Chapter 13 Therapeutic and Prosthetic Devices

- Medical electronic instrumentation  
  \{ diagnostic devices  
  \{ therapeutic and prosthetic devices  

13.1 Cardiac Pacemakers and Other Electric Stimulator

![Block diagram of an asynchronous cardiac pacemaker](image)

Figure 13.1 Block diagram of an asynchronous cardiac pacemaker

**Cardiac Pacemakers**

- Electric stimulator to treat heart block: electric stimulus conducted to the heart causes it to contract regularly
  - First degree heart block
  - Second degree heart block
  - Third degree heart block
- Asynchronous pacemaker in Fig. 13.1: free-running at a uniform fixed rate (70 ~ 90 bpm), not used any more
- Synchronous pacemaker: pacemaker stimulates the heart when needed (for example, pacemaker pulse may cause VT or fibrillation if it falls in the repolarization period following a spontaneous ventricular contraction)
  - Demand pacemaker (Fig. 13.3): timing circuit of a fixed rate of 60 ~ 80 bpm but with a feedback and reset, pacemaker is in standby mode if a normal heart contraction occurs within a fixed time
  - Atrial-synchronous pacemaker (Fig. 13.4): use an atrial electrode to detect atrial contraction, use ventricular electrodes to stimulate the ventricle synchronized with the atrial contraction
Combination of demand and atrial-synchronous pacemaker: operate as a demand pacemaker if no atrial conduction occurs.

Rate-responsive pacing (Fig. 13.5 and Table 13.1): pacemaker has a control algorithm to control the pulse generator using various physiological variables measured by implanted sensors.

- **External pacemaker**
  - IV percutaneous insertion of intracardiac electrodes
  - Patients in ICU or waiting for internal pacemaker implantation (a few days of use)
  - Patients recovering from cardiac surgery to correct temporary conduction disturbances
  - Emergency use: external transcutaneous cardiac pacemaker, 80 mA pulse, 50 cm² electrodes on the chest, painful

- **Power supply:** primary and secondary battery
  - Lithium iodide battery: 2.8 V open-circuit voltage, high source resistance

\[ 2\text{Li} + \text{I}_2 \rightarrow 2\text{LiI} \quad (\text{cathode: } \text{Li} \rightarrow \text{Li}^+ + e^-, \text{anode: } \text{I}_2 + 2e^- \rightarrow 2\text{I}^-) \]

- **Timing circuit:** when a stimulus should be applied to the heart?
  - Microprocessor control or quartz crystal control
  - Complex logic circuits
  - Rate: 60 ~ 150 bpm

- **Output circuit:** generate the optimized electric stimulus pulse by the triggering from the timing circuits
  - Constant-voltage amplitude pulse: 5.0 ~ 5.5 V, 500 ~ 600 µs
  - Constant-current amplitude pulse: 8 ~ 10 mA, 1.0 ~ 1.2 ms

- **Package**
  - Bio-compatibility
  - Protection of internal circuits from a corrosive environment
  - Minimal volume and mass
  - Titanium or stainless steel
  - Sealing: special electron beam or laser welding techniques

- **Lead wires** (Fig. 13.2)
  - Good electrical conductor
  - Mechanically strong (constant motion of the beating heart, patient movement)
  - Good electrical insulation (stimulation of other tissues, current shunting)
  - Interwound helical coils of spring-wire alloy molded in a silicone-rubber or
polyurethane cylinder

- Electrodes (Fig. 13.2)
  - Locations: epicardial, intramyocardial, or endocardial (intraluminal, electrodes are introduced through a shoulder or neck vein)
  - Polarity: unipolar (one electrode within the heart) and bipolar (two within the heart)
  - Same material as lead wires: platinum, platinum alloys, stainless steel+carbon+titanium, Elgiloy, MP35N

Figure 13.2 Two of the more commonly applied cardiac pacemaker electrodes
(a) Bipolar intraluminal electrode. (b) Intramyocardial electrode.

