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5 MINUTES A resting ECG is the standard of care for the initial assessment of many heart conditions — and it may be the most important thing you do for your patients in a day. It's imperative that everyone involved in your ECG workflow is aware of and compliant with the key fundamentals. If overlooked, the data captured by your ECG could be impacted, with consequences for resulting interpretations, diagnoses and patient treatment plans. When was the last time you reexamined how you prepare for and conduct ECG exams to ensure the best possible outcome? If it's been a while, here are some factors to consider that could be impacting your results. Electrode Storage And Selection An ECG is only as good as the waveform acquired. That's why each aspect of the exam is important, even down to how the electrodes themselves are handled and applied. A dry electrode with inadequate gel can reduce conduction of the ECG signal, compromising the data acquired. In most instances, this is simply the result of improper storage and can be easily avoided by following manufacturer's instructions and these simple guidelines: Open and remove electrodes from their pouch only when patient prep is completed and apply electrodes immediately. Store pouches with unused electrodes in a resealable zipper storage bag away from light and heat. Be sure to check the expiration date on your electrodes before use. In addition to proper storage, the type of electrodes used during an exam can make a difference — not all electrodes can be used with all ECG devices. Some tips to keep in mind are: Select the correct electrode for the type of ECG exam you are performing. Use one electrode brand at a time. Multiple electrode brands should not be mixed during a test as resistance may vary from one manufacturer to another. The best results can be achieved when there is equal signal from all electrodes. Never manually adjust electrode size or shape, as this could impact readings. For pediatric patients, use pediatric electrodes that have been designed by the manufacturer specifically for this patient population. High-quality ECG waveforms require good practices when prepping the patient and placing electrodes. Even for the most experienced clinicians, periodically reviewing best practices is worthwhile. If proper techniques have not been followed, ECG interpretation may be compromised before it even begins. Following these guidelines for patient prep consistency can help minimize motion and electrostatic artifact. It can also help ensure accuracy and comparability between traces done at different times, or across facilities. Improperly placed electrodes can potentially lead to mistaken interpretation, misdiagnosis of conditions and mismanagement of patient care.2 Patient preparation best practices: Clear away hair where electrodes will be placed to enhance contact and reduce patient discomfort during removal. Clean the skin to remove lotions, powders or oils that can impede electrical conduction, and dry thoroughly to improve electrode attachment. Abrade the skin to remove dead skin cells, reduce resistance and enable more of the ECG signal to reach the electrode. Taking just a few extra moments for patient prep can lead to higher quality exams the first time. Proper electrode placement is also critical, as even the slightest deviation from the correct position can create clinically significant changes.1 Improperly placed electrodes can potentially lead to mistaken interpretation, misdiagnosis of conditions and mismanagement of patient care.2 When it comes to an inaccurate ECG interpretation, the top factor cited is precordial electrode misplacement.2 According to the ACC and AHA, 5% of all ECGs performed are done with a lead reversal.3 Some lead reversals can be difficult to discern as an error and may lead to physicians incorrectly identifying arrhythmia where there is none.4 Make sure to review proper electrode placement. Many manufacturers include visual placement guidelines right on the device. Signal Interference Precautions An ECG signal can be interrupted by various types of "noise," producing artifacts that could impact the quality of your ECG data. Let's review some types of signal interference to be aware of: Electromagnetic interference (EMI) Electromagnetic interference (EMI) is a consequence of the growing use of smartphones and wearable devices such as smart watches and activity trackers. A review of clinical literature on this topic shows that: ECG systems can be vulnerable to interference generated by GSM mobile phones when placed too close (7.5 cm) to the electrodes on a patient.5 EMI was also detected when the phone was placed on top of the acquisition module.6 EMI was incorrectly diagnosed by clinicians, most frequently confused with atrial fibrillation, ventricular arrhythmias and pacemaker disfunction.6 To avoid this form of artifact, make sure the patient and anyone else present removes and turns off these electronic devices. External Forces External forces such as movement from nearby construction have been hypothesized to cause signal interference. This could be a consideration if your ECG devices use