# Curriculum for Clinical Cardiac Electrophysiology Training: Part I

**I. General objectives and length of training.**

The trainee in Clinical Cardiac Electrophysiology should acquire broad knowledge in all aspects of arrhythmology, including but not limited to bradyarrhythmias, tachyarrhythmias, syncope, non-invasive and invasive diagnostic electrophysiology, and interventional electrophysiology including catheter ablation and device implantation. The trainee should have sufficient knowledge of basic electrophysiology to understand current theories of the mechanisms of cardiac dysrhythmias and the rationale for both pharmacologic and non-pharmacologic therapy.

Candidates are eligible for training in Clinical Cardiac Electrophysiology if they have completed two to three years of training in Cardiovascular Disease and are or will be Board-Eligible in Cardiovascular Disease. The length of the Clinical Cardiac Electrophysiology training program is 1-2 years, with two years recommended for those desiring additional training in research and complex catheter ablation.

**II. Basic electrophysiology.**

**A. Objective.** In order to be a superior practitioner of Clinical Cardiac Electrophysiology, an understanding of basic cellular mechanisms as they relate to clinical practice is important.

**B. Teaching method.** Tutorial (direct discussion between the faculty and trainee; for example, during the portion of the electrophysiology study where atrial pacing is performed to assess sinus node automaticity, the basic cellular mechanisms of overdrive suppression of automaticity will be discussed); self-study; conferences.

**C. Content.**

1. Determinants of the normal cardiac rhythm (genesis of the resting potential and action potentials, ion channels, ionic currents).
2. Determinants of normal conduction (for example passive membrane properties, maximal upstroke velocity, cell to cell interaction).
3. Genesis of tachyarrhythmias (automaticity, triggered activity, re-entry, anisotropy, influence of various modulators such as autonomic tone and electrolyte disturbances).
4. Antiarrhythmic drug actions (modulated receptor hypothesis, antiarrhythmic drug classifications, cellular electrophysiologic effects of various classes of antiarrhythmic drugs).

**D. Education materials.**

1. Textbook: Zipes and Jalife, Editors, Cardiac Electrophysiology.
2. Fellow's Electronic Teaching File (reprints of seminal journal articles, which fellows will retain for personal reference).

**E. Evaluation.**

The resident's core knowledge of basic electrophysiology will be assessed in the tutorial process, by the Socratic method. A strength of this program is the high faculty to resident ratio, namely 5:2. The resident will evaluate the training program in writing every six months, and will be specifically asked to comment on whether each portion of the curriculum is achieving it's objectives. Although this training program does not have an electrophysiologist who performs basic electrophysiologic research, there are medical school faculty in the physiology section who have basic electrophysiology skills (for example patch clamp technique); if the trainee is specifically interested in basic electrophysiology, these faculty based at Dartmouth Medical School could serve as resources.

**III. Basic pharmacokinetics and pharmacodynamics.**

**A. Objective.**

A trainee in Clinical Cardiac Electrophysiology will be prescribing complex drug regimens with the potential for substantial toxicity, and should have an understanding of both basic and clinical pharmacokinetics.

**B. Teaching method:** Tutorial, self-study, conferences.

**C. Content.**

1. Basic pharmacokinetics (absorption, distribution, metabolism, elimination).
2. Clinical pharmacokinetics.
   A. Clearance, half-life, compartmental analysis, loading doses.
   B. Principles of drug level monitoring.

C. Drug interactions.

3. Pharmacodynamics (receptor theory, agonists/antagonists, therapeutic index).

4. Practical aspects of antiarrhythmic drug therapy (indications, contra-indications, dosing considerations).

5. Drug-device interactions (the effects of drugs on pacing and defibrillation thresholds).

**D. Educational materials.**

1. Textbooks: Zipes and Jalife, Editors, Cardiac Electrophysiology; Podrid and Kowey, Editors, Cardiac Arrhythmia.

2. Fellow's Electronic Teaching File

3. Clinical material: The trainee will have the opportunity to initiate antiarrhythmic drug therapy on a frequent basis for inpatients on the electrophysiology service or for inpatients seen in consultation. On average, the daily census of inpatients on antiarrhythmic drugs numbers 3 (including CCU patients on intravenous therapy and patients on the telemetry unit receiving oral antiarrhythmic drug therapy). In addition, during the resident's 1/2 day per week of Clinical Cardiac Electrophysiology clinic, there will be an opportunity for longitudinal follow-up of the patient on antiarrhythmic drug therapy, as well as the opportunity to initiate therapy for outpatients (for example AV nodal active drugs for supraventricular tachyarrhythmias).