Figure 13.5 Block diagram of a rate-responsive pacemaker
**Bladder Stimulators**

- Urinary incontinence and other neurological bladder dysfunction
- Urinary incontinence
  - Weak sphincter muscle surrounding the urethra
  - Increased pressure within the bladder due to coughing or laughing
  - Neurologically excited excessive contraction of the detrusor muscle of the bladder
- Electrical stimulator for urinary incontinence
  - Electrodes in or near the muscles or nerves involved in sphincteric control of the urethra (implantation, vaginal or anal insertion)
  - Pulse duration of 0.5 ~ 5 ms for muscle electrodes or 100 ~ 400 ms for neural electrodes
  - Pulse repetition rate of 20 ~ 100 pulses/s
  - Average stimulating current of about 1 mA
  - Transcutaneous RF powered electric stimulator (Fig. 13.6): for continuous stimulation
- Electrical stimulator to help patients void
  - Externally controlled stimulator causes the detrusor muscle to contract
- Multiple electrodes on or within the bladder wall or on the spinal nerves that innervate the bladder
- Electrical stimulator for sexual function in men with spinal cord injuries
- State of the art
  - Very small (2 mm in diameter) stimulator using microelectronics and microfabrication ⇒ can be injected into a muscle without surgical incision
  - Receives power from external device by transtcutaneous RF transmission
  - Multiple implanted stimulators can communicate with an external controller

![Diagram](image)

**Figure 13.7 A stimulator system for use on stroke patients suffering from gait problems associated with drop foot.**

**Muscle Stimulators**
- In physical therapy to determine the contractibility of a muscle
- Exercise of the temporary paralyzed muscle from muscle atrophy due to disuse: prevent the reduction of the muscle mass
- Functional electric stimulation (FES)
  - Muscle paralysis due to neurologic injuries
  - Many electrodes with different stimulation sequence from a controller produce movement
  - Patient controls the stimulators using normal muscle contractions (ex, contralateral shoulder)
• Dropfoot prosthesis (Fig. 13.7)
  □ Patients with strokes
  □ Gait problem known as dropfoot (unable to lift the ball of the foot ⇒ susceptible to tripping)
• Stimulators
  □ Mostly constant-current types charge transfer per pulse is constant for varying load impedance
  □ Pulse current of 2 ~ 20 mA with pulse duration of 1 ms
  □ Peak voltage of 3 ~ 30 V at the electrodes depending on the load

_Cochlear Prosthesis_
• Patients with hearing impairment from dysfunction of the sound-transducing apparatus of the middle and inner ear
• External unit and implanted unit (Fig. 13.8)
• Electrodes
  □ Inserted into the scala tympani, face the basilar membrane
  □ Fine wires cast in an elastomer (silicone) or an array of thin-film deposited electrodes on a flexible polymer substrate
• Encoding of speech into stimulus patterns ⇒ limited recognition of words

![Figure 13.8 Block diagram of cochlear prosthesis](image)

_Visual Prosthesis_
• Electrical stimulation of the occipital cortex and the optic nerve ⇒ sensation of light for a certain types of blindness
• Miniature array of stimulating electrodes
• Research area

_Pain Suppression and Transcutaneous Nerve Stimulation_
• Postoperative pain or pains related with terminal cancer
• Battery-powered or transcutaneous RF-powered stimulators
• Gate-control theory of pain: stimulation of certain neurons can have an inhibitory effect on the transmission of pain information through peripheral nerves to the spinal cord
• TENS
  □ From monopolar rectangular to biphasic spike pulses
  □ Modulations: amplitude, width, rate, or burst
  □ Up to 60 V and 50 mA, 2 ~ 200 pulses/s, 20 ~ 400 ms pulse width, 2 per second burst rate
  □ Wide variety of skin surface electrodes (ex, strips of silicone elastomer made conductive by loading with carbon particles)
• Pain suppression effect is not well understood, Placebo effect (?)

13.2 Defibrillators and Cardioverters

Figure 13.9 (a) Basic circuit diagram for a capacitive-discharge type of cardiac defibrillator. (b) A typical waveform of the discharge pulse. The actual waveshape is strongly dependent on the values of \( I, C, \) and the torso resistance \( R_L \).

- Cardiac fibrillation
  - Asynchronous contractions of myocardial cells
• Zero cardiac output ⇒ brain damage and death within 5 min
○ Defibrillator: defibrillation by electric shock using internal or external electrodes

**Capacitive-Discharge DC Defibrillators**
• Capacitive discharge circuit in Fig. 13.9

**Rectangular-Wave Defibrillators**
• Power control using SCR
• Less peak current
• No inductor
• Smaller size electrolytic capacitors
• No relay

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**Figure 13.10 Electrodes used in cardiac defibrillation** (a) A spoon-shaped internal electrode that is applied directly to the heart. (b) A paddle-type electrode that is applied against the anterior chest wall.

