ELECTROCARDIOGRAM MONITORING

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SUMMARY

Monitoring electrocardiogram in the perioperative period is among the foremost recommended standards. In addition to getting information about the cardiac status, respiratory rate monitoring and ventilator triggering are possible from ECG signals. A good knowledge on the basics with attention to technical details goes a long way towards dedicated patient care by the anaesthesiologist. Application of advanced technology in ECG monitoring gives maximum information and should be utilized to its fullest extent.

Keywords : ECG, lead, myocardial ischaemia, dysrhythmia

Introduction

As we enter 21st century, the focus on monitoring is shifting from invasive to non-invasive and miniaturization, modularity and computerization to cost containment and cost effectiveness. Outcome analysis is progressively receiving a higher level of importance over the scientific benefits of newer techniques.[1] Electrocardiogram is no exception to these generalizations.

The basis of accepting ECG as an useful monitor lies in the fact that, patient's condition under anaesthesia is well reflected by biological electric signals. Three points make this concept clear. First, cellular activity is due to modification of normal resting membrane potential. It is not directly measured in clinical practice rather the co-ordinated electrical activity of a group of active cells producing a changing pattern of electrical potential over the whole surface of the body is measured by electrodes. Second, the mechanism of transfer of electrical current in the tissue is the result of migration of ions in contrast to electrons in metal conductors. When a metal electrode is placed over the skin, any current that passes must therefore occur mainly as a result of electrons being exchanged for the ions. The amplitude of such signal is much lower (in the order of 1.5 mV) primarily due to electrical impedance of the tissue. This must be amplified and modified to make it possible for them to be usefully presented. Third, the biological potentials are complex which is very characteristic for ECG signals. According to Fourier analysis, any waveform can be transformed into a number of sine waves of different frequencies which when algebraically combined; a precise original waveform is constructed. ECG signals include frequencies from 0.05 to 200 Hz, but up to 100 Hz are adequate for clinical diagnostic purpose.[2] Such a potential recorded by a sensitive electromagnet constitutes an electrocardiogram.

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Historical milestones in ECG[3]

1887 : Augustus Desire Waller, recorded electric current preceding cardiac contraction.

1903 : Einthoven, developed string galvanometer.

1911 : Sir Thomas Lewis published his pioneering work on ECG

1929 : Dock, use of cathode ray oscilloscope for ECG

1932 : Wolferth CC and Wood CC, introduced chest leads

1942 : Goldberger E, Introduced unipolar limb leads

Pioneers in use of ECG in anaesthesia include J B Heard, AE Strauss, EB Krumbhaar & Michael Johnstone.

ECG has been included among the foremost monitoring standards by all recommending bodies around the globe. This is applicable for both general and regional anaesthesia techniques including the procedures under sedation.[4] The popularity it has gained among the clinicians is because of its non-invasiveness, moderate cost, simple to operate, continuous nature and minimal risk to the patient.[5]

The information gained by the anaesthesiologist from various preoprative sources of ECG are useful for optimal monitoring during intraoperative period. They are preoperative screening test, holter monitoring and stress test.[6]

Preoperative screening provides information on:

a) Ischemic events like unstable angina, variant angina & acute myocardial infarction.

b) Valvular, myocardial and pericardial diseases.

c) Conduction abnormalities and dysrhythmias.

d) Pacemaker function

e) Pulmonary and some systemic diseases

Holter monitoring provides information on transient ECG changes, which are not picked up by a standard 12 lead ECG. It also provides information on heart rate variability and signal average ECG.

Stress test is useful in providing diagnosis of probability of coronary artery disease and prognostic parameters like risk of myocardial infarction, sudden death and need for urgent surgery.

Perioperative monitoring provides information on:

a) Heart rate

b) Myocardial ischaemia

c) Dysrhythmia and conduction abnormality

d) Altered physiologic status.

e) Intracardiac catheter placement.

The lead system

Information obtained from ECG are best optimized with attention to detailed technical application of the lead system. Heart is situated in the center of the electric field which it generates. The electrical intensity diminishes as we go away from the heart. When the distance is more than 15 cm from the heart, the decrement is hardly noticeable and as all electrodes are placed at a greater distance than this, they are considered equidistant.[7]

There are 12 conventional leads, 6 in frontal plane (I, II, III, avR, avL & avF) and 6 in horizontal plane (V_1 to V_6). For monitoring purpose they can be conveniently grouped into four systems.[8]

a) Three electrode system

b) Modified three electrode system

c) Five electrode system

d) Invasive and epicardial leads

Three electrode system

Three electrodes are placed on right arm (RA), left arm (LA) and left leg (LL). For bipolar leads (I, II & III), one pair is selected for monitoring and the other one is used as a ground. For augmented leads (avR, avL & avF), one is exploring lead and the other two are connected to zero potential. Anterior wall myocardial ischaemia is not suitably monitored by this system.

