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An introduction to cardiac monitoring and rhythm interpretation

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AN INTRODUCTION TO CARDIAC MONITORING AND RHYTHM INTERPRETATION

ABSTRACT

This article is the first in a series which will explore the identification and management of cardiac arrhythmias within the peri-operative care setting. To improve patient safety, the number of patients who are monitored within the recovery room is rising, whilst cardiac monitoring remains a fundamental requirement for patient care during the anaesthetic phase. Therefore, the role of the peri-operative care nurse requires an ability to interpret cardiac arrhythmias and to subsequently instigate the appropriate management.

The purpose of this preliminary article is to establish the basic principles that underpin the identification and management of arrhythmias. Cardiac physiology is reviewed and then applied to the derivation of the waveforms of the normal ECG. The article continues with a summary of accurate electrode placement and some tips for troubleshooting in the presence of 'artifact'. A systematic analysis tool, which can be easily applied to clinical practice, completes the article.

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Continuous electrocardiograph (ECG) monitoring is a key aspect of anaesthetic and recovery care nursing. Cardiac monitoring is a minimum requirement during the anaesthetic phase of patient care (The Association of Anaesthetists, 1994) and is increasingly being incorporated into recovery rooms to increase patient safety, therefore rhythm interpretation is a core skill for peri-operative nurses to acquire (Carrie et al, 2001). Technological advances have led to sophisticated monitoring systems which incorporate a variety of alarm systems, computerised rhythm analysis and assessment of haemodynamic parameters. These systems enable continuous evaluation of the patient's status and contribute to safe, effective patient care. However, the basic components of any cardiac monitoring system allow the appraisal of the electrical activity occurring in the heart during each cardiac cycle and enables the identification of arrhythmias should they occur (Bryson, 1997). It should always be remembered that the technical skills involved are only an adjunct to care and the old adage 'look at the

patient, not just the monitor' should always be borne in mind (Woodrow, 1998).

An ECG is a graphic representation of the electrical potentials generated in the heart and thus in order to understand what is seen on the cardiac monitor a brief revision of cardiac physiology is required.

Overview of Cardiac Physiology

The cardiovascular system participates in many of the homeostatic mechanisms within the body. It enables the distribution of essential substances to the tissues and the removal of by-products of cellular metabolism. The circulatory system comprises a pump connected to a series of tubules that enable the delivery of oxygen to the tissues and the transportation of carbon dioxide to the lungs. The heart is the muscular pump that propels the blood around two separate systems – the pulmonary and the systemic circulations.

Figure 1: Cardiac Anatomy

The heart has four chambers: two thin walled atria and two larger, more muscular walled ventricles (fig.1). Each chamber is surrounded by walls formed by millions of muscle cells (myocytes) which when stimulated will contract together, forcing blood in a forward direction. When a chamber of the heart fills with blood, it is

termed 'diastole'. The term 'systole' refers to the contraction of the chamber and the ejection of its volume of blood.

Connected to the chambers are valves that facilitate the unidirectional blood flow generated by the heart. The valves that lie between the atria and the ventricles are known as the 'Atrioventricular' valves, with the mitral valve on the left side of the heart and the tricuspid valve on the right. The semilunar valves are connected to the ventricles and the vessels that arise from them i.e. the aortic valve lies between the left ventricle and the aorta, with the pulmonary valve between the right ventricle and pulmonary artery.

The heart can be perceived as two separate pumping circuits: the right atrium and ventricle generating the force for the pulmonary circulation and the left atrium and ventricle creating a pump for the systemic circulation. However, the pumps operate in synchrony, so that the atria contract together followed by the ventricles.

The Pulmonary Circulation

The right side of the heart will pump blood around the pulmonary circulation. Deoxygenated blood is delivered to the right atrium via the vena cavae and is released into the right ventricle when the tricuspid valve opens. The right ventricle then fills with blood (diastole) and once full, the tricuspid valve will close. The ventricular muscle then contracts, expelling the blood into the pulmonary artery (systole), crossing an open pulmonary valve. Once the blood has been ejected, the valve closes, enabling the ventricle to fill with blood from the atria once again.

