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Continuous ECG monitoring in hospital: part 2, practical issues

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Abstract

Continuous monitoring of the electrocardiogram (ECG) is a common intervention performed by cardiac nurses. In the first article of this two-part series, we evaluated the principal indications for ECG monitoring. These are the detection of arrhythmias, monitoring for myocardial ischaemia, and measurement of the QT interval. In this second article, the practical issues surrounding ECG monitoring are evaluated. The use of 3- and 5-electrode systems is discussed, and is related to ECG theory and normal coronary artery anatomy. Recommendations are made for lead selection, correct electrode placement, and the recording of 12-lead ECGs. The article concludes with a consideration of safe practice in respect of alarm management, and considers both individual and organisational approaches to reducing inappropriate alarms.

Key words

ECG monitoring, arrhythmia, myocardial ischaemia, QT interval, ECG lead

Introduction

Continuous monitoring of the electrocardiogram (ECG) is a common intervention performed by cardiac nurses. Last month, we evaluated the principal indications for ECG monitoring. These are the detection of arrhythmias, monitoring for myocardial ischaemia, and measurement of the QT interval. In this second article we conclude our review of the topic by examining the practical issues that nurses face in relation to ECG monitoring. These include correct electrode positioning, adequate skin preparation, and the appropriate selection of ECG leads. We evaluate the theory that underpins ECG monitoring, and provide practical advice on how to set up 3- and 5-lead monitoring systems. The article concludes with an evaluation of alarm management, and considers how to reduce inappropriate alarms and ensure patient safety.

Leads and electrodes

Before discussing specific issues relating to ECG monitoring, we need to define two key terms. In clinical practice, we often talk about a "3-lead ECG" or a "5-lead ECG". Unfortunately, this terminology is somewhat misleading. In ECG terms, a "lead" is a recording of the heart's electrical activity, taken from a specific anatomical location, and not an electrical cable (Garcia, 2015). For example, lead I views the heart from the left-hand side of the body, while lead aVF views it from below. These different leads are obtained from skin electrodes placed on the body. It would be more correct to describe monitoring systems as "3-electrode" or "5-electrode", and that's the convention we'll use in this article.

To understand the relationship between leads and electrodes, it's useful to think about the 12-lead ECG. A 12-lead ECG records 12 different electrical views of the heart, using 10 skin electrodes (Hampton, 2013). The leads can be divided into two groups (figure 1).

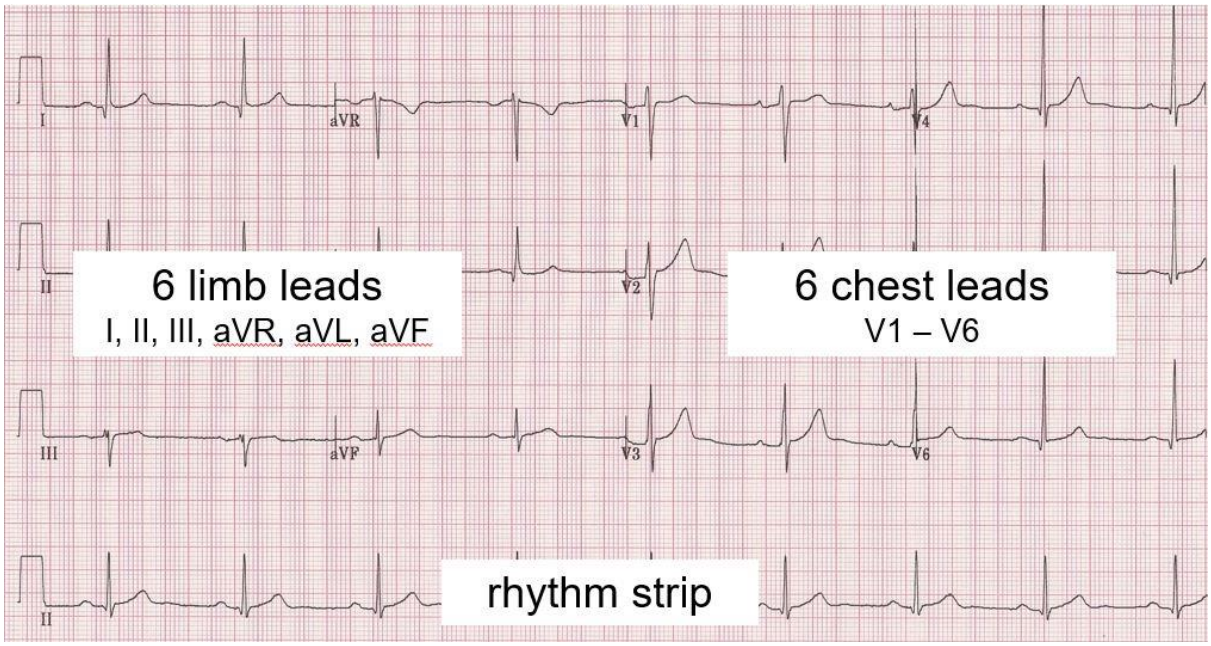

Figure 1. The layout of the 12-lead ECG. The rhythm strip is a longer printout of lead II.