**E. Evaluation:** The resident will be evaluated during the tutorial process, utilizing the Socratic method. The resident will evaluate the curriculum in writing every six months. A strength of this training program is a broad spectrum of clinical material, ranging from patients with new onset atrial fibrillation or symptomatic VPB's to patients with drug-resistant sustained ventricular tachyarrhythmias.

## IV. Electrocardiography.

**A. Objective.**

The Clinical Cardiac Electrophysiologist should be fully familiar with the indications and interpretation of the following electrocardiographic (ECG) tests: standard surface ECG's, ambulatory ECG's (Holter monitors as well as transtelephonic ECG transmissions from event recorders and transtelephonic ECG transmissions to evaluate pacemaker performance), continuous on-line ECG monitoring in-hospital (telemetry), exercise treadmill testing, analysis of signal-averaged ECG's, and analysis of microvolt-level T-wave alternans studies.

**B. Teaching method.** Since our trainees in Clinical Cardiac Electrophysiology are Board Eligible in Cardiovascular Disease, it is assumed that the trainee has acquired minimal competency for the interpretation of standard surface ECG's and exercise stress tests. A tutorial teaching method is utilized for electrocardiography; the trainee is asked to interpret for the faculty electrophysiologist multiple ECG's daily, during supervised experiences in the outpatient and inpatient arenas, including the electrophysiology laboratory. Other teaching methods include self-study and conferences.

**C. Content.**

1. Bradyarrhythmias (sinus node dysfunction, AV nodal and His Purkinje system dysfunction, bundle branch and fascicular blocks).

2. Supraventricular tachyarrhythmias (presence and location of accessory atrioventricular connections by surface electrocardiography, differential diagnosis of supraventricular tachyarrhythmias based on P wave characteristics, aberrancy).

3. Ventricular tachyarrhythmias (VT).

A. Types (non-sustained vs. sustained, polymorphic vs. monomorphic).

B. Etiology (coronary disease, cardiomyopathy, valvular heart disease, congenital heart disease, idiopathic VT, long QT syndromes).

C. Distinction between supraventricular tachycardia (SVT) and VT (AV dissociation, fusion or capture beats, morphology guidelines).

4. Ambulatory ECG recordings.

1. Holter monitoring.

2. Transient arrhythmia monitoring.

3. Transtelephonic evaluation of pacemaker function.

4. In-patient telemetry monitoring.

5. Signal-averaged electrocardiography (time domain vs. frequency domain).

6. Microvolt-level T-wave alternans studies (derived by pacing in the Electrophysiology Lab or exercise-treadmill testing).

**D. Educational materials:**

1. Textbooks are Kowey and Podrid, Editors, Cardiac Arrhythmia; Chou's Electrocardiography in Clinical Practice; Fisch's Electrocardiography of Arrhythmias; Pick and Langendorf, Interpretation of Complex Arrhythmias.
2. Fellow's Electronic Teaching File
3. Clinical material: The trainee will interpret multiple standard surface ECG's daily during both inpatient and outpatient encounters, as well as in patients coming to the electrophysiology laboratory. In our pacemaker clinic, 2200 patients are followed transtelephonically, resulting in daily ECG's. About 25% of these ECG's will be evaluated by the fellow, with supervision. The fellow will review Holter monitors, transient arrhythmia monitors, and exercise tests as they are ordered on outpatients and inpatients on the electrophysiology service, and will also have multiple opportunities to review telemetry strips on inpatients (the step-down cardiology unit has 47 telemetry beds). Signal-averaged electrocardiograms and T-wave alternans studies are ordered on a selected basis, about 25 times yearly. All of these will be reviewed by the trainee, under supervision.

**E. Evaluation**

The resident will be evaluated during the tutorial process, and will evaluate this portion of the curriculum every six months in writing. A strength of this training program is the scope and volume of surface electrocardiographic tracings.

