemaker, which became widely used throughout the hospitals for the emergency resuscitation of patients with asystole. In 1958, it was firstly described by Furman and Robinson the temporary pacing stimulation via peripheral venipuncture, allowing an immediate treatment for patients with severe bradyarrhythmia (2nd degree AV block Mobitz II; 3rd degree AV block; severe bradycardia) and/or hemodynamic instability. While these results were gratifying, external pacemakers were only practical for temporary use. It quickly became apparent that chronic pacing would best be achieved with a totally implantable system.

The first permanent pacemaker was implanted by Dr. Ake Senning in Sweden in 1958 in a patient named Arne Larsson. It was a totally implantable system that used an epicardial lead on the ventricle. Mr. Larsson actually had 26 pacemakers throughout his life. His story provides an excellent testimonial to the success of permanent pacing since after having

suffered from multiple daily syncopal spells just before he received his first pacemaker, went on with a productive life, until he died in 2001 at the age of 86 (CURTIS, 2010).

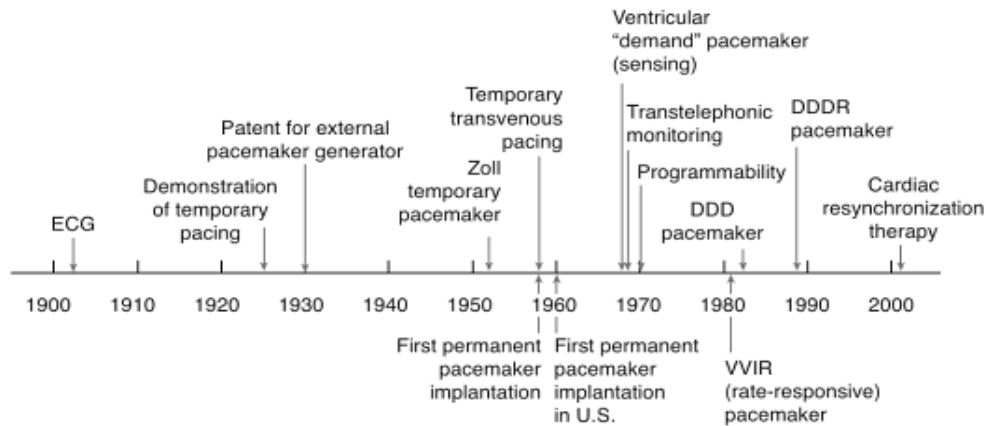


Figure 9. Major milestones in cardiac pacing.

Since its first establishment to the present day, cardiac pacing has gone through tremendous technological advances, either in software or hardware wise, being the primary goal an appropriate electric correction of the heart rate and the underlying conduction disorders, in order to simulate as best as possible the sinus node and to meet the needs of the patient, while minimizing the side effects. Moreover, is proved to be effective in improving the quality of life and to decrease the mortality and morbidity.

Between the varied components of the cardiac pacing that has been suffering huge developments (batteries, electrodes, materials, surgical techniques), we draw the attention for the advances in microelectronics, which have converted the pacemaker in a smart intelligent device, capable of performing a variety of “physiological” functions, adaptable to different clinical situations.

The electrical therapy with implantation of permanent pacemaker (PPM) is indicated in several clinical scenarios, including situations of bradyarrhythmia and/or symptomatic tachyarrhythmia (EPSTEIN *et al.*, 2008).

The establishment of consensus criteria and guidelines in order to standardize the indications for permanent pacemaker implantation has shown a significant contribution in the search for the best cost-benefit ratio. Thus, recommendations for cardiac pacing and device therapy is periodically updated, either regarding conventional indications (sick sinus syndrome, AV block and carotid sinus hypersensitivity) or the inclusion of new indications related to clinical entities susceptible of cardiac pacing as therapy (heart failure, vasovagal syncope, paroxysmal atrial fibrillation, hypertrophic obstructive cardiomyopathy).

SICK SINUS SYNDROME

The sinus node dysfunction is characterized by electrocardiographic and electrophysiological disorders involving the sinus node and its electrical connections, which is often the result of chronic fibrotic degeneration or calcification of the sinus node and/or the surrounding atrial tissues. The association of symptoms related to these disorders is called sick sinus syndrome (SSS). May be manifested by 3 different rhythm disorders:

- 1) benign sinus bradycardia or sinus pauses;
- 2) tachyarrhythmias - as paroxysmal AF, atrial flutter, atrial tachycardia (AT) and supraventricular tachycardia;
- 3) Bradi/tachycardia - alternating slow and fast rhythms.

The most serious symptom of SSS is the syncope or presyncope.

Indication of Class I (EPSTEIN *et al.*, 2008):

- 1) PPM is indicated for sinus node dysfunction with documented symptomatic bradycardia, including frequent sinus pauses that produce symptoms; for symptomatic chronotropic incompetence and for symptomatic sinus bradycardia that results from required drug therapy for medical conditions (Level of Evidence C).

Indication of Class IIb (EPSTEIN *et al.*, 2008):

- 2) Dual chamber PM is recommended in SSS with minimization of RV pacing, in order to avoid changes that may lead to desynchronization of the ventricles resulting in ventricular pacing from the RV apex pacing (Level of evidence C).

ACQUIRED ATRIOVENTRICULAR BLOCK

Atrioventricular block may require PM therapy for prognostic reason and pacing may be indicated in asymptomatic patients.

In first degree AV block, cardiac pacing is not recommended unless the PR interval is unable to adapt to the heart rate during exercise and is sufficiently long (usually > 300 ms) to cause symptoms (Class IIa; level of evidence C). In this situation, the recommended pacing mode when there is no chronotropic incompetence is VDD/DDD (Class IIa; level

of evidence A). The option for the VVI mode in these cases is less consensual (class IIb; level of evidence C); where there is chronotropic incompetence DDDR mode (Class IIa; level of evidence A) or VVIR mode is recommended (class IIb; level of evidence C) (EPSTEIN *et al.*, 2008).

Rate-responsive pacing is associated with better exercise performance, improved daily activities, decrease of symptoms of shortness of breath, chest pain and palpitations and improved quality of life, compared with fixed-rate pacing. Therefore, rate-adaptive pacing is the pacing mode of first choice and fixed-rate VVI pacing should be abandoned in patients with AV block and also permanent AF.

In second-degree type I AV block, the indication for permanent pacing is controversial, unless AV block causes symptoms or the conduction delay occurs at intra or infra His levels. The cause – effect relationship with symptoms is sometimes difficult to determine, especially when symptoms are non-specific and subtle. The progression to complete heart block is likely when there is a wide QRS complex (BRIGNOLE *et al.*, 2013).

PPM is recommended in patients with third or second-degree type II AV block irrespective of symptoms (Class I; level of Evidence C) (EPSTEIN *et al.*, 2008).

Furthermore, in patients with BBB or AV block and with reduced LVEF (<35%), RV pacing may worsen left ventricular dysfunction, and therefore biventricular pacing has been recommended. Another issue to consider is the place of conventional stimulation of the RV apex, which induces a pattern of LBBB and therefore leads to interventricular dyssynchrony. It has been proposed alternative RV pacing sites, such as pacing at the interventricular septum or at the right ventricular outflow tract (EPSTEIN *et al.*, 2008).

ATRIAL FIBRILLATION

The onset of AF is influenced by several factors such as the presence of structural heart disease, hypertension, congestive heart failure, age, SSS, or pacing mode (ISRAEL, 2006).

Several retrospective and randomized studies have demonstrated that pacing in the atrium reduces the incidence of atrial fibrillation compared to ventricular pacing in patients with AV block or SSS (ANDERSEN *et al.*, 1997; CONNOLLY *et al.*, 2000). However, this may occur because pacing in the right ventricular apex (RV) induces or sustains the atrial fibrillation,

while atrial pacing actually reduces the AF (SWEENEY *et al.*, 2003). The potential antiarrhythmic mechanisms of atrial pacing are essentially due to reduction in the dispersion of atrial refractoriness associated with bradycardia and due to suppression of premature atrial contractions and pauses.

In patients with indication for cardiac pacing with the purpose of preventing AF episodes, devices with specific algorithms for AF prevention must be implanted.

There are other clinical entities associated with disturbances of rhythm and conduction where permanent pacing plays an important therapeutic role:

- after acute phase of MI, permanent ventricular pacing is indicated for persistent and symptomatic third-degree AV block and second-degree AV block with or without alternating BBB (Class I; level of evidence C);
- in hypersensitive carotid sinus syndrome, PPM is indicated for recurrent syncope caused by spontaneously occurring carotid sinus stimulation and carotid sinus pressure that induces ventricular asystole of more than 3 seconds. (Class I; Level of Evidence C);
- after cardiac transplantation, PPM is indicated for persistent inappropriate or symptomatic bradycardia not expected to resolve (Class I; Level of Evidence C). In this situations, cardiac pacing has other goals as chronotropic support, AV synchrony and rejection monitoring;
- in patients with hypertrophic cardiomyopathy (HOCM), PPM is indicated in cases of symptomatic bradycardia induced by beta-blockers, when alternative therapies are not acceptable (Class IIa; level of evidence C); in cases of hypertrophic cardiomyopathy with resting or dynamic intracavitary gradient and drugs refractoriness (Class IIb; level of evidence C) (EPSTEIN *et al.*, 2008). DDD pacing with a short AV interval in patients with HOCM contributes to decreased LV end-systolic gradient. The pre-excitation of the right ventricular apex alters the pattern of the ventricular contraction creating a “dyssynchrony”. The changed activation pattern of the LV, along with the late activation of the basal part of the septum and reduced LV contractility, increases the LV systolic diameter and reduces the systolic anterior motion of the mitral valve.

3.2. IMPLANTABLE CARDIOVERTER DEFIBRILATOR

Sudden cardiac death is the initial presentation for many patients with cardiac disease. Dr Michel Mirowski was a pioneering cardiologist who recognized the public health importance of this fact. His efforts led to the development of the implantable cardioverter defibrillator that has revolutionized the ability to prevent and treat sudden cardiac arrest.

In 1968, Mirowski became the director of Sinai's Hospital coronary care unit and was given protected time for research. Fortunately for his research, the hospital had a division of biomedical engineering and an animal laboratory, where he joined with Morton Mower, a junior cardiologist with extensive animal research experience, to begin work on an ICD. Only a month later they successfully tested their first crude prototype, made from a broken external defibrillator paddle, on a dog, however there was remained considerable antagonism in the cardiology community toward the concept of the ICD.

In 1972, Mirowski was introduced to Stephen Heilman, a physician and engineer who had formed a small medical equipment company called *Medrad*. Heilman was excited by the concept of the ICD and immediately put the company's engineers at Mirowski and Mower's disposal. The partnership was fruitful and resulted in the production of the first ICD prototype small enough to be completely implanted in a dog in 1975. Mirowski and the group at *Medrad* further refined the prototype to make it suitable for human implantation and eventually received approval for such an implant from the FDA. After Mirowski and Mower enlisted the aid of colleagues at Johns Hopkins Hospital, cardiac surgeon Myron Weisfeldt and electrophysiologist Philip Reed, the first successful human implant of an ICD was performed in February 1980. Though the first ICD model was a success, it weighed 225 g, required a thoracotomy for implantation of the electrode patches, and was only capable of defibrillation.

In the years that followed, numerous advances in ICD design have been made, including the development of the capacity of synchronized cardioversion for ventricular tachycardia and the development of a catheter-electrode-based implantable without a thoracotomy, in a similar manner to the standard pacemaker.

Unlike the early prototypes, modern devices are much smaller, with the newest models weighing as little as 90 g and measuring less than a centimetre thick. In addition to having full pacemaker capabilities, all modern ICDs are capable of overdrive pacing (antitachycardia pacing), which can often terminate ventricular tachycardia without

resorting to shock therapy. ICDs are also available with biventricular pacing (cardiac resynchronization therapy) to improve symptoms in selected patients with advanced heart failure (DEYELL *et al.*, 2010).

Based on the results of several randomized trials supporting the benefit of ICD, the indications for ICD implantation have been classified into two categories: primary prevention and secondary prevention. Primary prevention refers to the prevention of SCD in individuals without a history of cardiac arrest or sustained VT. Secondary prevention refers to the prevention of SCD in those patients who have survived a prior cardiac arrest or sustained VT (EPSTEIN *et al.*, 2008).

According to NICE - National Institute for Health and Care Excellence (ADES *et al.*, 2007), which provides national guidance and advice to improve health and social care in England, ICDs are recommended:

As **primary prevention**, for patients who have:

∴ a history of previous (more than 4 weeks) myocardial infarction and:

either

- left ventricular dysfunction with an LVEF of less than 35% (no worse than class III of the NYHA functional classification of heart failure), **and**
- non-sustained VT on Holter, **and**
- inducible VT on a EP study

or

- left ventricular dysfunction with an LVEF of less than 30% (no worse than class III of the NYHA functional classification of heart failure) **and**
- QRS duration of equal to or more than 120 milliseconds

∴ have a familiar cardiac condition with a high risk of sudden death, such as long QT syndrome, hypertrophic cardiomyopathy, Brugada syndrome or Arrhythmogenic Right Ventricular Dysplasia, or have undergone surgical repair of congenital heart disease.

As **secondary prevention**, in patients that:

- have survived a cardiac arrest caused by either ventricular tachycardia or ventricular fibrillation;
- have spontaneous sustained VT causing syncope or significant haemodynamic compromise;
- have sustained VT without syncope or cardiac arrest, and also have an associated reduction in LVEF of 35% or less but their symptoms are no worse than class III of the New York Heart Association (NYHA) functional classification of heart failure.

For the specific group of patients with CHF, and that exhibit criteria for CRT, i.e. LVEF \leq 35% and QRS prolongation \geq 120 ms, is recommended devices for cardiac resynchronization with defibrillation function (CRT-D) to reduce mortality and morbidity in patients with class III/IV of NYHA that are symptomatic, despite optimal medical therapy received, and with an expected survival \geq 1 year (DICKSTEIN *et al.*, 2010).

The cardiac conditions with a high risk of sudden cardiac death mentioned before, such as LQTS, HCM, Brugada syndrome or ARVD are rare and, therefore, there are no large randomized studies that prove the actual effectiveness of these ICDs. However, the results of some small retrospective studies have lead the majority of the experts to believe that this measure is actually effective to reduce the mortality in individuals with these conditions (recommendation of class IIa; level of evidence C) (EPSTEIN *et al.*, 2008).

On the other hand, patients with VT or VF due to reversible causes should not receive an ICD. This includes patients with VT or VF within the first 48 hours of an acute MI due to electrolyte abnormalities or due to the effects of drug use or intoxication. Patients with incessant VT or VF are also not candidates for an ICD until their arrhythmia is brought under control with antiarrhythmic or ablation therapies.

Severe psychiatric conditions are also relative contraindications for an ICD, especially if follow-up will be difficult or if ICD discharges would exacerbate the psychiatric condition.

Patients with severe symptomatic heart failure (NYHA class IV) or with frequent hospitalizations are more likely to die from cardiac pump failure than VT or VF and should not have an ICD implanted unless their clinical status improves. Similarly, patients whose life expectancy is less than 1 year due to cardiac or non-cardiac disease are not likely to survive to benefit from an ICD.

3.3. CARDIAC RESYNCHRONIZATION THERAPY

The first papers regarding the short-term hemodynamic effects of LV pacing versus simultaneous stimulation of the LV and RV were published in the decade of the 70s. The application of techniques known as CRT began in 1994 when Cazeau *et al.* described the first cases of atrioventricular pacemakers implanted in patients with CHF and no indication for cardiac pacing (CAZEAU *et al.*, 1994).

Cardiac dyssynchrony is complex and multifaceted. Prolongation of the AV interval delays systolic contraction, which might then encroach on early diastolic filling. Atrial pressure falls as the atria relax. If ventricular contraction is delayed, then LV diastolic pressures will exceed atrial pressure causing diastolic mitral regurgitation. The loss of ventricular pre-load then leads to a reduction in LV contractility, due to loss of the Starling mechanism. Both inter and intra-ventricular conduction delays lead to asynchronous contraction of LV wall regions (ventricular dyssynchrony), impairing cardiac efficiency and reducing stroke volume and systolic blood pressure. Poorly coordinated papillary muscle function may cause or aggravate functional systolic mitral regurgitation. Impaired performance promotes adverse LV remodelling.