- The limb leads are I, II, III, aVR, aVL, and aVF. They are recorded using four electrodes; one attached to each limb. The standard position for these electrodes is on the wrists and ankles (Campbell et al, 2017).

- The chest (or precordial) leads are V1, V2, V3, V4, V5 and V6. They are recorded using the six electrodes placed across the chest. Unlike the limb leads, each electrode corresponds with a single ECG lead (Hampton, 2013).

The purpose of recording so many leads is to build up a three-dimensional picture of the heart's electrical activity (Garcia, 2015). The limb leads view the heart in a frontal plane, and see electrical activity from a number of different angles (figure 2). The chest leads view the heart in a transverse plane (i.e. through the chest wall), again from multiple angles (figure 3).

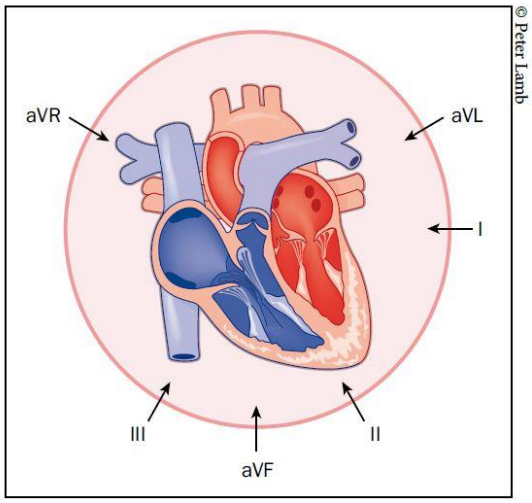

Figure 2. Anatomical perspective of the six limb leads

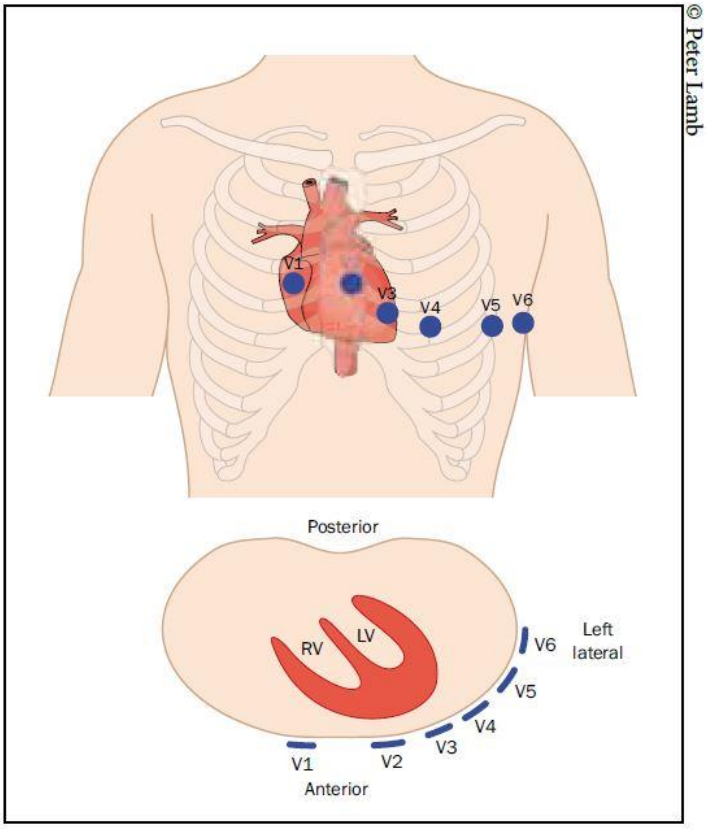

Figure 3. Anatomical perspective of the six chest leads

This detailed picture of cardiac electrical activity is extremely useful when diagnosing cardiac conditions such as ischaemia, which are often localised to one area of the heart. For this purpose, the ECG leads can be considered in three broad groups which correspond to anatomical regions of the heart, and the coronary arteries that supply them (Houghton and Gray, 2014): -

- **Inferior leads**: II, III and aVF. These leads view the heart from below, and get a good view of the diaphragmatic surface of the left ventricle. This area of the heart is supplied by the right coronary artery (RCA) in most people (Cademartiri et al, 2008).

- **Lateral leads**: I, aVL, V5 and V6. These leads view the left-hand side of the heart, and "see" the lateral wall of the left ventricle. The predominant artery supplying this region of the heart is the left circumflex artery (LCx) (Rinta-Kiikka et al, 2014).

- **Anteroseptal leads**: V1, V2, V3, V4. These leads sit over the front of the left ventricle, and view its anterior, apical and septal regions. These areas are supplied primarily by the left anterior descending (LAD) artery (Tortora and Nielsen, 2014).

Although continuous monitoring of all 12 ECG leads is possible, and is performed on some units, in many clinical areas only one or two leads are constantly evaluated. This reduces the number of electrodes that must be placed on the patient, as well as the complexity of the monitoring equipment required. It also reduces the number of electrical views obtained; careful lead selection is therefore required, especially when ischaemia monitoring is initiated (Sandau and Smith, 2009). The lead(s) selected will depend on the monitor being used, the number of electrodes, and the indication for monitoring. Let's examine the two common monitoring setups, 3-electrode and 5-electrode, and think about which ECG lead(s) might be selected for monitoring.