Modified three electrode system

Same three electrodes are used but with change in position on the body. MCL (modified chest leads), CS_5, CM_5, CB_5 & CC_5 are in this group. They offer the advantage of maximizing 'P' waves for dysrhythmia monitoring and increase sensitivity of three electrode system for anterior wall ischaemia monitoring. Out of these MCL_1 in ICU and CS_5 in OT are most commonly used.[9] Electrode placement is presented in Fig-1.[9]

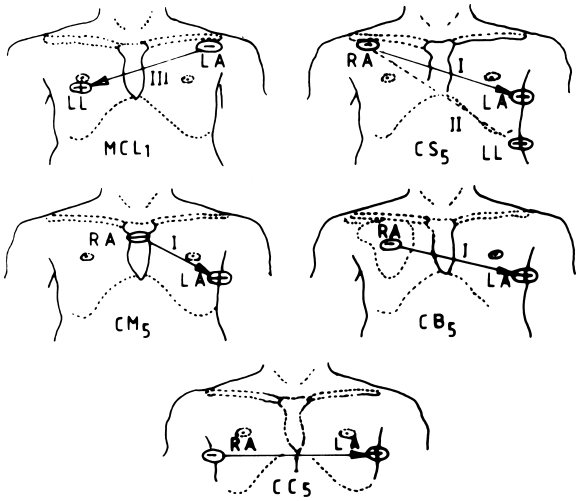

Fig -1 : Electrode placement for modified three electrode system

Polarity, lead selection and electrode placement in three and modified three electrode system is presented in Table-1.[10]

Table-1 : Electrode Position and their polarity for three and modified three electrode system.

Lead	RA	LA	LL	Lead Select
I	RA	LA	Ground	I
II	RA	Ground	LL	II
III	Ground	LA	LL	III
avR	RA	Ground	Ground	avR
avL	Ground	LA	Ground	avL
avF	Ground	Ground	LL	avF
MCL_1	Ground	Left clavicle	V_1	III
CS_5	Right Clavicle	V_5	Ground	I
CM_5	Manubrium	V_5	Ground	I
CB_5	Right Scapula	V_5	Ground	I
CC_5	Right anterior axillary line	V_5	Ground	I

Five electrode system

Out of total five electrodes, one is placed on each limb and one on the chest wall. All limb electrodes are connected to a common ground. Usually V_5 position is used for the chest electrode. The advantages of this system are

a) Seven leads can be monitored
b) All except posterior wall ischaemia can be monitored
c) Up to 95% of ischemic events can be diagnosed
d) Useful in differentiating atrial vs. ventricular dysrhythmias

Disadvantages are mostly technical. Left lateral thoracotomy precludes V_5 position. Being on the chest wall, waterproof isolation is required to get proper electric signals.

Invasive and epicardial ECG

Oesophageal leads in oesophageal stethoscope help in diagnosis of atrial dysrhythmias in 100% of cases compared to 54% for lead II and 42% for V_5 leads. In addition they are useful in detecting posterior wall ischaemia.

Endotracheal ECG through endotracheal tube, though currently not available commercially may be useful in paediatric patients for atrial dysrhythmia detection.

Electrodes through pulmonary artery catheters help in recording of intracavitary ECG, where atrial, ventricular and atrioventricular dysrhythmias and conduction blocks are diagnosed. They are also helpful in atrial and ventricular pacing.

Cardiac surgeons before sternal closure place epicardial leads in the form of pacing wires. They help in atrial and ventricular pacing. They are most useful in postoperative diagnosis of complex conduction problems and dysrhythmias.

Recommendations for ECG monitoring[11]

To fully optimize capabilities of ECG monitoring, particular attention is paid to the followings.

Patient electrode interface

Skin should be clean and free of dirt. It is best if skin is abraded lightly to remove part of the stratum cornium. Muscle artefacts are avoided if electrodes are placed over bony prominences whenever possible.