highly sensitive algorithms such as the VERITAS® interpretation algorithm employed by Hillrom™ devices. Like other anomalies that may occur during ECG acquisition, you may want to note in the patient record if such conditions exist during ECG acquisition. ECG interpretation depends on the quality of the data captured, not just the skill of the practitioner reading the data. Some factors that have a critical impact on the data captured include filtering and sampling. With a better understanding of these factors and their implications, you can take appropriate steps to achieve ECG results you can trust for diagnosis and treatment decisions. Filtering ECG filtering removes noise from ECG recordings. In so doing, it's intended to help physicians see waveform data more clearly, making ECGs easier to read and interpret. Filters can be very beneficial, if set to an appropriate threshold, and if the interpretive algorithm still looks at the original versus the processed waveform. While filtering can yield a clean-looking ECG, too much filtering can distort or remove authentic waveform data. The problem with overly filtered ECGs is that you may not know what you're missing. Physicians need to be aware of the filtering that takes place on any given ECG, and its potential impact on the interpretation. Governing bodies like the ACC, AHA and HRS publish adult and pediatric guidelines to: Limit filtering so not to sacrifice potentially lifesaving waveform data Clearly disclose filtering so physicians can more easily identify original vs. processed waveform data Ask Yourself These Questions: Are the filters set to the right threshold per ACC, AHA and HRS recommendations? How can I tell what is original vs. processed waveform data? Does the interpretation look at the original or the processed waveform? An ECG is really just a visual representation of the electrical activity of the heart. The electrical stimulus of the heart occurs continuously and in a repeated pattern to make the heartbeat. To accurately represent this activity in digital form, a resting electrocardiograph is tasked with collecting enough data points to reproduce the analog signal as close to the original as possible. The rate at which these data points are sampled can have a significant impact on ECG waveforms that have fast-moving or high-frequency components. Some examples of high-frequency information include: Pacemaker spikes High-frequency notches in the QRS complex Notches in Left Bundle Branch Block ECGs Consider The Following: Does the sampling rate support a frequency response that is aligned with the published guidelines? Is there any user intervention needed to enhance the pacemaker detection or display? The data captured by your ECG directly impacts the resulting interpretations, diagnoses and patient treatment plans. Whether you are involved in ECG acquisition or interpretation, spending a little more time considering these critical factors can help improve the accuracy of the data collected and the resulting ECG interpretation. Blog Home Latest Blog Posts: The Tragic Consequences of Neglecting In-Flight Medical Equipment: A Wake-Up Call for Airlines March 29, 2023 Heart Attack V.S Cardiac Arrest November 17, 2023 The Vital Importance of Comprehensive CPR, AED, and First Aid Training in Child Care Facilities: Meeting DCFS Standards November 9, 2023 Commotio Cordis; How it can happen to healthy athletes like Damar Hamlin November 17, 2023 The Importance of CPR: Understanding the Life-Saving Benefits of Cardiopulmonary Resuscitation. November 18, 2023 Hilton Chicago/Magnificent Mile Hotel On-Site Workplace CPR & AED Training March 10, 2024 Boost Workplace Safety with On-Site CPR & AED Training by Chicago CPR Academy February 19, 2024 Heat Stroke vs. Heat Exhaustion: How to Stay Safe in Chicago's Extreme Heat June 25, 2025 Ensuring Safety: Why Chicago Schools Must Prioritize CPR & AED Training for Staff July 29, 2023 The Convenience of Blended Learning: CPR, AED & First Aid Classes at Chicago CPR Academy October 15, 2023 The quality of the ECG signal is an important factor affecting the accuracy of analysis and proper interpretation, particularly for long-term ECG monitoring such as with Holter monitors or ECG patch devices. Misinterpretation can lead to a wrong diagnosis and consequently the selection of inappropriate treatment. The purpose of this article is to discuss possible ways of improving the quality of ECG signals in order to obtain more reliable results. Why does the quality of the ECG signal matter? Electrocardiography is a diagnostic procedure that measures the electrical activity of the heart. Contractions of the heart muscle are caused by electrical impulses, which, when recorded on a graph, form an electrocardiogram. Accurate ECG readings are crucial for proper diagnosis of heart diseases and monitoring of patients. Adequate signal quality will therefore allow rapid intervention in case of any health problems and possible abnormalities in monitored patients will be caught. Factors affecting the quality of the ECG signal To conduct a Holter test in an appropriate way, it is necessary to pay attention to the main factors that can interfere with the quality of