3-electrode ECG monitoring

3-electrode is the simplest form of continuous ECG monitoring, and is commonly employed in a range of clinical settings including cardiac and intensive care units, operating theatres, and resuscitation situations (Jevon, 2010). The system uses three limb electrodes, which are colour coded: -

- Right arm (RA – red)
- Left arm (LA – yellow)
- Left leg (LL - green)

Note that these colours refer to European equipment, and are different in the USA.

Rather than placing the electrodes on the limbs, they are positioned on the chest wall (Hatchett, 2017). This modification was first described by Mason and Likar (1966), and was developed for exercise testing. Moving the limb leads away from the extremities allows greater patient movement, and reduces artefact, making it suitable for both exercise testing and continuous ECG monitoring (Pahlm and Wagner, 2008). Although suitable for these applications, it should be noted that Mason-Likar electrode positions alter the amplitude of the QRS voltage in the inferior leads, and shift the cardiac axis to the right (Jowett et al, 2005). Diagnostic 12-lead ECGs should, therefore, be performed using limb leads placed at the limb extremities, and not on the chest wall (Campbell et al, 2017).

For continuous ECG monitoring, the positions of the three electrodes are as follows (figure 4): -

- RA (red) - below the right clavicle
- LA (yellow) - below the left clavicle
- LL (green) - on the lower part of the ribcage, on the left-hand side

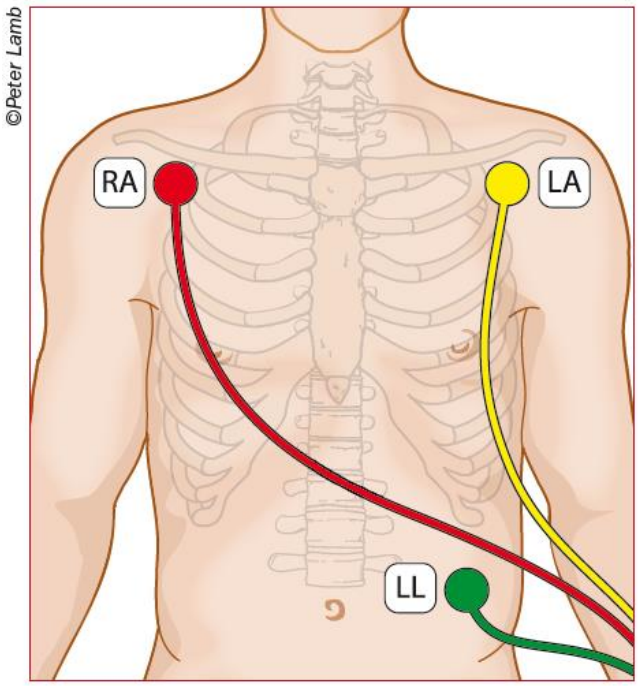

Figure 4. 3-electrode monitoring

Placement of ECG electrodes is a relatively simple task; however, care must be taken to ensure good adhesion and correct location (Hatchett, 2017). Skin must be dry and free from oil, loose skin flakes or excessive hair (Campbell et al, 2017). If necessary, skin should be cleaned with soap and water, or an alcohol wipe, prior to electrode placement. Loose skin can be removed by gentle exfoliation using a dry gauze swab, and chest hair removed by shaving or clipping in those areas where electrodes will be placed (American Association of Critical Care Nurses [AACCN], 2013). Although the placement of the arm electrodes below the clavicles is standard practice (Hatchett, 2017; Jevon, 2010), it should be noted that the right arm electrode is positioned where a defibrillator pad would be placed. In patients at high risk of cardiac arrest, or who may need transcutaneous pacing, placement of arm electrodes on the shoulders is recommended, keeping the chest clear for defibrillation pads (Resuscitation Council UK, 2016). For the same reason, the left leg electrode should be placed low down on the rib cage, and not immediately below the axilla.

3-electrode systems typically allow a single ECG lead to be displayed and monitored. The available leads with this setup are I, II and III. These are referred to as the standard limb leads, and are the three leads used in the early years of electrocardiography (AlGhatrif and Lindsay, 2012). For arrhythmia monitoring, lead II is typically selected as P-waves and QRS complexes are usually upright in this view, facilitating rhythm interpretation (Sandau et al, 2017). If lead II does not give a clear ECG trace, the monitor can be adjusted to display lead I or III (Hatchett, 2017). If the ECG trace is poor in all leads, electrode position and adherence should be checked. Although 3-electrode

systems are ideal for rhythm monitoring, the limited range of leads available make them a poor choice for monitoring ischaemia or the QT interval. For these applications, a 5-electrode system is better.