**Defibrillator Electrodes**
• Need an excellent contact to minimize heat dissipation at the electrode-skin contact ⇒ force activated switch
• Safe to use: good insulation to protect the operator
• Spoon-shaped internal electrode in Fig. 13.10
• Paddles in Fig. 13.10: external electrodes with about 100 mm in diameter, requires electrolyte gel for good contact
• Disposable electrodes
  □ Large pregelled ECG electrode with a 50-cm\(^2\) pregelled sponge backed by foil and surrounded by foam and pressure-sensitive adhesive
  □ Metal foil faced with conductive adhesive polymer, entire surface is pressure-sensitive

**Cardioverters**
• Combination of cardiac monitor and defibrillator (Fig. 13.11)
• Defibrillation to treat atrial arrhythmia (atrial tachycardia or flutter)
• Avoid any electric shock during the T-wave since this may produce ventricular fibrillation
• R-wave controlled switch ⇒ defibrillator is synchronized to the ECG signal ⇒ output occurs immediately after R-wave (30 ms delay)
• Can observe ECG on the cardioscope for the effectiveness of the therapy

![Diagram of ECG system](image)

**Figure 13.11 A cardioverter** The defibrillation pulse in this case must be synchronized with the R wave of the ECG so that it is applied to a patient shortly after the occurrence of the R wave.

**Implantable Automatic Defibrillators**
• Internal electrodes requires less energy (5 ~ 30 J) for defibrillation and achieves earlier defibrillation
• Sensing means for cardiac fibrillation or tachyarrhythmias: electrical and mechanical signals
• Power supply and energy storing element
• Similar to pacemaker for the treatment of bradyarrhythmias

13.3 Mechanical Cardiovascular Orthotic and Prosthetic Devices

 Mechanical devices with electronic instrumentations
  • Monitoring of hemodynamics
  • ECG, aortic and central-venous pressure waveforms
  • O₂ saturation and \( P_{O_2} \)
  • Monitoring of the device itself for any malfunction (gas leakage, blood loss, etc)

Cardiac-Assist Devices
• Aortic-balloon system or intraaortic balloon pump: a long sausage-shaped balloon is introduced into the aorta through a femoral artery
  ☐ Operation controlled by a sophisticated electronics using ECG or pressure signal
  ☐ At ventricular contraction, balloon collapse by suction \( \Rightarrow \) blood easily enters the aorta
  ☐ After the aortic valve closes, balloon is inflated by pressurized CO₂ gas (soluble in blood, less chance of gas embolism) \( \Rightarrow \) forces blood into the body
• VAD (ventricular assist device)

Pump Oxygenators
• During cardiac surgery (open-heart surgery), pump oxygenator replaces the functions of the heart and lung
• Connected between the superior and inferior venae cava, between the right atrium and femoral artery, or femoral-artery-to-femoral-vein-bypass to keep all cannula away from the heart
• Pumps
  ☐ Roller pump or multiple-finger pump with disposable tubing
  ☐ Pulsatile pump with appropriate check valves
• Oxygenators
  ☐ Film type: a large-surface-area film of blood is drawn into contact with a nearly 100 % O₂ atmosphere by rotating disks
  ☐ Membrane type: blood flows through fine tubes of a membrane permeable to gas, better for the blood since blood has no direct contact with gas (less chance of
emboli formation)

- Extra corporeal membrane oxygenator (ECMO) for infants with severe lung disease

![Diagram of a pump oxygenator](image)

**Figure 13.12 Connection of a pump oxygenator to bypass the heart** A disk-type oxygenator is used with a roller pump. Venous blood is taken from a cannula in the right atrium, and oxygenated blood is returned through a cannula in the femoral artery.

