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Equipment-related Electrocardiographic Artifacts

Causes, Characteristics, Consequences, and Correction

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Interference of the monitored or recorded electrocardiogram is common within operating room and intensive care unit environments. Artifactual signals, which corrupt the normal cardiac signal, may arise from internal or external sources. Electrical devices used in the clinical setting can induce artifacts by various different mechanisms. Newer diagnostic and therapeutic modalities may generate artifactual changes. These artifacts may be nonspecific or may resemble serious arrhythmia. Clinical signs, along with monitored waveforms from other simultaneously monitored parameters, may provide the clues to differentiate artifacts from true changes on the electrocardiogram. Simple measures, such as proper attention to basic principles of electrocardiographic measurement, can eliminate some artifacts. However, in persistent cases, expert help may be required to identify the precise source and minimize interference on the electrocardiogram. Technological advancements in processing the electrocardiographic signal may be useful to detect and eliminate artifacts. Ultimately, an improved understanding of the artifacts generated by equipment, and their identifying characteristics, is important to avoid misinterpretation, misdiagnosis, and iatrogenic complication.

CONTINUOUS electrocardiographic monitoring is now a basic standard of care in the operating room and the intensive care unit (ICU). Both of these environments have experienced an increase in the number of electrical devices used for patient care, with a consequent increase in the risk of interference. Accurate interpretation of the electrocardiogram requires that it be of high quality and free from distortion and artifact. Although technological advancement has increased the reliability of most apparatuses, interference of the displayed electrocardiogram still occurs.

Electrocardiographic artifacts originate from a wide range of sources, predominantly simultaneous use of other devices. Such equipment-related artifacts have been reported specific to patient groups[1–9] or to care areas such as the ICU,[10–12] neonatal ICU,[13–15] emergency room,[16] obstetric unit,[17] post–cardiac surgical ICU,[18,19] coronary care unit,[20] pediatric ICU,[21] acute medical ward,[22,23] and general ward.[18] Artifacts have occurred in various age groups, including premature babies,[14] neonates,[13,15] other pediatric groups,[6,21] young adults,[9,10,22,24,25] and geriatric patients.[8,9,26–30]

More detailed listings are shown in table 1. Additional information regarding this is available on the Anesthesiology Web site at http://www.anesthesiology.org.

However, accurate recognition of artifacts on the electrocardiogram is generally poor among physicians.[31] Misdiagnosis of artifact may subject patients to unnecessary diagnostic and therapeutic interventions for arrhythmia.[32] A review of six major clinical cardiology and electrocardiography textbooks do not discuss the topic,[33] and although electrocardiographic artifacts have been previously reviewed to some degree,[15,34–40] a detailed and contemporary review of equipment-related artifacts is still lacking.

The purpose of this article is to discuss the causes, characteristics, consequences, and correction of equipment-related artifacts on the monitored or recorded electrocardiographic tracing in the modern clinical setting.

Additional material related to this article can be found on the ANESTHESIOLOGY Web site. Go to http://www.anesthesiology.org, click on Enhancements Index, and then scroll down to find the appropriate article and link. Supplementary material can also be accessed on the Web by clicking on the "ArticlePlus" link either in the Table of Contents or at the top of the Abstract or HTML version of the article.

Origin and Measurement of the Electrocardiographic Waveform

Because of varying tissue resistances from heart to skin, attenuated body surface potentials have an amplitude of only 1% of the amplitude of transmembrane potentials (0.5 to 2.0 mV) across cardiac cells.[41] Voltage of several millivolts can be generated by physically stretching the epidermis.[42] The surface electrodes convert an ionic current into a flow of electrons.[43] Disposable electrodes develop ionic potentials at the electrode–electrolyte interface known as half-cell potentials.

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Table 1. Equipment or Its Component-related Electrocardiographic Artifacts

Transcutaneous electrical nerve stimulator[17,19,22,25,28,30,59]
Hemodialysis machine[10,11,21,29,57]
Evoked potentials monitoring unit[2,6,7,60]
Electrostimulators
Thalamic,[23,27,61] spinal cord,[24] peripheral nerve[9]
Other electrostimulators[26,62]
Cardiopulmonary bypass[1,56]
Ventilator—HFOV[12,13]
Intravenous fluid warmer/warming set[53,55]
ESWL[58]
Flexible bronchoscope[50]
Digital urine output/core temperature monitor[18]
Pressure-controlled irrigation pump[4]
Cell phone[16]
Sinus endoscope[51]
Intraoperative MRI[5]
Orthopedic shaver[8]
Monitor and its components
Manufacturing problem (50/60-Hz filter)[48]
Defective monitor insulation[52]

ESWL = extracorporeal shock wave lithotripsy; HFOV = high-frequency oscillatory ventilation; MRI = magnetic resonance imaging.

There may be an electrical potential across a pair of these electrodes equal to the algebraic difference of the two half-cell potentials, called the *offset potential*.[44] Electrode-related specific problems include excessive offset potential and polarization (buildup of electrical charge at its base plate as a result of current flow).[43] Impedance imbalance between the paired electrodes and movement of the electrodes can significantly distort or eliminate the electrocardiographic signal. Main power line (50/60 Hz), energy radiation from other electrical devices, and electromagnetic and radiofrequency interference can enter, *via* broken or poorly shielded leads.[45]

The output of electrocardiographic electrodes and their leads are amplified, filtered, and displayed by a variety of electronic devices to construct an electrocardiographic display or recording (fig. 1).

The performance of an amplifier is defined by its gain (ratio of output signal amplitude to the input signal amplitude), which for routine electrocardiography is 1,000.[41] The frequency range over which the amplifier accurately amplifies (bandwidth) should encompass 0.5–100 Hz, as required by the American Heart Association standard.[46]

The electrocardiographic signals must be amplified without including the many other electrical noise signals in the circuit, so as to minimize the signal-to-noise ratio. This is achieved with a differential amplifier, which detects the difference in potential between the two active electrodes and attenuates those signals common to both electrodes.[41] The common-mode rejection ratio is the ratio of differential voltage gain and the common-mode voltage gain and is a measurement of capability to reject the "noise."