the recorded signal. The most common mistake is placing the electrodes on the body in the wrong way or using poor quality electrodes. Sometimes the poor quality of the ECG can be caused by poor quality recorders. You can find insights on the differences between cable Holter monitors and ECG patch devices in our prior post here. Signal noise can also occur when a patient deals with the recorder in a wrong way and does not follow the cardiologist's/manufacturer's instructions (e.g. pulls the wires, detaches the electrodes). Fat or bones between the electrode's surface and the heart can also interfere with the quality of the recorded pulses. External factors such as a patient's movements or external sources of magnetic fields (e.g. mobile phone) also impair ECG quality. Effects of poor ECG signal quality Poor quality of the recorded signal can have consequences in the form of misinterpretation of false positive/false negative results. Wrong electrode placement or the patient's muscle movement can lead to the occurrence of artifacts on the ECG graph. False waves can be misinterpreted as real changes in the heart's electrical activity. Also, real waves can be distorted due to poor signal quality and misinterpreted as pathological. If the signal is too noisy, some significant abnormalities may go undetected. As a result, the test will have to be repeated, increasing costs and delaying (often crucial) diagnosis. ECG strip showing an example of false waves that could be misinterpreted as heart activity (source: Cardiomatics) ECG strip showing an example of waves distorted by noise that could be misinterpreted as pathological (source: Cardiomatics)Practical tips for improving ECG signal quality The basis of a well-performed Holter test is the proper placement of electrodes on the patient's body. Following the electrode placement configuration according to the device manufacturer's guidelines is necessary. The configuration is specific for each device. See below an example. Example of ECG manufacturer guidelines for how to properly place the electrodes (source: Bittium Faros Manual)Before sticking the electrodes, the skin needs to be shaved and cleaned with alcohol. During the test, the patient should also be careful not to detach the electrodes or damage the leads. Contact of the electrodes with water may distort the measurement, so taking showers during the Holter test is not advisable (unless the device is designed for that). Avoid all sources of external interference, such as limiting the use of a mobile phone that is a source of electromagnetic radiation. Also, medical personnel should be trained in best practices when performing and interpreting ECG tests. For the most accurate test results, use appropriate equipment: high-quality ECG recorders and specialized ECG analysis software, such as Cardiomatics. New technologies Today, there are modern technologies available, which can improve the quality of ECG signals. Adaptive digital filters are used to reduce noise and interference in ECG signals. These algorithms are capable of dynamical adaptation to changing conditions, which allows the effective elimination of various types of interference (e.g. 50/60Hz waves from the electrical grid, artifacts). Multi-scale analysis methods allow analysis of the ECG signal on multiple time scales. This makes it possible to detect the slightest changes in the recorded signal and, as a result, get rid of unwanted noise and artifacts. Artificial intelligence (AI) technologies, such as machine learning and deep neural networks, are increasingly being used to analyze ECG signals. Specialized, advanced artificial intelligence algorithms are able to automatically identify and eliminate artifacts, leading to more reliable results. Cardiomatics' AI-powered ECG analysis solution uses these state of the art techniques including signal normalization, signal filtering and deep neural network based detection and classification of QRS complexes, non-diagnostic parts of the signal, as well as identification of heart rhythms. This allows it to produce high quality results across a range of +40 compatible ECG device models. A Beginners Guide to Normal Heart Function, Sinus Rhythm & Common Cardiac Arrhythmias Electrical Interference Another disturbance or annoyance in terms of rhythm detection, emanating directly from the surrounding environment , is electrical interference. The ECG machine is designed to pick up electrical activity within the heart but it will pick up electrical activity from nearby machinery, such as: Pumps TV Drills Machinery Image: Electrical Interference So, what are you going to do if you get either of the problems above? You need to repeat the ECG but do as much as you can to correct any modifiable problems, eg Comfort of the patient Turn machines off Drugs to control symptoms Warm the patient Talk to the workmen Then repeat the ECG! If you repeat the ECG and it is the best you can do then make sure you write this on top of the ECG so you don't get an earful from the cardiologist on the ward round. School of Health Sciences B Floor (South Block Link) Queen's Medical Centre Nottingham, NG7 2HA Tel: +44 (0)115 823 0850 email: shs-enquiries@nottingham.ac.uk