## V. Invasive Electrophysiologic (EP) Studies

**A. Objective.**

A clinical cardiac electrophysiologist is expected to acquire expert knowledge of the indications for invasive electrophysiologic testing, and the diagnostic, prognostic, and therapeutic implications of this data. The trainee should have a good understanding of the equipment utilized (xray equipment, a programmable stimulator, a multichannel physiologic recorder, non-fluoroscopic 3-D mapping, intracardiac echo) as well as proper filter settings and the use of unipolar vs. bipolar recordings. The trainee will acquire the technical skills to cannulate peripheral veins and arteries, as well as placing catheters in all cardiac chambers. The resident should also understand the risks of diagnostic electrophysiologic studies and be able to manage complications (for example cardiac tamponade, refractory ventricular fibrillation).

**B. Teaching method.**

A faculty electrophysiologist is assigned to the electrophysiology laboratory for the week, and is responsible for carrying out all invasive electrophysiologic studies. The trainee is primary operator on all of these studies, and is closely supervised throughout the whole study by the faculty electrophysiologist. Both the cognitive and technical aspects of invasive electrophysiologic studies are discussed in a tutorial fashion on a daily basis. Other teaching methods include self-study and conferences.

**C. Content.**

1. Gross anatomy and fluoroscopic anatomy.
2. Evaluation of sinus node function.
3. His bundle recordings and the evaluation of the AV node and His Purkinje system.

A. Natural history of various conduction disorders; significance of HV interval prolongation and atrial pacing-induced infra-Hisian block.

B. Indications for permanent pacing in various conduction disorders.

4. Supraventricular tachyarrhythmias.

A. Mechanisms, and electrophysiologic techniques distinguishing between types of SVT (for example ventricular extrastimulus technique during SVT).

1. Atrial arrhythmias (for example sinus node re-entry, inappropriate sinus tachycardia, unifocal atrial tachycardia).
2. Junctional arrhythmias (for example AV nodal re-entry, junctional ectopic tachycardia).
3. SVT utilizing accessory atrioventricular connections (for example WPW, and tachycardias utilizing a Mahaim fiber).

B. The use of various pharmacologic agents in the course of evaluating patients with SVT (for example adenosine, atropine, isoproterenol).

C. Serial electropharmacologic testing.

5. Ventricular tachycardia and ventricular fibrillation.

A. Electrophysiologic techniques for determining the mechanism of wide complex tachycardias.

B. The sensitivity and specificity of various programmed stimulation protocols for VT/VF induction in various types of heart disease.

C. Serial electropharmacologic testing.

D. Stimulation protocols for tachycardia termination.

**D. Educational materials.**

1. Textbooks: Josephson, Clinical Cardiac Electrophysiology: Prystowski and Klein, Cardiac Arrhythmias

2. Fellow's Electronic Teaching File

3. Clinical material: A steady volume of patients at our training center requires diagnostic electrophysiologic testing for ventricular and supraventricular tachyarrhythmias, wide complex tachycardias of undetermined etiology, and syncope of undetermined etiology. In 1995, 121 patients had primary electrophysiologic studies and 63 had follow-up electrophysiologic studies for a variety of indications. These totals do not include patients undergoing radiofrequency catheter ablation (see below).

**E. Evaluation.**

The trainee spends a large percentage of his/her time in the electrophysiology laboratory, namely 1/2 day or more four days weekly. A faculty electrophysiologist is present on these occasions, and directly evaluates the fellow's cognitive and technical skills. The trainee will have the opportunity to evaluate each portion of the curriculum in writing, every six months.

## VI. Endocardial mapping/catheter ablation

**A. Objective.**

The trainee should acquire the knowledge for endocardial mapping of all monomorphic supraventricular and ventricular tachyarrrhythmias, in all cardiac chambers. Furthermore, the trainee should be familiar with the indications, technical aspects, and complications of catheter ablation for these tachyarrhythmias.

**B. Teaching method.**

The trainee is first operator on 1-2 catheter ablations per week, supervised by one or more faculty electrophysiologists. Other teaching methods include self-study, and conferences.

**C. Content.**

1. General interpretation of local electrograms (activation times, late potentials, fractionated electrograms, continuous electrical activity, effects of filtering).