Nevertheless, differences in the electrode impedances and stray currents through the patient, cables, and monitor can transform a common-mode voltage into a false differential signal that cannot be suppressed, even by an infinitely high common-mode rejection ratio.[43]

Instrumentation for electrocardiographic recording includes high- and low-frequency electronic filters designed to minimize artifact while preserving the integrity of the signal.[47] "Notch" filters reduce interference due to mains frequency range 50/60 Hz. However, a manufacturing error led to an uncommon occurrence of 60-cycle interference manifesting in several operating rooms. The notch filter was adjusted for a foreign alternating current voltage frequency in cardiac monitors destined for the US market.[48]

An analog-to-digital converter allows the digitization of continuous analog signals into binary bits. This permits various digital filtering and pattern recognition algorithms used for subsequent processing, to operate in real time.

Time- and temperature-related drift of components should be minimal. Patient and ground leakage current should be as per the national electrical safety standard. The maximum patient leakage current for electrocardiographic monitors (type CF equipment) is 0.01 mA in the normal condition and 0.05 mA for the single-fault condition. For proper display, appropriate setting of gain, display size, and sensitivity controls are needed. Conversely, wrongly set gain and display size may lead to T waves being counted as QRS complexes, leading to erroneous display of heart rate. It is only when all of these factors are carefully examined and realized that reliable interpretation of a consistent and quality electrocardiographic signal allows appropriate clinical decision making. Takla *et al.* [49] recently reviewed the technological advancements in the processing of the electrocardiographic signal.

Sources of Artifact Affecting the Interpretation of the Electrocardiogram‡

Some of the devices generating artifacts on the electrocardiogram are listed in table 1.

Equipment Inducing Movement Artifacts

Motion may generate electrocardiographic artifact. Both movement of the electrocardiographic lead on the left leg by an intraaortic balloon pump catheter and electrode movement due to a pneumatically driven pump have simulated conduction disturbance and arrhythmia.[3,20]

Similarly high-frequency oscillatory ventilation (frequency between 4–15 Hz) caused high-frequency artifacts due to skin/electrode movements. It appeared as atrial flutter/fibrillation in a neonate[13] and ventricular

‡ See figure 1.

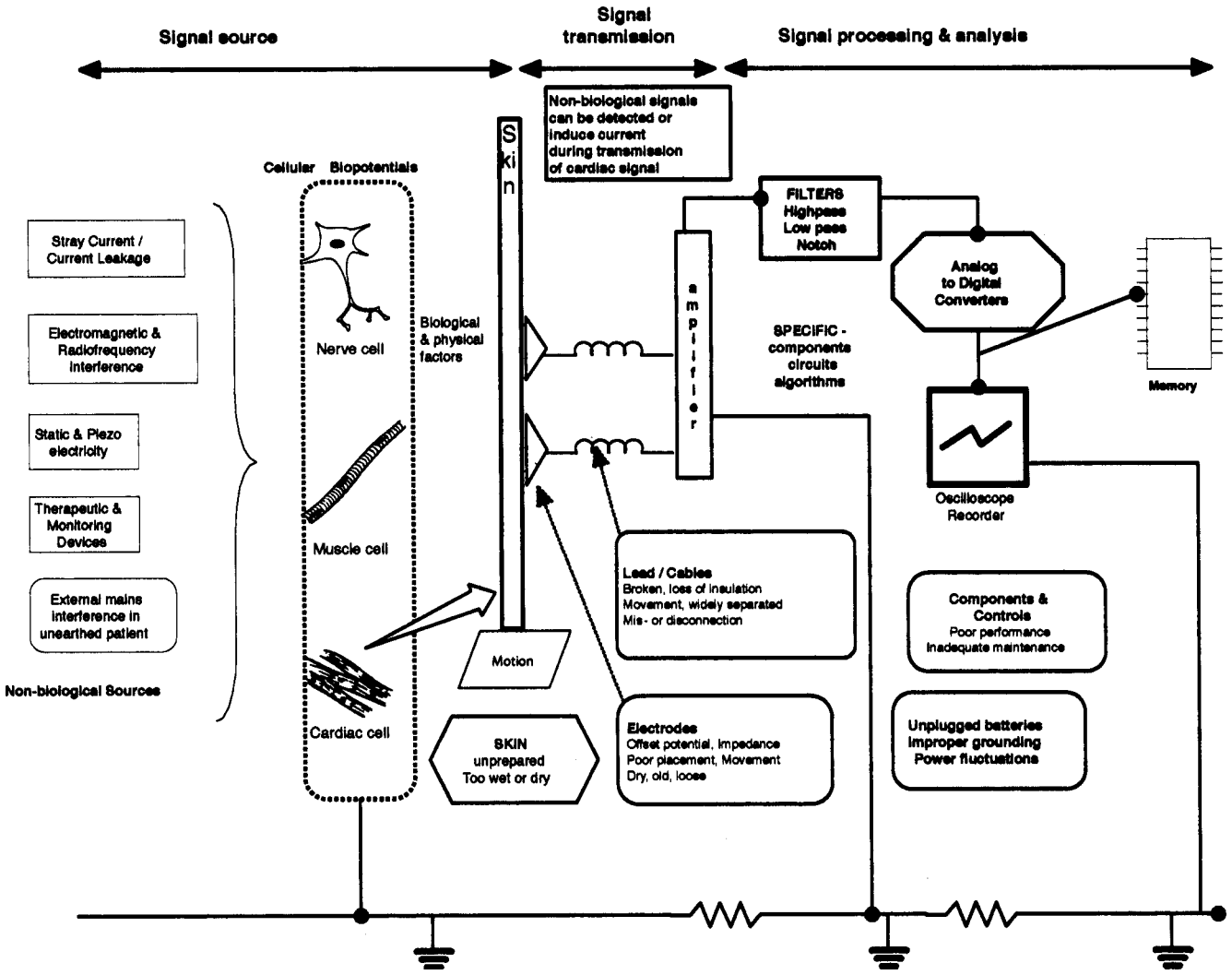

Fig. 1. Factors affecting the transmission of electrocardiographic signal and sources of artifacts.

tachycardia in an adult[12] on both oscilloscope and 12-lead electrocardiograph.[12,13]

Current Leakage, Grounding Failure, and Interference by Capacitance

Depending on the type of equipment used, electrical current may leak and pass through a patient. Apart from posing a serious electrical hazard, it can cause artifacts on the electrocardiogram.