Electrodes and connecting cables

Electrodes should all be silver-silver-chloride type with hydrogel spread uniformly. Avoid needle electrodes to prevent thermal injury. Maintain integrity of insulation and continuity of connecting cables. Cables should not twist on themselves and should not cross other cables especially pulse oximeter cables.

Filtering system

Used to filter out environmental artefacts. In monitoring mode, frequencies of 0.5 to 40 Hz are allowed. Here wandering baseline is eliminated and QRS complex height and ST segment changes are distorted. In diagnostic mode, frequencies of 0.05 to 100 Hz are allowed. It does not filter high frequency signals and useful for ischaemia detection.

Display of ECG

Most are cathode ray oscilloscope type. One mV (equal to 10 mm) calibration is required for ST segment analysis. Always keep a hard copy of ECG for analysis. Computerised analysis is currently available. For cardiac surgery, five-electrode system with two simultaneous lead displays should be available.

Artefacts of ECG

The causes of ECG artifacts are : a) Poor skin contact b) Gel drying up due to exposure to air for long time c) Damaged cables d) Skeletal muscle contraction e) Electrocautery

While using electrocautery, place the ground plate in such a way that, current path from the surgical site to ground plate is far from chest.

Normal electrocardiogram

An ECG will have a 'P' wave due to atrial depolarization. 'QRS' complex is because of ventricular depolarization. The P-R interval is mainly due to delay in the AV node. 'T' wave is due to ventricular repolarisation. 'U' wave comes after 'T' wave and is of uncertain aetiology. This sequence is the hallmark of normal sinus rhythm.[12] A normal waveform is presented in Fig-2.[12]

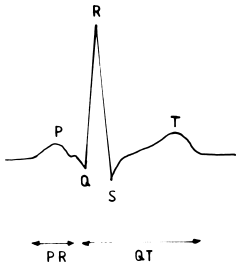

Fig -2 : Normal Electrocardiagram

Normal parameters are enumerated below[13]

Rate : 60 to 100 per minute in adults with less than 10% variation

'P' Wave : Always present, uniformly rounded without peaking or notches. Amplitude is less than 3.0 mm with duration between 0.06 to 0.1 second. It is upright in lead I,

II, aVF and V_4 to V_6. It is inverted in avR and variable in other leads.

'PR' interval: 0.12 to 0.20 seconds (0.11 to 0.18 seconds in children)

'QRS' complex : Follows 'P' wave at 1:1 ratio. Duration is between 0.04 to 0.1 second. Amplitude varies between 5 to 25 mm in limb leads, 6 to 30 mm in V_1 and V_6, 7 to 30 mm in V_2 and V_5 and 8 to 30 mm in V_3 and V_4 leads.

'Q' wave : Duration is less than 0.03 second. Amplitude is 1 to 2 mm in lead I, aVL, V_5 and V_6 , it is deeper in aVR and lead III.

'QT' interval : It is less than 50% of preceding RR interval. Corrected interval is less than 0.42 second.

'ST' segment : Follows isoelectric line with normal variation

a) Slight curve at proximal 'T' wave
b) Less than 1 mm elevation in precordial leads
c) Less than 0.5 mm depression

'T' wave : Asymmetric and slightly rounded without sharps. Upright in leads I, II & V_3 to V_6. Inverted in avR and variable in other leads.

Myocardial ischaemia monitoring

It is well documented that intraoperative ischaemic events in patients correlate well with post operative myocardial ischaemia and other morbidity, hence treatment or prevention of ischaemia leads to prevention of perioperative cardiac morbidity.[14] No single monitor is ideal. They range from cellular event monitoring by nuclear magnetic resonance imaging (NMR) spectroscopy, through extra cellular events using myocardial pH probes to global contractility using left ventricular pressure-volume catheterization.[15] Electrocardiography, echocardiography, pulmonary artery catheterization and metabolic sampling are common methods used

ECG though commonly used in the detection of myocardial ischaemia, has no standard criteria for the diagnosis. ST segment abnormality though most specific, 'T' wave inversion, QRS and 'T' axis alteration, 'R' and 'U' wave changes, new dysrhythmias and ventricular ectopy are other indicators.[16]

The basis of ST segment changes is due to repolarisation. K_{ATP} channels, a subtype of potassium channels present in cardiac myocytes regulate cellular response to hypoxia and ischaemia. When there is an insult, these channels open up and cells begin loosing potassium. This alters electrochemical potential which is recorded on surface ECG as ST segment alteration.[17]