**Total Artificial Heart**

- Implanted in thoracic cavity (ex: Jarvic 7)
- Pneumatic or electric connection to an external drive apparatus
- Maximal survival of 620 days after surgery (many technical problems need to be solved)
- Role as a bridge until a natural donor heart is available

### 13.4 Hemodialysis

- Artificial kidney (Fig. 13.13): periodically connected to the circulatory system of uremic patients to remove metabolic waste products from the blood
  - Exchanger: dialysis chamber with a compartment for patient's blood, another compartment for the dialysate, and a semipermeable membrane between them
• Dialysate delivery system:
  ✗ Three basic types of exchangers
  • Coil dialyzer: the most commonly used
    ◦ A tube made of semipermeable-membrane material wound into a coil
    ◦ Dialysate are circulated between individual turn of the coil
    ◦ Coil must be long for a large effective surface area of mass transport ⇒ high resistance to blood flow ⇒ needs a pump in series with the arterial blood supply ⇒ increased pressure improves the ultrafiltration rate of the membrane
    ◦ Dialysate needs to be forcibly circulated for rapid mixing ⇒ another pump is required
  • Parallel-plate dialyzer
    ◦ Similar to multi-layer parallel-plate capacitors with plates made of semipermeable-membrane material
    ◦ Blood circulates between alternate pairs of plates and dialysate circulates between the other plates
    ◦ Blood flows in thin sheets to maximize the surface-to-volume ratio
  • Hollow-fiber kidney
    ◦ 10,000 ~ 15,000 hollow fibers (external diameter of about 0.2 mm and a length of about 150 mm) connected in parallel
    ◦ Blood flows in the lumen of the fibers and dialysate surrounds them
    ◦ Walls of the fibers serve as semipermeable membrane
    ◦ Dialysate is pumped through the space surrounding fibers
  ✗ Dialysate delivery system (Fig. 13.13)
    • Metering pumps mix the concentrated dialysate with water
    • Another pump circulate the dialysate through an exchange chamber
  ✗ Electronic instruments
    • Leakage in the semipermeable membrane ⇒ immediate blood loss
      ◦ Optical leakage detector (colorimetric or optical density change): dialysate is a clear liquid and blood is red
    • Major leaks or clotting
      ◦ Monitoring of pressure change in the blood compartment
    • Any abnormality in gross concentration of electrolytes in dialysate
      ◦ Measure the conductivity of the dialysate in mixing chamber using impedance technique
    • Air bubble in the blood stream life-threatening air emboli bubble detector before
blood reenters the body (also used in pump oxygenator) ⇒ impedance technique

Figure 13.13 An artificial kidney
The dialysate delivery system in this unit mixes dialysate from a concentrate before pumping it through the exchange chamber.

13.5 Lithotripsy

- Kidney stones great discomfort and loss of kidney function
  - Lithotomy: open incision surgical technique
  - Lithotripsy: noninvasive or minimally invasive surgical technique, disintegration of the stone in vivo into small particles so that they can pass through the urinary tract
- Percutaneous lithotripsy
  - Small incision ⇒ a probe insertion under X-ray fluoroscopy
  - Mechanical shock wave by controlled electric discharge (spark) or ultrasonic wave break up the stones
  - Pieces are removed using other probe or passed through the urinary tract
- Extracorporeal shock-wave lithotripsy (Fig. 13.14): entirely noninvasive
  - Many mechanical shock waves to an ellipsoidal reflector
  - Waves are focused at one focal point several centimeter away from the reflector
• Patient and reflector are submerged in demineralized and degassed water on a gantry support
• Biplane X-ray system positions the patient so that the stone is located at the focal point
• High-voltage (about 20 kV) pulse at the spark gap produces a shock wave
• The same X-ray system monitors the disintegration of the stone
• Operator adjusts the patient position
• Up to 2000 shocks are used to reduce the stone into 1 ~ 2 mm fragments
• Most patients resume full activity within two days

Figure 13.14 In extracorporeal shock-wave lithotripsy, a biplane x-ray apparatus is used to make sure the stone is at the focal point of spark-generated shock waves from the ellipsoidal reflector.

13.6 Ventilators

Ventilator or respirator assists patients in ventilating their lungs in respiratory therapy
• Controller: machine determines respiratory ventilation
• Assister: machine assists the spontaneous ventilation of a patient

Ventilator
• Negative-pressure ventilator (more physiological): patient body is in a sealed chamber ⇒ chamber pressure is reduced ⇒ negative pressure within the thorax ⇒ inhale ⇒ return chamber pressure to atmospheric ⇒ lungs recoil and exhale
• Positive-pressure ventilator: blow air into the lungs by increasing the pressure in
the trachea (inhale) ⇒ lungs recoil when the positive pressure is removed (exhale)

Ventilator
• Time-cycled
  □ Used with negative-pressure ventilator
  □ Time period for negative pressure is controlled by microprocessor and
    solenoid valves
• Volume-cycled (or -controlled):
  □ It does not cycle until a given volume of air has been administered
  □ Pressure override valve for safety: machine cycles if pressure exceeds a
    predetermined value before the administration of the required volume of air
• Pressure-cycled
  □ Air is administered to a patient until the pressure reaches a predetermined
    limit