5-electrode ECG monitoring

In 5-electrode monitoring, two additional electrodes are added (figure 5): -

- A right leg electrode (RL - black)
- A chest electrode (V - white)

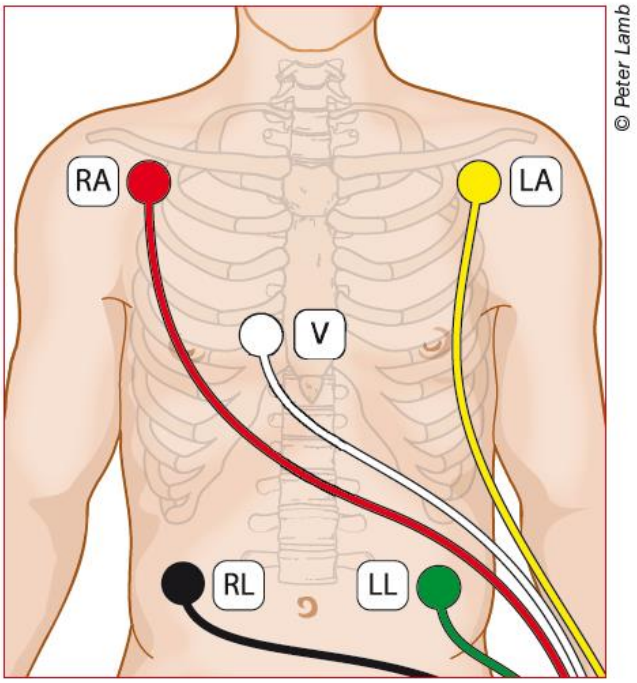

Figure 5. 5-electrode monitoring

The right leg electrode is placed on the lower ribcage, to the right-hand side of the body. Placement of this electrode makes the remaining limb leads available; the "augmented" limb leads aVR, aVL and aVF (Hampton, 2013). The chest electrode is typically placed in the V1 position – the fourth intercostal space at the right sternal margin (Hatchett, 2017). This lead gets a good view of atrial electrical activity, so is useful in rhythm interpretation (Bennett, 2013). It is also useful in the diagnosis of bundle branch blocks (BBB), as characteristic QRS changes are seen in V1 (Garcia, 2015).

If a different chest lead is required, the white electrode must physically be moved to that position. For example, to monitor V4, the white electrode must be placed in the fifth intercostal space, in the mid-clavicular line (Campbell et al, 2017). As 5-electrode monitors often allow two ECG leads to be displayed and monitored, leads II and V1 are recommended for arrhythmia monitoring (Sandau and Smith, 2009).

If a change in rhythm is detected during monitoring, and time allows (i.e. the patient is not in cardiac arrest or close to it), a 12-lead ECG should be recorded using standard electrode positions (Pitcher and Nolan, 2015). This ensures documentation of the arrhythmia, and may be helpful for rhythm interpretation. Information available on the 12-lead may also have prognostic importance, or guide future treatment such as catheter ablation (Bennett, 2013).

ST-segment monitoring

As discussed above, lead selection is one of the most important considerations in ST-segment monitoring (Sandau et al, 2017). Ischaemia is often localised to one area of the heart; the leads that "see" that area must be monitored if ischaemia is to be detected. If patients present with an ischaemic ECG, this should form the basis for initial lead selection by identifying the "ST fingerprint" (Collins, 2010). This refers to the pattern of ST elevation or depression seen at admission; the leads showing the most important changes are selected for subsequent monitoring.

When no prior ischaemic changes have been recorded, the leads that are most likely to detect ischaemia should be selected (Sandau and Smith, 2009). Myocardial infarction most often affects the anteroseptal and inferior regions of the heart (Hreybe and Saba, 2009). In suspected ACS, selection of leads monitoring these regions is therefore suggested; leads III and V3 are common choices (Collins, 2010). In a study using experimental coronary artery occlusion, ST elevation was greatest in these two leads, although aVF had the greatest sensitivity and specificity for right coronary artery occlusion (Haeberlin et al, 2014).

Following cardiac surgery, or PCI, lead selection should be guided by the vessels that have been revascularized; for example, V3 is a good choice following PCI to the LAD (Sandau et al, 2017). Given the limitations imposed by continuous monitoring (e.g. limited lead choice, modified electrode positions), a standard 12-lead ECG should be recorded at least once per shift, and whenever significant changes in ST-segments are detected (Sandau and Smith, 2009).

The main limitation to ST-segment monitoring, aside from those discussed above, is the large variation in the ST-segment itself. There are multiple causes of ST-segment elevation or depression, many of which are benign or unrelated to cardiac ischaemia (Garcia, 2015). The ST-segment is deviated in bundle branch blocks, ventricular pacing, ventricular hypertrophy, and chronic digoxin use (Houghton and Gray, 2014). Evaluation may be difficult or impossible in patients with these conditions. ST-segment monitoring is also difficult in restless patients, because of artefact, and should not be attempted if patients are agitated (Sangkachand et al, 2011).

Monitoring the QT interval

There are three methods of monitoring the QT interval; continuous fully automated, semi-automated, and manual (Sandau et al, 2017). The method chosen will depend to some degree on the monitoring equipment available, as well as usual practice within the individual unit.