Cardiac resynchronization therapy helps to restore AV, inter and intra-ventricular synchrony, improving LV function, reducing functional mitral regurgitation and inducing LV reverse remodelling, as evidenced by increases in LV filling time and LVEF, and decreases in LV end-diastolic and end-systolic volumes, mitral regurgitation and septal dyskinesia. The dominant mechanism of benefit is likely to vary from one patient to the next and within an individual patient over time. It is possible that no single measure will accurately predict the response to CRT, since the mechanism of benefit is so heterogeneous.

The CRT also carries an antiarrhythmic effect and its benefits may occur through multiple mechanisms. The first pathophysiological mechanism is related to the myocardial reverse remodelling observed in CRT. The myocardial fibre shortening can lead to a reduction of triggered activity or to possible modifications of re-entrant circuits. The hemodynamic improvement and consequent decrease in sympathetic tone is another mechanism contributing for the antiarrhythmic effect. Increased sympathetic tone is associated with a higher substrate for arrhythmias through multiple mechanisms (triggered activity, shortening of refractory periods, etc.). Finally, the stimulation of both ventricles in simultaneous can be associated with electrophysiological effects which lead to a lower

percentage of arrhythmias. The preventive effect of electrophysiological inducibility is probably related to a lower dispersion of refractoriness, once during simultaneously biventricular stimulation, depolarization and repolarization phases occur within a short interval of time, reducing the reentry gap of the stimulus through zones of slow conduction (MONT, 2005).

Currently, the main goal of the CHF treatment, in addition to relieving symptoms, preventing major morbidity and reducing mortality, attempts to prevent significantly the progression of the disease, especially the transition from asymptomatic LV dysfunction to significant CHF. Although CRT is mainly indicated to restore the ventricular synchrony, not every patient with CHF exhibits ventricular dyssynchrony, and therefore, it is important an accurate selection of patients undergoing CRT (KENNY, 2007).

PATIENTS IN SINUS RHYTHM

There is conclusive evidence of both short and long-term benefits of CRT in patients with NYHA class III from a series of randomized and controlled trials. MIRACLE (ABRAHAM *et al.*, 2002), COMPANION (BRISTOW *et al.*, 2004) and CARE-HF (CLELAND *et al.*, 2005) demonstrated the benefits of CRT in the quality of life, in the New York Heart Association functional class, in the exercise capacity and, on the other hand, in the reduction of hospital admissions secondary to CHF.

Indication of Class I (BRIGNOLE *et al.*, 2013):

- 1) CRT-P/CRT-D is recommended in chronic HF patients, on sinus rhythm with LBBB with QRS duration > 150 ms and LVEF ≤ 35%, who remain in NYHA functional class II, III and ambulatory IV despite having received optimal medical therapy (Level of evidence A).

Recommendations	Class ^a	Level ^b
1) LBBB with QRS duration >150 ms. CRT is recommended in chronic HF patients and LVEF ≤35% who remain in NYHA functional class II, III and ambulatory IV despite adequate medical treatment. ^d	I	A
2) LBBB with QRS duration 120–150 ms. CRT is recommended in chronic HF patients and LVEF ≤35% who remain in NYHA functional class II, III and ambulatory IV despite adequate medical treatment. ^d	I	B
3) Non-LBBB with QRS duration >150 ms. CRT should be considered in chronic HF patients and LVEF ≤35% who remain in NYHA functional class II, III and ambulatory IV despite adequate medical treatment. ^d	IIa	B
4) Non-LBBB with QRS duration 120–150 ms. CRT may be considered in chronic HF patients and LVEF ≤35% who remain in NYHA functional class II, III and ambulatory IV despite adequate medical treatment. ^d	IIb	B
5) CRT in patients with chronic HF with QRS duration <120 ms is not recommended.	III	B

Table 3. Indications for cardiac resynchronization therapy in patients in sinus rhythm.

PATIENTS IN ATRIAL FIBRILLATION

AF is the most common arrhythmia in patients with HF. The EuroHeart Failure survey reported that up to 45% of patients with HF also presented with intermittent or permanent AF. The overall prevalence of new-onset AF in patients hospitalized for congestive heart failure was 13%, ranging from 8% to 36% in different European regions. In chronic HF, the prevalence of AF is linked directly to disease severity, ranging from 10% to 20% in mild to moderate CHF up to 50% in patients with advanced disease. Incident AF is associated with a worse prognosis but it is unclear whether patients with chronic AF have a worse prognosis than those in sinus rhythm, after correcting for age and co-morbidity. AF may simply be a marker of more severe disease.

There are two ways of considering CRT for AF patients: (a) AF patients with moderate to severe HF and a haemodynamic indication for CRT and (b) patients with a fast ventricular rate with HF or LV dysfunction justifying a strong rate control strategy with an AV junction ablation. The table 4 shows the recommendations develop by the European Society of Cardiology (ESC) in association with the European Heart Rhythm Association (EHRA) for cardiac resynchronization therapy in this group of patients (BRIGNOLE *et al.*, 2013).

Recommendations	Class ^a	Level ^b
1) Patients with HF, wide QRS and reduced LVEF: IA) CRT should be considered in chronic HF patients, intrinsic QRS ≥120 ms and LVEF ≤35% who remain in NYHA functional class III and ambulatory IV despite adequate medical treatment ^d , provided that a BiV pacing as close to 100% as possible can be achieved.	IIa	B
IB) AV junction ablation should be added in case of incomplete BiV pacing.	IIa	B
2) Patients with uncontrolled heart rate who are candidates for AV junction ablation. CRT should be considered in patients with reduced LVEF who are candidates for AV junction ablation for rate control.	IIa	B

Table 4. Indications for cardiac resynchronization therapy in patients with permanent atrial fibrillation.

PATIENTS WITH HEART FAILURE AND CONVENTIONAL PACEMAKER INDICATIONS

Previous studies have clearly shown that RV apical pacing might have deleterious effects on cardiac structure and function. Moreover, different clinical trials have shown that there was a positive correlation between the percentage of RV pacing and the occurrence of adverse events. Therefore, additional benefit of biventricular pacing should be considered in patients requiring permanent or frequent RV pacing for bradycardia, who have symptomatic HF and low LVEF. In fact, results from small randomized trials are encouraging, demonstrating clinical subjective improvement, less hospitalization and

improved cardiac function on the CRT study phase compared with the RV study phase. The above results are consistent with those found in other observational studies in which patients underwent CRT upgrade because of worsening of severe symptoms of HF and deterioration of cardiac function several months or years after RV pacing for bradycardia.

Recommendations	Class ^a	Level ^b
1) Upgrade from conventional PM or ICD. CRT is indicated in HF patients with LVEF <35% and high percentage of ventricular pacing who remain in NYHA class III and ambulatory IV despite adequate medical treatment. ^d	I	B
2) De novo cardiac resynchronization therapy. CRT should be considered in HF patients, reduced EF and expected high percentage of ventricular pacing in order to decrease the risk of worsening HF.	IIa	B

Table 5. Indications for upgraded or *de novo* cardiac resynchronization therapy in patients with conventional pacemaker indications and heart failure.

Finally, five studies compared the clinical outcomes of patients who received an upgrade to CRT with those who received a *de novo* CRT implant for conventional indications. During the subsequent follow-up of 3 to 38 months, upgraded patients showed similar improvement to the *de novo* patients. In particular, the European CRT Survey showed that there were no significant differences in clinical outcomes, mortality or complication rates between upgrades and *de novo* procedures. Furthermore, it is important to highlight that upgrade to CRT is associated with a high complication rate, which was 18.7% in a recent large prospective trial. The decision to upgrade should therefore be made after careful assessment of the risk–benefit ratio.

Despite the lack of large randomized trials, there is sufficient evidence and general consensus that, in patients paced for conventional bradycardia who, during follow-up, develop severe symptoms of HF and have depressed EF, an upgrade to CRT pacing is likely to reduce hospitalization and improve their symptoms and cardiac performance (BRIGNOLE *et al.*, 2013).

3.4. RADIOFREQUENCY ABLATION

Catheter ablation, especially with radiofrequency energy (RF), was the more significant progress and with greater impact in cardiology in the recent years. Radiofrequency ablation has become the standard method for the management of many types of cardiac arrhythmias. Its safety and efficacy have been well described and the final outcome of RF-

based ablation is frequently so satisfying that many patients would prefer it over medical therapy. Radiofrequency ablation takes advantage of physical properties of resistive heating. Electrical voltage produced by the RF generator is impressed upon the tissue and causes electrical force emanating from the tip of an intracardiac catheter electrode positioned against the cardiac tissue, which is transformed into heat by resistive mechanism. This local heating is then dispersed to surrounding tissue by conductive mechanism. As such, deeper tissue is heated to a lesser degree than the endocardial surface. This heating of heart muscle cause irreversible damage and thereby prevent heart racing.

Since its introduction into the clinic in 1982 with the ablation of anomalous atrioventricular pathways, this was later followed and demonstrated by the effectiveness in the curative treatment of conditions such as ablation of accessory pathways associated with pre-excitation syndromes and in supraventricular tachyarrhythmias, particularly nodal reentrant tachycardias. Subsequently, and in the current decade, the ablation therapy has been used in the treatment of atrial tachycardias, atrial Flutters, Atrial Fibrillation and ventricular tachycardias (O'ROURKE *et al.*, 2002).

RF ABLATION FOR ATRIOVENTRICULAR NODAL REENTRANT TACHYCARDIA

The AV node includes "fast" pathways with atrial connections located anteriorly and "slow" pathways with atrial connections located posteriorly. In the most common type of AVNRT, the slow pathway is used for anterograde conduction and the fast pathway is used for retrograde conduction. Both pathways are needed to maintain AVNRT. The atrial connection of either the fast or slow pathway can be ablated, thereby eliminating AVNRT. Slow pathway ablation is preferred because of a lower incidence of producing AV block, a greater likelihood of maintaining a normal PR interval during sinus rhythm, and its efficacy in the atypical forms of AVNRT.

Recommendation of Class I (ZIPES *et al.*, 1995):

- 1) Patients with symptomatic sustained AVNRT that is drug resistant or the patient is drug intolerant or does not desire long-term drug therapy.

RF ABLATION OF ATRIAL TACHYCARDIA, FLUTTER AND FIBRILLATION

The use of ablation for symptomatic AF has increased over the past 10 years in the UK. In 2010, approximately 5000 ablation procedures for AF were performed. There is a good understanding that treating AF with ablation early within its clinical course gives better results than after it has been present for many years. In addition, there is evidence that in individuals who have advanced heart disease, ablation results are less successful.

AF has historically been classified into 3 groups: paroxysmal - where AF starts and stops of its own accord; persistent where AF requires medical intervention, in the form of electrical cardioversion, to restore normal sinus rhythm; and permanent – where AF is accepted in the long-term.

The initial studies of AF ablation were performed mainly on younger patients with paroxysmal AF and structurally normal hearts. In general this represents a group of patients early in the clinical course of their AF illness. A cost-effectiveness analysis of these studies has shown that ablation is cost-effective in comparison to medical therapy in this group of patients.

Ablation is now also increasingly used in patients with persistent AF. Some of these patients have this pattern of AF early within their clinical course and have been shown in observational studies to have similarly good results to patients with paroxysmal AF. It is important for the clinician when selecting patients with persistent AF for ablation to be mindful of the clinical aspects that predict the best chances of a successful result. In general, however, patients with persistent AF more often require repeat procedures to achieve a successful result and longer-term follow-up data is not yet available (COWAN *et al.*, 2014). There are increasing numbers of publications related to ablation of atrial tachycardias, including tachycardia in the region of the sinus node and ablation of inappropriate sinus tachycardia. Radiofrequency ablation has also been effective in eliminating counterclockwise atrial flutter.

Recommendations of Class I (ZIPES *et al.*, 1995):

- 1) Patients with atrial tachycardia that is drug resistant or the patient is drug intolerant or does not desire long-term drug therapy;
- 2) Patients with atrial flutter that is drug resistant or the patient is drug intolerant or does not desire long-term drug therapy.

Recommendations of Class II (ZIPES *et al.*, 1995):

- 1) Atrial flutter/atrial tachycardia associated with paroxysmal AF when the tachycardia is drug resistant or the patient is drug intolerant or does not desire long-term drug therapy;
- 2) Patients with AF and evidence of a localized site(s) of origin when the tachycardia is drug resistant or the patient is drug intolerant or does not desire long-term drug therapy.

RF ABLATION OF ACCESSORY PATHWAYS

The safety, efficacy and cost-effectiveness of radiofrequency ablation of an accessory AV pathway has made ablation the treatment of choice in most patients who have AV reentrant tachycardia or atrial fibrillation (or other atrial tachyarrhythmias) associated with a rapid ventricular response via the accessory pathway. This procedure also carries some complications as possibility of valve damage, pericardial tamponade, AV block, and pulmonary or systemic emboli, although rare late deaths have been reported.

Recommendations of Class I (ZIPES *et al.*, 1995):

- 1) Patients with symptomatic AV reentrant tachycardia that is drug resistant or the patient is drug intolerant or does not desire long-term drug therapy;
- 2) Patients with atrial fibrillation (or other atrial tachyarrhythmia) and a rapid ventricular response via the accessory pathway when the tachycardia is drug resistant or the patient is drug intolerant or does not desire long-term drug therapy;

RF ABLATION OF VENTRICULAR TACHYCARDIA

Radiofrequency ablation of VT has been used with varying degrees of success in patients with ischemic disease, cardiomyopathy, bundle branch reentry, and various forms of idiopathic VT. Mapping and ablation techniques differ, depending on the type of VT. In patients without structural heart disease, only a single VT is usually present, and catheter

ablation is curative. In patients with extensive structural heart disease, especially those with prior MI, multiple VTs are often present. Catheter ablation of a single VT in such patients may be only palliative and may not eliminate the need for other antiarrhythmic therapy.

Recommendations of Class I (ZIPES *et al.*, 1995):

- 1) Patients with symptomatic sustained monomorphic VT when the tachycardia is drug resistant or the patient is drug intolerant or does not desire long-term drug therapy;
- 2) Patients with bundle branch reentrant ventricular tachycardia;
- 3) Patients with sustained monomorphic VT and an ICD who are receiving multiple shocks not manageable by reprogramming or concomitant drug therapy.

Although RF ablation has been widely used on a daily practice, this technique has some limitations. The success of reaching deeper tissue is not only dependent on those basic physical properties of RF energy. Other variables, such as electrode-to-tissue contact and tissue geometry and pathology also play a big role.

The dependence of effective RF ablation upon good contact also limits the utility of this method for the creation of linear ablation. With RF technology, linear ablation using stationary catheter would require delivery of RF energy over multiple electrodes simultaneously. Thus, to create linear lesion, the point-and-drag method is still frequently used. Several new methods are being employed to overcome uneven RF delivery with the multipolar catheter technique. Another limitation to the use of conventional RF technology for the creation of linear lesion lies in its limited depth. While a 3-5 mm ablation depth may be sufficient in some instances, it would be unlikely to produce uniform transmural lesion in some areas of the heart with widely variable thickness, such as the trabeculated portion of the right atrium. An appreciation of the biophysics and pathophysiology of RF energy heating of myocardium during catheter ablation will help the operator to make the proper adjustment to optimize ablation safety and success. A tissue temperature of 50°C needs to be reached to achieve irreversible tissue injury. This likely occurs as a result of sarcolemma membrane injury and intracellular calcium overload. The 50°C isotherm determines the boundary of the lesion. Greater lesion size is achieved with high power delivery and higher

intramural tissue temperatures. Monitoring surface temperature is useful to help prevent boiling of blood with coagulum formation and a sudden increase in electrical impedance.

Although this limitation, recent progress with cooling and irrigation of the electrode has improved RF ablation ability in producing deeper lesions (LIEM & DOWNAR, 2001).

