Lecture Six

Ambulatory Cardiac Monitor

Introduction

Ambulatory cardiac monitoring aims to diagnose cardiac abnormalities by continuously recording ECG over 24–72 hours and to study and evaluate symptoms indicative of cardiac arrhythmias leading to palpitations, dizziness, or syncope. Some ambulatory monitors also have an event monitor feature activated when the person notices symptoms. Ambulatory monitoring of ECG is commonly called 'Holter cardiography', after Dr. Norman Holter who introduced this concept in 1962.

Principle Ambulatory cardiac monitoring is advised when a person has symptoms of abnormal working of the heart, but a resting ECG does not indicate a clear cause. The person is asked to wear the ECG electrodes on the chest, and the electrodes are connected by wires to a small, portable recording device. This can detect certain abnormal heart rhythms that may occur only once a while or they may occur only under certain conditions, such as stress or activity. Currently, there are a number of devices that have been developed for ambulatory ECG monitoring. They include Holter monitor, event recorders, real-time continuous cardiac monitoring systems, and implantable loop recorders. Each type of ambulatory monitor has unique features related to the duration of recording time and ability to send the recordings to a central monitoring station.

There are two categories of cardiac monitors: external monitors and implantable or insertable monitors.

● *External monitors*: They are designed for short-term use and include traditional heart monitors commonly known as Holter or event monitors for diagnosing heart rhythm problems. They are typically attached to the outside of a patient's body for between 24 hours and 30 days. Another type of external monitor is the patch type of monitor.

● *Implantable or insertable monitors*: They are designed for long-term use to determine causes of infrequent, unexplained arrhythmias. The small device is implanted just under the skin of the chest during an outpatient procedure. The device detects and records abnormal heart rhythms over long periods of time, which could be up to three years.

Holter Monitor

The basic components of a Holter monitor consist of a portable ECG recorder and a Holter analyser or scanner.

ECG Recorder

The recorder is a compact, lightweight ECG machine that records the electrical activity of the heart continuously while the subject is not in the hospital or the physician's office. The recording may be done for three or more leads, usually for 24 hours or longer. The ECG electrodes are connected to a small piece of equipment that is attached to the patient's belt or hung around the neck, which keeps a log of the heart's electrical activity throughout the recording period. The patient is asked to maintain a diary to document the time when symptoms are experienced and their description. After the one- to two-day recording period is completed, the patient returns the monitor to the doctor. The data stored is downloaded to a local workstation. The computer-scanned Holter recording is read by a trained person and the physician for final review and interpretation.

The current state of Holter technology uses small recorders (size, 70 mm ×95 mm ×20mm; weight, about 190g) using a flashcard to record and store data from several ECG leads attached to the patient's chest as shown in Figure 1. The digital recorder has high memory, and it is possible to have the monitoring time much more than 24 hours if required. In addition, the recorded signals are digital, and can be transmitted to the monitoring centre by any digital transmission system. The ECG information can be processed quickly with computer software. This facilitates early availability of the patient's report, allowing treatment to be started without much delay.

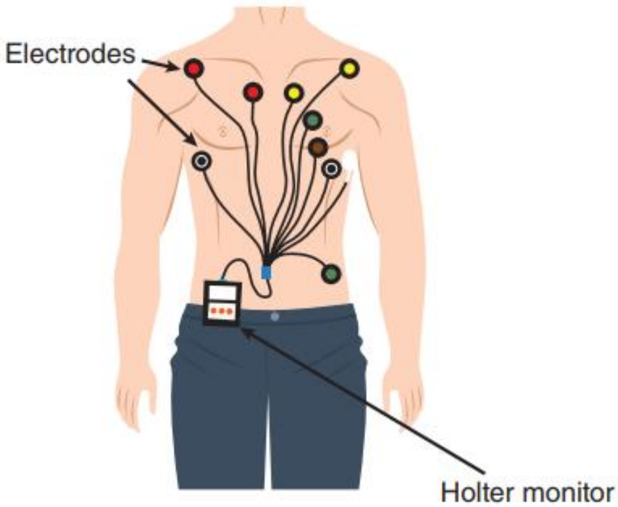

Figure 1. Holter monitor in use.

Newer Holter monitors are available with up to two weeks of recording capability. The recorders are operated by a patient-activated event marker that also specifies the time of the day. The major advantages of Holter monitoring are the ability to continuously record ECG data and that patient participation is not required in the transmission of data. The recorder is more likely to detect abnormal heart rhythm and can also help evaluate the patient's ECG during episodes of chest pain due to cardiac ischemia.