Electrical current leakage from both intravenous fluid infusion controllers[14] and the light intensity controls of a fiberoptic bronchoscope[50] caused interference with electrocardiographic monitoring. Stray current from loose electrical wiring of a microdebrider for sinus surgery has led to artifact resembling ventricular tachycardia[51] (fig. 2), whereas electrical noise from a pressure-controlled irrigation pump, during shoulder arthroscopy, generated pseudo–atrial flutter or fibrillation changes on the monitor.[4]

Chase and Brady[52] reported wide QRS complex tachycardia due to placement of new electrical lines near a monitor whose internal insulation was broken.

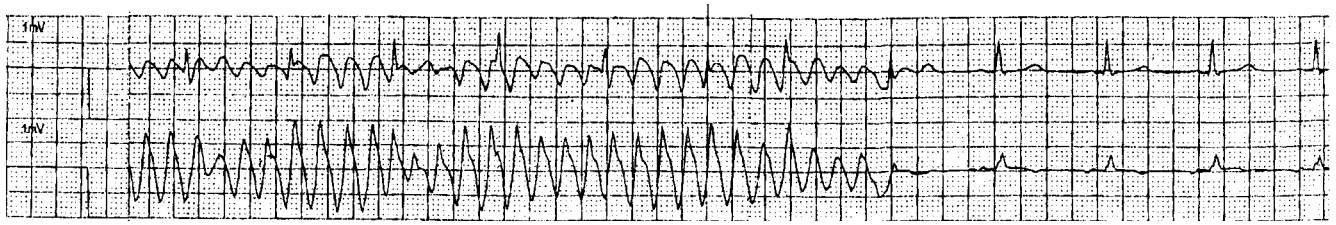

Fig. 2. Electrocardiographic artifact mimicking ventricular tachycardia during endoscopic sinus surgery. Adapted from Gaiser *et al.*[51]; with permission.

Capacitive coupling between metal plates of a faultily grounded fluid warmer and the insulated plastic fluid package led to pacemaker spikes appearing, coincident with use of the warmer.[53]

Several cases of electrocardiographic artifacts mimicking atrial flutter or ventricular tachycardia occurred with the use of a urine output/core temperature monitor and cardiograph, where a signal generated in the isolation circuitry of the urine output monitor was conducted to the patient and then to the cardiograph.[18] Signals unintentionally produced in one device have the potential to be transmitted to another, by capacitive coupling through the patient.

Static and Piezoelectric Effects

Piezoelectricity is an electrical charge generated by the mechanical deformation of polymeric materials. Plastics also generate static electricity when constantly rubbed and separated by dissimilar nonconductive surface materials.

Static charge and subsequent artifact generation can result due to droplet formation associated with the use of infusion pumps,[54] and a blood/fluid warming set.[55] The amplitude and frequency of the artifacts were inversely related to the drop rate.

Khambatta *et al.*[1] found an incidence of 68% in a study of electrocardiographic artifacts during cardiopulmonary bypass. They identified static electricity generation between polyvinyl chloride tubing and the pump roller head as source of artifactual arrhythmia. In another case, a loose electrode connection accentuated the contribution of static electricity toward a reproducible artifactual atrial flutter during cardiopulmonary bypass.[56]

Piezoelectric or static electrical signals, in the presence of poor electrode contact, lessen the common-mode rejection capabilities of the differential amplifiers, and set the stage for the recording of spurious signals.

In the ICU, artifacts in the form of pseudo–atrial flutter-fibrillation have been described in patients receiving dialysis (fig. 3)[10,11,21,29,57] due to the generation of static and piezoelectric currents in pumps rotating between 50 and 600 rpm. Such currents flow into the patient *via* fluid in the tubing and are detected by the electrocardiographic electrodes.[11] Development of a periodic electrostatic charge could also cause a periodic variation in the body surface potential measured during the electrocardiographic monitoring and recording, by either inductive or capacitive interference.[57]

Static electricity can be generated with the use of synthetic clothing and carpeting in dry atmosphere. A life-threatening electrocardiographic artifact was described by Schiller,[58] where static electricity (generated as a technician slapped a panel of styrofoam against his thigh) was detected as an R wave, and fired an electrocardiographic-triggered lithotripter asynchronously.

The currents associated with piezoelectric or static electricity pose no electrical safety risk in themselves.[39]

External Electrostimulators

Transcutaneous Electrical Nerve Stimulator. Transcutaneous electrical nerve stimulator (TENS) produces an electrical current with variable frequency, amplitude, and duration and delivers it through bipolar skin electrodes, placed at various locations.

Depending on the mode used, *e.g.*, continuous (40–150 Hz) or pulsed (acupuncture-like bursts 100 Hz at 1–2 Hz intervals), high- or low-frequency artifacts can occur.[17,19,22,25,28,30,59] There may be various reasons for such interference, including detection and amplification of the stimulus, and saturation or blocking of the input amplifier by the TENS output. Rapid pulses produced by the TENS, close to electrocardiographic electrodes, can also trigger the detection system of implanted pacemakers. This has been described with TENS electrodes inserted in the lower thoracic epidural space[59] or applied to the parasternal,[19,25] thoracolumbar,[30] and midthoracic regions.[22]

Somatosensory Evoked Potentials Unit. This involves application of 10–20 mA stimuli at a rate of 4–5 Hz (240–300 per minute). The artifacts produced by somatosensory evoked potentials (SSEPs)[60] typically mimic a supraventricular tachycardia (SVT) rate between 250[2] and 300[6] per minute. Pseudo-SVT has been reported with the use of dermatomal sensory evoked potentials units.[7] Interestingly, in a 3-yr-old child, pseudo-SVT started with placement of an electrocardiographic electrode close to stimulating electrodes and disappeared on its relocation.[6] Marco and Rice[2] argued that artifact associated with SSEP monitoring is most likely due to an improper connection in the stimulating pathway or unbalanced impedance between stimulating electrodes, producing excessive voltage across the recording inputs. These voltage differences are detected, not only by recording electrodes on the scalp, but also by electrocardiographic electrodes.