The deoxygenated blood now within the pulmonary artery is distributed throughout the pulmonary capillary bed. This facilitates the transfer of oxygen from the alveoli to the haemoglobin within the blood cells. Once saturated with oxygen, the blood returns to the heart via the pulmonary veins, which empty into the left atrium. The pulmonary circulation is now complete.

The Systemic Circulation

The left side of the heart propels oxygenated blood around the systemic circulation, including the coronary arteries, the brain, the gut, the kidneys and the reproductive organs. The volume of blood ejected from the left ventricle is known as the 'cardiac output'.

The blood within the left atrium, which is now saturated with oxygen empties into the left ventricle across an open mitral valve. Once ventricular diastole is complete, the mitral valve will close and the myocytes will simultaneously contract. Once the pressure within the left ventricle has risen, the aortic valve will be forced open and the blood will be ejected into the aorta, from where it will be transported via the arteries and capillaries to each tissue within the body.

The body's tissues have a high affinity for oxygen at this time, facilitating the diffusion of this substance from the blood into the cells. Conversely, the haemoglobin now develops a strong affinity for carbon dioxide, which it readily takes up. The blood now returns to right atrium, via the venous system, and thus to the pulmonary circulation for the deposition of CO₂ and the uptake of O₂.

The Conduction System

In the healthy heart, the chambers contract in synchrony – the atria followed by the ventricles, to optimise the cardiac output. This process is brought about by the rapid transmission of an electrical signal from cell to cell within the cardiac muscle wall. The spread of this electrical impulse occurs in an organised manner, enabling the synchrony described above.

Within the heart wall, there are two types of myocyte – contractile myocytes and pacemaker myocytes. Each contractile myocyte receives an electrical stimulus that tells them to contract. The electrical stimulus is generated by the pacemaker myocytes, which together form the conduction system. The conduction system discharges and delivers the impulses in a regular, organised pattern that triggers the co-ordinated contraction of the atria and the ventricles.

Unlike other types of muscle cell, the pacemaker myocytes have the ability to generate an electrical impulse without receiving a stimulus from the brain. Thus when the heart is disconnected from the nervous system, the heart will continue to beat, as is seen in heart transplant operations.

The pacemaker cells lie together to form the conduction system (*Fig.2*). The healthy conduction system ensures that each myocyte receives an electrical stimulus to enable it to contract in synchrony, forming the cardiac cycle. The formation and passage of the electrical stimulus through the heart will now be described.

"The heart can be perceived as two separate pumping circuits"

Figure. 2 Diagram of the Conduction System

Atrial Conduction

The sino-atrial node (SA node) is located within the right atrium. It generates an electrical impulse 60 – 100 times per minute and is responsible for disseminating each impulse into the surrounding myocytes. Thus, it is the primary pacemaker of the heart.

Once generated, the myocytes rapidly transmit the electrical stimulus across the atria, causing the cells to contract. This process occurs within one tenth of a second (100msecs) in the healthy heart.

Ventricular Conduction

Once the impulse has spread across the atria, it reaches the cells of the **Atrioventricular Node**. As the name would suggest, the AV node is located between the atria and the ventricles, which are separated by a ring of fibrous tissue (annulus fibrosus) – part of the heart’s skeleton.

Once the impulse reaches the AV node, there is a short delay in its transmission to the Bundle of His. At this time, the atria have ejected their blood into the ventricles and this delay optimises ventricular diastole. The AV node then releases the electrical impulse into the **Bundle of His**, where the conduction system bifurcates into the **Left and Right Bundle Branches**. The bundle branches then divide into millions of microscopic fibres known as the **Purkinje fibres** that infiltrate the myocytes. The electrical impulse is then delivered into these myocytes, which then pass the stimulus to all the ventricular muscle cells. The ventricles then contract simultaneously.

Cardiac Pacemakers

The sinoatrial node is the primary pacemaker of the heart. Should it fail to generate an impulse, a support mechanism is in place in that other parts of the conduction system can take over as the pacemaker.