In summary, RF catheter ablation remains the dominant modality for ablative therapy of arrhythmias. This technology is simple, has a high success rate, and has a low complication rate. Alternative sources of energy are being tested. Cryoablation and ablation using laser and microwave energy have being tested and promoted as being easier, safer, or more efficacious but clinical data are still limited. Despite the fact, they are unlikely to supplant RF energy as the first choice for ablation of most arrhythmias (HUANG & WOOD, 2010).

Chapter II

INTERNSHIP ACTIVITY

1. CONCEPTUALIZATION

The internship was performed under the second year of the Master's Degree in Cardiac Physiology – specialization in Arrhythmology, in order to understand and participate in the daily dynamics of a Cardiac Department, addressing both the diagnosis and the treatment of arrhythmias.

The main goal of the internship was to apply scientific and technical knowledge acquired during the course in the daily practice and in the clinical context, whether in the field of non-invasive electrocardiography as well as in invasive Pacing and Electrophysiology areas.

Thus, the practice was composed of several modules having the highest workload focused on the Pacing and Electrophysiology areas.

The completion of this Master's degree allowed me to (re)acquire and develop varied expertise in Arrhythmology, from basic concepts and principles of electrocardiography to electrophysiological interpretation of complex arrhythmias, as well as its implications in the daily clinical practice.

2. METHODOLOGY

2.1. INTERNSHIP ORGANIZATION

The internship was comprised of 400 hours allocated as follows: 130 hours of Pacing; 130 hours of Electrophysiology; 110 hours of non-invasive Electrocardiography and 30 hours of Cardiac Imaging.

These modules were divided between two hospitals of the National Health Service Foundation Trust in the United Kingdom. The non-invasive electrocardiography module (Holter and Exercise Tolerance Test) was performed at the Luton and Dunstable Hospital, integrated in my professional activity, and supervised by Roderick Macintosh, Principal Cardiac Physiologist. On the other hand, the invasive modules of Pacing and Electrophysiology were performed at the Harefield Hospital, part of the Royal Brompton & Harefield Hospital NHS Foundation Trust - one of the largest and most experienced centres in the world for heart and lung transplants, with an worldwide reputation for heart and lung research, and supervised by Robert Edwards, Senior Chief Cardiac Physiologist.

Among the various existing labs for the diagnosis and/or treatment of heart disease at Harefield Hospital, there is lab dedicated to electrophysiology studies exclusively. The lab is fully equipped for the performance of electrophysiology studies and radiofrequency ablation in cases where this is indicated. In the centre of the room there is a tilting table; at the bedside of the patient a C-arm X-ray equipment; in the opposite side to the operator all the additional equipment that allows monitoring and tracking of the whole procedure, as the fluoroscopy monitors, the polygraph monitors, the ECG monitor, a defibrillator and the RF delivery equipment. The two anatomical mapping systems, Carto 3 and NavX, are also located in this area. Both disinfection area and the storage room for the material required during the procedures, and also a cleaning zone and deposit of sterile materials are "inside" the room itself, allowing easy, fast and constant access by the multiple members of the team.

The Cardiac department also has an area devoted to non-invasive cardiology with plenty of rooms intended for clinical use, two of which are exclusively used for the Pacing clinic. The time allocated for the interrogation of each patient's device is about 20 to 30 minutes.

Regarding the clinical practice at Harefield Hospital, it was necessary to sort some bureaucratic issues which encompass a formal request and consequent authorization: firstly to my superiors Jenny Cadman (Deputy for Cardiology Department) and Roderick Macintosh (Senior Chief Cardiac Physiologist); posteriorly, to Julie Rochelle and Robert Edwards, Principal Cardiac Physiologist and Senior Chief Cardiac Physiologist for EP Laboratory respectively. To complete the authorization process, the request was submitted to the Board of Directors at the Royal Brompton & Harefield Hospital.

As it would not be possible my absence from my professional activity for a consecutive period of time in order to complete the internship, a special request was drawn up in order to gain permission to perform my weekly work time in only 4 days (instead of the ordinary 5 days), in order to obtain one day available per week to fulfil the total number of hours required in the academic calendar.

2.2. SCHEDULE

The second year of the Master was compound by four simultaneous activities: a revision of the literature; the clinical practice in non-invasive electrocardiography; the clinical practice in Pacing and Electrophysiology; the elaboration of a final internship report.

During the internship, it was necessary to make three requests for postponement of six months in order to complete the hours concerted in the academic calendar and its final report.

The organization of the second year of the Master's degree is outlined in following table:

TASKS	2012				2013								2014											
	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
LITERATURE REVIEW																								
NON INVASIVE ECG MODULE																								
PACING & EP MODULES																								
FINAL REPORT																								

Table 6. Schedule of the internship.

2.3. DATA COLLECTION METHODOLOGY

The revision of the literature was performed via scientific research in online platforms such as Cardiosource, PubMed and NHS Athens, where papers from various newspapers and journals in the areas of interest were identified, as well as via the consultation of some textbooks.

The clinical information regarding the procedures observed/performed was also obtained by consulting the patient’s medical records placed in the hospital’s database.

It is important to mention that all the ethical provisions regarding patient confidentiality and anonymisation were met throughout the internship.

2.4. STATISTICS

The data collected during the clinical practice was entered and organized in a database, being statistically analyzed with the SPSS 17.0 statistical software.

3. RESULTS

The results presented in this chapter focus essentially on the two main areas that constituted this internship: the pacing clinic and electrophysiology studies, mostly realized at Harefield Hospital NHS Foundation Trust.

Let us begin by describing the Electrophysiology module, a period where we watched and collaborated on several studies, in which multiple data relating to the respective procedures were collected, allowing the preparation of this report.

We performed 41 EP studies, almost equally distributed between the genders, with a slight predominance of the female gender.

		Age (years)					
		N	N (%)	Mean	Standard Deviation	Minimum	Maximum
Gender	Female	22	53,7	48,545	19,942	18,00	86,00
	Male	19	46,3	62,474	12,144	40,00	80,00
	Total	41	100	55,000	18,017	18,00	86,00

Table 7. Demographic characterization according to age and gender.

By the analysis of the table 7 we also verified that the mean age of subjects was 55 +/- 18.017 years and that the males underwent the procedure at an older age.

Type of procedure

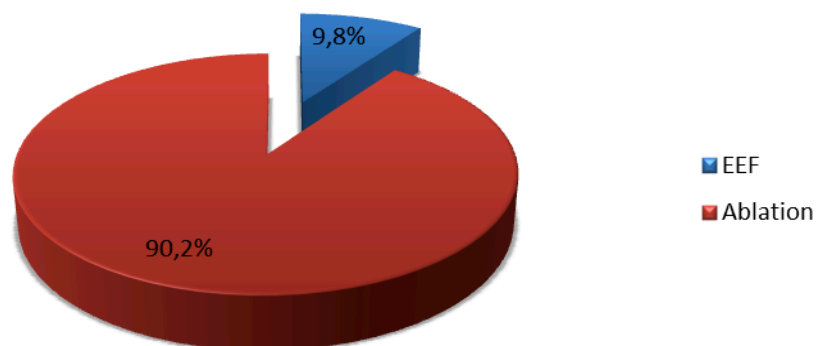


Chart 1. Distribution by type of procedure.

Regarding the type of procedure, we can verify through the chart 1 outlined above that the ablation therapy was attempted in most of the studies (90,2%); only in four cases this therapeutic approach was not performed. These studies where ablation was not applied were carried out in subjects whose symptoms were palpitations and with the following indications of documented VT, Atrial tachycardia and palpitations (2 subjects). In all of them, it was not possible to induce tachycardia and thus given as completed study with no therapeutic attempt. Note that all subjects had sinus rhythm on the baseline ECG at the entry to the laboratory.

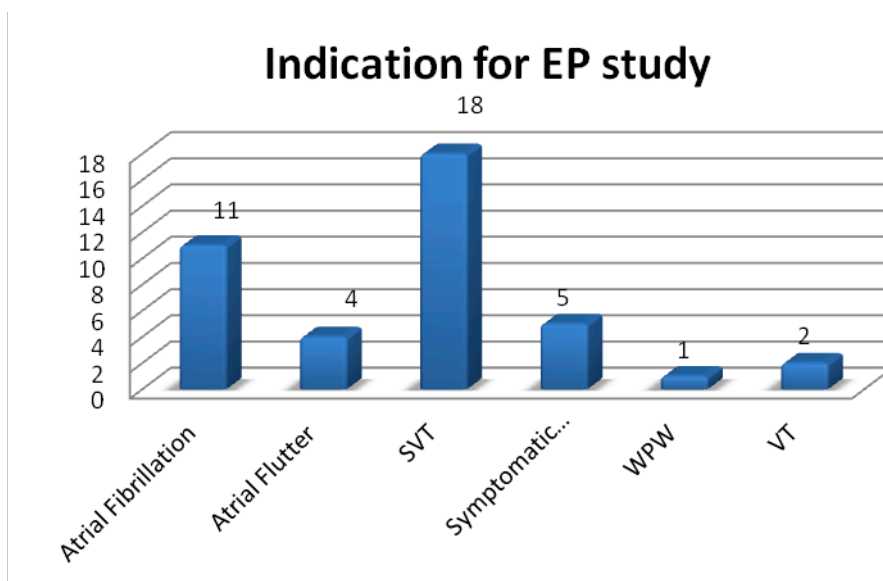


Chart 2. Indication for EP study.

Considering the indication for EP study, we can verify that the major indication found study was SVT, followed by Atrial Fibrillation. Among the patients referred due to SVT, 13 were diagnosed with AVNRT, 3 with focal atrial tachycardia, 1 with AVRT (with concealed accessory pathway) and there was a patient where it was not possible to induce any arrhythmia. Regarding the patients referred with Atrial Flutter, the EP study showed that 3 patients had typical counterclockwise flutter while one patient had atypical clockwise CTI flutter.

By the analysis of the chart 3, we conclude that the symptom mostly present in individuals who underwent EP study and/or ablation was palpitations, in 78% of cases (n = 32), followed by dyspnoea (n = 7) and dizzy spells (n = 2). There were no cases of asymptomatic subjects prior to the procedure.

Symptoms

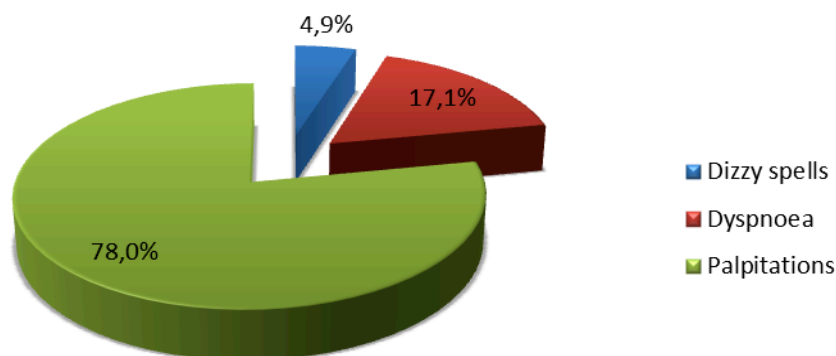


Chart 3. Symptomatology prior to the procedure.

Having said that, we looked for a possible association between symptomatology and the presence (or absence) of cardiac pathology. Thus, through the analysis of the table 8, we verified that all subjects who presented with symptoms of dyspnoea or dizzy spells have a history of cardiac disease, such as Heart Failure, Coronary Artery Disease, valvular heart disease or Cardiomyopathy. In contrast, in the group who had symptoms of palpitations the majority (71.9%) have a background without any known cardiac disease.

		Comorbidity							Total
		Apparently normal heart	Cardiomyopathy	Congenital Structural Defect	Coronary Artery disease	Heart Failure	HTN	Valvular Heart disease	
Dizzy spells	N	0	0	0	0	0	2	0	2
	% in group	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%	0,0%	100,0%
	% total	0,0%	0,0%	0,0%	0,0%	0,0%	4,9%	0,0%	4,9%
Dyspnoea	N	0	3	0	0	3	0	1	7
	% in group	0,0%	42,9%	0,0%	0,0%	42,9%	0,0%	14,3%	100,0%
	% total	0,0%	7,3%	0,0%	0,0%	7,3%	0,0%	2,4%	17,0%
Palpitations	N	23	1	1	2	1	2	2	32
	% in group	71,9%	3,1%	3,1%	6,3%	3,1%	6,3%	6,3%	100,0%
	% total	56,1%	2,4%	2,4%	4,9%	2,4%	4,9%	4,9%	78,1%
Total	N	23	4	1	2	4	4	2	41
	% total	56,1%	9,8%	2,4%	4,9%	9,8%	9,8%	4,9%	100,0%

Table 8. Comorbidity characterization and its distribution according to symptomatology.

The most frequent arrhythmias found as a diagnostic of the EP study were the AVNRT (n = 13) and atrial fibrillation (n= 11), as we can visualize on the chart 4.

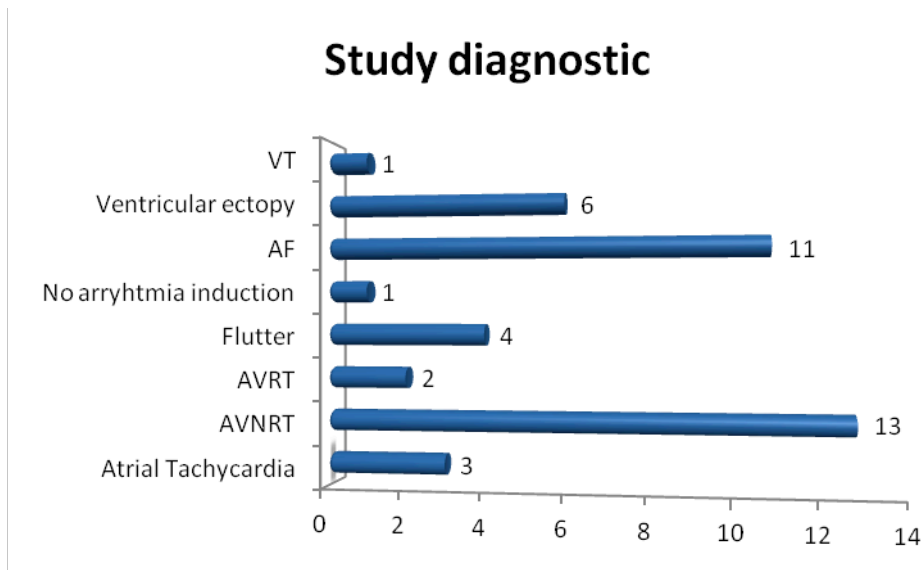


Chart 4. Diagnostic of the EP study.

Amongst the 11 subjects where the presence or induction of atrial fibrillation was confirmed during the EP study, 5 subjects had persistent AF, already present in the baseline ECG prior to the procedure, and 6 subjects had paroxysmal AF with sinus rhythm in the baseline ECG prior to the procedure.

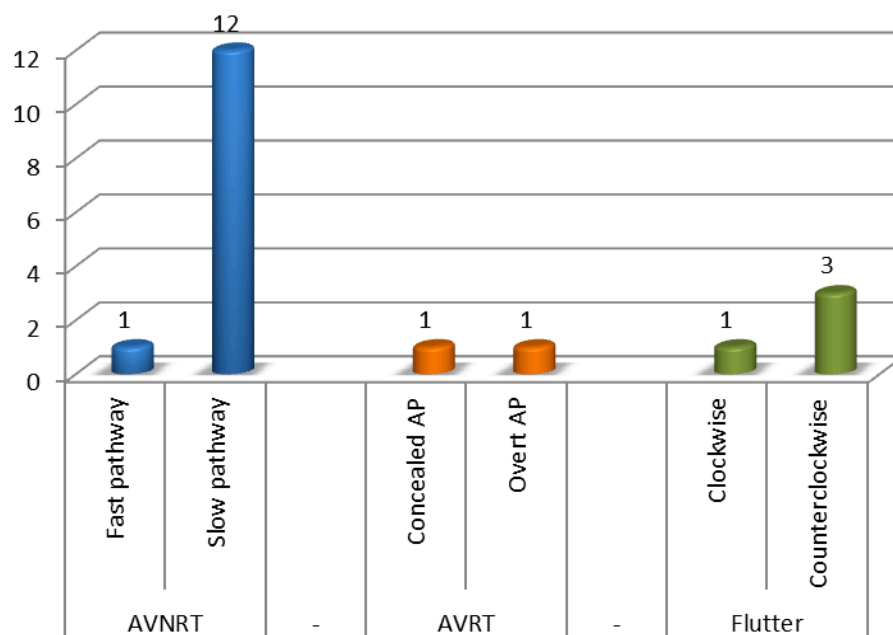


Chart 5. Prevalence and distribution of supraventricular arrhythmias according to the mechanism.