An electrocardiogram, or ECG, is a test that records the electrical activity of the heart, providing a graphical representation of its rhythm. Sometimes, the recording picks up signals that do not originate from the heart itself. These disturbances, known as artifacts, are electrical noise that can obscure the true cardiac tracing. Because these false signals can mimic serious heart problems, understanding how to recognize them is a fundamental part of interpreting ECGs correctly. Sources and Appearances of ECG Artifacts One of the most frequent types is somatic artifact, also called muscle tremor, which is caused by electrical signals from skeletal muscles. It appears as a fuzzy or jagged baseline on the ECG and can be triggered by patient movement, shivering, or tense muscles from anxiety. Conditions like Parkinson's disease can also produce these small, erratic spikes throughout the tracing. Another source of distortion is alternating current (AC) interference. This artifact originates from external electrical equipment, like power lines or cell phones, near the ECG machine. It creates a very regular, fine line superimposed over the cardiac rhythm. In countries with a 60 Hz power supply, this is known as 60-cycle interference, which the ECG machine picks up. A wandering baseline appears as a slow, undulating drift of the entire tracing up and down. This is caused by issues that affect the connection between the electrode and the skin. Common causes include patient breathing or other body movements that alter electrode contact. A poor skin-electrode interface from oily skin or insufficient conductive gel can also lead to this baseline drift. Problems with the ECG equipment itself are a significant source of artifacts. Loose or disconnected electrode leads can result in a wildly erratic line or a flat line that could be mistaken for cardiac arrest. A poor connection can be caused by adhesive patches losing stickiness, improperly placed electrodes, or fractured cables, creating a nonsensical tracing. Distinguishing Artifacts from True Cardiac Events A primary step in ECG interpretation is determining if an unusual pattern is a genuine arrhythmia or an artifact by checking the patient. An individual with a life-threatening arrhythmia would show clinical signs, such as dizziness or loss of consciousness. If the patient is stable and comfortable but the monitor shows a chaotic rhythm, the cause is likely an artifact. True cardiac events tend to follow physiological patterns, whereas artifacts are often more chaotic. A key technique is to look for underlying normal QRS complexes—the part of the ECG representing the main contraction of the ventricles—marching through the noise. If clear, normal beats can be seen at regular intervals, the interference is likely an artifact superimposed on a normal rhythm. Another analytical method involves comparing signals across different ECG leads. A true cardiac event is a global phenomenon in the heart and should appear with logical consistency across multiple related leads. An artifact caused by a single faulty electrode or localized muscle movement may be confined to just one or two leads. Sometimes, an artifact can mimic specific arrhythmias, which requires careful analysis. For instance, rhythmic muscle tremors can create a pattern that looks like atrial flutter or ventricular tachycardia. If the underlying rhythm is perfectly regular and the patient has a known tremor, the unusual waves are likely artifactual. A person cannot have a normal sinus rhythm and ventricular tachycardia simultaneously. Strategies for a Clean ECG Tracing Obtaining a high-quality ECG tracing begins with patient preparation. Ensuring the patient is comfortable, warm, and relaxed can reduce somatic artifacts from shivering or muscle tension. The patient should be instructed to lie still and breathe normally during the recording. Simple measures like providing a blanket can prevent shivering and lead to a cleaner signal. Proper electrode application is fundamental to preventing wandering baseline and artifacts from poor connections. The skin should be clean, and hair may need to be shaved to ensure direct electrode adhesion. Using fresh electrodes with adequate conductive gel ensures a solid electrical interface. Confirming that each lead wire is securely attached also prevents signal interruptions. The electrical environment can also be managed to minimize interference. Unplugging or moving non-essential electrical devices, such as fans and phones, away from the patient and the ECG machine reduces AC interference. Ensuring the ECG machine itself is properly grounded is another important step in preventing this artifact. Finally, a routine check of the equipment can prevent artifacts caused by hardware faults. Before a recording, it is good practice to inspect lead wires and cables for signs of wear or damage. Ensuring that all connections from the electrodes to the machine are secure can prevent the sudden, erratic lines associated with a loose lead. These checks can save time and prevent misinterpretations. 