https://doi.org/10.35336/VA-1487

METHODS OF ANESTHESIOLOGICAL SUPPORT IN THE ELECTROPHYSIOLOGICAL LABORATORY

V.I.Steklov[1], E.A.Kim[1], M.V.Emelianenko[2], S.O.Lependin[1], F.G.Rzaev[3]

[1]Central Military Clinical Hospital named after P.V. Mandryka of the Ministry of Defense of the Russia, Russia, Moscow, 8a Bolshaya Olenya str; [2]Clinical City Hospital named after M.P. Konchalovsky, Russia, Moscow, Zelenograd, 2 Kashtanovaya str; [3]Clinical City Hospital named after I.V. Davydovsky, Russia, Moscow, 11 Yauzskaya str.

The article presents modern methods of anesthetic aids used in the case of such interventional and surgical interventions as implantation of a pacemaker, cardiac resynchronization therapy, cardioverter defibrillator and catheter ablation. The advantages, disadvantages and problematic issues of anesthesia are discussed depending on the type of intervention and the patient's condition. Based on the analyzed data, it is concluded that anesthesia during interventions in patients with arrhythmological profile is a global practice and emphasizes the positive impact of anesthesia methods on the quality and safety of procedures performed.

Key words: pacemaker; cardiac resynchronization therapy; cardioverter defibrillator; catheter ablation; anesthesia

Conflict of Interest: none.
Funding: none.
Received: 17.03.2025 **Revision Received:** 19.06.2025 **Accepted:** 26.06.2025
Corresponding Author: Steklov Vladimir, E-mail:vsteklov@yandex.ru

V.I.Steklov - ORCID ID 0000-0001-6790-9401, E.A.Kim - ORCID ID 0000-0002-9427-3207, M.V. Emelianenko - ORCID ID 0000-0002-9919-2203, S.O.Lependin - ORCID ID 0000-0001-8670-8787, F.G.Rzaev - ORCID ID 0000-0002-4094-7771

For citation: Steklov VI, Kim EA, Emelianenko MV, Lependin SO, Rzaev FG. Methods of anesthesiological support in the electrophysiological laboratory. *Journal of Arrhythmology.* 2025;32(3): 64-72. https://doi.org/10.35336/VA-1487.

In recent decades, there has been a marked increase in the number of procedures performed on the cardiac conduction system. Contemporary interventional catheter-based technologies, employing radiofrequency current, cryoablation, electroporation, and methods of electrocardiotherapy - including implantation of permanent pacemakers (PPM), implantable cardioverter-defibrillators (ICD), and devices for cardiac resynchronisation therapy (CRT) - have assumed a leading role in the management of various cardiac arrhythmias and conduction disorders, congestive heart failure, as well as in the primary and secondary prevention of sudden cardiac death (SCD) [1].

The implantation of cardiac rhythm management devices, catheter ablation (CA), and electrical cardioversion constitute interventions that require anaesthetic support. The principal objectives of anaesthetic management in the electrophysiology laboratory are the suppression of conscious perception, autonomic and nociceptive blockade, muscle relaxation, and the monitoring and, if necessary, substitution of vital functions.

At present, there are no clearly defined recommendations regarding the methods of pharmacological sedation, the agents of choice, or their dosing regimens tailored to the specific procedural requirements of particular arrhythmias. This article provides a comparative analysis of the published literature on the efficacy and safety of various anaesthetic strategies in the setting of arrhythmias, including general, regional, and infiltration anaesthesia, supplemented by pharmacological sedation or total intravenous anaesthesia [1, 2].

In light of the above, the objective of this study was to analyse the problem of anaesthetic management in patients with arrhythmias and conduction disorders undergoing interventional and surgical procedures.

DEFINITION AND CLASSIFICATION OF ANAESTHETIC METHODS

Most interventions involving the cardiac conduction system (implantation of an antiarrhythmic device, intracardiac electrophysiological study, electrical cardioversion, and catheter ablation [CA]) may be accompanied by general discomfort and painful sensations, while patient immobility is required to enhance the safety and quality of the procedure (particularly when using three-dimensional mapping and navigation systems). In global medical practice, various anaesthetic approaches are employed: local (infiltration, regional block), general (inhalational and non-inhalational anaesthesia, with respiratory support or complete substitution of external respiration), as well as combined and multimodal techniques [3].

Sedation, although a component of general anaesthesia, has in contemporary practice become widely applied as a stand-alone method during a variety of therapeutic and diagnostic procedures - both invasive and non-invasive - where it is necessary to ensure the patient's psychological comfort, alleviate agitation, maintain a required position, or in the context of intensive care [4].

Sedation (from the Latin sedatio - "calming"; also referred to as pharmacological sleep or medically induced coma) is defined as an artificially induced state achieved by the administration of sedative agents, characterised by a controlled reduction or absence of consciousness, with preserved protective reflexes, adequate spontaneous breathing, and responsiveness to external physical stimuli [5]. Other authors define sedation more broadly as a combination of pharmacological and non-pharmacological measures aimed at ensuring the patient's physical and psychological comfort during medical procedures [6].

Pharmacological sedation (PS) attenuates the endocrine-metabolic stress response, improves the balance between oxygen delivery and consumption, and thereby contributes to a reduced incidence of intra- and postoperative complications [7].