Peripheral Nerve Stimulator. Rozner[9] reported two cases of electrocardiographic interference associated with the application of 50–100 Hz tetany, which re-

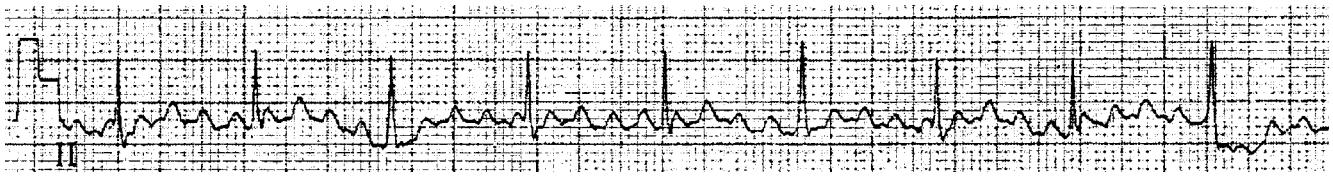

Fig. 3. Electrocardiogram showing presumed atrial flutter during continuous venovenous hemofiltration. The changes were seen on the monitor as well as the 12-lead electrocardiograph. Adapted from Biswas and Thompson[21]; with permission.

placed genuine pacemaker spikes with artifactual pacemaker spikes on the display.

Implanted Electrostimulators

Recently, newer treatment modalities with the use of electrostimulators have caused unique disturbances during electrocardiographic monitoring or recording. High-frequency artifacts have been reported with the use of deep brain stimulators for advanced Parkinson disease,[23,27,61] spinal cord stimulators for chronic pain,[24] and abdominal electrostimulators as a part of dynamic gracioplasty.[26]

In the case of deep brain stimulation, artifacts occurred when unipolar settings were used, and were absent when bipolar settings were used.[61] Gastric electrical stimulation, used for refractory diabetic gastroparesis, stimulates the stomach musculature approximately 12 times per minute, with default voltages of 1–4 V. One such device was damaged during direct current cardioversion for ventricular fibrillation arrest, subsequently giving rise to low-frequency spikes and artifact on the electrocardiogram.[62]

Electromagnetic and Radiofrequency Interference

Electromagnetic interference resulting in artifacts on the electrocardiogram has been described with the use of cell phones.[16] The effect depends on distance, frequency over which they operate, and technology used for communication. It also depends on the ability of medical devices to resist electromagnetic interference. Walkie-talkies used by maintenance and security personnel cause more interference than cell phones because they operate at lower frequency and have a higher power output.

In the modern neurosurgical operating room, high-field magnetic resonance imaging (MRI) is used to facilitate surgery. Electrocardiographic artifacts can arise from either static or pulsed (dynamic) magnetic fields. In the presence of a static magnetic field, electrical voltages may be generated within the body due to flow potentials, which are the result of blood moving within the patient.[63]

In a dynamic magnetic field, rapidly switched magnetic gradients can induce electrical interference in monitoring leads. In both of these circumstances, artifacts may vary in their frequency and time of occurrence, even mimicking atrial flutter and ventricular tachycardia or fibrillation.[5] Radiofrequency pulses can also cause problems if not properly removed from the amplification system.[63]

Electrocautery-induced electrical interference on the electrocardiogram is mainly due to very high-frequency currents (radiofrequency range) of 800,000 to 1 million Hz (800–1,000 KHz). Other contributing factors are power line (50/60 Hz) and low-frequency noise (0.1–10 Hz) from intermittent contact of the electrosurgical units with the patient's tissues.

Other sources of environmental electrical interference are radiofrequency transmitters. Such interference is picked up by electrical conduction or induction. Surrounding power cords, electrical instruments, and transformers all radiate electrical energy, which becomes electrically or magnetically coupled to the body. Personal pagers, handheld two-way radios, and cell phones are also radiofrequency transmitters and generate interference in the environment. A patient with a permanent pacemaker in postoperative care experienced high-frequency pseudopacer spikes on his electrocardiographic trace.[64] Despite intensive investigation, no cause could be found other than radiofrequency emission.

Other Hospital Equipment Causing Electrocardiographic Interference

Poor performance of conventional electrocardiographic or arrhythmia monitoring has been described due to radiated and conducted interference from a wide variety of sources, such as isolated power supply line isolation monitors, power distribution system components, televisions, radio, elevator motors, fluorescent lights, light dimmers, and smoke detectors.[34] Arthroscopic shavers (used in orthopedic tissue resection) have been reported as causing pseudo–ventricular fibrillation.[8]

Recognition and Identification

The development of artifacts during electrocardiographic monitoring is common, and often of no clinical significance. Most of the time, artifacts may be easily recognizable, and therefore are neglected. However, startling and unexpected appearance of some artifacts can be confusing and deceiving. Knowledge of the characteristics of artifacts may lead to their correct diagnosis, exclusion as causes of concern, and elimination from the environment.

History, Clinical Examination, and Investigations

Equipment-related artifacts have occurred commonly in the presence of sinus rhythm.[2,6,7,11,17,22,26,51,53–55,60,62] The interference on the electrocardiogram may be nonspecific.[1,5,17,23,24,26,55,58,60,61] Artifacts may mimic the range of pathophysiologic electrocardiographic findings (table 2).

New arrhythmia in an asymptomatic patient, with unchanged clinical cardiovascular signs, and where peripheral pulse rate correlates with apical pulse and QRS complexes on the monitor, should raise the suspicion of artifacts.[2,4,6–8,12,16,51,52]

However, occasionally artifact may appear in the presence of an established abnormal rhythm such as atrial fibrillation[8,25] and where a permanent pacemaker exists.[9,64] It can occur in a patient who is critically ill as a result of severe disease[22] and may compound diagnostic confusion. The first indications of the cause of artifact