2022 Apr 3;24(9):1512–1537. doi: 10.1093/europace/euac040 Interference is defined as disturbance generated by an external source that potentially affects the functioning of cardiac implantable electronic devices (CIEDs)—i.e. cardiac pacemakers (PMs), implantable cardioverter defibrillators (ICDs), cardiac resynchronization therapy (CRT) devices, and implantable loop recorders (ILRs).1 Energy forms such as radiation, magnetic or electromagnetic fields (EMFs), as well as acoustic signals potentially cause interference due to oversensing (i.e. signals that are sensed by the device that do not reflect myocardial depolarization) and subsequently temporary suppression or inappropriate delivery of device therapy, programming errors (device reset), or even permanent CIED malfunction (Table 2). Signals causing interference with CIED: possible effects and considerations Signal type Common sources Possible effects Incidence Specific considerations Electromagnetic fields Electrocautery D, O, R, I H Effect depends on field strength as well as distance to the generator and leads Radiofrequency catheter ablation for cardiac arrhythmias D, O, I H Non-cardiac radiofrequency ablation O, I M Radiofrequency identification devices O, I L Electrical stimulation therapy (TENS, EMS, SCS) O, I H Therapeutic diathermy O, I L Therapeutic ionizing radiation Gamma rays D, O, R, I, sudden battery depletion L Effect depends on accumulated radiation dose on the generator and specifically neutron contamination Photon beam M Proton beam H Carbon ion L Acoustic waves Lithotripsy D, O, I L Shockwave may cause mechanical derangement Miscellanea Electrical cardioversion or defibrillation R, D M Electroconvulsive therapy I M Tissue expanders employing magnets I L Effect depends on location with respect to CIED Electromyograms O L Effect depends on location with respect to CIED Multiple signals Magnetic resonance imaging (MRI) D, O, R, I, sudden battery depletion H Effect depends on MRI conditionality and programming of device The majority of interference sources are non-biological in origin and occur in the hospital environment,2 and most inappropriate CIED responses are potentially avoidable. Electromagnetic interference (EMI) can be detected by device interrogation and analysis of intracardiac electrocardiograms (Figure 1B) and is not a rare finding in CIED patients: in single-centre studies, the incidence of EMI in CIED was determined as 1.87% per patient-year, while episodes with clinical impact were present in 0.27%.3,4 (A) Inhibition of right-ventricular pacing by unipolar electrocautery during revision of the atrial lead in a 64-year-old PM-dependent patient: ECG Leads I and II and invasive blood pressure measurements are shown; arrows indicate the initiation of cautery bursts (arrow), leading to pacing inhibition and subsequent drops in blood pressure. (B) Ventricular oversensing in a 69-year-old VVI-ICD patient with ischaemic cardiomyopathy during TENS: electrical bursts result in the inhibition of ventricular pacing and detection of VF leading to shock therapy (arrow).Thus, information about sources, mechanisms, device effects, and EMI prevention is important for CIED patients as well as caregivers. A panel of 20 CIED experts was set up by EHRA to write an international consensus statement. Members of associated societies, i.e. the US (HRS), the Latin American (LAHRS), and the Asian Pacific Heart Rhythm Society (APHRS), also designated two authors each to complete the collaborative group. Sections of the consensus were divided according to the type of medical intervention and special foci were defined for surgical procedures (electrocautery), therapeutic radiation, and magnetic resonance imaging (MRI). The authors were asked to perform a detailed literature review including case reports, observational studies, and randomized trials published until 30 June 2021 and to weigh the strength of evidence for or against a particular procedure based on these published trials and/or on expert opinion. In controversial areas, a consensus was achieved by agreement of the expert panel after detailed discussions. Technical features from manufacturers published in the literature or operating manuals were also taken into account. Categories of the consensus document were used according to the Colour Heart (Table 1). Categories used in the document according to the color heart table. Consensus statement Definition Symbol Indicated or 'should do this' Scientific evidence that a treatment or procedure is beneficial and effective, or is strongly supported by authors' consensus May be used General agreement and/or scientific evidence favour the usefulness/efficacy of a treatment or procedure Should not be used Scientific evidence or general agreement not to use or recommend a treatment or procedure Multiple sources of interference exist in the hospital environment. Potential-associated risks depend on patients' characteristics, the intervention, and the CIED used. Both EMFs and radiation can affect CIED function.5 Details on possible effects and incidence are listed in Table 2. Oversensing by EMI can result in a variety of CIED behaviours: in pacing systems, oversensing of noise on the atrial channel will result in triggered ventricular pacing or inappropriate detection of atrial high-rate