Figure 2 illustrates the block diagram of a portable ECG recorder. The design shown has fewer patient electrodes with just two leads for acquisition of ECG and one driven lead. The basic analog front end (AFE) allows to acquire ECG signals from multiple channels, which are multiplexed. A typical AFE from analog devices is the ADAS-1000 family, which can be used with three or five electrodes and a driven lead. It also includes necessary circuitry such as 'lead off' detection and defibrillator protection main filter. It also contains analog signal conditioning circuitry, A/D conversion, power management functions, and digital I/O to interface directly to a suitable microcontroller. The AFE chip can communicate via a basic SPI interface with the microcontroller and consumes only about 20 mW of power. The low power consumption is necessary for a portable ECG recorder. The recorder has also a provision for wireless transmission of ECG information over a short range.

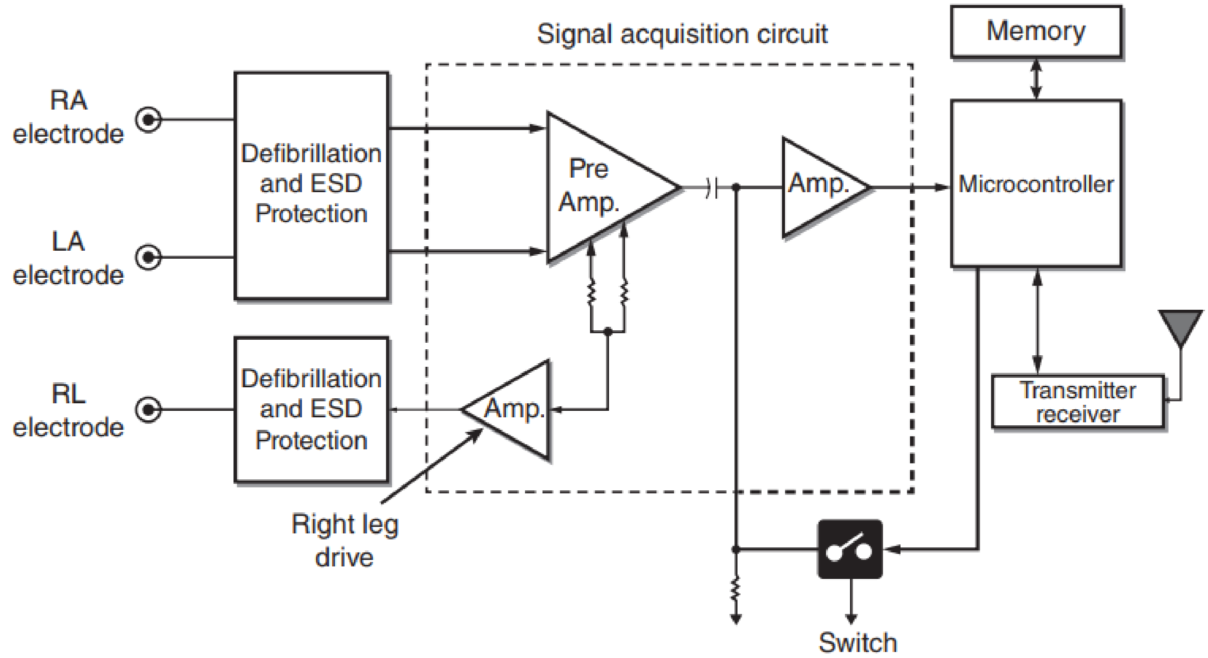

Figure 2. Block diagram of a single-lead Holter monitor.

Holter Analyzer (Scanner)

One major problem, which is inevitably faced when examining long-term recordings, is the huge quantity of data that becomes available in a 24-hour recording easily containing in excess of 100000 beats. A convenient way of managing enormous ECG data would be to perform real-time rhythm analysis in the recorder itself and discard normal signals instead of recording the total information. Earlier replay and analysis equipment relied on visual inspection of the replayed signals in accelerated time. With manual observer detection, the doctor watches for clues of abnormal beats while playing the tape back at 60–120 times real time. The process is exceedingly tedious and time-consuming and causes high boredom, and consequently fatigue levels can be subject to error. The use of computers for ECG data analysis has revolutionized the process of automatic analysis of the ECG data and offers features such as auto analysis and complete editing capabilities, thus allowing a fast and accurate report. They also display R–R interval histograms and look for essential arrhythmic conditions such as bradycardia, tachycardia, dropped beat, and premature beat. When such abnormalities are recognized, they are written out on a pen recorder for subsequent examination.