Table 2. Types of Equipment-related Artifacts

Artifacts/Pseudoarrhythmias	Equipment That Caused It
Nonspecific artifacts	CPB,[1] intraoperative high-field MRI,[5] TENS,[17] internal electrostimulators,[23,24,61,62] CVVH,[29] blood/fluid warmer,[55] ESWL,[58] evoked potential monitoring units[60]
Pseudowaves	
QRS	Infusion rate controller[14]
P	IABP-induced movement artifact[20]
Pseudosupraventricular	
Premature atrial contraction	IABP[20]
Sinus tachycardia	Intravenous drop counter[54]
Supraventricular tachycardia	SSEP monitoring units[2,6,7]
Atrial flutter	Pressure-controlled irrigation pump,[4] prisma system for CVVH,[11,21] HFOV,[13] digital urine output/core temperature monitor,[18] TENS,[25] pressure CPB[56]
Atrial fibrillation	Pressure-controlled irrigation pump,[4] HFOV,[13] flexible bronchoscope[50]
Pseudoventricular	
Ventricular premature beats	Intravenous infusion pump[39,65]
Ventricular tachycardia	Intraoperative high-field MRI,[5] orthopedic shaver,[8] HFOV,[12] digital urine output/core temperature monitor,[18] sinus microdebrider,[51] electrical interference due to break in monitor's line insulation[52]
Ventricular fibrillation	TENS[28] (in the presence of ICD), intraoperative MRI[5]
Pseudopacemaker	
Spikes	Peripheral nerve stimulator,[9] TENS[19,22,59] intravenous fluid warmer[53,55]
Runaway pacemaker	TENS[59]
Loss of pacemaker spikes	Peripheral nerve stimulator[9]

CPB = cardiopulmonary bypass; CVVH = continuous venovenous hemofiltration; ESWL = extracorporeal shock wave lithotripsy; HFOV = high-frequency oscillatory ventilation; IABP = intraaortic balloon pump; ICD = intracardiac device; MRI = magnetic resonance imaging; SSEP = somatosensory evoked potential; TENS = transcutaneous electrical nerve stimulator.

may indeed arise from incidental investigations, such as a chest radiograph revealing TENS electrodes[22] or an abdominal computed tomography image revealing an implanted electrostimulator.[26]

Information from Other Monitored Parameters

Correlation with other monitored parameters may provide clues allowing the exclusion of genuine changes. Other waveforms providing rate and rhythm may not be consistent with the artifactual rhythm, *e.g.*, plethysmographic,[2,4,7,8,12,51] direct arterial blood pressure,[12] and central venous pressure.[21] Pulse rate from plethysmograph and direct arterial blood pressure trace will indicate true heart rate in case of pseudo–atrial fibrillation or –ventricular tachycardia. Conversely in case of true atrial fibrillation, these monitors may underestimate heart rate. In case of pseudo–atrial fibrillation, *a* waves on central venous pressure trace still may be seen.

If this seemingly obvious comparison is missed, it can lead to inappropriate management.[2,6] However, based on our personal observations, SSEP monitoring can also induce rate changes in the pulse oximeter waveform and value, confusing diagnostic resolution of arrhythmia. The use of electrocautery may be associated with loss of the pulse oximeter waveform, removing it as a source of comparison to electrocardiographic changes.

Appearance and Disappearance in Relation to Use of Equipment

Transcutaneous electrical nerve stimulator and other electrostimulator-induced artifacts have frequently disappeared once deactivated,[59] whereas the sudden appearance of new "supraventricular arrhythmias" on the electrocardiogram, coincident with the start of SSEP monitoring[2,6,7] (fig. 4) and hemodialysis,[11,21] are highly suggestive that the changes are artifactual. Communication with the neurotechnician during SSEP monitoring can confirm the diagnosis of pseudo-SVT.[2,6,7]

The "on–off test" is a simple method of eliminating medical devices from consideration as sources of artifact, *e.g.*, cardiopulmonary bypass,[1] dialysis unit,[21] and intravenous infusion pumps.[65] Intermittently appearing artifacts should be suspected and tested in this fashion.[8,12,21,51] Random appearance is most likely due to either mechanical movement or loosening of electrodes.[26,61]

Unless recognized and rectified, these artifacts may occur and recur in many patients.[1,18]

Features on Electrocardiogram

Depending on the cause, an artifact can appear in specific leads only[3,7,20] or all 12 leads.[12,13,21,23,61] The artifact may appear regularly on the electrocardiogram,[10,28,30,65] although its relation with the QRS complexes may not be consistent.[22,25,30,62] Synchronous and visible notching consistent with the underlying ventricular rhythm marching through the pseudodysrhythmia is a key feature that favors pseudodysrhythmia over true dysrhythmia.[66] Normal P waves in artifactual atrial flutter and normal QRS complexes in case of pseudo–ventricular tachycardia can be seen.

The low-frequency artifacts due to TENS are easily misinterpreted and misdiagnosed as implanted pace-

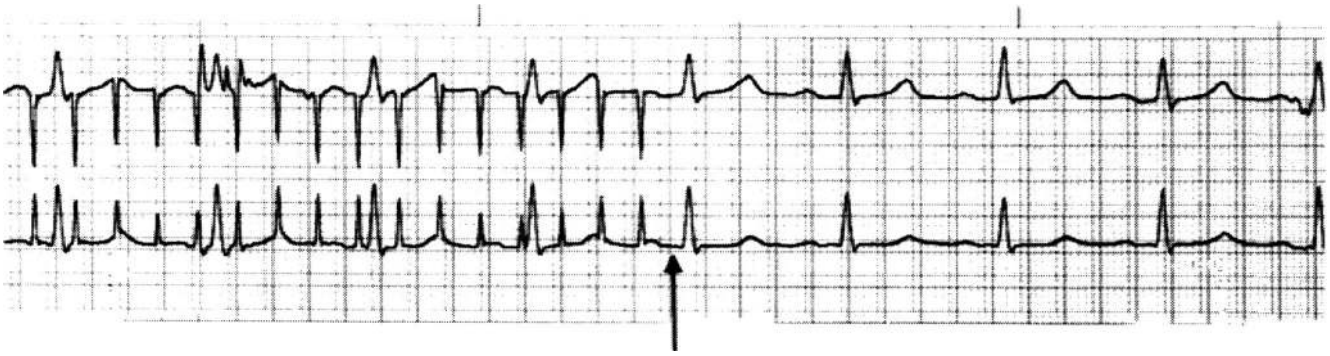

Fig. 4. Artifactual narrow complex supraventricular tachycardia during somatosensory evoked potentials monitoring. The *arrow* indicates when the stimulus was stopped. Adapted from Marco *et al.*[2]; with permission.

maker malfunction.[22,30] High-frequency electrical spikes caused by TENS may resemble a runaway pacemaker[18] or cause unrecognizable changes.[17,19]

Shape of the artifacts can be variable in different leads.[4,13,28,59] Differential artifact, variable frequency, and amplitudes in different electrocardiographic leads have been described recently with spinal cord and deep brain stimulators[24,27] (fig. 5). Artifact morphology depends on the position of the generator and electrodes.