If the AV node does not receive a stimulus from the atria, it will generate an electrical impulse at a rate of 40-60bpm. The Bundle of His, Bundle Branches and Purkinje fibres are also capable of generating an impulse if they fail to receive a stimulus, but only at a rate of 20-40bpm.

Table 1: Cardiac Pacemakers

Pacemaker	Rate
Sinoatrial node (SA Node) Dominant pacemaker	60-100bpm
Atrioventricular node (AV node) Escape pacemaker	40-60bpm
Bundle of His, Bundle Branches, Purkinje Fibres Escape pacemaker	20-40bpm

Components of the ECG

The ECG, as previously stated, is a graphic representation of the electrical activity generated by the heart during the cardiac cycle (Moriarty, 1999). Monitoring electrodes placed on the body’s surface detect this electrical activity and it is transmitted via monitoring leads to either an oscilloscope or to recording paper where it is amplified and displayed as a series of waveforms. Willem Einthoven, a Dutch physiologist, designated the ECG waveforms as P, QRS and T over nine decades ago and we remain indebted to his development of the ECG for its clinical application today (fig. 3) (Xiao, 1996: Goldberger, 1999).

The basic ECG waves are labelled alphabetically and begin arbitrarily at the P wave.

Figure. 3 Diagram of P QRS T

“The sinoatrial node is the primary pacemaker of the heart”

Table 2: ECG Waveforms

◆ The 'P' wave represents atrial depolarisation (atrial stimulation)
◆ The 'QRS' complex represents ventricular depolarisation (ventricular stimulation)
◆ The 'ST segment', 'T' wave and, if present 'U' wave represent ventricular repolarisation (ventricular recovery)

When there is no electrical activity present, the ECG will show a straight line, called the isoelectric line.

ECG paper

The P-QRS-T sequence is recorded on special ECG graph paper which consists of small grid-like boxes which are intersected with dark and light vertical and horizontal lines, thus forming small and large boxes (Huszar, 2002). Each small box is 1 millimetre square (1 mm²) and each large box is 5 millimeter square (5 mm²) (fig.4). The paper allows measurement of time (along the horizontal axis) and voltage (or amplitude) along the vertical axis. Conventionally the paper moves through the ECG machine at 25 mm/second and at this speed, each small box horizontally represents 40 milliseconds (msec) in time and each large box represents 200 msecs. 5 large boxes therefore represents 1 second. ECG paper is also marked with short vertical lines, denoting 3 second and 6 second intervals of time; the significance of these lines is apparent later in this article when calculation of heart rate is discussed.

Figure 4: ECG paper

Vertically, the graph measures the voltage or amplitudes of ECG waveforms. Each small square measures 1 mm amplitude, each large square measures 5 mm amplitude. Conventionally, the electrocardiograph is calibrated (standardised) so that a 1 millivolt

(m-v) electrical signal generates a 10 mm deflection on the ECG (1 m-v = 10 mm). In most monitoring systems the calibration can be set at one-half or two-times the normal value. As the ECG is standardised, the ECG waveforms can be described in terms of both amplitude (voltage) and duration (time). In clinical practice, amplitude is measured in mm and duration is measured in msecs.

ECG waveforms

P wave

The first deflection is termed the P wave. It is normally a positive deflection (above the isoelectric line) and is a manifestation of atrial depolarisation as a response to the sino-atrial node stimulus.

- ◆ **Normal values** duration 100 msecs or less
amplitude – 2.5 mm or less

(hint: remember 2 _ boxes x 2 _ boxes)

P-R interval

The P-R interval represents the time it takes for the electrical stimulus to spread from the SA node, across the atria and through the AV junction (Goldberger, 1999). It is measured from the beginning of the P wave to the beginning of the QRS complex – i.e. P-Q or P-R.

- ◆ **Normal values** duration – between 120 and 200 msecs

QRS complex

The QRS complex is a large amplitude waveform and it represents the time taken for the impulse to spread through the right and left ventricles (ventricular depolarisation). The complex is termed a 'QRS' if there is an initial deflection below the isoelectric line ('q' wave) and a second deflection below the isoelectric line ('S' wave) which occurs after the R wave. Not all QRS complexes contain a 'q' and and 'S' wave, but all complexes will comprise of an R wave.