In the chart 5, we can verify the distribution of the different tachyarrhythmias characterized by a reentrant mechanism. 12 cases of typical slow-fast type of AVNRT and 1 case of atypical fast-slow type were observed. Furthermore, it was successfully performed ablation of a mid-septal accessory pathway in two cases: a 37 years female patient with pre-excitation pattern in the baseline ECG (overt accessory pathway); a 40 years male patient with history of palpitations, sinus rhythm on baseline ECG and possible episode of SVT (concealed accessory pathway). Regarding the atrial flutter, it was observed a successful ablation in 3 subjects with typical counterclockwise flutter and in 1 subject with atypical clockwise flutter.

We now present results from a more technical point of view. Regarding the use of new non-fluoroscopic mapping techniques that we address with some detail in the chapter I of this report, we can conclude straight away that these resources are used on a daily basis, being almost certain its utilization in cases of Atrial fibrillation, Atrial flutter and ventricular ectopy/tachycardia, whose aim is to find the focus of origin of the arrhythmia.

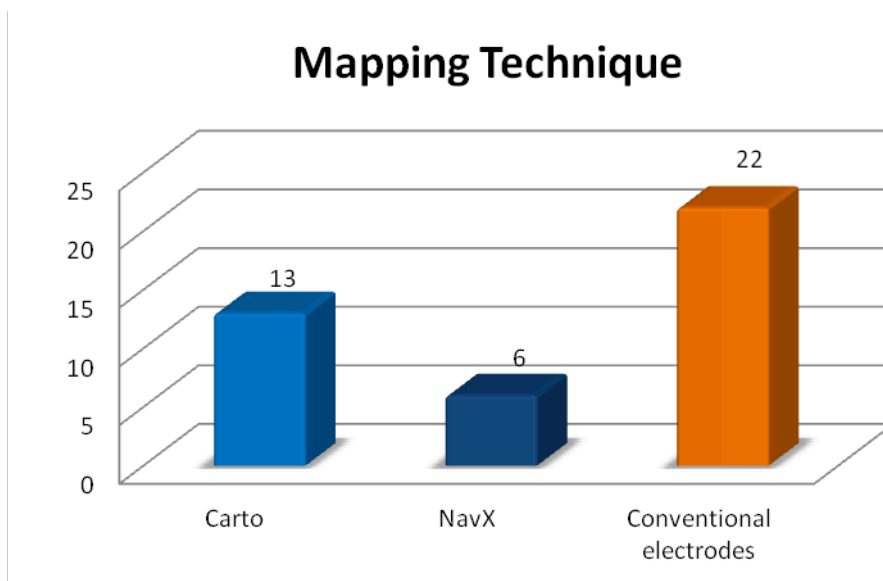


Chart 6. Characterization of the sample according to mapping technique used.

The conventional electrodes mapping technique was used in 22 cases (53,7%) and one of two electroanatomical mapping techniques in 19 cases (46,3%).

		Mapping Technique			
		Carto	NavX	Conventional electrodes	Total
Atrial Fibrillation	N	5	4	2	11
	% in group	45,5%	36,4%	18,2%	100,0%
AVNRT	N	0	0	13	13
	% in group	0,0%	0,0%	100,0%	100,0%
AVRT	N	0	0	2	2
	% in group	0,0%	0,0%	100,0%	100,0%
Flutter	N	3	1	0	4
	% in group	75,0%	25,0%	0,0%	100,0%
Atrial Tachycardia	N	0	1	2	3
	% in group	0,0%	33,3%	66,7%	100,0%
No arrhythmia induction	N	0	0	1	1
	% in group	0,0%	0,0%	100,0%	100,0%
VT/ectopics	N	5	0	2	7
	% in group	71,4%	0,0%	28,6%	100,0%
Total	N	13	6	22	41
	% total	31,7%	14,6%	53,7%	100,0%

Table 9. Characterization of the mapping technique used according to the study diagnostic.

As mentioned above and by the analysis of the table 9, we verify that 3D mapping technique (Carto or NavX) was used in most cases of atrial fibrillation and ventricular ectopy/tachycardia (81,8% and 71,4% of these, respectively) and in all cases of Flutter (n = 4). In contrast, the conventional electrodes system was used in all cases of reentrant tachyarrhythmias, AVNRT (n = 13) and AVRT (n = 2).

Successful ablation was considered in cases with confirmation of no induction of arrhythmia after ablation; on the other hand, partial success was considered in cases where it was not possible to confirm the total suppression of the arrhythmia circuit or ventricular ectopy.

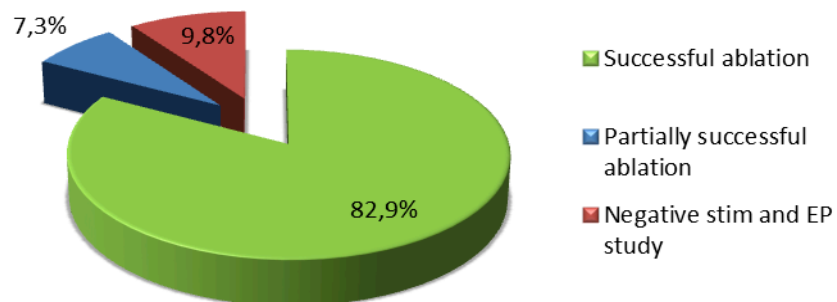


Chart 7. Outcome of the electrophysiology studies.

We can observe from the chart 7 that over 80% of the studies have been completed successfully, i.e. the outcome was the successful ablation of the arrhythmia. However, in 3 of the procedures where ablation therapy was applied, it was not possible to fully eliminate the arrhythmia. Two of these cases refer to patients with persistent atrial fibrillation:

- the first, technically successful pulmonary veins (PV), LA “roof”, Mitral valve isthmus (MVI), complex fractionated electrogram (CFE) and cavotricuspid isthmus (CTI) ablation, although not fully proven block at the end;
- the second, successful isolation of 3 of 4 PVs with residual connection to the lower right PV (bi-directional) and roof line with unproven block.

The third case refers to a patient with background of Cardiomyopathy, presenting with dyspnoea and frequent symptomatic ventricular ectopy, with origin in the right ventricular outflow tract. In this case, there was incomplete suppression of the ectopy.

The real incidence of complications in electrophysiology studies (especially catheter ablation) varies according to the experience of the professionals. Today, with enhanced access to new technology and expertise that provides additional safety to radiofrequency ablation, complications during and after the procedure has become minimized. Still, these happen and the most frequent is the pericardial effusion with possible cardiac tamponade.

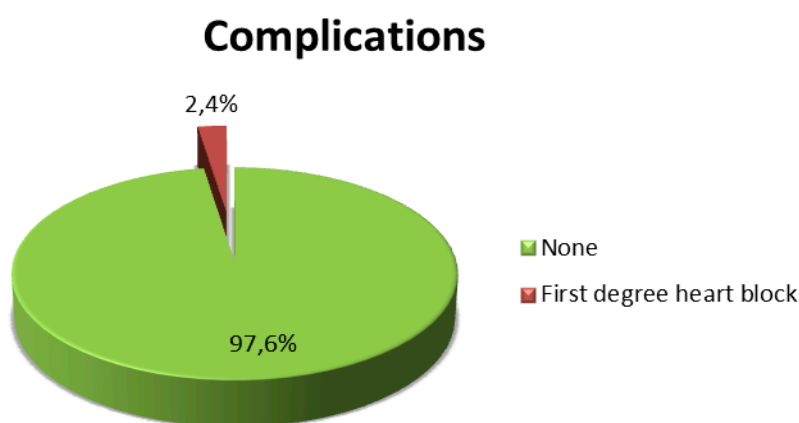


Chart 8. Complications during and after the EP study.

There was only a minor complication in the 41 studies observed: a first degree AV block in an individual with successful slow pathway ablation for AVNRT, where the conventional electrodes system was used as mapping technique. This is a minor complication still somewhat frequent in this type of procedure.

The performance of a TOE prior to the procedure is recommended for the treatment/ablation of atrial tachyarrhythmias, in order to exclude the presence of atrial thrombus. Its formation is favoured and potentiated by the substrate of the arrhythmia; and the embolic risk is also boosted by reversing these arrhythmias back to sinus rhythm (principal aim of the ablation in these cases).

The transseptal approach is performed when there is a need to access the left atrium. This happens in cases of pulmonary veins isolation for the treatment of atrial fibrillation, atrial tachycardias where the arrhythmia circuit extends to this cavity, and AVRT where the accessory pathway is only achievable through the left atrium.

		Approaches						
		TOE		GA		Transseptal puncture		Total
		Yes	No	Yes	No	Yes	No	
Atrial Fibrillation	N	9	2	9	2	9	2	11
	% in group	81,8%	18,2%	81,8%	18,2%	81,8%	18,2%	100,0%
AVNRT	N	0	13	0	13	0	13	13
	% in group	0	100%	0	100%	0	100%	100,0%
AVRT	N	0	2	1	1	1	1	2
	% in group	0	100%	50%	50%	50%	50%	100,0%
Flutter	N	3	1	4	0	0	4	4
	% in group	75%	25%	100%	0%	0%	100%	100,0%
Atrial Tachycardia	N	1	2	1	2	1	2	3
	% in group	33,3%	66,7%	33,3%	66,7%	33,3%	66,7%	100,0%
No arrhythmia induction	N	0	1	0	1	0	1	1
	% in group	0%	100%	0%	100%	0%	100%	100,0%
VT/ectopics	N	0	7	1	6	0	7	7
	% in group	0%	100%	14,3%	85,7%	0%	100%	100,0%
Total	N	13	6	16	25	11	30	41
	% total	31,7%	14,6%	39%	61%	26,8%	73,2%	100,0%

Table 10. Patient's preparation according to the indication for intervention.

There were 2 cases of AF where the transseptal approach and TOE were not performed once the outcome was AV node ablation with implantation of single chamber pacemaker.

Looking at the following chart 9, we can observe that the interventions for AF ablation took longer on average, followed by the interventions for AVRT, Atrial tachycardia and ventricular tachycardia/ectopy. In contrast, the interventions whose aim was to terminate the Flutter circuit took less time on average. AF, VT and AVRT are complex procedures and, therefore, also resort to three-dimensional mapping systems.

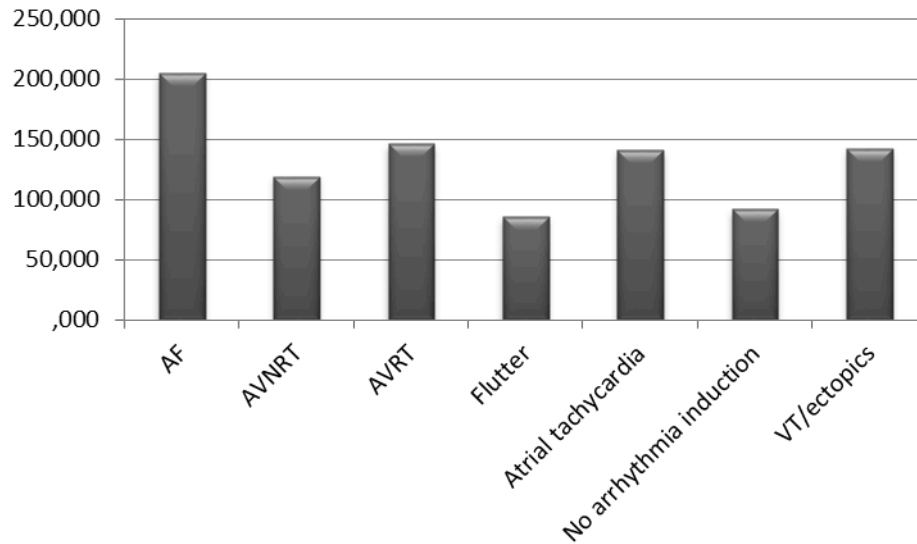


Chart 9. Procedure duration according to the underlying arrhythmia.

On the other hand, atrial flutter and AVNRT are procedures with anatomical substrates that favour well designed and located arrhythmias.

	Procedure duration (minutes)					
	N	N (%)	Mean	Standard Deviation	Minimum	Maximum
Atrial Fibrillation	9	23,1	204,667	90,269	100,00	360,00
AVNRT	13	33,3	118,846	27,009	85,00	169,00
AVRT	2	5,1	146,000	79,196	90,00	202,00
Flutter	4	10,2	85,500	44,613	46,00	136,00
Atrial tachycardia	3	7,7	140,667	77,822	55,00	207,00
No arrhythmia induction	1	2,6	92,000	.-	92,00	92,00
VT/ectopics	7	18,0	142,429	62,222	60,00	215,00
Total	39	100	132,873	63,522	46,00	360,00

Table 11. Relationship between the study diagnostic and the procedure duration.

We can verify on the table 11 that the procedures for AF ablation lasted on average about 3h30mins. On the opposite, the procedures for Atrial Flutter ablation had an approximate duration of 1h30mins, nearly less than half of the time. Just for curiosity, we also find that the longer procedure (AF) had the duration of 6 hours, while the shorter procedure (Atrial Flutter) had the duration of less than an hour.

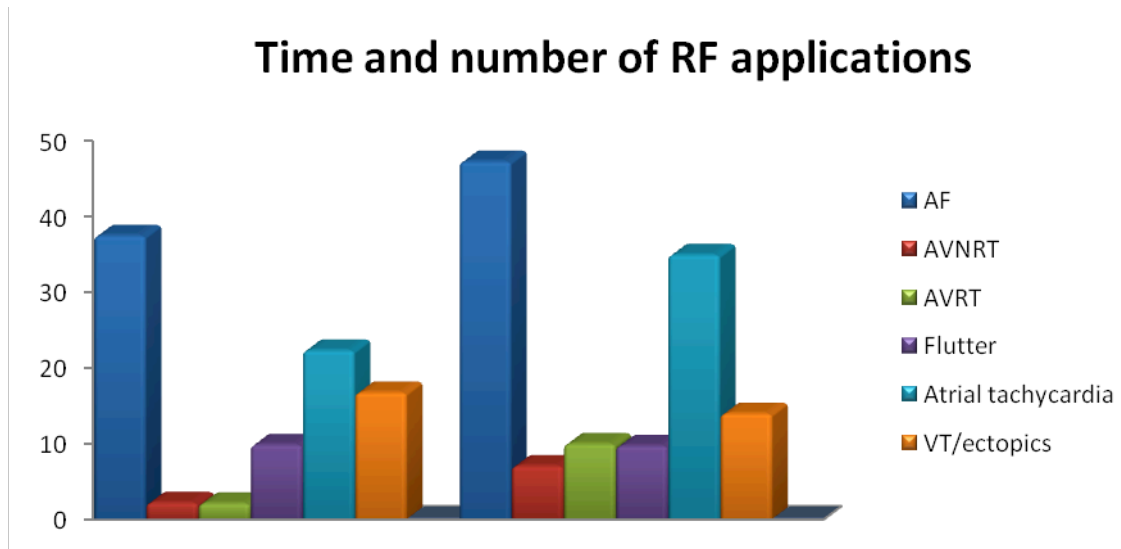


Chart 10. Distribution of RF total time and number of applications according to underlying arrhythmia.

In agreement with the average duration of procedures, we also find in the chart 10 that the time and number of radiofrequency energy used for ablation therapy is greater in cases of atrial fibrillation and posteriorly in atrial tachycardias. On the other hand, it is possible to observe that reentrant tachycardias are those that require less radiofrequency ablation, since the goal in these arrhythmic substrates is to destroy the viability of the accessory pathway, and once located, corresponds to a very limited area of intervention.