Other Environmental Factors

Artifacts arising from static electricity may be affected by temperature and relative humidity.[1] Artifacts will not respond to administration of antiarrhythmic drugs or other therapeutic measures,[2,6,11,65] and the lack of any response to intervention should at least raise the suspicion of an extrinsic source of pseudoarrhythmia.

Changes on the electrocardiographic tracing may also be reproducible within simulated scenarios.[25,55,56,58] It has been suggested that a baseline electrocardiogram be recorded after the placement of a spinal cord stimulator.[24] It may define artifacts possible with that device and can be used for future reference.

Possible Consequences

Inappropriate diagnostic and therapeutic interventions are a serious concern of misdiagnosed artifacts. Consequences of electrocardiographic artifacts range from simple alarm activation to drastic diagnostic and therapeutic actions, even by well-trained clinicians. Knight *et al.*[32] reported on serious consequences, including placement of a permanent pacemaker and internal cardiac defibrillator, arising from mimicked ventricular tachycardia.

Fortunately most equipment related artifacts occur in environments that often offer ready corroboration of arrhythmia, which may include checking a short list of ventilator, hemodialysis machine, pulse oximeter, infusion pumps, and even electric bed.[18]

Transcutaneous electrical nerve stimulator–induced artifacts can be misinterpreted as pacemaker malfunction, despite the absence of a permanent pacemaker,[22,30] even confusing diagnosis by a cardiologist.[30] In one instance, artifact occurred in a collapsed patient, and the physician initially made a diagnosis of ventricular perforation due to pacemaker lead.[22] In a patient with cardiogenic shock, persistent artifact compromised electrocardiographic evaluation. After coronary angioplasty, the source of artifact was identified as an abdominal electrostimulator which was visible on previous radiologic image.[26]

One TENS unit created an electrical artifact that was interpreted by an internal cardiac defibrillator as ventricular fibrillation leading to the delivery of four discrete shocks.[28]

During cardiopulmonary bypass, it may be impossible to differentiate between artifacts and ventricular fibrilla-

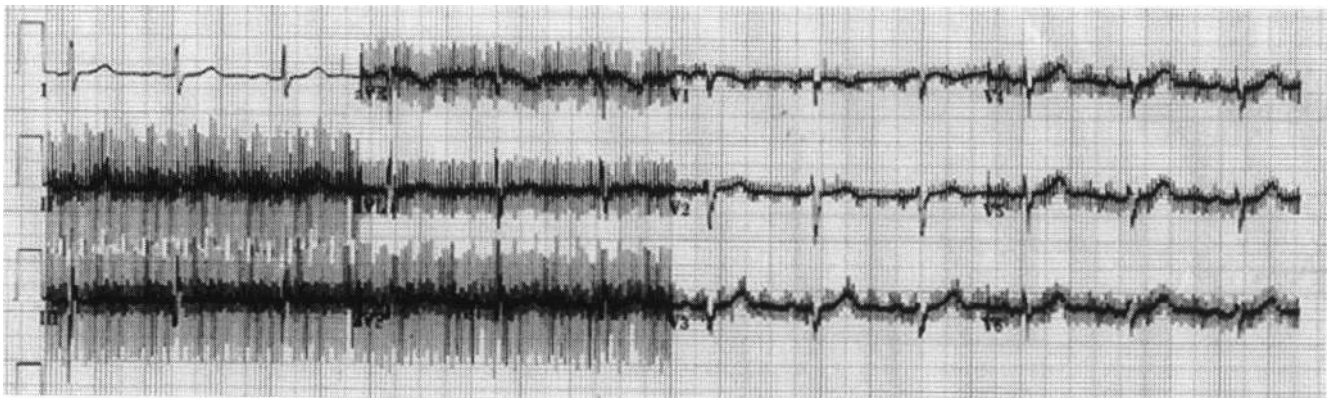

Fig. 5. Twelve-lead electrocardiograph with a spinal cord stimulator on, showing high-frequency and variable amplitude artifacts. Artifacts are absent in lead I (see text for details). Adapted from Siddiqui *et al.*[24]; with permission.

tion after cardioplegia, and the electrocardiogram can not be relied on to document cardiac standstill.[1] After rewarming and defibrillation, it may be difficult to tell when patient's own rhythm returns, and it may not be possible to diagnose and treat conduction abnormalities by observing the electrocardiographic tracing.[1]

A Valsalva maneuver and four doses of adenosine were administered to a 3-yr-old child to correct pseudo-SVT during SSEP monitoring.[6] The apparent reversion of the "SVT" to sinus rhythm after adenosine administration was in fact due to concurrent cessation of the SSEP stimulus.

Another patient received electrolyte supplements, fluid boluses, antiarrhythmic drugs, and synchronized direct current shock because of misdiagnosis of atrial flutter during a 12-h period of continuous dialysis.[11] Pseudo–atrial flutter diagnosis was confirmed upon the filter clotting and the apparatus being stopped.

Similarly, high-amplitude distortion spikes caused an electrocardiographic-synchronized lithotripter to fire rapidly and dangerously.[58]

Meharg[65] reported erroneous administration of lidocaine and high doses of various antiarrhythmic drugs for pseudoventricular premature complexes, which were, in fact, associated with the use of infusion pumps.

Sakiewicz *et al.*[29] described an unusual cause of intraaortic balloon pumping in a series of four patients, due to electrical interference arising during continuous dialysis. The intraaortic balloon pump was set to trigger upon detecting the R wave on electrocardiogram. The irregular spikes were identified by the intraaortic balloon pump as cardiac in origin and consequently induced erratic inflation.