events and mode switching. Oversensing in the ventricular channel will be interpreted as intrinsic R-waves and typically result in the inhibition of ventricular pacing, which may cause asystole and syncope in PM-dependent patients (Figure 1A). In an ICD, oversensing on the ventricular channel will not only cause ventricular pacing inhibition but is also likely to result in shock therapy for ventricular fibrillation (VF), if it lasts long enough (Figure 1B). Whereas transient EMI can temporarily modify CIED function, longer and repeated episodes are able to change the setting of the device to a programming that does not resolve spontaneously after EMI discontinuation. This behaviour may result in a 'backup mode', 'reset mode', or 'power on reset', which can make reprogramming the device necessary. In ILR, electrocautery, radiation, and MRI do not change programmed parameters, sensing fidelity, or battery parameters but may cause artefacts in stored electrocardiograms (Table 3).6 Possible effects of EMI on PM, ICD, and ILR Pacemakers (PM) Effect (T/P) Pacing inhibition in the ipsilateral chamber (e.g. ventricular pacing inhibition due to oversensing on the ventricular channel) T Cross-chamber pacing in the contralateral chamber (e.g. ventricular pacing due to oversensing on the atrial channel) T Alteration of rate responsive behaviours (e.g. activation of CIED sensor by monitoring equipment)7,8 T Asynchronous pacing, loss of AV (atrioventricular) synchrony in dual-chamber devices, e.g. due to noise reversion mode T Inappropriate automatic mode switching or atrial anti-tachycardia pacing due to oversensing in the atrial channel T Modification of measured pacing/sensing thresholds T Run-away PM (PM-induced tachycardia as a result of EMI) P Power on reset and backup mode P Implantable defibrillators (ICD) Effect (T/P) Modified anti-bradycardia function (as in PM above) T Inappropriate shocks or anti-tachycardia pacing, if oversensing in the ventricular channel occurs due to EMI T Long–short–long sequence pacing or inappropriate pacing related pro-arrhythmia T Truncation of pacing output when EMI is sensed on the defibrillation circuits9 P Sudden battery depletion P Implantable loop recorders (ILR) Effect (T/P) Artefacts mimicking tachyarrhythmias10 T Proper planning of the procedure is essential to ensure CIED patient safety and that the procedure runs smoothly. The following points need to be addressed (Table 4). Checklist before the procedure Understanding of the planned procedure (e.g. target zone of radiotherapy, indication, and anatomic location of surgical procedure, prone patient position during intervention, etc.) ✓ Identification of device (CIED type, manufacturer, battery status, settings, etc.) ✓ Evaluation of PM-dependency ✓ Risk stratification for periprocedural (ventricular) arrhythmias ✓ Estimation of likelihood of electromagnetic (or other) interference ✓ Determination of needs and means of CIED function (i.e. magnet application vs. reprogramming) ✓ Details about device type, manufacturer, battery status, and CIED settings need to be determined prior to the intervention. If medical records or a device card are not available, a chest X-ray is very helpful and can determine the type of device (appendix; Figures 7 and 8) and whether there are any abandoned leads. Alternatively, an algorithm11 and two systems based on artificial intelligence, available as an App ('Pacemaker-ID')12,13 or as a web-based platform,13 have been shown to yield accuracies of 85, 89, and 71%, respectively, to identify the device manufacturer, based upon chest X-ray.14 Chest X-ray to identify the type of CIED: typical X-ray pictures of the single-chamber PM (AAI, VVI), dual-chamber PM, single-chamber ICD, dual-chamber ICD, CRT device (PM and ICD), an S-ICD, a leadless PM, an epicardial PM and an implantable loob recorder (ILR) are shown; importantly, generators of transvenous devices can be implanted in a left and right pectoral pocket, a leadless PM is not equipped with a generator and the can of an S-ICD and an ILR are located on the left lateral thorax. Identification of the CIED manufacturer based on X-ray markers: X-ray opaque symbols of individual manufacturers marked with a red ellipse and enlarged on the background of the CIED silhouette. (A) CIED manufactured by Biotronik, (B) by Medtronic, (C) by St Jude Medical/Abbott, (D) by Boston Scientific, and (E) by Ela/Sorin. Flowchart for evaluating magnetic resonance imaging in CIED patients. MRI, magnetic resonance imaging; SAR, specific absorption rate. aConsider only if there is no imaging alternative and the result of the test is crucial for applying life-saving therapies for the patient. Adapted from the 2021 ESC guidelines on cardiac pacing and CRT.45For ILR, no specific measures are needed, except for retrieval of stored electrograms, as these might be overwritten by artefacts during the procedure. Pacing dependency is defined as the absence of intrinsic escape rhythm or a low heart rate (usually 15 cm away from the pulse generator for backup pacing/defibrillation (ideally in an anteroposterior position) to avoid damage of the CIED.24 Also, electrosurgery grounding pads should be placed >15 cm