The clinical practice in Pacing focused essentially on follow-up of devices, with observation and interrogation of pacemaker, ICDs and CRTs. The time allocated for each patient is about 20 to 30 minutes. Each device follow-up always begins by monitoring the patient with a 3 lead ECG in order to have a trace during the entire clinic (on a proper monitor placed for the purpose). In addition, a rhythm strip is always acquired before and after the interrogation of the PM (for documentation purposes). The device is then interrogated with the corresponding programmer, in order to obtain all the information contained in the device, but essentially the pacing and sensing thresholds, catheters impedances, battery voltage, total times of stimulation by the device, episodes of arrhythmia(s) and therapy deliveries in the case of an ICD.

Any necessary changes or optimizations such as sensitivities, intervals, pacing or algorithms adjustments are then performed (always considering the clinical history and state of the patient) and a further appointment is scheduled for continued monitoring of

the device (in 1, 3, 9 months post-implantation and then yearly for pacemakers; every 3 months in case of ICD and CRT devices). If appropriate, the substitution of the generator is requested. Besides the interrogation, verification and optimization of the device, it is also a Cardiac Physiologist's responsibility to take notice of the clinical condition of the patient and, if needed, refer him for a Cardiology review or Warfarin clinic, for clinical follow-up and optimization of medical therapy.

In order to trace a drawing of the pacing clinic observed and performed in this internship, we examine some data such as: pacing clinic location, manufacturer, type of device, reason for implant, anomalies/dysfunctions identified, optimizations performed and prevalence of rate response on and pacing dependent patients.

We have performed a total of 283 devices follow-up in individuals of both genders, predominantly in male subjects (64,3%).

		Age (years)					
		N	N (%)	Mean	Standard Deviation	Minimum	Maximum
Gender	Male	182	64,3	72,110	13,382	25,00	97,00
	Female	101	35,7	76,495	14,378	21,00	97,00
	Total	283	100	73,675	13,881	21,00	97,00

Table 12. Demographic characterization of the pacing sample according to gender and age.

It is possible to verify by the analysis of table 12 that the mean age of the sample was 73 ± 13.881 years, the younger subject was a female patient with 21 years and the older subjects were both male and female patients with 97 years of age.

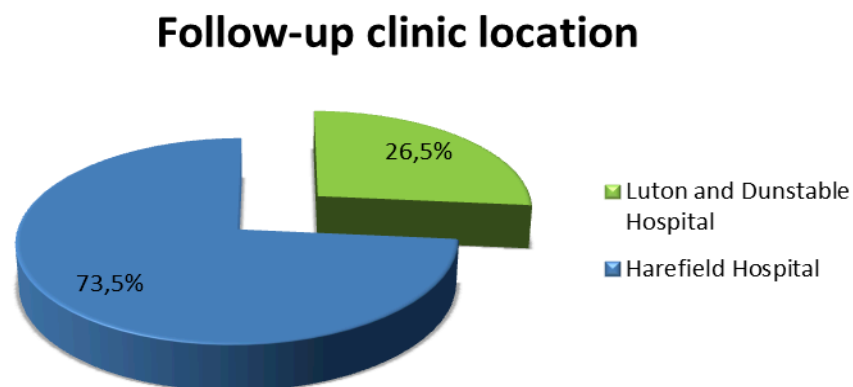


Chart 11. Distribution of devices follow-up according to location.

As stated earlier, the clinical practice in Pacing was divided between two sites, being the vast majority of the follow-ups performed at Harefield Hospital (n = 208) and a smaller number at the Luton and Dunstable Hospital (n = 75), once the first is a specialized hospital for Cardiology with two to three pacing clinics running daily, while the Luton and Dunstable Hospital is a district general hospital with a single pacing clinic running twice a week.

Let us observe now a graph (chart 12) illustrating the characterization of the observed pacing clinics by type of device.

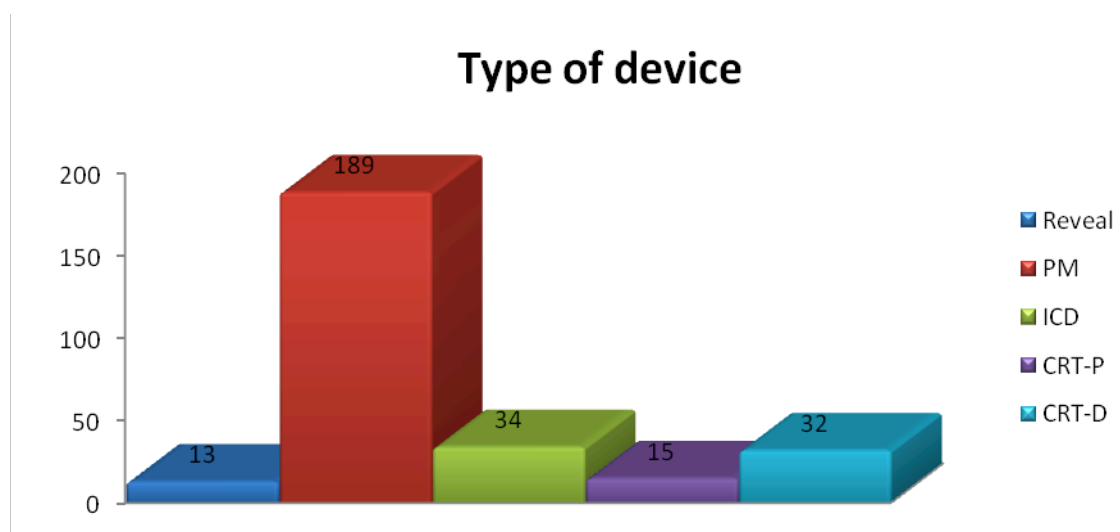


Chart 12. Characterization of pacing sample according to type of device.

We find that the majority of the follow-ups (66,8%) were performed in individuals with standard pacemakers, being the remaining third of follow-ups performed on other devices such as Reveal, ICD, CRT-P and CRT-D.

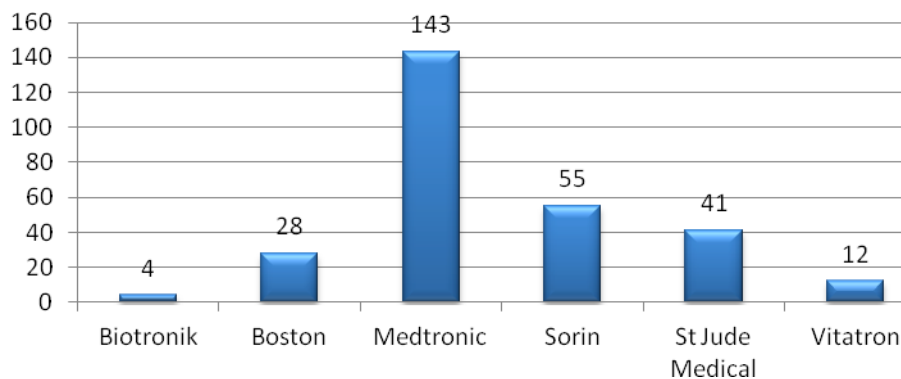


Chart 13. Distribution of devices followed-up according to manufacturer.

We also verify by looking at chart 13 that the vast majority of devices were manufactured by Medtronic (including the Reveal devices). On the other hand, there were very few patients being followed in clinic with a Vitatron (n = 12) or Biotronik (n = 4) pacemaker.

Once from the clinical point of view it does not add any supplementary information, we will no longer analyse and discuss the data related to Reveal devices, displaying only activity data regarding Pacemakers, ICD and CRT devices.

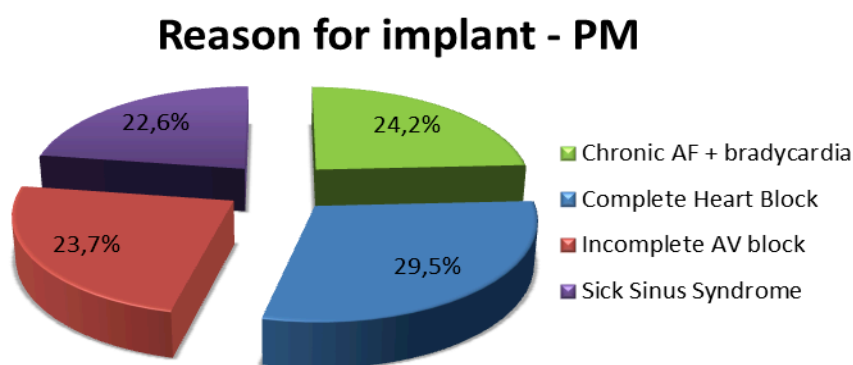


Chart 14. Reason for implant of pacemaker.

We can verify on the chart 14 that there is an equitable distribution between the four reasons for pacemaker implantation in our activity. On the other hand, when regarding indication for ICD implant, sustained VT + syncope (47,1%) was the main reason observed for the implantation of this type of devices (chart 15).

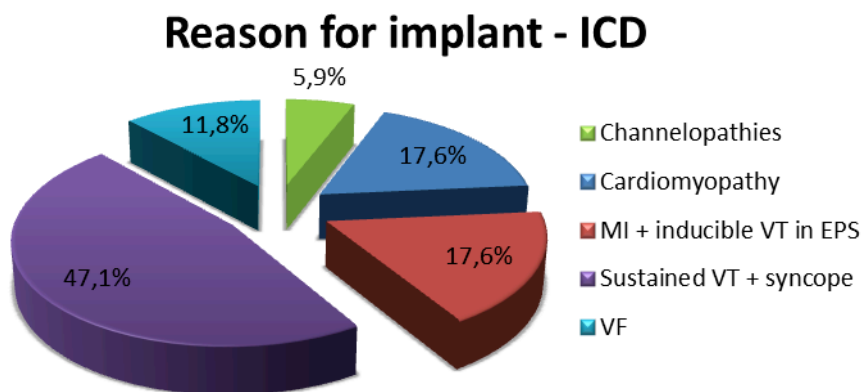


Chart 15. Indication for implant of ICD.

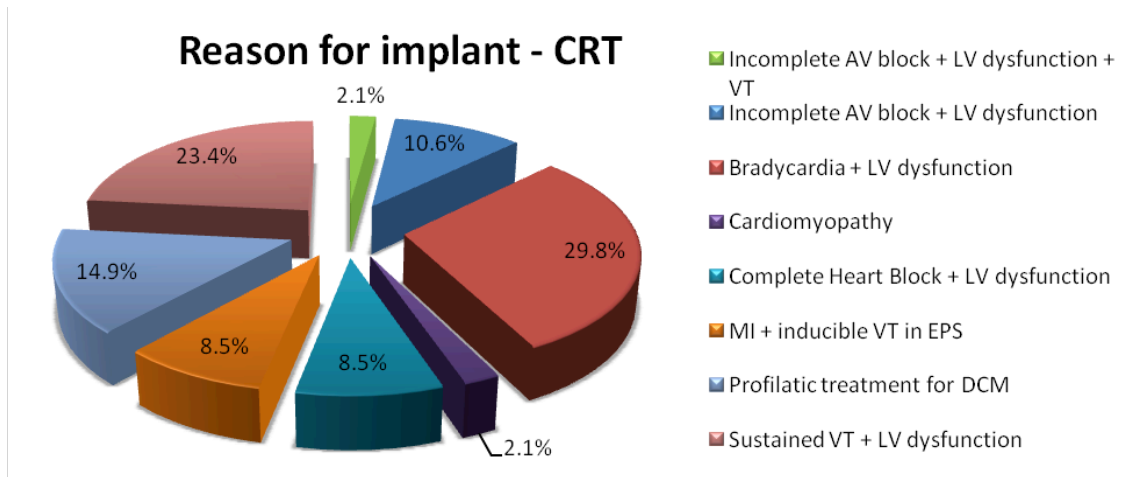


Chart 16. Reason for implant of CRT device.

Within the varied indications for Cardiac Resynchronization Therapy devices implantation, the presence of bradycardia with LV dysfunction (29,8%) and the occurrence of sustained VT associated with LV dysfunction (23,4%) were the two main reasons seen.

On a general descriptive way, we can verify on the chart 17 that the vast majority of devices were programmed on DDD, followed by DDD with Rate-response on. On the other hand, devices programmed with pacing mode VDD or VDIR were rarely seen.

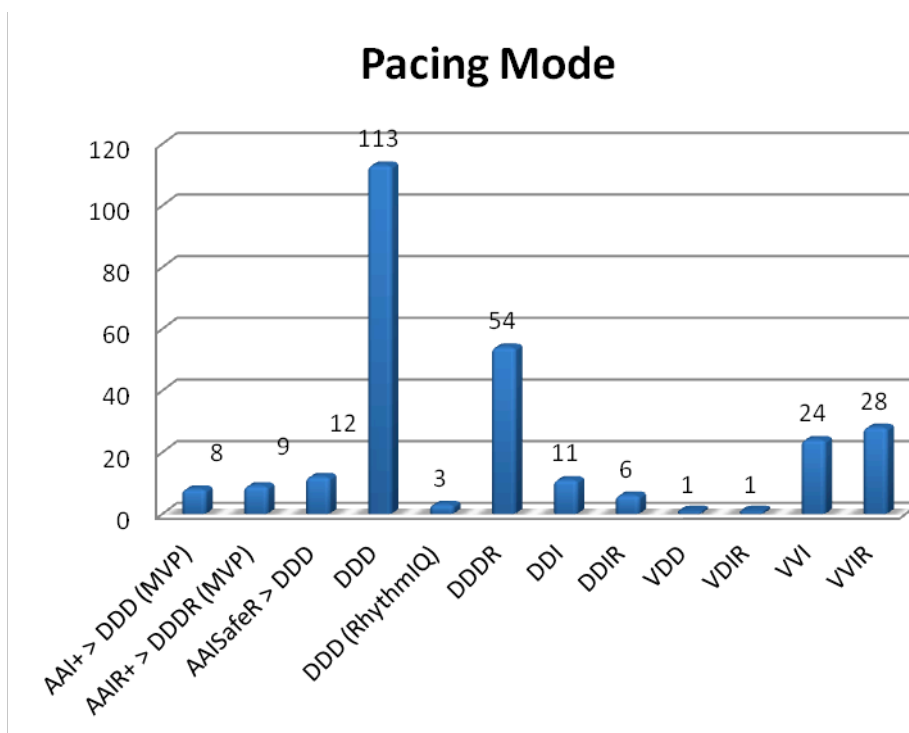


Chart 17. Characterization of pacing sample according to type of device.

We can observe through the table 13 that were observed dysfunctions and optimization in all types of devices. It is also possible to verify that only 10% of the subjects presented with dysfunction of the device; the majority of the dysfunctions founded were increased threshold (n = 7), ventricular fusion (n = 5), undersensing (n = 4), diaphragmatic stimulation (n = 4) and dislocated lead (n = 3).

		Device dysfunctions		Device optimizations	
		Yes	No	Yes	No
PM	N	18	172	51	139
	% no grupo	9,5%	90,5%	26,8%	73,2%
ICD	N	3	31	12	22
	% no grupo	8,8%	91,2%	35,3%	64,7%
CRT	N	6	40	16	30
	% no grupo	13,0%	87,0%	34,8%	65,2%
Total	N	27	243	79	191
	% total	10,0%	90,0%	29,3%	70,7%

Table 13. Prevalence of device dysfunctions and optimizations.

On the other hand, the device was optimized in 79 subjects, approximately a third of the cases (29,3%). The output was reprogrammed (either increased, reduced or changed in configuration) in 39 cases; the pacing mode was changed in 7 cases; the PVARP was extended in 3 cases; the Rate-response was switched on in 5 cases and sensivity was altered in 3 cases.

		Rate Response		Pacing Dependent	
		Yes	No	Yes	No
PM	N	79	111	69	121
	% no grupo	41,6%	58,4%	36,3%	63,7%
ICD	N	9	25	1	33
	% no grupo	26,5%	73,5%	2,9%	97,1%
CRT	N	16	30	16	30
	% no grupo	39,5%	60,5%	39,5%	60,5%
Total	N	104	166	86	184
	% total	38,5%	61,5%	31,9%	68,1%

Table 14. Prevalence of pacing dependent subjects and rate response on.