Holter analysis systems typically use formal and heuristic feature extraction technique to analyse, for example QRS morphology, QRS width, QRS absolute area, QRS offset, and QRS peak-to-peak amplitude and prematurity. Then, the individual QRS complexes are classified into Normal, Ventricular, Paced, Artifact, or others. The types of analysis generally carried out include mean heart rate, minimum and maximum heart rates, premature ventricular arrhythmias, runs of three or more ventricular ectopics, premature supraventricular ectopic beats, supraventricular tachycardia, and ST segment measurements. Colour-coded beat identification on a computer monitor greatly enhances the ability to discriminate and validate the computer analysis of abnormal beats. Pacemaker analysis is done to analyse the pacemaker's functioning and the heart's response. A typical printout of Holter analysis of multichannel data is shown in Figure 3.

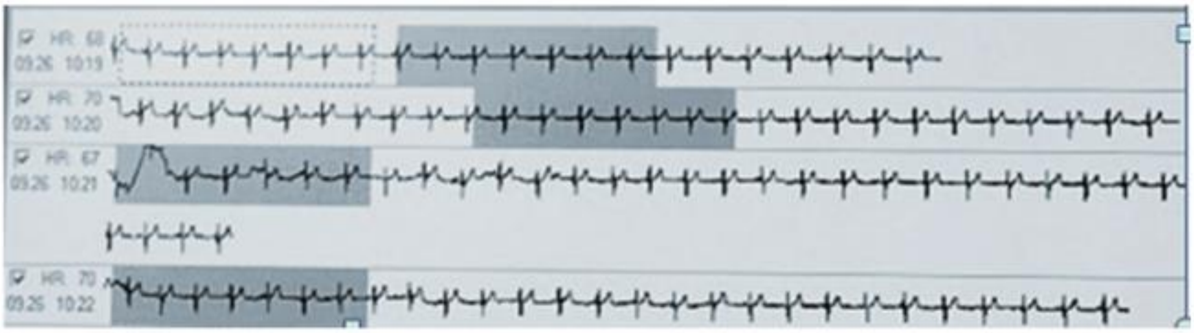

Figure 3. Typical display of ECG analysis of a Holter monitor. The patched portions indicate abnormal ECG patterns.

Event Recorder

Event or patient-activated recorders are not conventional, continuous Holter recorders, but systems that can provide limited monitoring for a specific type of cardiac event. This device is also worn during normal daily activities, including sleeping, but can be taken off during showers and baths. Small electrodes attached to the chest are connected to a small box about the size of a portable tape player and worn on a belt or shoulder strap. A typical event recorder from M/s Northeast Monitoring, United States, is shown in Figure 4. This device has a combination 14-day Holter plus 30-day event recorder integrated into a single unit that is designed for deployment to patients in either ‘Holter’ or ‘Event’ mode. Holter mode is available with 3-, 5- or 7-lead patient cables to capture elusive cardiac events – every beat, all the time. When it is deployed as an event monitor, it uses a 2- or 3-lead cable. The data is analyzed with proprietary software, which is transmitted via telephone or read directly from the speech discrimination (SD) data card.

Figure 4. Typical event recorder from M/s Northeast Monitoring, United States.

When the person feels some abnormal symptoms, he/she presses a button and the recorder is activated. The monitor records the event for the 60seconds prior to pushing the button and up to 60 seconds after the event. Thus, event recorders document and record abnormal beats but provide no analysis. The recording can be sent immediately or saved and transmitted over the phone. A new form of this device has recently become available that allows automatic transmission of triggered events over the cellular network and there is no requirement for the patient to transmit the data. Event recorders are useful in detecting events such as myocardial ischemia by identifying ST segment changes and measuring heart rate variability in assessing a patient at risk.

Some event recorders are automatically triggered when slow, fast, or irregular heart rates are recognized. Once activated with such an event, data is stored for a programmable fixed amount of time before the activation and a period of time after the activation. These devices are generally referred to as external loop recorders (ELRs).

Real-Time Cardiac Monitoring Systems

Real-time continuous cardiac monitoring systems combine the benefits and overcome the limitations of Holter monitors and standard ELRs. They are worn continuously and are similar in size to the standard ELR. They automatically record and transmit arrhythmic event data from ambulatory patients to an attending monitoring station. With these devices, cardiac activity is continuously monitored by three chest electrodes that are attached to a pager-sized box. The collected data is then transmitted to a portable monitor that has a built-in cell phone and needs to be in proximity to the patient to receive signals. This monitor analyses the rhythm data continuously and automatically for presence of arrhythmia.