In rare circumstances, it may be difficult or impossible to adequately explain electrocardiographic artifacts; this has previously forced consideration of closing affected beds in a cardiac ICU.[18]

In reports of equipment-induced artifactual ventricular tachycardia, none of the patients proceeded to therapeutic intervention.[8,12,51] This may be because most of these patients were in the operating room and ICU, where unexpected but obvious artifactual changes were inconsistent with the other monitored values and waves, allowing deductive comparison.

If these pseudoarrhythmias are not recognized and rectified, even if untreated, they may possibly be incorporated into the medical record, with a longer-term contribution to confusion and misdiagnosis.

Consequences of equipment-related artifacts are summarized in table 3.

Table 3. Consequences of Equipment-related Artifacts

Technical
Erroneous alarm activation
Inability to obtain satisfactory electrocardiogram[18,23]
Unnecessary repeated electrocardiographic measurements[17]
Unnecessary electrical checking of outlets, leakage, grounding, and safety standards
Unnecessary unplugging,[55] replacement,[29,55,60] and electrical checking[18,29,55,60] of other monitors and equipment[55]
Physician related (no harm to patient)
Confusion and puzzling to various staff[65]
Emergency call for physician to attend[12]
Interference in the clinical evaluation, monitoring, and diagnosis[1,3,26,56]
Failure to evaluate the effects of interventions[1]
Unnecessary investigations: electrolytes,[7,21] arterial blood gases[7]
Cardiology consultation[30,59]
Brief interruption of the therapy or surgical procedure[3,9]
Pulmonary artery catheter taken out[21]
Patient related (near misses or harm to the patients)
Malfunction of ESWL[58] and IABP[37] due to interference with the triggering based on R wave
Unnecessary ICU admission
Wrong diagnosis: malfunctioning of pacemaker in the absence of pacemaker[22,30] or other various arrhythmia[2,6,11,18,65]
Return of symptoms if electrostimulators are deactivated[23]
Unnecessary therapeutic interventions
Fluid bolus[11]
Valsalva maneuver[6]
Electrolytes (potassium, magnesium) supplement[11]
Antiarrhythmic
Lidocaine and other antiarrythmics[65]
Adenosine (repeated four times)[6]
Amiodarone for pseudo–atrial fibrillation[11]
Esmolol for supraventricular tachycardia[2]
Synchronized DC shocks[11]
DC shocks from ICD[17]
Medicolegal/administrative
Administrative problems: closure of the affected beds[18]
Documentation in notes and charting of electrocardiogram with artifacts

DC = direct current; ESWL = extracorporeal shock wave lithotripsy; IABP = intraaortic balloon pump; ICD = intracardiac device; ICU = intensive care unit.

Solutions

Certain surgical environments and procedures (*e.g.*, neurosurgery) are more likely to generate artifact than others, and suspicion of this possibility is an important part of problem solving by the physician.

Unrecognizable interpretable interference of short-term duration may not necessitate any action, although it can trigger unnecessary alarms. Recognized artifacts of longer duration require analytical correction to monitor and diagnose genuine electrocardiographic changes (fig. 6).

The technological standard and quality of medical devices should be to the level specified by national and professional organizations. Periodic professional maintenance for operational and electrical safety, of not only the electrocardiographic monitors but all the electrical equipment in the operating room and ICU, remains essential.

General Measures

Appropriate skin preparation, electrode and lead placement, and vigilance against broken or misplaced leads, low batteries, or unplugged monitors should be the responsibility of and easily corrected by the clini-

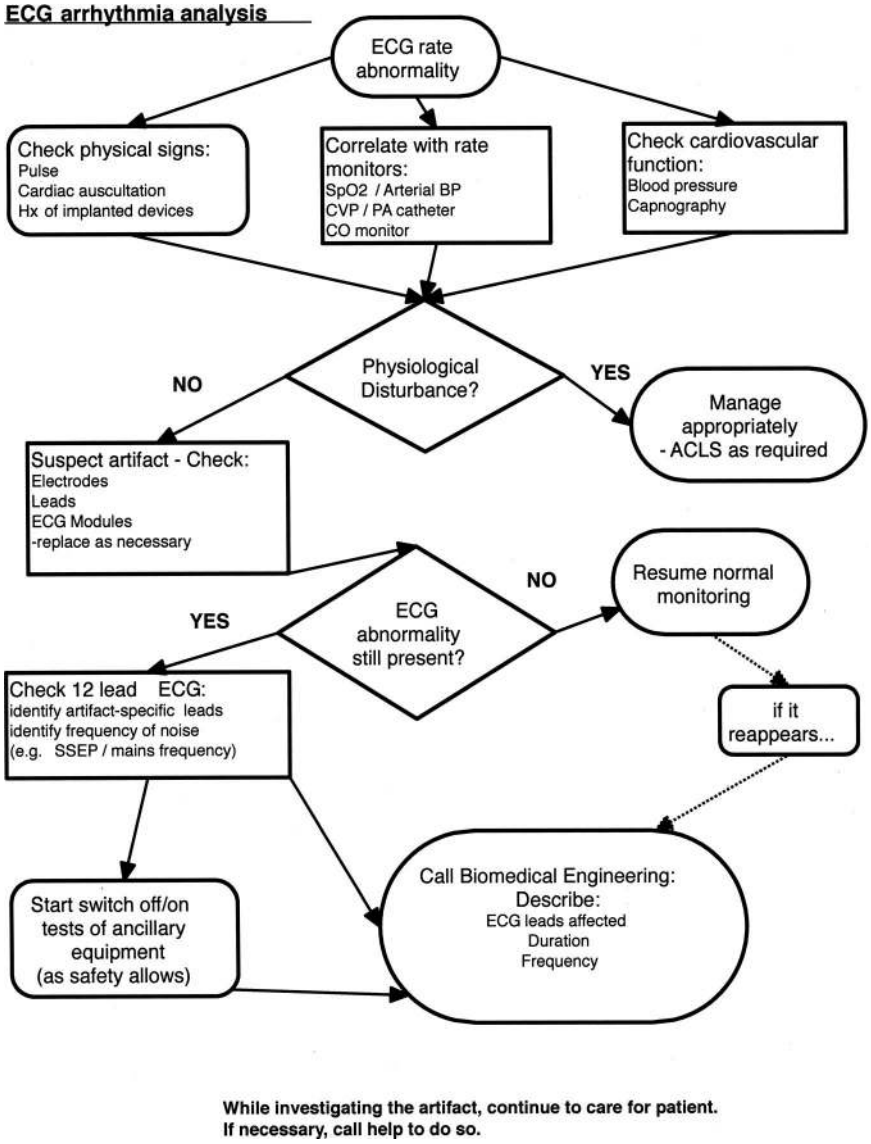

Fig. 6. Electrocardiographic (ECG) rate analysis algorithm and steps to be taken if equipment-related artifacts are suspected. ACLS = advanced cardiac life support; BP = blood pressure; CO = cardiac output; CVP = central venous pressure; Hx = history; PA = pulmonary artery; Spo_2 = oxygen saturation measured by pulse oximetry; SSEP = somatosensory evoked potential.