Some patients experienced improvement in quality of life when the rate response algorithm is switched on, whilst others do not feel much progress. However, has been increasingly used in daily practice. During the pacing clinic were observed 104 (38,5%) patients whose device had the rate response on. Finally, from all the patients observed in the pacing clinic, 86 subjects were pacing dependent (31,9%).

Chapter III

SELECTED CLINICAL CASES

Clinical Case 1

1. INTRODUCTION

Despite Atrial fibrillation being by far the most common Supraventricular tachycardia seen throughout cardiac patients, the most common reentrant SVT seen is Atrioventricular Node Reentrant Tachycardia (NATALE *et al.*, 2011).

The precise anatomic site and nature of the pathways involved have not yet been established, and several attempts to provide a reasonable hypothesis based on anatomic or anisotropic models have been made. There has been considerable evidence that the right and left inferior extensions of the human atrioventricular node and the atrionodal inputs they facilitate may provide the anatomic substrate of the slow pathway, and a comprehensive model of the tachycardia circuit for all forms of AVNRT based on the concept of atrionodal inputs has been proposed. Still, however, the circuit of AVNRT remains elusive.

AVNRT occurs in 50% to 60% of patients presenting with regular narrow complex tachycardia (NCT), ie, QRS duration < 120 ms, unless aberrant conduction, which is usually of the right bundle branch type, or a previous conduction defect exists. Tachycardia-related ST depression and RR interval variation may be seen. It is more frequent in women than men (2:1) and may first present with recurrent palpitations at any age, although most commonly between 30 and 50 years (KATRITSIS & CAMM, 2010).

2. PRESENTATION

A female patient, 65 years, was referred by the Consultant Cardiologist of a district general hospital with a history of palpitations and some episodes of dizziness. Symptoms slightly improved with flecainide. A 24 hours tape performed in January 2013 showed an episode

of what looks like AVNRT, although non-sustained, with possible short RP and a jump at the point of initiation of the tachycardia.

The patient was later admitted to the Accidental & Emergency Department of other general hospital in the same month of January and the ECG recorded showed tachycardia at 206 bpm, which was terminated with adenosine. The transthoracic echocardiogram showed no structural heart disease and good left ventricular systolic function.

The procedure was initiated by monitoring the patient to the polygraph and the monitor/external cardioverter. Patient monitoring included the placement of electrodes to obtain the 12 electrocardiographic leads and the placement of a paddle in the dorsal area of the patient to work as a return for RF generator.

The multidisciplinary team was composed by one interventional Electrophysiologist, two Cardiac Physiologists, a Radiographer, a nurse and myself, as an intern.

The four diagnostic catheters selected for the performance of the procedure were: two quadrapole catheters of Bard Electrophysiology, Viking 6F model, length 115 cm (for HRA and RV); one decapole catheter of *Bard Electrophysiology*, Dynamic 6F model, length of 110 cm and tip of 2 mm (for Coronary Sinus); and one quadrapole catheter (specially shaped "His hugger") of *St. Jude Medical*, Supreme CRD-2 6F model with a length of 120 cm (for His). Regarding the ablation, it was selected the quadrapole ablation catheter of *Biosense Webster*, Celsius 7F model with 115 cm of length and tip of 4 mm.

The catheters were introduced using the Seldinger technique through the right and left femoral veins and placed in the traditional position mapping:

- HRA: placed either in the right atrial appendage (RAA) or on the laterall wall of the RA, registering the atrial activation sequence;
- His: seated across the AV junction at the top end of the Triangle of Koch;
- CS: placed through the CS ostium (which arises in the right atrium at the bottom corner of the Triangle of Koch) in the coronary sinus, the perfect conduit around the AV groove of the left Atrium and Ventricle, making it possible to record the electrical activity on the left side of the heart;
- RV: positioned in the RV apex.

The baseline ECG prior to the procedure showed sinus rhythm with heart rate of 92 bpm. The following intervals were measured: PR = 136ms; QRS = 84ms; QT = 396ms.



Figure 10. 12 lead baseline ECG showing sinus rhythm with a ventricular rate of 92 bpm.

Following the setting of the diagnostic catheters in the correct positions, we obtained the following intracardiac electrogram, which shows a normal depolarization sequence of the cardiac conduction system.



Figure 11. Intracardiac recordings taken at baseline. 4 leads surface ECG (I, aVF, V1, V6), 2 bipolar recordings from the high right atrium (HRA), 3 bipolar recordings from the His bundle region (distal = HISd, intermediate = HISm and proximal = HISp), five bipolar recordings from the coronary sinus (CSp = proximal, CS 7-8, CS 5-6, CS 3-4, CSd = distal); 1 bipolar recording from the RV apex (RVp).

The study started with pacing from ventricles to assess the retrograde properties of the heart conduction system. With a drive train of 600 ms and an extra-beat of 290 ms, we registered a VA prolongation of greater than 50 ms over an S2 decrement of 10 ms, this is defined as VA jump. In the retrograde limb, it is possible to see that VH prolong which is indicative of infra-hisian decrementation or block, but in this instance there was no change in VH time suggesting the existence of dual AV nodal physiology.

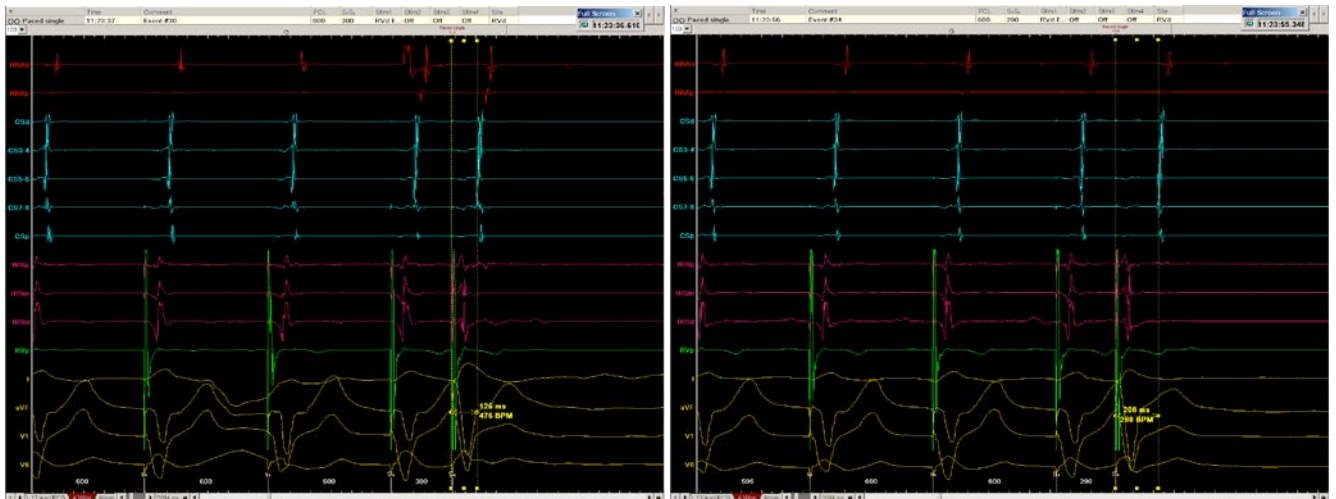


Figure 12. Intracardiac recordings taken during programmed ventricular stimulation. (left) With a coupling interval of 300 ms the VA interval is 126 ms and (right) with a coupling interval of 290 ms it suddenly increased to 208 ms.

An ectopic induced a NCT with VA time of 110 ms post-catheter insertion. Onset suggestive of AVNRT and not AT, but non-sustained and no diagnostic maneuvers were possible. Of interest, earliest A in prox-mid CS which lends evidence to AVNRT.



Figure 13. Intracardiac recording showing the NCT initiated by catheter-induced atrial ectopic.

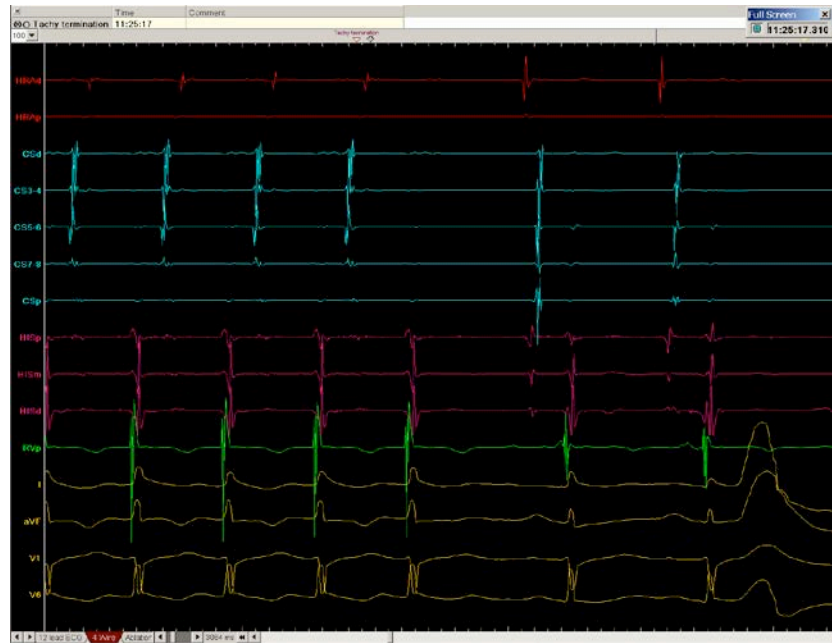


Figure 14. Intracardiac recording showing termination of tachycardia with a V-A-V response.

CS activation during the tachycardia remained consistent to that of the retrograde curve with CS 7-8/5-6 leading, indicative of a circuit involving the AV node/triangle of Koch area. Due to CS 7-8 leading, we elected to do parahisian pacing to assess the nodal response in attempt to identify the presence of an accessory pathway.



Figure 15. Intracardiac recording showing parahisian pacing. Response indicative of nodal conduction.

After parahisian pacing, we moved to investigate the anterograde refractory period. This was done with a drive train and shortening S2 extras. During the anterograde curve, we saw a prolongation of the AH interval greater than 50 ms over decrement of S2 by 10 ms.

During atrial testing, after the jump had occurred, we saw that there were incidences where the atrium was depolarized retrogradely, seemingly related to our paced extra. When this occurs with a consistent pattern then this is termed an “echo”. In this study, during the ARP we saw these on multiple occasions. The pattern showed a short VA time, which is consistent with a typical echo seen with dual node physiology. Due to inability to induce the tachycardia, we used single and double sensed extras and, again, we were able to reproduce single echoes easily.

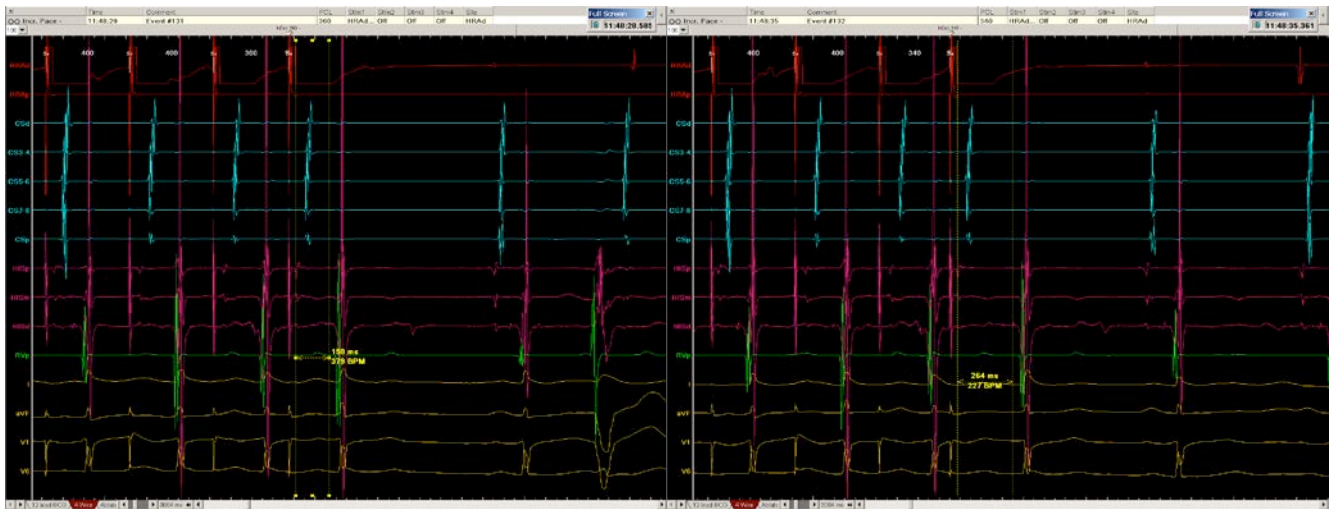


Figure 16. Intracardiac recordings taken during programmed atrial stimulation showing an AH jump.



Figure 17. Intracardiac recordings taken during programmed atrial stimulation from CS with single sensed extra with a short VA return time.

Following the inability to induce tachycardia, we administered isoprenaline. This failed to induce any tachycardia and therefore atropine was also tried.

Following both administrations of medication, we ran full EP maneuvers in order to test these effects on cardiac electrophysiology.

During these EP tests, we had two episodes of a 1:1 broad complex tachycardia (BCT) with LBBB aberrancy; short atrial entrainment consistent with an atrial reciprocating mechanism, i.e. not VT. CS activation also consistent with previous findings of nodal mechanism.



Figure 18. Intracardiac recordings taken during programmed stimulation with an infusion of isoprenaline IV showing induction of sustained broad complex tachycardia with LBBB aberrancy, VA association and relatively short VA time (cycle length = 240 ms).

During BCT, some ventricular entrainment was attempted however this pacing terminated tachycardia on first non-fused QRS without atrial capture (figure 19), again suggestive of an atrial mechanism and lending evidence to the lack of an accessory pathway.

Although the tachycardia itself was not proven to be AVNRT, we were able to suggest that this mechanism was not mediated by an accessory pathway, and the consistency of induction, termination and response to pacing was unlikely to be an AT. The BCT was proven not to be VT and in the light of the patient incessant tachycardia, the most likely diagnosis was AVNRT, with a slightly atypical pattern, with retrograde conduction via slow pathway and anterograde conduction via the fast pathway.

In this situation, and due to the relative risk to the patient of AV node damaged, the case was discussed with another Electrophysiologist and there was reasonable evidence to offer slow pathway ablation in the view of highly symptomatic status.



Figure 19. Intracardiac recordings showing tachycardia termination with entrainment.

The radiofrequency was delivered on the slow pathway site but was stopped on a first attempt due to ventricular ectopics and few rapid junctional beats. Eventually, during ablation the patient showed a stable junctional rhythm, indicative of ablation around the slow pathway and therefore, 60 seconds was delivered at this site.



Figure 20. Intracardiac recordings during RF delivery with induction of few rapid junctional beats.

After the delivery of radiofrequency, a retest was performed and a bidirectional slow pathway block was confirmed.



Figure 21. Intracardiac recordings taken during ventricular stimulation showing VA block.

There were no complications registered during the procedure. It was considered a successful RF ablation procedure. Slow pathway block was showed and tachycardia was non-inducible at the end. Non-sustained HRA-leading atrial tachycardia was also induced on few occasions, however of uncertain clinical relevance hence not mapped.

The patient was discharged with the usual pharmacological therapy and informed to contact the Cardiac Department in case of recurrence.

3. DISCUSSION

Catheter ablation of AVNRT is highly successful with minimal complications: the main one being inadvertent damage to the compact AV node and/or conduction system leading to heart block and the need of permanent pacemaker implantation in approximately 0.5 – 1% of patients. Modification or complete ablation of the slow AV nodal pathway has a “cure” rate of about 95%, so these patients can stop their drugs with confidence.