- ◆ **Normal values** duration – no more than 100 msecs
amplitude – this may vary from 4 mm to 20 mm and is partly dependant upon age, gender, body size and ethnicity.

ST segment

The ST segment represents the early part of ventricular repolarisation. It is measured from the end of the QRS complex – the 'J' point to the beginning of the T wave.

"When there is no electrical activity present, the ECG will show a straight line, called the isoelectric line"

- ◆ **Normal values** duration – 200 msec or less, dependant on heart rate amplitude – the ST segment should be flat to the isoelectric line, however slight deviation of less than 1 mm above or below the line may be seen in some leads (Goldberger, 1999)

T wave

Ventricular depolarisation is also represented by the T wave. Generally the T wave is identified as the first abrupt deviation from the isoelectric line after the ST segment. A normal T wave is sharply or bluntly rounded and usually asymmetric in shape. The T wave should have the same polarity as the QRS complex – hence if the QRS complex is positive, the T wave will also be positive.

U wave

The U wave is a small rounded deflection which may appear after the T wave. Its exact function is not known but it probably represents late ventricular repolarisation (Goldberger, 1999). The U wave normally follows the same polarity as the T wave, but its duration and amplitude are not normally defined.

Sinus rhythm

Sinus rhythm is the normal rhythm of the heart, and can be said to be present when all the component waveforms are present – P wave, PR segment, QRS complex, ST segment and T wave. Sinus rhythm originates in the sino-atrial node and is defined as a heart rate between 60 and 100 beats per minute.

Calculating heart rate

Various methods exist to measure heart rate in clinical practice. The simplest method to use is to count the number of QRS complexes present in a 6-second strip and to multiply this figure by 10.

- ◆ **Example** if there are 7 QRS complexes in a 6 second interval, the heart rate is: $7 \times 10 = 70$ beats per minute

Lead positioning

The electrical current generated by the contraction of myocytes in the cardiac cycle can be recorded at the skin using electrodes.

These electrodes are connected to an electrocardiograph (ECG) or cardiac monitor to amplify, display and record this electrical activity (Huszar, 2002).

Three Lead Monitoring

The electrodes (or 'leads') are placed onto the body on different sides of the heart. These leads are arranged in such a way to enable the recording of the electrical activity from different directions.

Figure 5: Lead Placement in Three Lead Monitoring

The leads are labelled as follows:

- ◆ Right arm (RA) = Red electrode.
- ◆ Left arm (LA) = Yellow electrode
- ◆ Left leg (LL) = Black or green electrode.

There are many mnemonics available to help remember this pattern – 'Ride Your Bike' being particularly popular. The leads placed in this way generate a triangle, with each electrode being equidistant from the heart.

The exact location of the electrodes is very important, as different positions will generate very different pictures of the heart (Ide, 1995). The arm electrodes should be placed on the shoulders, close to where the arm meets the thorax (*fig 5*). Electrode placement on the posterior aspect of the shoulder is also acceptable (Jacobson, 1998). The 'left leg' electrode should be placed either beneath the lowest rib on the left side of the thorax or above the hip (*fig. 5*) (Jacobson, 1998).

In many circumstances, for example severe trauma or surgery, it is impractical to use these positionings. Thus, here are some simple principles to enable you to select alternative lead positions.

- ◆ Placement of the electrode over soft tissue will facilitate the detection of an electrical impulse. Avoid selecting sites situated over bony prominences or areas of dense fat or muscle (McConnell, 2001)

"The U wave normally follows the same polarity as the T wave, but its duration and amplitude are not normally defined"

- ◆ The leads should be equidistant from the heart (Huszar, 2002). Therefore, if you are placing the 'right arm' (red) and 'left arm' (yellow) electrodes on the shoulders, the black electrode should be positioned just above the left hip. However, if you have used the right and left wrists, the black electrode should be placed on the left ankle.
- ◆ While needing to be equidistant from the heart, the leads must not be placed too close together. However, the further the electrodes are away from the heart, the smaller the recorded trace will be.
- ◆ When placing electrodes, they should not be placed in the recommended positions for defibrillation pads. This is strongly advised as removal and replacement of monitoring leads can delay vital early defibrillation.