If an arrhythmia is detected, the monitor automatically transmits recorded data by wireless network or landline to a central monitoring station for subsequent analysis. Data can also be recorded through patient-triggered activation. The staff working at a monitoring station analyse live incoming patient data and contact the patient and/or the physician if an urgent intervention is required. This technology is referred to as mobile or real-time cardiac telemetry systems (MCOT).

The Heartrak Smart shown in Figure 5 from M/s Mednet Healthcare Technologies is a typical example of such a device that records and transmits real-time ECG data. To record an event, the patient presses the RECORD button and to transmit the event, the patient dials the toll-free Receiving Centre number. The Receiving Centre operates 24 hours a day, 365 days a year. The Heartrak Smart should be placed over the mouthpiece of the phone to transmit the stored ECG for analysis. The device includes 20 minutes of ECG memory and programmable features to meet various monitoring requirements. The patient can wear the monitor on his/her waist, place in his/her shirt pockets, or wear around his/her neck with a cord.

Figure 5. Real-time continuous cardiac monitoring system and Heartrak Smart from M/s Mednet Healthcare Technologies, United States.

ECG Patch Monitoring

With the developments in microelectronics and wireless technologies, wearable ‘on-body’ ECG patch monitoring devices have appeared to meet the needs of ambulatory monitoring. These devices are small, unobtrusive, and easy to use as shown in the Figure 6. The ECG patch is a hybrid system in which electronic circuit assembly and textile has been integrated on a flexible polyimide substrate. Such a system is highly flexible and stretchable and can fit body curves without causing any discomfort to the wearer.

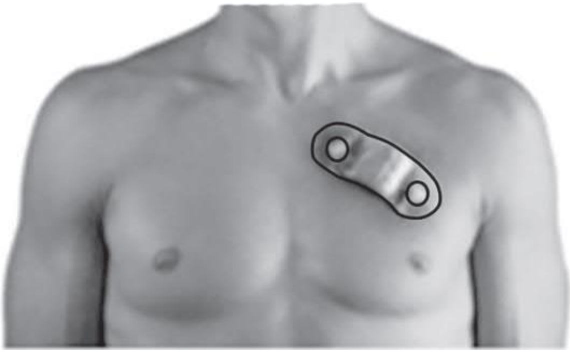

Figure 6. ECG patch in use.

ECG is acquired by using standard ECG electrodes that are attached to the body. It can therefore be used to monitor cardiac activity when the person is 'on the move' in daily-life conditions. The patch is a single-lead ECG monitor that is applied to the left pectoral region. The patch can be placed on the arm or on the leg for monitoring muscle activity (electromyogram, EMG).

A typical ECG patch monitor consists of a system-on-a chip that converts single channel analog ECG signals to digital format, a low-power Bluetooth low-energy processor (2.4 GHz) that transmits the data, and a lithium polymer battery (175 mAh). The device has a fork antenna and a snap-on connector for connection to the electrodes. The total size of the flexible core part is 60 × 20 mm^2. The signal from the wireless ECG patch can be sent to a receiver connected to a PC or to a data logger for later download on a computer. With this technology, analysis can be done at any time as the patients are continuously monitored and any cardiac events recorded are instantaneously forwarded directly to the monitoring centre, which is viewed by the physician or clinician who is alerted to the event. This results in immediate diagnosis and faster treatment.

Some patch devices typically include memory storage for medium-term use ranging from days to several weeks, depending on the device. One example of this technology is the Zio Patch (iRhythm Technologies, San Francisco, CA), a waterproof, single-use, continuous ECG monitor that can be worn for up to 14 days and returned for analysis and reporting to the medical consultant. The limitation of this technology is that the patch offers only single lead as opposed to the multiple channels available with conventional Holter monitoring. The patch can be configured for the automatic detection of any combination of the most commonly occurring arrhythmias, plus any patient-activated event. The recordings include 20 seconds pre-event and are configurable for up to seven minutes post-event. Recently, 3-lead ECG continuous long-term patch devices have also become available. These devices are targeted towards medical and research applications such as post cardiac surgery or stroke recovery patients and drug discovery companies.