Continuous, fully automated QT interval monitoring is a feature available on some, but not all, modern patient monitors (Chenoweth et al, 2017). Special software allows the monitor to sample all available ECG leads, and calculate representative QT and RR intervals. These are used to calculate the QTc automatically every five minutes, with the result displayed on the monitor (Zhou et al, 2009). This has the advantage that changes in the QTc can be mapped over time; significant

prolongation can be picked up quickly and acted on. A study by Chenworth et al (2017) demonstrated moderate correlation between measurements using an automated system and 12-lead ECGs. The authors concluded that while the automated system was useful for trend evaluation, 12-lead ECG remains the standard for evaluation, and should be used to confirm the QT interval before changes to treatment are made.

In semi-automated systems, electronic callipers are accessed via the monitor, and are used to measure the QT interval and RR interval on the displayed rhythm strip. The monitor uses these values to calculate the QTc (Sandau et al, 2017). Although this allows more flexibility than an automated system, and greater human oversight, it also means that nurses must remember to take measurements. Unless this is incorporated into standard observation charts and clinical routines, it may be forgotten (Pickham and Drew, 2008). As with fully automated systems, significant changes must be corroborated by 12-lead ECG.

Manual evaluation implies measurement of the QT interval using manual callipers and a 12-lead ECG. This remains the gold standard for evaluation of the QT interval, and is probably the most widely used method in clinical practice (Chenworth et al, 2017; Pickham and Drew, 2008; Sandau et al, 2017). In practice, many clinicians use the QTc calculated by the ECG machine, which is printed at the top of the recording. While this is often the most accurate calculation of the QT interval, ECG machines are not infallible and manual verification is recommended (Bennett, 2013). Most clinicians use Bazett's formula to calculate QTc from the QT and R-R intervals (Rautaharju et al, 2009) (figure 6). This is fairly straightforward: -

- The QT interval appears longer in some leads than others, and may be difficult to measure if the onset and offset of waveforms are unclear. Choose a lead in which the QT appears the longest, and which also has a clear beginning to the QRS complex, and a clear end to the T-wave (Pickham and Drew, 2008). Rautaharju et al (2009) suggest that leads V2 and V3 often have the longest QT intervals, while Yaldren and Richley (2014) suggest lead II as the clearest for measurement. Other suggested leads are I, III and V5 (Yaldren and Richley, 2014).

- Measure from the beginning of the QRS complex to the end of the T-wave. Do not include U-waves; if they merge with the T-wave, choose a lead in which they do not appear if possible (Rautaharju et al, 2009). Multiply each millimetre by 0.04 seconds to calculate the QT interval. If you don't have callipers, count small squares; each small square is 1 millimetre.

- Next, measure the preceding R-R interval; this is the time interval between the two previous QRS complexes. This is best measured by placing the tips of the callipers on the peaks of the R-waves (Garcia, 2015). If the ECG shows atrial fibrillation, a mean R-R interval should be calculated by either adding the shortest and longest R-R intervals, and dividing by two, or by averaging multiple R-R intervals (Sandau et al, 2017). Multiply the number of millimetres by 0.04 seconds to give the R-R interval, and then work out the square root using a calculator.

- Divide the square root of the R-R interval into the QT interval to give the QTc in seconds (figure 6). Multiply by 1000 for the same value in milliseconds.

- A number of online calculators exist to make this easier. All you need to use them is the heart rate, and measured QT interval. One example can be found at https://www.mdcalc.com/corrected-qt-interval-qtc

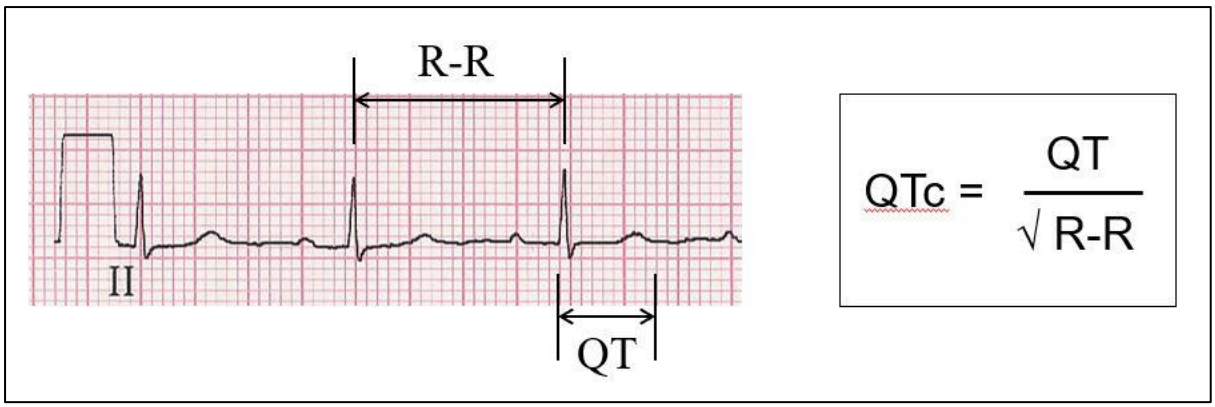

Figure 6. Using Bazett's formula to calculate the QTc from the QT and R-R intervals

Note that because 12-lead ECG machines measure the QT interval in all 12 leads, and calculate using the earliest QRS and latest T-wave, the QTc will often be slightly longer than that calculated manually using a single lead (Rautaharju et al, 2009). For manual calculations, use the same lead for every measurement; document the QTc in the patients notes (Pickham and Drew, 2008).