Five Lead Monitoring

The correct placement for cardiac monitoring with 5 leads is described below (Ide, 1995).

- ◆ Right arm (RA) = Red electrode
- ◆ Left arm (LA) = Yellow electrode
- ◆ Left leg (LL) = Green electrode.
- ◆ Right leg (RL) = Black electrode
- ◆ Modified chest lead 1 (MCL₁) = White electrode

The recommended electrode placement for RA and LA remains the anterior aspect of shoulder. LL and RL should be placed above the hips. MCL₁ monitors the heart from the V₁ position on the 12-lead ECG – i.e to the right of the sternum in the 4th intercostal space.

The use of five leads creates multiple different views of the heart, with many monitors able to display 2 or more leads simultaneously (Jacobson, 1998). The practitioner can then select the lead(s) they wish to view or record through the monitor equipment. This can enable detection of pre-morbid and morbid conditions such as arrhythmias and myocardial infarction.

Connecting the Electrodes

As each electrode is recording the electrical activity through the skin, it is imperative that there is good, secure contact between the electrode and the skin surface. The gel, placed under each electrode by the manufacturer, aids the conduction of the electrical field across the skin to the electrodes. However, contact can be impeded when the skin is not clean or has lots of hairs. McConnell (2001) recommends the following:

- ◆ Wash the skin with warm soapy water and thoroughly dry it prior to lead placement (unless it is an emergency situation). If the skin is sweaty, dry with a cloth prior to application of electrodes.
- ◆ If the skin is hairy, trimming the skin prior to electrode placement is recommended. Do not shave the hair as this may irritate or damage the skin.
- ◆ Electrodes should be changed only when necessary and applied to a slightly different position each time. This will ensure that consistency is maintained, without causing irritation to the patient's skin.

Troubleshooting

Frequently when recording from a cardiac monitor, the trace appears jagged or has abnormal waves or spikes present. This is known as 'artifact' (Woodrow, 1998). This occurs because the monitor is recording not only the electrical activity of the heart, but also any additional internal or external activity. Causes of such interference include muscle tremor, for example if the patient is shivering, or interference from alternating current (AC) equipment (Huszar, 2002).

Loose electrodes and connections to the cardiac monitor are common causes of artifact that can be easily rectified. When artifact is observed on the monitor, always assess the patient first and reassure them that there is a problem with the equipment and not with them! Check the electrodes and connections and replace as necessary. Televisions, mobile phones and infusion pumps are examples of equipment that frequently generate sufficient AC current to interfere with monitoring equipment.

"Loose electrodes and connections to the cardiac monitor are common causes of artifact that can be easily rectified"

“ECG monitoring and analysis is becoming an increasingly vital skill for anaesthetic and recovery nurses”

By addressing the above issues, you are likely to find the cause of the interference. If the problem persists, it may be worth changing the monitor and the connections, as it is imperative that an interpretable trace be obtained.

Putting it into practice

ECG monitoring and analysis is becoming an increasingly vital skill for anaesthetic and recovery nurses. Basic interpretation requires an understanding of the principles described above, but as with any skill frequent practise will be necessary. Diagnosis of cardiac rhythms requires a systematic approach and future articles will use the analysis tool (table 3) to help you to identify arrhythmias.

Systematic Analysis Tool
◆ Determine the rate of the P waves and the QRS complexes
◆ Determine the amplitude and duration of the P wave
◆ Measure the PR interval
◆ Determine the amplitude and duration of the QRS complexes
◆ Determine the amplitude and duration of the ST segment
◆ Measure the amplitude and duration of the T waves
◆ Identify the cardiac rhythm

Table 3: Systematic Analysis Tool for Cardiac Rhythms

Future articles in this series will investigate arrhythmias that originate in the atria, AV node, and ventricles and will also discuss appropriate nursing actions and medical treatments. The final article will explore the complexities of the 12-lead ECG and its interpretation.

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