The ST segment

Routine monitoring of bedside ECG fails to diagnose ischaemic events. New monitors have gained credibility for their accuracy in recording ST segment with online analysis and trending facility. Commonly applied standard criteria suggested by Ellestad and colleague includes horizontal or down sloping depression of more than 1 mm at 60 msec from the 'J' point lasting for at least 60 seconds.[18] This has been accepted by American college of cardiology. ST segment depression indicates subendocardial ischaemia and elevation indicates transmural ischaemia. Up sloping ST depression of at least 1.5mm and measured 80msec after 'J' point is also a marker of ischaemia, but with shorter duration, it looses its validity.[19]

'J' point depression alone and rapidly returning up sloping depression are normal. There are some non-ischaemic causes that alter ST segment. They include, use of digitalis, electrolyte abnormalities, hyperventilation, WPW syndrome, chronic hypertension and severe aortic stenosis. Some conditions confound ST segment analysis. They are change in body position, lead position, recent defibrillation and hypothermia.

Automated ST segment monitoring

First reported by Kortly and associates in 1984. Few landmark points on the ECG trace need to be defined for this purpose. Isoelectric line is at PR point. 'J' point is where QRS complex changes its slope. ST point is a fixed distance from 'J' point. Vertical difference between ST point and PR point is the ST segment change. This is presented in Fig-3.[20] Computer assisted ECG interpretation is highly advantageous in the OT. The computer calculates the measurements after scanning different segments for voltage change after filtering out noise and baseline shift. ST point is taken either 60 or 80msec after 'J' point. User can also set measuring points using designated keys and changes made for one lead is applicable to all. For analysis beats are not recognized, when there are less than eight normal looking beats per

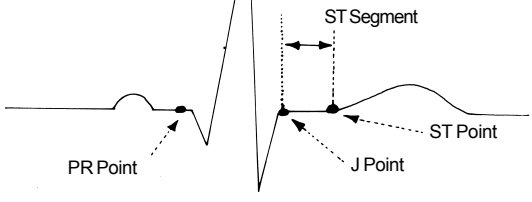

Fig - 3 : Automated ST segment monitoring; reference points

minute and in presence of RBBB, WPW syndrome and motion artefacts. Appropriately acquired waveforms are stored, analyzed and a total of nine such waves are maintained for each lead.[20]

The monitor can be programmed to signal three ST segment conditions, maximal depression, maximal elevation and maximum allowable change in last five minutes. Any user set limit violation activates alarm message. Various companies provide their own algorithms. Isoelectric point is taken 80msec before 'R' wave and 'J' point is 40msec after 'R' wave in HP monitors by default. This is presented in Fig-4.[20] Trending facilities are available at 15, 30 and 60 seconds apart. Both three and five lead systems are compatible for analysis.

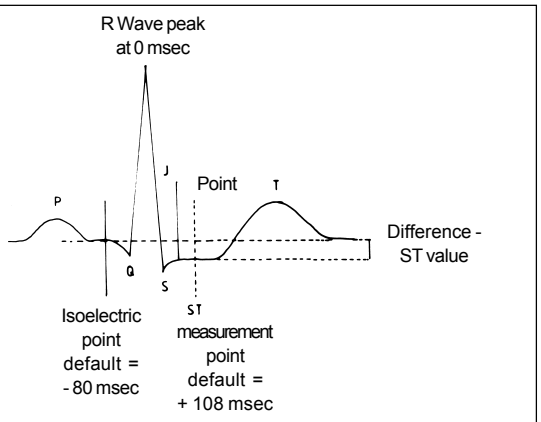

Fig - 4 : Adjustable reference points for automated ST segment analysis

Lead selection

For ischaemia monitoring, single best lead is V_5. V_4, II, V_3 and V_6 are in decreasing order of sensitivity. Chances of ischaemia detection among combined leads is; V_5 & II in 80%, V_4 & V_5 in 90%, V_4, V_5 & II in 96% and II & V_2-V_5 in 100% of cases.[21] V_4R and CB_5 are suitable for right sided ischaemia detection. V_7, V_8 and V_9 are suitable for posterior ishemia detection.[22]

In a five electrode system, Leads II, III and aVF reveal disease in right coronary artery (inferior wall). Lead V_1 to V_6 represent left anterior descending and circumflex artery distribution; V_1, V_2 & V_3 for anteroseptal wall, V_3, V_4 & V_5 for anteroapical wall and V_4, V_5 & V_6 for anterolateral wall. Lead V_1 & aVL detect ischaemia in posterior wall.[23]