cian, before any therapeutic intervention for arrhythmia. Loose electrodes (*e.g.*, application of sterilizing prep solutions) will cause impedance imbalance and ultimately will decrease the system's common-mode rejection capabilities.[56]

Physical movement of electrodes should be watched for and prevented during use of high-risk equipment such as high-frequency oscillatory ventilation.[12,13]

Electrocardiographic electrodes can be positioned away from the stimulating needle electrodes of SSEP, *e.g.*, moving the electrocardiographic electrode from the forearm to the shoulder removed repetitive artifacts associated with SSEP stimulation.[6] Marco and Rice[2] suggested careful insertion and monitoring of stimulating needle electrodes, together with care in the arrangement of stimulator cables for SSEP monitoring. Use of esophageal electrocardiographic probes may be useful in eliminating the occurrence of SSEP related interference in electrocardiographic trace.[6]

Specific Electrical Problems

Apparatuses should be placed within a maintenance schedule to anticipate and prevent problems of grounding, current leakage or breaks in insulation, which otherwise may lead to artifacts.[51–53,67]

Elimination of, or Conductive Pathway for, Static and Piezoelectricity

Prevention of the generation of static and piezoelectricity with the use of roller pumps needs technological innovation. In these conditions, provision of an electrically conductive pathway that prevents charge separation and accumulation is needed. Appropriate grounding of the fluid pathway in a patient undergoing continuous renal replacement therapy immediately eliminated pseudo–atrial flutter.[10]

During cardiopulmonary bypass, cool and dry conditions increase generation of static electricity, because charge does not dissipate easily. Spraying water, poly-

ethylene glycol, or silicone on the external surface of the cardiopulmonary bypass tubing improves the quality of electrocardiographic tracing.[1] An alternative solution is to use electrically conductive and grounded cardiopulmonary bypass tubing, which, offering a low resistance pathway for static charge to dissipate, would effectively short-circuit any generated piezoelectric voltage.[1]

Alternatively, Metz[67] used a static grounding lead between pump housing and the cardiopulmonary bypass circuit temperature port to remove electrocardiographic interference.

Electrostimulator-related Artifacts

Transcutaneous electrical nerve stimulator machines can be switched off or deactivated by the use of magnet to record unpolluted electrocardiogram.[59] If an electrocardiographic diagnosis is required in patients with implanted electrostimulators, the option of switching off the electrostimulator should not be taken lightly. In the case of deep brain or spinal cord stimulators, this may possibly cause severe recurrence of symptoms,[23] and exposed tremor may possibly create increased movement artifact. Increases in medication may be required to support a transient cessation of activity of deep brain or spinal cord stimulators for diagnostic resolution.

In the case of deep brain stimulators, switching the stimulation to a bipolar setting with appropriate selection of new stimulation parameters (*i.e.*, active contacts, voltage, pulse width and frequency) is also an option. It may be necessary to consult the specialist who programs the patient's deep brain stimulators or other electrostimulators.[61]

Minimization of Electromagnetic and Radiofrequency Interference

The range of frequencies over which devices operate can make control of interference difficult. The Emergency Care Research Institute (Plymouth Meeting, PA) recommends that cell phones and walkie-talkies be kept at a distance of at least 1 m and 6–8 m, respectively, to minimize interference. Alternative communication technologies, including microcell systems, low-power cordless phones, and Voice over Internet Protocol phones, provide many of the same benefits as a conventional cell phone but may carry less risk of electromagnetic interference.

In patients undergoing specialized investigation such as MRI, it may also be difficult to avoid electrocardiographic artifacts. Several strategies can be used to improve the quality of the electrocardiogram during MRI, including the use of complex signal processing techniques[68] and high-resistance or even fiberoptic leads to electrically isolate the electrocardiographic circuit.[69] The combined use of both Weiner (off-line) and least-mean-square (on-line) filtering has been reported to suppress magnetic field gradient artifacts before the acquired electrocardiographic signal was processed within the arrhythmia algorithm.[70]

During intraoperative high-field MRI, there should be good communication between the anesthesiologist, the neurosurgeon and, the MRI technician to provide information about the duration and character of the planned scanning sequences.

Other Common Measures

It is important to educate the patient receiving any nerve and muscle stimulating devices that electrocardiographic interference can result with the use of this device, and to inform other treating physicians. Sakiewicz *et al.*[29] suggested that various electrical systems should be tested for compatibility before combined use.

Whether there exists an optimal arrangement of electrical equipment to reduce artifact is unknown, but separation of devices can reduce both radiofrequency-induced and possibly static electricity–induced artifacts. Hazard warnings and explanations in the manufacturer's handbook should be known to the users and clinicians. Manufacturers do issue warnings on electrocardiographic artifacts, associated with the use of their product (verbal communication of Santosh Patel, M.D., F.R.C.A., with Medtronic, Minneapolis, MN, November 2006).

Conclusion

There remains a need for continued technological improvement of medical equipment against the challenges of static, electromagnetic, and radiofrequency interference. These arise from existing and developing medical technologies as well as communication devices used in patient care areas.

Diagnosis of artifact demands the same attention to detail as does the diagnosis of disease. If not done correctly, both present adverse implications for pathology and patient care. However, systematic appraisal of the presentation, with a thorough knowledge of patient history, correlation with other monitors, and appropriate investigation of surrounding equipment usually allows swift determination of the cause and appropriate action for resolution.

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