The suggested frequency of QT monitoring is a minimum of eight hourly, however frequency should be increased for patients who are clinically unstable, or whose QTc is already prolonged (Sandau et al, 2017). Progressive increases in QTc should be reported to the patient's medical team, and urgent advice sought if the QTc exceeds 500ms as a change in treatment, for example drug discontinuation, may be required (Bennett, 2013). Bear in mind that increases in QRS width will also increase the QTc; if the patient has a bundle branch block or is ventricularly paced, the effect of increased QRS width on the QT interval should be factored in (Rautaharju et al, 2009). Close monitoring for TdP is essential in any patient with significant QT prolongation.

Alarm management

The final consideration in continuous ECG monitoring is alarm management. Alarms are an essential element of any monitoring system; their purpose is to alert the clinician to a change in physiological parameters that requires action (Spratt, 2016). Unfortunately, most alerts are false alarms; in other words, they do not require intervention on the part of the nurse. Drew et al (2014) studied audible alarms in an intensive care unit over a 31-day period. On average, there were 187 alarms per bed per day, of which less than 12% required action.

This high burden of false alarm is widely reported in the literature, and is undesirable for several reasons (Graham and Cvach, 2010). Firstly, false alarms add to the clinical workload; dealing with them reduces the time available for more important patient care. Secondly, regular false alarms desensitize staff, and may lead to slow or inadequate responses when genuine emergencies occur. Pelter and Drew (2015) describe the case of a man admitted for observation with chest pain and a non-diagnostic 12-lead ECG. During the night shift, the monitor alarmed repeatedly because of "bradycardia" and "asystole". Each time, the patient was checked, and the rate and rhythm were normal. After consulting with the on-call doctor, the nurse switched off the alarms. When the patient was checked several hours later, he was cold and pulseless; the presumed cause of death was ventricular arrhythmia secondary to myocardial ischaemia. This was not detected because the alarms had been disabled. Similar case studies have been reported elsewhere; a US report on the

problem documented 98 adverse events in four years, 80 of which resulted in death (Joint Commission, 2013).

The level of harm reported makes appropriate alarm management a priority for any nurse caring for monitored patients. Alarms needs to be sensitive enough to detect important changes in patient physiology, but not so sensitive that insignificant changes or artefact trigger alarms (Spratt, 2016). Alarms can be divided into three categories: -

- **Parameter violation** - upper and lower limits for physiological measurements are set by the user, and the alarm sounds if the parameter is exceeded. In ECG monitoring, parameter alarms would include upper and lower heart rate limits, ST-segment deviation, and QTc prolongation.
- **Arrhythmia** - ECG rhythm is constantly evaluated by software that analyses waveform morphology and rhythm. An alarm sounds if an abnormal rhythm is detected.
- **Technical** – for example poor signal, lead disconnection, and power failure.

Parameter violations are the most common cause of false alarms, and often result from limits that are too narrow (Spratt, 2016). Typical default settings for heart rate are a low of 60bpm, and a high of 120bpm. If the patient has a naturally low resting heart rate, or is beta-blocked, the alarm will constantly sound when the rate falls below 60. Given that no action is taken in this case, a lower limit would be more appropriate. Similarly, a patient with atrial fibrillation, and a heart rate averaging 110bpm, will frequently trip the upper alarm limit due to fluctuation in heart rate. A higher upper limit is appropriate if the problem is known, and treatment already underway (Pelter and Drew, 2015). This underlines the importance of patient assessment; alarms should be checked and adjusted to individual circumstances when taking over the care of any monitored patient, and should only sound when an actionable change in physiology occurs (AACCN, 2013). Changes to default settings within organisations can also be helpful. Altering default heart rate limits to a low of 50bpm, and a high of 150bpm, reduced alarm frequency by 43% in a study by Graham and Cvach (2010).

Preventing false arrhythmia and technical alarms relies largely on correct electrode placement, and appropriate lead selection (Sendelbach and Funk, 2013). Poor skin preparation can result in lead detachment, and unnecessary alarms, whilst poorly sited electrodes can suffer from poor signal or interference from patient movement (Hatchett, 2017). Selecting the best lead for monitoring rhythm, ST-segment or QTc has been discussed already, however lead selection must also include assessment of the size of the QRS complex and T-wave (Pelter and Drew, 2015). A low amplitude QRS complex can result in under-detection by the monitor, and result in false bradycardia or asystole alarms. This was the cause of the false alarms in the case study discussed earlier. A lead with a T-wave that is very tall can result in overcounting – the monitor thinks the T-wave is another QRS, and double counts the heart rate as a result. When false alarms occur, electrode placement, lead selection, and alarm parameters should all be reviewed with the aim of preventing further false alarms. Alarms should never be permanently silenced (Pelter and drew, 2015). Training is recommended to ensure that clinicians are familiar with monitoring equipment, and know how to adjust and troubleshoot alarms (AACCN, 2013).