Dysrhythmia and conduction abnormality monitoring

Average incidence of intraoperative dysrhythmia is reported up to 84% under anaesthesia. Under general anaesthesia it is higher than regional (66% vs 42%), during thoracic surgery it is higher than peripheral surgery (93% vs 56%), in intubated patients it is higher than non-intubated patients (72% vs 44%). Many of them cause haemodynamic disturbances, tachycardia induced myocardial ischaemia and are forerunner of serious physiologic disturbances.[24, 25]

To enhance the likelihood of dysrhythmia detection, the anaesthesiologist must do everything to increase the ability to recognize the same in the intraoperative period.[26]

a) Audible 'R' wave detector should be turned "on" b) Use leads with maximal information c) To know that when one lead is insufficient use the other leads d) Set the monitor to monitoring mode.

Mechanism of dysrhythmia

Normal heart beat originates from SA node, which dominates other pacemaker cells lying in atrial wall, AV node and Purkinje fibers. Propagated action potential proceeds from sinus node through downstream cells to myocardial cells. Slowing down of action potential at the AV node allows optimal ventricular filling. SA and AV nodal cells are slow response cells with slow upstroke velocity, maximal diastolic transmembrane potential of –60 to –80 mV and low amplitude. Atrial, ventricular and Purkinje cells are fast response cells with resting membrane potential of – 80 to – 95 mV. Dysrhythmias are due to defective impulse formation (automaticity) or defective propagation. In abnormal automaticity, SA nodal automaticity is decreased or latent pacemaker automaticity is enhanced or resting membrane potential of fast response cells is lowered.[27] Defective propagation is due to loss of membrane potential in depressed fast response cells. Mechanism of different dysrhythmia is presented in Fig-5.

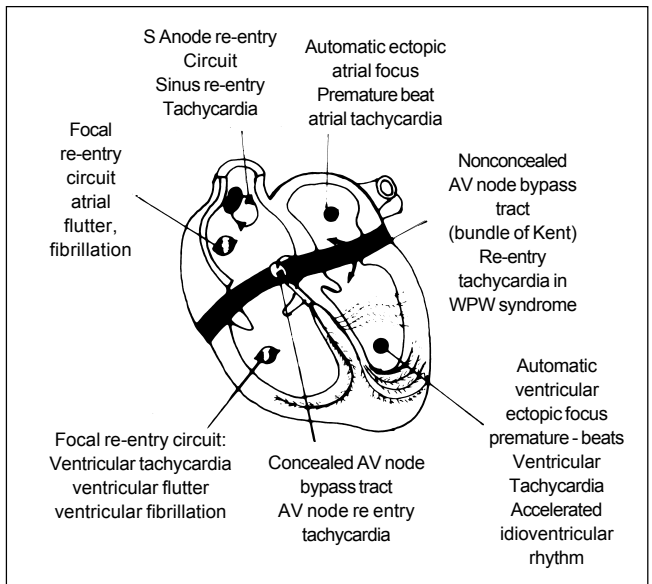

Fig - 5 : Mechanism of action for various dysrhythmias

Common perioperative dysrhythmias

Supraventricular dysrhythmias

Sinus bradycardia: 'P'waves occuring at a rate of less than 60 per minute with 'PR' interval more than 0.12 seconds. It occurs due to high vagal tone as with neostigmine administration or reduced sympathetic discharge as with high spinal block.

Sinus dysrhythmia: There occurs varying 'P-P' interval, which cycles with or without respiration. They are physiological.

Sinus arrest and SA exit block: There is a pause in 'P' wave with new 'P-P' interval (variable in sinus arrest and exact multiplication of normal interval in SA exit block). High vagal tone or digitalis are usual causes.

Sick sinus syndrome : In this dysrhythmia, a combination of sinus bradycardia, sinus arrest, supraventricular tachy-brady syndrome are seen. Coronary artery disease with subsequent ischaemia is the common aetiology

Sinus tachycardia: Normal 'P' waves occuring at a rate of more than 100 per minute is the hallmark feature. Catecholamine excess, surgical stress, hypovolaemia, hypercapnia and hypoxia are usual causes.

Wandering pacemaker : Diagnosed by variable 'P' wave morphology with changing 'PR' interval. Often seen with potent volatile anaesthetics.