Continuous-positive-airway-pressure device for newborns (Fig. 13.15)
• Monitor the properties of the inspired gas and generate alarms
• Pressure sensing: semiconductor strain-gage pressure sensor
• Temperature sensing: thermistor and bridge circuit
• Fraction of O₂ in the inspired air (FI O₂): fuel-cell type O₂ sensor generates a
  current proportional to $P_{O_2}$, temperature compensation is needed
• ADC and microprocessor circuitry

High-Frequency Ventilators
• Ventilation frequency is much higher than normal respiration rate
  □ Frequency: 60 ~ 3600 min⁻¹ or 1 ~ 60 Hz (900 min⁻¹ or 15 Hz is popular)
  □ Inspiration-to-expiration ratio: 1:1 ~ 1:4
  □ Waveshapes: sinusoidal, rectangular
  □ Volume of air moved per breath is on the order of the anatomical dead space of
    the pulmonary system
• Principle
  □ Increased mixing in the airway due to turbulence, asymmetric velocity profiles,
    and molecular diffusion at high frequencies
  □ Mixed gas in the airway reaches the alveoli
• Instrumentation
  □ Large loud speaker can generate the high-frequency pressure waves
- High-frequency jet ventilation uses a small-diameter tube in the trachea to inject short pulses of high-pressure oxygen at high frequencies
- Piston pump can alternately compress and depress a column of gas that is coupled to the airway through an endotracheal cannula
- Motor-driven rotating valve can be used to connect the airway alternately to a high-pressure and a low-pressure source of gas

**Figure 13.15**
An instrumentation system for recording pressure, temperature, and percentage of $O_2$ in inspired air coming from a continuous-positive-airway-pressure apparatus.

### 13.7 Infant Incubators
- Premature newborns are unable to regulate their temperature
- Infants in a chamber with a maintained and elevated temperature requires minimal $O_2$ good for premature newborns who are more susceptible to respiratory problems
Warm-air convection incubator
- Temperature-controlled air is passed through the chamber: proportional control system in Fig. 13.16, control parameter is either the air temperature or skin temperature of the baby
- Overheating alarm and/or heater power reduction switch
- Patients can be accessed only through arm ports

Radiant warmer incubator
- Open structure ⇒ easy access to infants
- Radiant heating element (electric heater with heat reflector) produces heated air and heat convection
- Thermistor on the chest or abdomen of the infant measures skin surface temperature ⇒ proportional control of the current in heating element
- Thermistor is covered by a thermal insulator (foam pad with special tape) to avoid direct heating from the heat source

Apnea monitor
- Transthoracic impedance
- Movement of the baby using a displacement detecting pad
- Movement of the baby's chest wall
- Alarm control for 15 ~ 30 s of apnea

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**Figure 13.16** Block diagram of a proportional temperature controller used to maintain the temperature of air inside an infant incubator.
13.8 Drug Delivery Devices

- Continuous drug administration within a narrow therapeutic range

**Drug Infusion Pumps**

- IV therapy using a gravity-feed fluid reservoir
  - Inexpensive, widely used
  - Not accurate
- Volumetric controller
  - LED and photodetector detects drops in a drip chamber of a conventional IV set
  - A valve between the fluid reservoir and the drip chamber is controlled
- Peristalsis pump (such as roller pump): inner diameter of the tubing and the propagation velocity of peristalsis wave determine the rate
- Stepping motor with an angular velocity control by digital electronics (Fig. 13.17)
  - Precise control of infusion rate
- Operating mode
  - Open-loop system: fixed infusion rate (manual control)
  - Closed-loop system: sensor $\Rightarrow$ control algorithm $\Rightarrow$ infusion rate

![Block diagram of the electronic control system for a fluid or drug delivery pump](http://ejwoo.com)

**Ambulatory and Implantable Infusion Systems**

- Miniature insulin pumps: mostly open-loop (lack of implantable glucose sensor)
- Implantable drug delivery
  - Miniature pump (slightly larger than cardiac pacemakers)
  - Drug reservoir: concentrated agent in a constant pressure, percutaneous refill
  - Long thin capillary tube: high resistance, steady and slow infusion to the vein
  - Drug delivery to a specific tissue: cancer chemotherapy
  - Artificial pancreas (Fig. 13.18): implantable closed-loop drug delivery system,
no usable glucose sensor yet

- Long-term drug delivery using passive device
  - Polymer matrix with drug is implanted in tissue
  - Drug is slowly dispersed throughout the body through capillaries
  - Thin polymer cylinder is injected beneath the skin to deliver the hormone progesterone for several months to women
  - Simple, open-loop

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**Figure 13.18** A block diagram of an implantable artificial pancreas showing the major components of the system.