AVNRT has been traditionally classified as slow-fast or typical AVNRT, and fast-slow or atypical AVNRT, according to the conventional description of dual AV junctional pathways. The fast pathway of the reentry circuit runs superiorly and anteriorly in the triangle of Koch, whereas the slow pathway runs inferiorly and posteriorly close to the CS

ostium. Indeed, in the majority of slow–fast cases of AVNRT, the site of the earliest atrial activation is close to the apex of Koch's triangle, near the AV node-His bundle junction, i.e. anterior to the AV node. In the fast–slow form, the site of the earliest atrial activation is usually recorded posterior to the AV node near the orifice of the coronary sinus.

Considering this, and although AVNRT represents the most common paroxysmal SVT in the human and has a successful rate of treatment by ablation with minimal complications, several questions and obscure points remain. This old model of the reentrant circuit comprised two anatomically distinct limbs confined to the AV node can provide explanations for many aspects of the electrophysiological behaviour of these tachycardias. However, these pathways have not been demonstrated histologically and, despite several attempts to provide a reasonable model based on anatomic or functional anisotropic characteristics, the exact circuit responsible for the reentrant tachycardia is unknown.

Nevertheless, it is now known that discontinuous refractory periodic curves may not be present in all patients with AVNRT. Anterograde dual pathways are demonstrable in 75% of patients with tachycardia, and AVNRT may occur in the presence of continuous AV nodal conduction curves. Conversely, anterograde dual pathways can be demonstrated in subjects without tachycardia (KATRITSIS & CAMM, 2006).

It is now becoming evident that fast–slow AVNRT may be of the (usual) posterior, anterior, and middle type according to the mapped location of the retrograde SP.

Previous studies have reported on a posterior (or type B) variety of presumed slow–fast AVNRT, with long ventriculoatrial intervals and the earliest retrograde atrial activation near the coronary sinus ostium. Posterior fast pathways have been reported in up to 6% of patients with AVNRT. Eccentric retrograde atrial activation of the fast–slow as well as the slow–slow forms has also been reported. HWANG *et al.* (1997) reported that the earliest retrograde atrial activation was recorded within the CS in 0% (0/310 patients) among typical form and in 43% (20/46 patients) among atypical form, while NAM *et al.* reported its incidence of 6% (3/52 patients) among typical form and 80% (8/10 patients) among atypical form. CHEN *et al.* reported its incidence of 8% (16/211 patients) among typical form and 14% (2/14 patients) among atypical form.

Others observations should be considered as the inferior nodal extensions model of the AVNRT circuit. The inferior nodal extensions are basically part of the AV node and facilitate atrial inputs that also contain transitional cells connecting atrial myocardium with the nodal extensions. They have been proposed as the anatomic substrate of the slow

pathway. Recent studies have shown that extrastimuli delivered at the left inferoparaseptal area, close to the His bundle, may reset the AVNRT probably by engaging the left inferior nodal extension. Additionally, JACKMAN *et al.* reported that the leftward posterior nodal extension constituted the retrograde limb of the reentrant circuit and the SP ablation at the earliest retrograde activation site within the proximal CS was, therefore, required to eliminate atypical AVNRT with the eccentric CS activation pattern. Conversely, others postulated that the retrograde left-sided atrionodal connection was an innocent bystander; therefore, conventional right-sided SP ablation was sufficient to eliminate inducibility of atypical AVNRTs with the eccentric CS activation pattern (NATALE *et al.*, 2011).

Therefore, this makes the diagnosis and classification of the arrhythmia more complicated and sometimes impossible to identify a single AVNRT form, as various AVNRT types could be explained on the basis of variable anatomical characteristics and orientation of these extensions.

The pattern of conduction as well as the incessant nature seen in patients with the fast–slow form of AVNRT can also be seen in atrioventricular reentrant tachycardia due to the presence of concealed septal accessory pathways with decremental properties. And in certain cases of fast–slow or slow–slow AVNRT, retrograde activation is even suggestive of a left lateral accessory pathway. Thus, in the presence of a narrow QRS tachycardia, AVNRT should also be differentiated from atrial tachycardia or orthodromic atrioventricular reentrant tachycardia due to an accessory pathway.

AVNRT VS. ATRIAL TACHYCARDIA

Demonstration of change in AA interval when a ventricular extrastimulus is delivered during tachycardia, tachycardia termination by a ventricular extrastimulus that did not conduct to the atrium, constant His-atrial interval of the return cycle after introduction of a premature atrial impulse with a wide range of coupling intervals during tachycardia, and demonstration of ventricle to atrium to His sequence during retrograde initiation of tachycardia indicate aetiology other than atrial tachycardia. The difference in the AH interval between atrial pacing and the tachycardia may also allow differentiation of atypical AVNRT from other types of long RP tachycardias. A variation of AH > 40 ms indicates AVNRT, whereas in patients with AVRT due to septal pathways or AT these differences are < 20 and 10 ms, respectively. Finally, the difference of the post-pacing interval and the tachycardia cycle length, as described by Michaud *et al.*, may also be of help.

AVNRT vs. AVRT DUE TO SEPTAL ACCESSORY PATHWAYS

The eccentric retrograde atrial activation during ventricular stimulation or tachycardia and the demonstration of continuous AV or VA conduction curves usually characterizing non-septal concealed accessory pathways differentiate this form of atrioventricular reentry from AVNRT. However, AVNRT is now known to occur with eccentric atrial activation and, in addition, decremental septal pathways may mimic AVNRT especially of the fast–slow or slow–slow forms. Septal pathways may have the property of decremental conduction and normal atrial retrograde activation during tachycardia.

In case of relatively delayed retrograde conduction that allows the identification of retrograde P waves, ECG criteria can be applied for diagnosis. The presence of a pseudo-r' wave in lead V1 or a pseudo-S wave in leads II, III, and aVF has been reported to indicate anterior AVNRT with an accuracy of 100%. A difference of > 20 ms in RP intervals in leads V1 and III was indicative of posterior AVNRT rather than AVRT due to a posteroseptal pathway. The documentation of pre-excited beats as well as AV dissociation and the induction of bundle branch block during tachycardia may assist the differential diagnosis. The demonstration of AV block or AV dissociation during tachycardia is characteristic of AVNRT excluding the presence of an accessory pathway. Similarly, the development of bundle branch block either spontaneously or after introduction of ventricular extrastimuli during AVNRT does not change the AA or HH intervals. A significant change in the VA interval with the development of bundle branch block is diagnostic of orthodromic AVRT and localizes the pathway to the same side as the block.

In summary, AVNRT types are classified as typical (slow–fast) and atypical (fast–slow and slow–slow), according to the ratio of atrial-His/His-atrial intervals, the VA interval measured on the His bundle and high right atrial electrograms, and the site of the earliest retrograde atrial activation. However, variable sites of retrograde atrial activation have been described for all types of this arrhythmia. Therefore, several electrocardiographic and electrophysiological criteria and manoeuvres such as identification of retrograde P waves on the ECG, development of AV or bundle branch block, his-synchronous ventricular extrastimulation, AH interval, VA conduction indices or retrograde conduction are essential and have to be carefully used for differential diagnosis of narrow complex tachycardias, essentially with atypical characteristics.

Clinical Case 2

1. INTRODUCTION

Ventricular tachycardia - in contrast to most supraventricular arrhythmias, is serious and life threatening. These arrhythmias are most common shortly after acute myocardial infarction but they also occur remote from AMI and in young individuals with apparently normal hearts in whom the prevalence is approximately 0.1% of population. Patients who have experienced ventricular arrhythmia or who are at risk of ventricular arrhythmia require careful expert clinical assessment by an Electrophysiologist. Patients require treatment of their underlying heart condition and risk stratification for the development of future life-threatening arrhythmia. Patients at high risk of this arrhythmia usually require an implantable cardioverter defibrillator. Ablation therapy is used increasingly in the management of patients with ventricular arrhythmia and may be used as the primary treatment (usually in patients with a normal or near normal heart) but in patients with structural heart disease it is usually adjunctive therapy to an ICD. Patients who experience repeated ICD shocks due to recurrent VT suffer a high level of morbidity and VT ablation is also valuable in the management of this patient group.

2. PRESENTATION

March 2011

Asian male patient with 58 years referred by the Consultant Cardiologist of a district general hospital with some non-sustained VT on an Holter recording and a QRS of just about 120 ms on resting ECG. Known background of non-ischemic dilated cardiomyopathy, severe left ventricular dysfunction, normal coronary arteries and asthma.

Patient refers an exercise tolerance around 100 yards on the flat and he can manage stairs without stopping, though these are an effort. No orthopnea described but paroxysmal

nocturnal dyspnea (PND) was present in the past. Considering his history, the decision to implant a CRT-D was made and this device was implanted in March 2011.

Pacing clinic :: July 2011

On the pacing clinic for a 3 months follow-up, the device trends show biventricular pacing only 88% of the time, frequent ventricular ectopics, couplets, triplets and a five beat Salvo. Initially, the patient did feel some improvement after the CRT-D implanted, although he does feel his breathlessness has returned (no PND, peripheral edema, dizziness or chest pain reported). Discussed with Consultant Cardiologist who felt that his ectopic frequency was contributing to his breathlessness and also the fact that he was not in biventricular pacing 100% of the time. Bisoprolol taken increased to 7.5 mg.

Cardiology clinic :: November 2011

Patient became more breathless and describes episodes of PND and breathless on minimal exertion. It was seen in pacing clinic showing heavy ectopic burden (despite increased Bisoprolol). The team decided to initiate Amiodarone.

Pacing clinic :: November 2012

On the yearly pacing clinic follow-up, patient presented with increased breathlessness at rest and ankle oedema lasting for 2 weeks. The device readings showed his premature ventricular contractions (PVC) count had risen from 7% to 12% more recently, which was impeding the proper function of the CRT device.

Arrhythmia clinic :: December 2012

Although his biventricular pacing initially was beneficial for his symptoms, it seems that after a first few months it plateaued and he was now back in NYHA class III functional status. His biventricular pacing percentage had been consistently suboptimal below 90%, mainly due to heavy burden of ventricular ectopic activity as well atrial fibrillation. Going through his 12 lead ECG, he had at least 2 different morphologies of ventricular ectopics, both coming from RV and LV outflow tract.

The patient decided to firstly try the spironolactone and see if this could improve his symptoms and then he would reconsider the invasive options.

EP clinic :: February 2012

From ECG monitoring and exercise test it was clear that he had at least 2 types of outflow tract-type ectopy, one possibly originating from the aortic cusps on the left side, and the other likely being from the high RVOT.

Patient was then listed for outflow tract ventricular ectopy ablation as the ectopy burden had increased with a drop in biventricular pacing once more.

The procedure began by monitoring the patient to the polygraph, the monitor/external cardioverter and to the Carto navigation system. Patient monitoring included placing electrodes for obtaining 12 electrocardiographic leads; a paddle in the dorsal area of the patient to act as a "return" for RF generator and a specific Carto 3 electrodes kit.

This navigation system enables viewing of conventional catheters in real time, without exposure to X-ray radiation. Also allows to view the points of the heart where RF energy is applied, using them to create a three-dimensional geometry of the heart.

The multidisciplinary team was composed by one Interventional Electrophysiologist, two Cardiac Physiologists, a Radiographer, a nurse and myself, as an intern.

The diagnostic catheter selected to perform the procedure was one quadrapole catheter of *Bard Electrophysiology*, Viking 6F model, length of 115 cm (for RV). Regarding the ablation, it was selected the *ThermoCool SmartTouch* bi-directional navigation catheter of *Biosense Webster*, 8F model with 115 cm of length and tip of 3,5 mm.

The baseline ECG shows sinus rhythm with monomorphic ventricular ectopy. An assessment of the origin of the ectopy based on the prior and present ECGs confirms the suspicion of probable RVOT and/or Aortic cusp origin (figure 22). There was also the suspicion that one of these morphologies was fusion with intrinsic QRS.

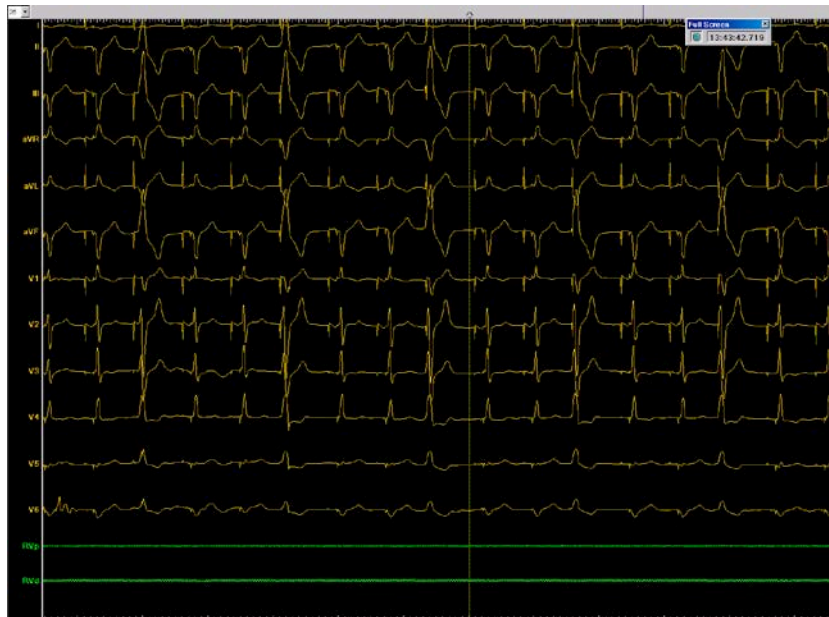


Figure 22. Baseline 12 leads ECG with clinical ectopy.

We begin the procedure by attempting pace mapping in the RVOT. The ECG below shows the danger of undersensing during pacing.

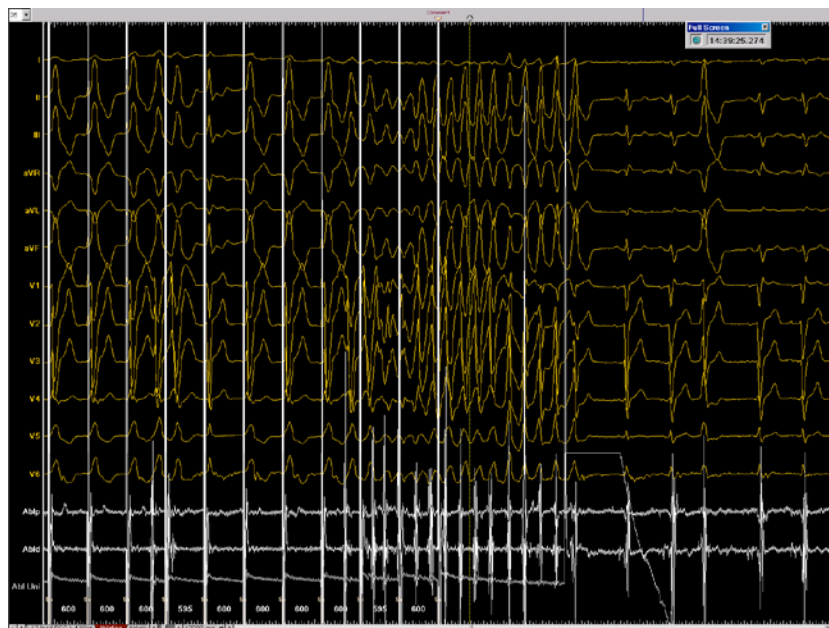


Figure 23. Attempted pace mapping with good match but non-sustained VT with undersensed pace on.

Some ventricular ectopics showed early map signal on the ablation catheter. Pacemapping was then attempted and a good RS match was seen (figure 24).