Premature atrial beats : Premature 'P' waves come with 'PR' interval more than or equal to 0.12 seconds. They are quite common under general anaesthesia and precipitated by increasing catecholamine levels, myocardial ischaemia, chronic pulmonary disease and intraatrial catheters.

Atrial flutter : Typical atrial flutter consists of saw tooth flutter waves with no isoelectric interval. Usual rate is between 250 and 350 per minute with 2:1 to 3:1 block. Leads II, III, V_1 & aVF are suitable for monitoring.

Atrial fibrillation : Irregularly irregular 'RR' interval with chaotic baseline is the diagnostic feature. Long standing hypertenion, hyperthyroidism, mitral valve disease and ischemic heart disease are common aetiology.

Atrioventricular junctional rhythm

AV junctional escape beats : This occurs due to slowing of sinus rate. Long 'RR' interval and normal QRS complex with no definite relation to 'P' waves makes the diagnosis. There may be retrograde 'P' waves following QRS complex. They are common in young healthy individuals.

Junctional rhythm : Occurs when AV node completely takes over genesis of heartbeat. Usual rate is 50 to 70 per minute. When sinus rate is same as junctional rate, 'P' wave marches in and out of 'QRS' complex. This is called isorhythmic AV dissociation and is commonly seen with volatile anaesthetics.

AV junctional tachycardia : 'P' waves are absent and rate is between 70 to 100 per minute. They are seen in patients with significant heart disease, digitalis overdose and after open heart surgery.

Ventricular dysrhythmias

Premature ventricular beats (PVB)

They are early bizarre appearing 'QRS' complexes wider than 0.12 seconds with 'T' waves opposite to QRS direction. There may be retrograde 'P' wave (in leads II, III and avF). There is a compensatory pause. They should be differentiated from premature atrial beats by presence of compensatory pause and VA association. Two consecutive beats make a couplet and three make a triplet. One uniform PVB associated with every consecutive sinus beat is called bigeminy, associated with every two sinus beats is trigeminy and with every three is called a quadrigeminy. PVBs of different morphology are known as multiform. Coronary artery disease, hypertension, hypothyroidism and valvular heart disease are common aetiology. Without heart disease it can be seen with hypokalaemia, hypoxia, and hypercarbia. During thoracic and cardiac surgery myocardial manipulation can precipitate this.

Ventricular tachycardia :

Three or more PVBs in a row with usual heart rate between 110 to 250 per minute. It must be differentiated from supraventricular tachycardia by response to vagal maneuvers and presence of premature 'P' wave.

AV conduction block

First degree heart block

'PR' interval exceeds 0.20 seconds. Can occur during general anaesthesia under potent volatile anaesthetics especially in patients on beta blockers and calcium channel blockers.

Second degree heart block

Some of the 'P' waves are transmitted others are not.

In type I (Wenckebach block) 'PR' interval progressively lengthens till a non conducting 'P' wave. It is relatively benign unless associated with hypotentsion or bradycardia. They occur in young healthy patients with high vagal tone under inhalational anaesthesia.

In type II 'P' waves are not followed by QRS complex, but 'PR' interval of conducted beats are constant and normal. It indicates serious underlying heart disease and also seen during rewarming phase of CPB.

Third degree heart block

'P' wave & 'QRS' complexes have separate and independent rates. QRS morphology is usually wide. Its sudden appearance during anaesthesia may cause profound hypotention and circulatory collapse needing immediate attention.

ECG manifestations of altered physiological status

They are due to electrolyte imbalance, drug overdose, acid base disturbances or CNS disorders. Only those changes occurring in the perioperative period are described here.

Hypokalaemia

Common in surgical patients due to diuretic therapy and hyperventilation. Low amplitude or inverted 'T' waves, increase in height (more than 0.5 mm in lead II and 1 mm in V_3) & duration of 'U' waves and ST segment depression of more than 0.5 mm are ECG findings. PVBs, PABs and AV junctional disturbances are common dysrhythmias.

Hyperkalaemia

Peaked 'T' wave, wide QRS complex, ST segment elevation are ECG features. Slowing of sinus rhythm and AV conduction disturbances are common dysrhythmias. VF is rare.

Hypocalcaemia

Prolonged QT interval and ST segment are common. T wave inversion is seen in severe cases. No dysrhythmia has been described.

Hypercalcaemia

Shortened QT interval with prolonged PR interval is seen. VF can occur in severe cases.