away for CIED. A magnet (≥10 G) should be readily available at all times for all CIED patients. A second or stronger magnet may be required to close the reed switch in obese individuals or deeper implants. Ideally, CIED-trained personnel and programmer should be available onsite, as changes in a patient's condition during a procedure may require reprogramming (e.g. requirement to accelerate pacing rate in an ICD patient in whom magnet application only results in inactivation of anti-tachycardia therapy). The principal risk of CIED patients undergoing surgery is EMI due to electrocautery, which may result in the inhibition of pacing, noise reversion mode (with asynchronous pacing), and inappropriate ICD therapy due to oversensing. The incidence of adverse events occurring during surgery is most likely under-reported, and may even go unnoticed (e.g. inappropriate shocks in a patient under myorelaxants). The intraoperative risk of inference increases with closer proximity to the CIED, specifically to the leads, and with the mode of electrocautery (uni- or bipolar, coagulation/high voltage vs. cutting/low voltage). Previous recommendations of the American Society of Anesthesiologists state that inactivation of ICD therapy is not necessary, if surgery is conducted with unipolar electrocautery below the umbilicus.23,25 However, this may not be the case if the return electrode is placed close to the device,19,26 or if a full-body return electrode pad is used (e.g. Megadyne™ pads), as inappropriate ICD shocks have been described in these instances.26–28 In a prospective multicentre observational study including 331 CIED patients undergoing surgery, reprogramming was only performed in ICD patients and in PM-dependent patients, if surgery was performed 80 G field strength. The site of magnet placement is important11 and some devices may require a more eccentric application of the magnet regarding the generator casing in order to optimize field alignment. Magnet response in PM and ICD is summarized in Tables 6 and 7. Magnet response with PM (modified from Jacob et al.11) Manufacturer Default responsea Remarks Abbott DOO/VOO/AOO 100 bpm Can be programmed to 'OFF'; if AutoCapture is enabled the device will go to high output mode for the duration of magnet placement Biotronik 'AUTO' mode: DOO/VOO/AOO 90 bpm for 10 beats, then back to programmed mode Can also be programmed to 'ASYNC' with continued DOO/VOO pacing at 90 bpm (also during standard device interrogation), or to 'SYNC' (with continued programmed pacing at lower rate limit) mode Boston Scientific DOO/VOO/AOO 100 bpm Can be programmed 'OFF' and 'store EGM' with storage of electrograms and no change in pacing Medtronic DOO/VOO/AOO 85 bpm No magnet response for Micra© leadless PM; for older devices (e.g. Adapta©, Sensia©); magnet application is ignored within 1 h of device interrogation, unless data are manually erased at the end of the session Microport/Sorin DOO/VOO/AOO 96 bpm Can be programmed 'OFF' Magnet response with implantable cardioverters (ICD) (modified from Jacob et al.11) Manufacturer Signal Default brady mode Default tachy modea Remarks Abbott None No change Detection and therapy off Can be programmed to 'OFF' Biotronik None No change Detection off Since Lumax series: effect lasts for 8 h only even if magnet is still in place Boston Scientific (including S-ICD) Acoustic signal No change Therapy off Can be programmed to 'OFF' Medtronic Acoustic signal No change Detection and therapy off Microport/Sorin None DOO/VOO/AOO 96 bpm without rate response or mode switch; max. pacing output Detection off For Platinium© devices, the magnet rate is not enabled In PM, the application of a magnet leads to asynchronous pacing (AOO, VOO, or DOO mode) at the magnet rate (Tables 6 and 7). Of note, in Biotronik PM models, magnet response is only active for 10 beats, and the device reverts to normal synchronous pacing immediately afterwards (Auto-Mode). This requires repeated perioperative application of the magnet to avoid interference. Alternatively, the magnet response can also be programmed asynchronously (Async). However, with this programming, the magnet mode will also be continuously active during routine device interrogation, which is not optimal for follow-up. Older Medtronic devices (pre Advisa®/Astra®/Azure® series) suspend magnet detection for 60 min after removal of the programming head, rendering the application of a magnet shortly after programming useless (unless data are manually erased at the end of the session). Finally, Medtronic Micra® leadless PMs do not have any magnet response. Asynchronous pacing might cause stimulation in the vulnerable phase and result in ventricular pro-arrhythmia. Therefore, patients need to be monitored during magnet application or operation in an asynchronous mode and emergency equipment including an external defibrillator with transcutaneous pacing capabilities needs to be readily available. In ICD, magnet application will only disable detection of tachyarrhythmias (and thereby antitachycardia therapy) without affecting pacing mode (except for some Microport/Sorin ICD; Tables 6 and 7). Therefore, device reprogramming is necessary for PM-dependent ICD