Conclusion

ECG monitoring can be a lifesaving intervention when used appropriately, however patients must be carefully selected, and the right type of monitoring instigated. This monitoring compliments, but does not replace, the need for regular evaluation using a 12-lead ECG, which remains the gold standard for assessment of rhythm, ischaemia, and repolarisation.

Key areas issues in ECG monitoring include adequate skin preparation, correct siting of electrodes, and well-judged lead selection. Good practice in these areas ensures effective monitoring, and helps to prevent false alarms. Practice must be underpinned by a knowledge of the patient's history and previous ECGs, the reason for monitoring, and an understanding of ECG theory. Nurses must be familiar with the equipment used, and know how to adjust and troubleshoot alarms. Most importantly, all clinicians need to recognise the limitations of continuous ECG monitoring, and ensure that action or omission does not result in monitoring failure.

Key points

- Common monitoring setups include 3- and 5-electrode systems. 3-electrode systems can monitor ECG leads I, II or III, and typically display a single lead. 5-electrode systems can monitor these leads plus aVR, aVL, aVF, and a single chest lead. 5-electrode systems can often display two ECG leads.

- For arrhythmia monitoring, lead II is usually selected on 3-electrode systems. On 5-electrode systems, V1 is usually added.

- For ST-segment monitoring, lead selection is determined by the circumstances and prior ECG. In known or suspected ACS, lead selection is based on ST-segment changes on the presenting ECG; if these are absent, leads III and V3 are commonly monitored. Following cardiac surgery or PCI, lead selection should be based on the arteries that have been revascularized.

- In QT interval monitoring, the QTc may be measured automatically, semi-automatically, or manually. Measurement by 12-lead ECG is considered the gold standard; many clinicians use the machine calculated QTc, although manual verification is recommended. When evaluating the QTc manually, select a lead in which the QT appears the longest, but in which QRS onset and T-wave offset are clear. Use Bazett's formula to convert QT to QTc.

- Alarms are essential, and alert clinicians to important changes in physiology. They are often poorly used, resulting in multiple false alarms, and alarm fatigue. Individualising alarm parameters, correct electrode placement, and well-judged lead selection reduces the number of false alarms. The cause of false alarms should always be investigated; alarms should never be permanently disabled.

CPD questions

1. Find out what type of monitors are in use on your ward or unit. Make sure that you know how to switch between ECG leads, and alter alarm parameters.
2. Would you know how to monitor a patient for ST segment changes, or QT prolongation? If not, find out how this is usually done on your ward or unit, and familiarise yourself with the changes that occur on the ECG, and how to measure them.
3. Think about a busy shift that you have worked recently. How much time did you spend dealing with unnecessary alarms? In hindsight, how could you have reduced this?

References

AlGhatrif M, Lindsay J (2012) A brief review: history to understand fundamentals of electrocardiography. *Journal of community hospital internal medicine perspectives*. 2(1):14383.

American Association of Critical Care Nurses (2013) AACCN practice alert: Alarm management, available at https://www.aacn.org/clinical-resources/practice-alerts/alarm-management accessed 20/12/2017.

Bennett DH (2013) *Bennett's Cardiac Arrhythmias: Practical notes on interpretation and treatment*, 8th edition, London: Hodder Arnold.

Cademartiri F, La Grutta L, Malagò L, Alberghina F, Meijboom WB, Pugliese F, Maffei E, Palumbo AA, Aldrovandi A, Fusaro M, Brambilla V, Coruzzi P, Midiri M, Mollet NRA, Krestin GP (2008) Prevalence of anatomical variants and coronary anomalies in 543 consecutive patients studied with 64-slice CT coronary angiography, *Eur Radiol*, 18: 781–791.

Campbell B, Richley D, Ross C, Eggett CJ (2017) Clinical Guidelines by Consensus: Recording a standard 12-lead electrocardiogram. An approved method by the Society for Cardiological Science and Technology (SCST). Available at: http://www.scst.org.uk/resources/SCST_ECG_Recording_Guidelines_2017 (accessed 30/11/2017)

Chenoweth JA, Hougham AM, Colby DK, Ford JB, Sandhu J, Albertson TE, Sutter ME (2017) Monitoring the corrected QT in the acute care setting: A comparison of the 12-lead electrocardiogram and bedside monitor. *The American Journal of Emergency Medicine*. In press.

Collins ML (2010) Using continuous ST-segment monitoring, *Nursing2016*, 40:11-3.

Drew BJ, Harris P, Zègre-Hemsey JK, Mammone T, Schindler D, Salas-Boni R, Bai Y, Tinoco A, Ding Q, Hu X (2014) Insights into the problem of alarm fatigue with physiologic monitor devices: a comprehensive observational study of consecutive intensive care unit patients. *PloS one*. 9(10):e110274.