Digitalis toxicity

Digitalis decreases effectiveness of sodium-potassium ATPase causing decrease in intracellular potassium and increase in intracellular sodium. These changes lead to loss of resting membrane potential. Almost all dysrhythmias are reported. Atrial tachycardia with AV block is commonest. PABs and PVBs are also seen. Factors that increase digitalis induced dysrhythmia are, hypokalaemia, increased catecholamine, hypercalcaemia, hypoxia and hypercapnia.

Theophylene

This drug inhibits phosphodiesterase thus increases intracellular cyclic AMP, which causes bronchodilation and increases automaticity of the heart. Serum level exceeding 20 microgram per liter is arrhythmogenic but excess level does not increase chances of dysrhythmia.[28] Supraventricular tachydysrhythmias are commonest.

Volatile anaesthetics

Halothane, enflurane & isoflurane decrease SA nodal discharge rate. Halothane and enflurane decrease AV nodal and Purkinje fiber conduction. Isoflurane prolongs Purkinje fiber conduction. Dysrhythmias most commonly seen are bradycardia and AV junctional rhythm. These agents sensitize heart to adrenaline with varying potency. Mean dose of epinephrine for ventricular dysrhythmia are, 2.1 micro $gmkg^{-1}$ for halothane, 6.7 micro $gmkg^{-1}$ for enflurane and 10.9 micro $gmkg^{-1}$ for isoflurane. So it has been recommended to keep adrenaline dose below 1.0 micro $gmkg^{-1}$.

Acid-Base abnormalities

There are no conclusive reports. These abnormality induced ECG changes are due to autonomic imbalance, electrolyte changes and cellular hypoxia.

Central nervous system disorders

Most common CNS lesion causing ECG changes is subarachnoid haemorrhage (SAH). QT interval prolongation, ST segment elevation or depression, inverted or tall T waves and rarely 'Q' waves are seen. Common dysrhythmias are PVBs, VT and sinus tachycardia. In patients with increased ICP, bradycardia develops due to autonomic imbalance.

Intracardiac catheter placement

ECG monitoring helps in proper localization of intracardiac monitoring catheters.

a) For correct placement of CVP catheter in SVC-RA junction
b) Differentiating PA and RV tracings during pulmonary artery catheterization

ECG also helps in correct diagnosis of pulsus alternance and pulsus paradoxus

ECG monitoring in special situations

1. Paediatric patients
2. ECG during cardiopulmonary bypass (CPB)
3. Magnetic resonance imaging (MRI)
4. In presence of pacemaker
5. Fetal surgery
6. ECG during transport

Paediatric patients

ECG in paediatric patients gives information on rate, rhythm and complex morphology. ECG in infants is characterized by "three Rs"; rapid rate, rightward QRS and right ventricular dominance. QRS axis more than or equal to 30^0 suggests serious congenital heart disease like double outlet right ventricle with VSD, tricuspid atresia or endocardial cushion defect. Extreme right axis deviation or axis in north-west region is seen in transposition of great arteries.

Heart rate:

1. Rapid rate requires a monitor with digital rate meter and with adjustable gain to eliminate artefact.
2. 'T' waves are much larger due to close proximity of electrodes to the heart, hence error in counting is a possibility and ability to remove this artefact is helpful.
3. Variable speed control facility (50mmsec^{-1} and 100mmsec^{-1}) for rhythm analysis should be available.

Electrode placement[29]

a. Placed on extremities so that, movement artifacts from breathing is eliminated. Adult size electrodes can be wrapped around the limb.

b. Smaller electrodes generate higher current density in presence of electrosurgical units which can cause burns particularly with older units

c. They should not be placed on bony prominences

d. To avoid trauma to fragile ribs, snap-on electrodes should be snapped to the cable before being stuck to the chest

e. In premature infants they should be changed as infrequently as possible and should never be put on nipple buds.

ECG monitoring during cardiopulmonary bypass[30]

ECG interference is common during cardiopulmonary bypass. Ventricular fibrillation can occur at least twice, once during cooling and other during rewarming. After administration of cardioplegia differentiation of ECG artefact from VF may be difficult, although momentary cessation of pump can be done. Interference is believed to be due to creation of static electricity at the pump head-tubing interface and piezoelectric transduction due to compression of pump tubing. Some recommendations are made to overcome them a) spraying of water via automizer to the pump head and b) creation of electric contact between patient or circulating perfusate and grounded pump housing cabinet. There is some chance of microshock (described later) but this should not be a problem during CPB. This connection should be removed as soon as patient is off bypass.