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**Anesthesia Machines**

- Administration of volatile anesthetic agents to patients in OR through their lungs
- Gas supply and delivery system
  - Oxygen and nitrous oxide are mixed in the desired proportions
  - Flow is adjusted using flowmeters and valves
- Vaporizer
  - Gas is bubbled through or passed over the volatile anesthetic agent in the liquid phase
  - Gas flow rate determines the amount of anesthetic agent administered
- Patient breathing circuit: closed circuit
  - Delivery of anesthesia-producing gases to the patient via a one-way valve through one section of tubing
  - Removal of expired gases from the patient via another one-way valve through different section of tubing
  - Expired gases $\Rightarrow$ carbon dioxide absorber $\Rightarrow$ reintroduced into the inspiratory line
- Expired gases ⇒ scavenging system ⇒ atmosphere
- Reservoir bag of low-pressure gas to manually assist ventilation if needed
- Can be connected to a ventilator

### 13.9 Surgical Instruments

**Electrosurgical Unit**

- Electrocautery apparatuses: cutting and hemostasis in OR
  - Incise tissue
  - Destroy tissue through desiccation
  - Stop bleeding by causing coagulation of blood
- RF spark between a probe and tissue ⇒ local heating ⇒ damage to tissue
- Basic electrosurgical unit (Fig. 13.19)
  - High-power high frequency generator
  - Modulator: waveform generation
  - Coupling circuit: output control
- Output
  - Different waveforms (Fig. 13.19) for different jobs
  - RF sine wave frequency: 250 ~ 2000 kHz
  - Pulse rate: 120 pps
  - Open-circuit voltage: 300 ~ 2000 V
  - Power into a 500-Ω load: 80 ~ 200 W
- Cutting: higher frequency, voltage, and power
  - CW RF source with some amplitude modulation
  - Frequency: 500 kHz ~ 2.5 MHz
  - Open-circuit voltage: up to 9 kV
  - Power: 100 ~ 750 W
- Bloodless cutting
  - Blended waveform
  - Frequency: same as cutting
  - Higher voltage and power than cutting alone
- Block diagram (Fig. 13.20)
- Active electrodes
  - Scalpel-like probe
  - Hand switch on the handle
- Dispersive electrodes
- Large, low current density return electrode
- Large reusable metal plate under the buttocks or back
- 70-cm² disposable electrode on the thigh: gel-soaked sponge, metal foil backing, foam and pressure-sensitive adhesive, resistive
- Thin Mylar insulator backed by foil with its entire face coated with pressure-sensitive adhesive: capacitive
- Good contact to avoid any hot spot (high current density, high temperature)

Figure 13.19 (a)
Block diagram for an electrosurgical unit. High-power, high-frequency oscillating currents are generated and coupled to electrodes to incise and coagulate tissue. (b) Three different electric voltage waveforms available at the output of electrosurgical units for carrying out different functions.
Radiofrequency (RF) Catheter Ablation

- Localization of extra-conductive pathways within the heart
- RF current at about 500 kHz is delivered using a catheter-tip active electrode
- Dispersive electrode on the remote site (skin surface)
- Temperature-controlled RF ablation using a thermistor on the tip of the electrode
- Heated tissues with a temperature higher than 50 °C are destroyed (ablated) to cease abnormal conduction

13.10 Therapeutic Applications of Laser

- Focused coherent light with high intensity ⇒ tissue vaporization ⇒ coagulated incision
- Power to cut tissues ranging from skin to bone: 25 ~ 100 W ⇒ large laser
- Optical couplings (lens, mirror, fiber) can be cumbersome
- Control of breeding
  - Photocoagulation and heating
  - Fiber-optic endoscope ⇒ coagulation of bleeding gastric ulcers
- Laser photocoagulator in ophthalmology: repair detached retina
- Dentistry
- Oncology
- Clinical laboratory