Garcia TB (2015) *12-lead ECG: The Art of Interpretation.* 2nd Edition. Burlington, Ma : Jones and Bartlett

Graham KC, Cvach M (2010) Monitor alarm fatigue: standardizing use of physiological monitors and decreasing nuisance alarms, *American Journal of Critical Care*, 19(1):28-34.

Haeberlin A, Studer E, Niederhauser T, Stoller M, Marisa T, Goette J, Jacomet M, Traupe T, Seiler C, Vogel R (2014) Electrocardiographic ST-segment monitoring during controlled occlusion of coronary arteries. *Journal of Electrocardiology*. 47(1):29-37.

Hampton JR (2013) *The ECG made easy*, 8th edition, London: Churchill Livingstone.

Hatchett R (2017) Cardiac monitoring and the use of a systematic approach in interpreting electrocardiogram rhythms, *Nursing Standard*, 32, 11, 51-62.

Houghton AR & Gray D (2014) *Making sense of the ECG: A hands-on guide*, 4th edition, Boca Raton: CRC Press.

Hreybe H & Saba S (2009) Location of Acute Myocardial Infarction and Associated Arrhythmias and Outcome, *Clinical Cardiology*, 32(5), 274-277.

Jevon P (2010) An introduction to electrocardiogram monitoring, *Nursing in Critical Care*, 15(1), 34-38.

Joint Commission (2013) *Sentinel Event Alert Issue 50: Medical device alarm safety in hospitals,* available at https://www.jointcommission.org/sea_issue_50/ accessed 20/12/2017.

Jowett NI, Turner AM, Cole A, Jones PA. (2005) Modified electrode placement must be recorded when performing 12-lead electrocardiograms. *Postgraduate Medical Journal*. 81(952):122-5

Mason RE, Likar I. (1966) A new system of multiple-lead exercise electrocardiography. *Am Heart J* 71:196.

Pahlm O, Wagner GS. (2008) Potential solutions for providing standard electrocardiogram recordings from nonstandard recording sites. *Journal of Electrocardiology.* 41(3):207-10.

Pelter MM, Drew BJ (2015) Harm from alarm fatigue, Agency for Healthcare Research and Quality, available at https://psnet.ahrq.gov/webmm/case/362/harm-from-alarm-fatigue (accessed 06/12/2017)

Pickham D, Drew BJ (2008) QT/QTc interval monitoring in the emergency department. *Journal of Emergency Nursing*. 34(5):428-34.

Pitcher D, Nolan J (2015) *Peri-arrest arrhythmias.* Resuscitation Council UK, London. http://tinyurl.com/ogeh2jt (accessed 30/11/2017)

Rautaharju PM, Surawicz B & Gettes LS (2009) AHA/ACCF/HRS Recommendations for the Standardization and Interpretation of the Electrocardiogram. Part IV: The ST Segment, T and U Waves, and the QT Interval. A Scientific Statement from the American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society, *Circulation*, 119, e241-e250.

Resuscitation Council (UK) (2016) Advanced Life Support. Seventh edition. RCUK, London.

Rinta-Kiikka I, Tuohinen S, Ryymin P, Kosonen P, Huhtala H, Gorgels A, Bayes de Luna A, Nikus K (2014) Correlation of Electrocardiogram and Regional Cardiac Magnetic Resonance Imaging Findings in ST-Elevation Myocardial Infarction: A Literature Review, *Ann Noninvasive Electrocardiol*, 19(6), 509–523.

Sangkachand P, Sarosario B, Funk M (2011) Continuous ST-segment monitoring: nurses' attitudes, practices, and quality of patient care. *American Journal of Critical Care*. 20(3):226-38.

Sandau KE, Funk M, Auerbach A et al (2017) Update to Practice Standards for Electrocardiographic Monitoring in Hospital Settings: A Scientific Statement From the American Heart Association, *Circulation,* 136:e273–e344. DOI: 10.1161/CIR.0000000000000527

Sandau KE, Smith M (2009) Continuous ST-segment monitoring: 3 case studies in progressive care. *Crit Care Nurse.* 29(5):18-30.

Sendelbach S, Funk M (2013) Alarm Fatigue; A Patient Safety Concern. *AACN advanced critical care*. 24(4):378-86.

Spratt G (2016) Three steps to reduce alarm fatigue and improve patient safety, *AARC Times,* August 2016, 13-16.

Tortora GJ & Nielsen MT (2014) *Principles of human anatomy*, 13th edition, Hoboken, NJ : Wiley.
Yaldren J & Richley D (2014) Accurate measurement and assessment of the QT interval, *British Journal of Cardiac Nursing,* 9(3), 137-141.

Yaldren J & Richley D (2014) Accurate measurement and assessment of the QT interval, *British Journal of Cardiac Nursing,* 9(3), 137-141.

Zhou SH, Helfenbein ED, Lindauer JM, Gregg RE, Feild DQ.(2009) Philips QT interval measurement algorithms for diagnostic, ambulatory, and patient monitoring ECG applications. *Ann Noninvasive Electrocardiol*. 14(suppl):S3–S8