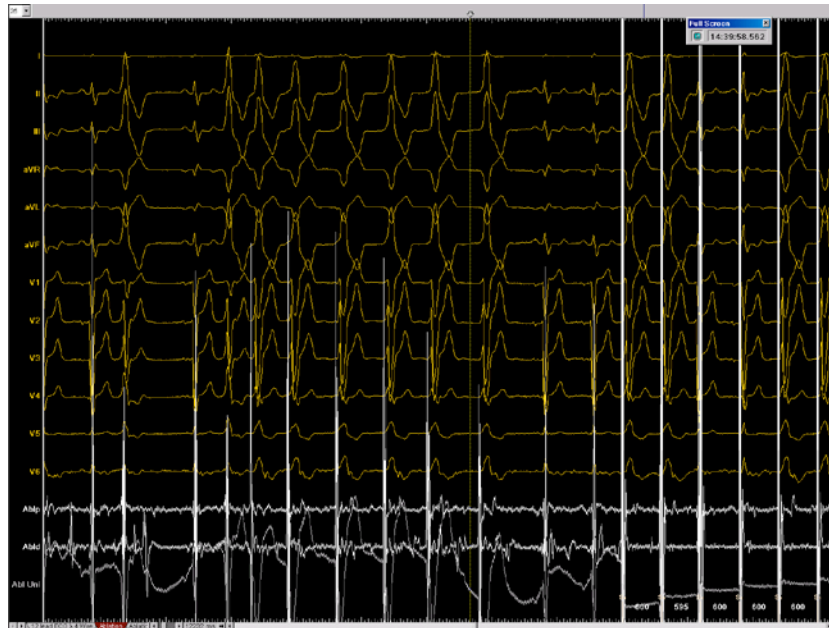


Figure 24. Early map signal seen with ventricular ectopics; then pacemapping with good RS match.



Figure 25. Surface ECG and intracardiac signs showing earliness of map to RS in RVOT.

We attempted ablation and some clinical ectopy was seen during RF. However, this failed to decrease the ectopic burden (figure 26).

Considering this, we then move to the LV, targeting LVOT and Aortic root. A Carto geometry was created of the aortic root and the high portion of the LVOT. Extensive mapping done in Aortic root between RCC and LCC, being difficult to capture for pacemapping but early signals seen during clinical ectopy. Some RF ablation performed in this area with some increase in clinical ectopy seen during ablation but the ectopic burden remained high (figure 27).



Figure 26. Surface ECG showing clinical ectopy during RF ablation.



Figure 27. Onset of ablation with spontaneous clinical VE.

Following some ablation the decision was taken to perform an angiogram of the coronary sinus in order to see if there was a venous branch, which might allow us to map the epicardial surface of this area. The angiogram showed a large anteroseptal branch and the ablation catheter was manipulated into this vein. Pacemapping and early signal interpretation showed the earliest ablation signal during clinical ectopy.



Figure 28. Surface ECG and CS map signal showing early signal on map during ectopic (caliper shows map 14 ms pre QRS).

There was also an excellent pacemap in this distal CS area and therefore RF was applied at this site. In order to perform RF ablation in CS, we changed the RF settings for 25 W with a high flow of 30 ml/min.



Figure 29. Surface ECG and intracardiac signals showing pace map from CS.

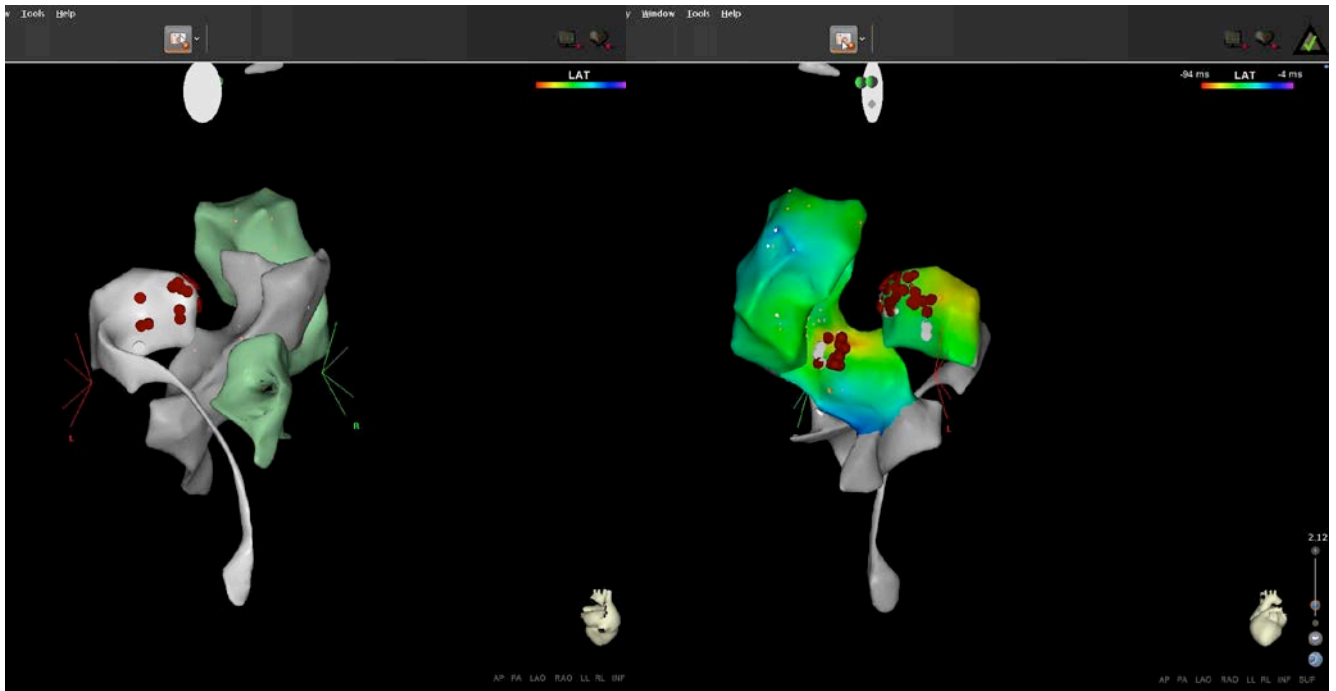


Figure 30. Three-dimensional geometry showing the distal CS and its proximity to the Aortic root and LVOT (left). Local activation map showing early signals in Aortic root (right).

It was performed 3 ablation attempts in each identified origin focus suppressing the ectopy.

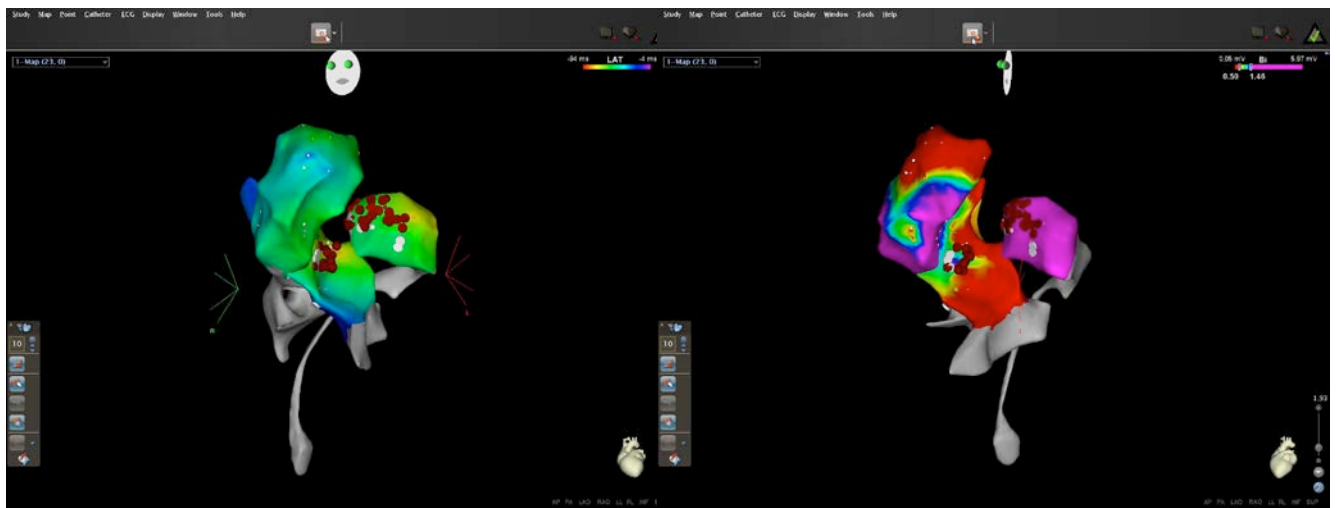


Figure 31. Three-dimensional geometry showing the sites of ablation (red spots) on the left. 3D geometry showing bipolar map with exit of ectopy on scar border (right).

There was stable sinus rhythm thereafter and this presentation remained for 20 minutes after the RF application (figure 32).



Figure 32. Final surface ECG with no ectopy, 20 minutes after RF application.

In the rhythm strips below we can see the difference in ectopy frequency prior and post-procedure, allowing us to considerate successful ablation of VEs from proximal anterior interventricular vein opposite Aortic root, accessed via CS.

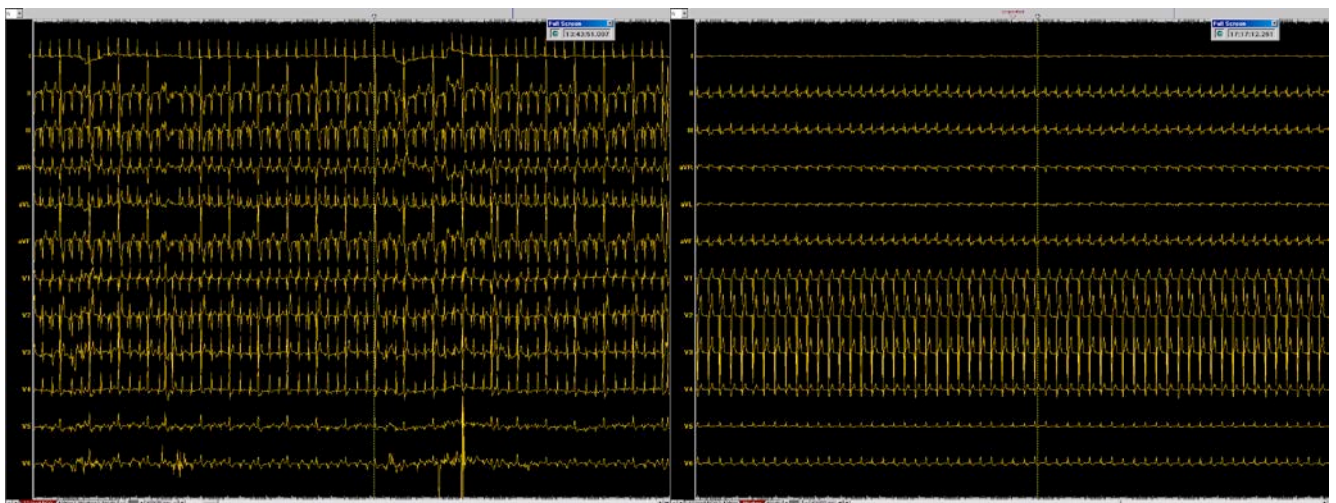


Figure 33. Baseline rhythm strip at 6mm/s showing frequency of ectopy (left). Case end with rhythm strip at 6mm/s showing corresponding lack of ectopy (right).

Patient was discharge and was seen 6 months later in EP clinic. The patient has been feeling much better with far less ectopics than before. His ECG showed reasonably frequent OT ectopics with similar morphology to previous, sometimes in couplets. However, there has been clinical improvement with evidence of reduced ectopic burden via his pacing check.

3. DISCUSSION

Ventricular premature contractions originating in the right ventricular outflow tract are often associated with triggered or reentry mechanisms but may more rarely be related to increased automaticity. These individuals are usually symptomatic, with great impact on their quality of life, and they often exhibit refractoriness to the pharmacological therapy.

The region of RVOT and LVOT is the most common origin of VT and PVCs, accounting for approximately 10% of all patients referred for evaluation of VT. More than 70–80% of these arrhythmias originate from the RVOT. Other origins include the pulmonary artery, near the bundle of His, the LVOT, the aortic sinuses of Valsalva, the coronary sinus and cardiac veins, the mitral and tricuspid valve annuli, and the epicardium.

The focal VT origin can be identified from activation and/or pace mapping. Although activation mapping is the strategy of first choice, pace mapping can be used to identify a region of interest and then refine position based on activation, and can be the major guide to the ablation site when spontaneous arrhythmia is infrequent. Pace mapping should be done at the VT rate. The site where pacing exactly reproduces the 12-lead ECG of the spontaneous or induced VT should be sought. The spatial resolution of pace mapping is limited and in some patients a perfect pace map is seen at sites up to 2 cm away from the VT origin. Pacing at stimulus strengths only slightly greater than threshold is desirable to avoid capture over a large area that may reduce accuracy.

More and more labs are using three-dimensional electroanatomical mapping systems to assist in relating the anatomy to the mapping data. The development of this technology has shown great ability to identify the focal point of origin of the ectopy. The point of activation is determined as the earliest point with respect to the beginning of the QRS complex. In unipolar mapping there is a QS morphology with rapid deflection in the electrogram. The point of origin is thus identified before the propagation of the activation wave. In the RVOT, bipolar electrograms typically have normal amplitude (e.g., 1.5 mV) and are sharp, without fragmentation. Activation at the site of successful catheter ablation precedes the onset of the surface QRS complex by 10 to 60 ms. The bipolar electrogram may display high-frequency low-voltage activity preceding the main local ventricular electrogram component (ALLOT *et al.*, 2009).

The successful ablation of ectopy in the RVOT using three-dimensional mapping systems is described to be above 80% and with no recurrence. There are a few important factors to be

considered: the RF application reduced to the point of activation; the reduced use of fluoroscopy and the ability to identify more than one early activation point (regardless of their proximity), which with conventional mapping would have been difficult to identify (INFANTE *et al.*, 2011).

There are no controlled or multicentre trials of ablation. In reported case series, acute success rate of RF catheter ablation of RVOT-VT is 65–97% and typically exceeds 80%; recurrence of arrhythmia has been reported in up to 5% after acutely successful ablation. Failure is usually due to inability to induce the arrhythmia for mapping. Complications are rare, but perforation and tamponade are reported and ablation of foci near the His bundle region can result in heart block.

Radiofrequency ablation with solid 4 mm tip electrodes at maximal temperatures of 50°C – 70°C and power settings of 50W is usually sufficient when mapping is adequate. Use of 8 mm electrodes with higher power or irrigated electrodes is usually not necessary; avoiding steam pops from high-power ablation is particularly desirable to avoid perforation when ablation is performed in the RVOT, once its leftward posterior aspect is only 4 mm from the left main coronary artery and therefore that is a theoretical risk of coronary artery injury with ablation.

Sustained monomorphic ventricular tachycardia (SMVT) is not common in non-ischaemic dilated cardiomyopathies but 80% of those that occur are due to scar-related reentry, with the remainder due to bundle branch reentry or a focal origin. Scars are probably due to progressive replacement fibrosis. Compared with post-infarction VT, areas of scar are smaller, but patients who present with SMVT typically have multiple morphologies of VT inducible. Magnetic resonance imaging with delayed Gd enhancement and voltage mapping demonstrates that scars are often adjacent to a valve annulus. Transmural scar is rare and intramural scars are common. These features likely account for the general perception that ablation of VT is more difficult when compared with that in the post-MI population. When endocardial ablation fails, epicardial mapping usually shows that more extensive scar is present in the epicardium (ALIOT *et al.*, 2009).

The following data is from a few single-centre studies. In a series of 19 patients with recurrent SMVT due to dilated cardiomyopathy, endocardial ablation abolished all inducible VT in 14 patients. After a follow-up of 22 months, five patients were alive without VT recurrence. In a series of 22 patients, epicardial mapping and ablation was

performed if endocardial ablation failed. Scar-related reentry circuits were identified in the endocardium in 12 patients and in the epicardium in all 7 who underwent epicardial mapping after failed endocardial ablation. At least one VT was abolished in 16 of 22 patients and all VTs were abolished in 12 of 22 patients. During a mean follow-up of 334 days, VT recurred in 46% of patients, one patient died of heart failure, and cardiac transplantation was performed in two patients.

Ablation can be life-saving in patients with incessant VT or VT storm. In these small series, no serious complications were reported, although septal ablation produced anticipated AV block in one patient (ALLOT *et al.*, 2009).

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