patients. It is important to be aware of the response (i.e. transient audible tone) which results from effective magnet application. Some devices (Biotronik, Abbott, and recent Microport/Sorin ICD) do not emit any indication of a magnet response, and it may be preferable to reprogramme the device in these instances. Application of magnets on the ICD for procedures using electrocautery more than 15 cm from the device simplifies workflow and has been shown to be safe with a significantly shorter duration of inactivated ICD therapy compared with device reprogramming in a single randomized study.31 However, magnet placement may not be adequate in some procedures, specifically if prone or lateral positioning is needed for surgery. Thus, CIED reprogramming should be performed before the procedure starts and remain effective during the entire procedure if the device is located close to the operative field (16 Hz) sensed events within refractory or right after blanking periods are likely to represent noise. Signals sensed during this noise sampling window result in resetting of this window and extension of the blanking period with repetitive sensing leading eventually to asynchronous pacing at the basic rate with short AV delays. Importantly, ICD therapies are usually not disabled by noise detection. Placing a magnet ≥10 G field strength over the cardiac device results in a change of programming to a manufacturer-specific 'magnet mode' by closing the 'reed switch'.11,126 Magnets provided by device manufacturers are usually of >80 G field strength. Of note, the magnets are best placed directly on the top of the device. But there are exceptions and the position of the magnet is recommended to be eccentric over the bottom or top end of the CIED.11 Legacy PM and ICD contain a magnetic reed switch that is closed by a static magnetic field. Because of inadvertent activation or closure in most contemporary ICD, the magnetic reed switch and its function have been largely replaced by other technologies (integrated solid-state detection Boston Scientific; Hall effect sensor Medtronic; telemetry coil Sorin Group; GMR circuit St Jude Medical). For PM, magnet application generally results in asynchronous pacing. In ICD, a magnet disables tachycardia detection without having an effect on pacing mode or rate. Using this simple manoeuvre pacing inhibition in PM as well as anti-tachycardia therapies can be actively avoided or treated, if interference due to procedures is anticipated. However, it is strongly recommended for the user to be thoroughly familiar with the specific 'magnet mode' for each individual CIED (Tables 6 and 7). Device interrogation and programming avoids over- and undersensing of EMF and other signals causing interference in CIED and potential clinical consequences. Specifically, an asynchronous mode is programmed (i.e. A00, V00, or D00) before surgery in PM-dependent patients with a high risk of interference and during MRI to avoid oversensing. Moreover, tachycardia detection and/or anti-tachycardia therapy is inactivated in ICD and CRT-D devices, if a significant risk of EMI is anticipated. A basic rate increasing the intrinsic heart rate ≥20 bpm should be programmed to avoid pacing into the vulnerable phase of the cardiac cycle and rate response should be inactivated. Asynchronous pacing might cause stimulation in the vulnerable phase and result in ventricular pro-arrhythmia. Moreover, ICD patients are at risk for sustained ventricular arrhythmia as long tachycardia detection and/or therapy is inactivated. Thus, patients should be monitored during magnet application and as long an asynchronous mode is programmed ICD therapy is inactivated. Both magnet application and CIED reprogramming have their advantages and limitations. Magnets are easily available and there is no specific training needed, whereas device reprogramming needs specific training, but may be customized (Table 11). Thus, specific CIED management needs to be chosen on an individual basis. Advantages and disadvantages of magnet application and reprogramming of CIED Availability Effect Disadvantages Advantages Magnet application UbiquitousNo training neededEasily accessible ICD: disabling only tachycardia detection and/or therapyPM: asynchronous pacing mode up to 100 bpmSensor unaffected Magnet dislodgementObesity or deep position of CIED may hamper magnet effect 'Magnet mode' may be inactivatedICD: pacing inhibition still possiblePM: asynchronous stimulation resulting in haemodynamic impairment Immediately availableEmergency setting to avoid shocks (ICD) or secure stimulation (PM)No reprogramming needed CIED reprogramming LimitedDepending on trained personnel and programmer Programming individual pacing mode (e.g. for CRT)Possible to enable tachy therapyPossible to enable rate response Time-consumingReprogramming neededSpecially trained personnel necessaryIndividual management dependent on manufacturerPotential risk of programming errors (e.g. leaving ICD therapies inactivated at discharge) 'Customized' programmingStable setting during interventionsImmediate device interrogation to reveal potential damage See Figure 7. 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