2. Pacing techniques that assist in mapping (entrainment, resetting).

3. The biophysics of tissue damage with various ablative techniques (radiofrequency energy, cryoablation).

4. The indications for catheter ablation and complications specific to the type of ablation.

A. Unifocal atrial tachycardias, atrial flutter, AV nodal re-entry, tachycardias utilizing accessory atrioventricular connections, monomorphic ventricular tachycardia, atrial fibrillation.

**D. Educational materials.**

1. Textbooks: Josephson, Clinical Cardiac Electrophysiology; Kowey and Podrid, Editors Cardiac Arrhythmia; Zipes, Editor, Cardiac Ablation of Arrhythmias.

2. Fellow's Electronic Teaching File

3. Clinical material: 4-5 endocardial mapping/radiofrequency catheter ablation procedures are performed at our center each week.

**E. Evaluation.**

The resident is evaluated during the process of performing the mapping/ablative procedure (closely supervised by the faculty clinical electrophysiologist). The trainee evaluates each portion of the curriculum in writing, every six months. It is recommended to the fellows that they consider two years of training if they want more experience in mapping and ablating some of the rare cardiac dysrhythmias that they may only encounter on a few occasions in one year of training.

**F. Catheter ablation of atrial fibrillation and ventricular tachycardia**

It is recommended that fellows do two years of training if they want to achieve competency in atrial fibrillation ablation, and in mapping and ablating other complex tachyarrhythma substrates such as

ventricular tachycardia in structural heart disease.

These types of ablations are challenging and still evolving, and require multi-modality imaging including pre-operative MRI or CT scans of the chamber of interest, electroanatomic mapping, registration and merging of these images, and intracardiac echocardiography (especially for atrial fibrillation).

In the first year of training, the fellow will need to spend substantial time learning the non-catheter manipulation aspects of these procedures, including electrogram analysis on the multichannel physiologic recorder and utilizing the electroanatomic mapping equipment. As these skills are mastered, progressive responsibility for the technical aspects of the procedure will likely proceed in this order: vascular access including transeptal access to the left atrium or left ventricle, construction of a 3-D electroanatomic map, relatively focal ablation (e.g. pulmonary vein isolation), and finally linear ablation. Given safety limitations with regard to fluoroscopy time (and time in the left sided cardiac chambers) for these complex and typically lengthy procedures, the fellow's time on the ablation catheter may be limited depending on the patient's needs and the fellow's progression in the acquisition of the requisite technical skills.

**VII. Implantable devices**

**A. Objective.**

Trainees in Clinical Cardiac Electrophysiology should be capable of selecting patients for permanent pacemakers and implantable cardioverter-defibrillators (ICD's), and should be able to implant these devices independently. Furthermore, they should be aware of all aspects of post-operative patient care and long-term follow-up in patients with implantable devices.

**B. Teaching method.**

In our institution, all pacemakers and ICD's are implanted skin to skin by the electrophysiologists in the electrophysiology laboratory. Cardiothoracic surgery back-up is readily available but rarely required. The trainee is prime operator on every implant, and scrubs with a faculty electrophysiologist. Other teaching methods include self-study, and conferences.

**C. Content.**

1. Sterile operating room technique.

2. Surgical skills for vascular access, creating subcutaneous and submuscular pockets, and tunneling electrodes.

3. Engineering aspects of electrical sensing and stimulation, and pulse generator design.

4. Indications for the use of implanted devices for the management of bradyarrhythmias and tachyarrhythmias.

A. Types of pacemakers and defibrillators (Inter-Society Commission for Heart Disease Resources coding system).

5. Measurement of sensing thresholds, pacing thresholds, and defibrillation thresholds.

6. Methods for pacemaker and ICD follow-up.

A. Differential diagnosis of failure to sense or pace, or "inappropriate" ICD shocks.

B. Use of external programmers.

C. Indicators of cell depletion.

D. Management of complications of device therapy (including surgical complications such as infection).

**D. Educational materials.**

1. Core textbooks. Ellenbogen, Kay, and Wilkoff, Editors, Clinical Cardiac Pacing.

2. Fellow's Electronic Teaching File

3. Clinical material: Our center implants 300 devices (pacemakers and defibrillators combined) annually. We follow about 1700 patients in our pacemaker and ICD clinic (> 25% are ICD patients; April 2004). These patients rotate through the fellow's Clinical Cardiac Electrophysiology clinic (1/2 day per week), providing the opportunity for the longitudinal care of patients with implantable devices. In addition, the trainee performs a pre-operative assessment of both outpatients and inpatients requiring devices, supervised by a faculty electrophysiologist.