ECG monitoring in MRI room[31]

As per guidelines of American society of anaesthesiologists, ECG, heart rate, blood oxygenation (oximetry) and noninvasive blood pressure measurements should be monitored in MRI requiring anaesthesia or sedation. Monitoring the ECG in the MR environment is particularly challenging because of the inherent distortion of the ECG waveform. This effect is seen primarily when blood, a conductive fluid, flows through the static magnetic field of the MR system. The induced biopotential is seen primarily as an augmentation of T wave amplitude, although other nonspecific waveform changes are also apparent on the ECG. Because an elevated T-wave is associated with true physiologic disorders, the static magnetic-field-induced ECG distortions may be problematic. For this reason, a baseline recording of the ECG prior to placing the patient inside the MR system may be necessary.

Additional artifacts caused by the static, gradient, and RF electromagnetic fields can severely distort the ECG, making observation of morphologic changes and detection of dysrhythmia quite difficult. To minimize some of these artifacts, a variety of filtering techniques are used. Other techniques to decrease ECG artifacts include: using ECG electrodes that have minimal metal, selecting electrodes and cables that contain no ferromagnetic metals, placing the limb electrodes in close proximity to one another, keeping the area between the limb electrodes and leg electrode small, placing the area of the electrodes near or in the center of the MR system, and twisting or braiding the cables

ECG in a patient with pacemaker

Most anaesthesiologist care for patients with pacemaker during anaesthesia. Before providing anaesthesia, information should be obtained from record of pacemaker insertion, pacemaker identification carried by the patient or from the cardiologist who has inserted it. ECG is taken to confirm its proper functioning. The features are

a) A pacing spike before P or QRS or both depending on the chamber paced.

b) Rate is within 2 per minute of the set rate.

c) Normal sinus rhythm with no spikes indicate intrinsic rate higher than set rate.

d) Rate can be slowed down by edrophonium below the set rate to check its function.

If in doubt the electrophysiologist should be consulted.

ECG during transport

The anaesthesiologist holds the key position during transport of a critically ill patient. ECG monitoring using a standard battery operated transport monitor gives information on arrhythmia and heart rate. Commonest problem encountered is motion artefact. Dedicated filtering system and special electrodes are available. One such is RAM (reduced artefact monitoring) electrode. The conductive adhesive gel is flexible and remains in contact even when there is tugging. It also reduces problems of artefact. The adhesive is heat activated, so adheres well in sweating patients also.

Fetal ECG

Fetal ECG is a method for monitoring fetal cardiac cycle. This is helpful in assessment of fetal well being during fetal surgery. During labour, detection of fetal hypoxia is possible in 75% cases from ST segment and 'T' wave changes.

There are two types of systems in use; direct, in which scalp electrodes are used and indirect, where ECG is sensed from maternal abdominal wall. Direct recording is performed only during labour. The difficulties faced are mainly for abdominal ECG. The magnitude of fetal signal is several micro volts compared to 1 to 2 mV of maternal ECG. Other sources of difficulty are from maternal muscle activity and other equipment. In addition fetal movement and reduction in signal from advanced gestational age are to be kept in mind.

Electrical hazards

There is always a danger of ventricular fibrillation when electrical current passes through myocardium. When a potential difference applied across two points of the body, a current flows and the current transferred to the heart is dependent on the resistance. All modern monitors can deliver current. When skin is offering resistance, at least 100 mA current is required to cause VF; this is known as macroshock. Incidence of macroshock is rare and is prevented by usual electric precautions. Situations arise when skin resistance is eliminated, where 0.1 mA current can cause VF; this is known as microshock. Incidence of microshock is higher. Invasive ECG, needle electrodes and cardiac catheters filled with conducting solution are likely causes. Any electric bridge between monitoring equipment and catheter or lead in proximity with myocardium should be avoided in addition to good equipment design and maintenance.

Conclusion

Intraoperative monitoring, identification of critical incidents and institution of appropriate therapy are sole responsibility of the anaesthesiologist. Cardiac system monitoring is as important as oxygenation or ventilation monitoring especially in cardiac patients and in elderly population. Electrocardiogram is the basic tool for cardiac system assessment. Knowledge of ECG needs to be updated frequently as its usage and technical advances are growing. Use of information both from surface and invasive ECG help the anaesthesiologist for optimal patient care. MRI, CPB and transport are special situations requiring special attention. Finally ECG should be continuously monitored starting before induction, during positioning, while shifting till after recovery in postoperative care unit.

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