Ambulatory ECG with Wearable Electrodes

A further development that overcomes the problem of carrying typically 6 to 10 wires worn around the body throughout the day is by the use of a wearable electrocardiogram (ECG) acquisition system implemented with planar fashionable circuit board (P-FCB)-based shirt. Dry electrodes are screen-printed directly on fabric that allows long-term monitoring without skin irritation. The ECG monitoring shirt exploits a monitoring chip with a group of electrodes around the body, and both the electrodes and the interconnection are implemented using P-FCB to enhance wearability. P-FCB allows the monitoring shirt to bend freely and to closely attach to the body, so a subject will feel comfortable during monitoring in everyday life.

The system is composed of P-FCB electrodes, the ECG monitoring chip, an 8051 microcontroller, an external memory, a debug interface, and a universal serial bus interface. The ECG monitoring chip includes an instrumentation amplifier with a programmable gain amplifier, an analog-to-digital converter (ADC), a compression accelerator, and an encryption block. The ECG monitoring chip is composed of an instrumentation amplifier with a programmable gain amplifier a 10-bit ADC and other associated circuitry and P-FCB electrodes. The electrodes are capacitively coupled to the instrumentation amplifier input.

Implantable Loop Recorders

The patients who experience very infrequent cardiac events would requiring long-term monitoring for detection of such abnormalities. This requirement is met by employing an implantable loop recorder, a thin device inserted just under the patient's skin in the chest area during an outpatient surgical procedure. These leadless devices as shown in Figure 7 record a single-lead ECG signal with two electrodes within the device. The device can be triggered automatically or by patient activation via placement of an activator over the device. When symptoms are felt, the patient places a handheld activator over the recorder to activate the storage of cardiac rhythms both retrospectively and prospectively for several minutes. The loop memory enables the device to be activated even after symptoms have resolved, which means that such devices can be used even in the presence of incapacitating symptoms, which normally prevent the activation of ECG monitoring in devices not having this feature. Auto-triggering technology can be adapted to memory loop devices as per predesigned programs. For example, the monitors can be programmed to detect heart rates greater than 175 bpm, less than 35–40 bpm, or an asystole of greater than three seconds. These devices also have provision of remote transmission of data and have a battery life in excess of 36 months. The 'Reveal' from M/s Medtronic USA is a typical example of an implantable loop recorder that is an auto-triggered or patient-activated rhythm recording device. The use of such implantable ambulatory monitors is considered medically necessary only in the small subset of patients who experience symptoms of cardiac problems infrequently that a prior trial of Holter monitor and other external ambulatory event monitors has been unsuccessful.

These devices are equipped with a memory loop and, once activated by the patient at the time of a symptom by means of an external activator, store a one-lead ECG tracing, both retrospectively and prospectively, for several minutes. By implementing dedicated algorithms and sensing parameters similar to those of implanted cardioverter defibrillators (ICDs) and pacemakers, the implantable cardiac monitors are also able to automatically detect any kind of arrhythmic event: from bradycardia to asystole and from atrial fibrillation to ventricular tachycardia.

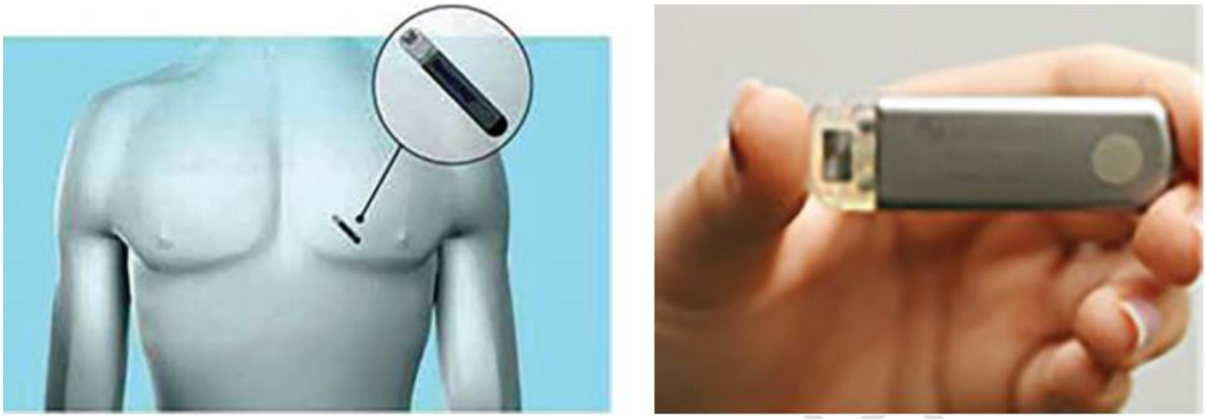

Figure 5.7 Implantable loop recorder. Source: With Courtesy of M/s Medtronic, USA.