**E. Evaluation.**

The resident in Clinical Cardiac Electrophysiology is continuously evaluated as part of the tutorial process. The resident has the opportunity every six months to evaluate the curriculum in writing. A strength of this program is that device implants are totally under the aegis of Clinical Cardiac Electrophysiology.

**VIII. Autonomic testing**

**A. Objective.**

Clinical Cardiac Electrophysiologists are expected to be capable of performing head-up tilt testing as part of the evaluation of patients with syncope of undetermined etiology. In addition, the electrophysiologist should be familiar with other forms of autonomic testing which may prove useful in evaluating a patient's risk for sudden death (for example heart rate variability and T wave alternans assessment).

**B. Teaching method.**

The fellow will perform about 50 tilt tests yearly, under the supervision of a faculty electrophysiologist. Patients undergoing tilt testing for syncope of undetermined etiology also receive a formal consultation from a Clinical Cardiac Electrophysiologist, prior to performing the tilt test. The primary teaching method is tutorial, but self-study and conferences are also utilized.

**C. Content.**

1. Indications and limitations of head-up tilt testing in the evaluation of syncope.

A. The sensitivity and specificity of various tilt protocols; normal and abnormal blood pressure and pulse responses to head-up tilting.

B. Pharmacologic and non-pharmacologic therapies for autonomically-mediated syncope.

2. Autonomic testing to assess patients at risk for sudden cardiac death: heart rate variability and baro- receptor sensitivity.

**D. Educational material.**

1. Textbook: Podrid and Kowey, Editors, Cardiac Arrhythmia.
2. Fellow's Electronic Teaching File
3. Clinical material: Our center performs 2-3 tilt tests weekly for syncope of undetermined etiology.

**E. Evaluation.**

The trainee is evaluated during the tutorial process, in part utilizing the Socratic method. The trainee has the opportunity every six months to evaluate all aspects of the curriculum in writing.

**IX. Research**

**A. Objective.**

Trainees in Clinical Cardiac Electrophysiology should understand the design and interpretation of research studies, and the responsible use of informed consent. They should be able to critically assess the medical literature with regard to new therapies and techniques. A meaningful research experience, tailored to the needs of the individual trainee, is required.

**B. Teaching method.**

All electrophysiology faculty participate in clinical research, with one (Dr. Steiner) designated as the Director of Electrophysiologic Research. At a minimum, the trainee will be exposed to some of this research, including participation in multi-center studies as well as original research. Self-study and conferences represent other teaching methods.

**C. Content.**

1. The design of various types of research studies.
2. Interpretation of research studies, including basic statistics (confidence intervals, tests of statistical significance, linear correlation, multi-variate analysis, meta-analysis, and decision analysis).
3. FDA requirements for informed consent and protection of human subjects.

**D. Educational materials.**

1. Fellow's Electronic Teaching File
2. Clinical material: Clinical Cardiac Electrophysiology is a new and rapidly changing field. Clinical research can be incorporated into the daily routine.

**E. Evaluation.**

Even for trainees headed for a career in private practice, we require research exposure since we feel this is a scholarly activity that will make the clinical practitioner of Cardiac Electrophysiology critically aware of how the scientific basis of the field is advanced. The trainee is evaluated as part of the tutorial process, which is tailored in part to the research interests of the trainee. It is expected that each trainee will

have completed a manuscript suitable for publication, prior to the end of training. The resident has the opportunity to evaluate this part of the curriculum every six months in writing.

The principle faculty in Clinical Cardiac Electrophysiology are heavily invested in patient care, but still committed to performing some clinical research. The faculty and trainees have from 1/2 to 1 day weekly of protected time for research. There are other potential research mentors in our medical center, especially those in Dartmouth's well-known Center for the Evaluative Clinical Sciences (includes researchers skilled in outcomes analysis, decision analysis, cost-efficacy analysis, etc.).