Depending on the depth of wakefulness (consciousness), the following levels of PS are distinguished:
1. Minimal (anxiolysis) or mild (superficial) sedation: the patient remains awake and in verbal contact with the physician, though perception, cognitive function, and coordination may be impaired.
2. Moderate sedation: characterised by depression of consciousness. The patient responds to verbal commands or light tactile stimulation and is capable of cooperation. Airway support is not required, spontaneous ventilation remains adequate, and cardiovascular function is preserved.
3. Deep sedation: verbal contact with the patient is lost; the patient is asleep but responds to strong (painful) stimuli. Airway support may be required, with possible impairment of spontaneous ventilation and cardiovascular function.
4. General anaesthesia (GA): consciousness is completely suppressed for the duration of the intervention using intravenous hypnotics or inhalational anaesthetics. External respiration is maintained by mechanical ventilation [8].

Approaches to anaesthetic management in the electrophysiology laboratory may therefore vary - from anxiolysis to general anaesthesia with full substitution of respiratory function - depending on the type of arrhythmia and the nature of the intervention.

ANAESTHETIC MANAGEMENT DURING PACEMAKER IMPLANTATION

The initial stages of implanting electronic devices for electrotherapy required thoracotomy; however, since the late 1980s this procedure has become minimally invasive and is now performed without general anaesthesia [9]. In routine practice it is carried out under local infiltration anaesthesia. In recent years, there has been increasing application of serratus anterior plane block (SAPB), blockade of the intercostobrachial and intercostal nerves from the third to the sixth, as well as of the long thoracic nerve (PECS II block), performed under ultrasound guidance in the setting of mild or moderate pharmacological sedation (PS) [10, 12].

Authors have reported the feasibility and effectiveness of SAPB in providing anaesthesia/analgesia during subcutaneous ICD implantation, enabling a reduction in the requirement for sedation and a shorter procedural duration. Results from a single-centre study demonstrated that local anaesthesia with sedation is a safe and feasible option for cardiac rhythm management device implantation, including complex procedures such as ICD and cardiac resynchronisation therapy defibrillator (CRT-D) implantation [13]. At the same time, this approach cannot be relied upon as a stand-alone method owing to the technical features of regional blockade and pharmacological sedation or GA cannot be excluded. In our view, SAPB at present can be considered an adjunctive component within a multimodal anaesthetic strategy.

For PS, the benzodiazepine sedative midazolam is most commonly used at a dose of 2-4 mg, or 1-2 mg in patients aged over 75 years and weighing less than 70 kg, in combination with an opioid analgesic - fentanyl (50-100 μg), nalbuphine (0.27 ± 0.05 mg/kg), or other opioid agents. The advantages of midazolam over other benzodiazepines had already been recognised in the 1980s: rapid onset of action, short duration after bolus administration, and the ability to induce anterograde amnesia. These properties provide broad opportunities for use in invasive interventions, eliminating procedure-related discomfort, while the rapid elimination of midazolam ensures adequate spontaneous respiration [14, 15]. The report by D. J. Fox and colleagues confirmed the safety and efficacy of this sedation method in the implantation of more than 500 ICD and CRT devices [16].

In current practice, alongside midazolam, 1% propofol solution is increasingly used during cardiac rhythm management device implantation [17]. Continuous intravenous administration of propofol provides rapid recovery, reduced postoperative nausea and vomiting, and shorter post-anaesthesia recovery times [18]. However, T. Trouvé-Buisson and colleagues, in a study involving 269 patients undergoing cardiac electronic device implantation and lead extraction under propofol, reported respiratory complications in 19% of cases, including hypoxia (86%), apnoea (30%), and aspiration (2%) [19].

In a retrospective analysis of 197 ICD or CRT implantations using propofol and midazolam, K. Pandya and colleagues found that these agents, administered for moderate sedation, induced hypotension in 25% of ICD patients and in 56% of CRT patients, with correction of arterial blood pressure using inotropes required in 10% of ICD procedures and in 24% of CRT procedures [20].

ANAESTHETIC MANAGEMENT DURING CARDIAC RESYNCHRONISATION THERAPY DEVICE IMPLANTATION

Among the most vulnerable patients in the electrophysiology laboratory are candidates for CRT. These patients typically present with advanced heart failure, severe impairment of left ventricular systolic function, and mechanical dyssynchrony resulting from bundle branch block with a QRS duration exceeding 130-150 ms. All these factors, together with the longer procedural time required for positioning the left ventricular lead into the target vein of the coronary sinus, substantially increase the risk of intraoperative complications.

Initially, during CRT implantation, the left ventricular lead was fixed epicardially to the lateral wall of the left ventricle, which necessitated thoracotomy under GA. Today, however, epicardial leads are in most cases successfully placed through the venous system of the heart without thoracotomy and without GA [21].

Many investigators have demonstrated that performing the procedure under local anaesthesia is safer and does not adversely affect the procedural outcome. Thus, in a retrospective analysis of 341 CRT implantations performed under GA, hypotension occurred in 43% of cases, compared with only 4% of cases when local anaesthesia combined with mild or moderate PS was used. Inotropic support was required to correct hypotension in one-quarter of patients [22]. Another study yielded similar results: hypotension occurred more frequently in patients undergoing GA (26% versus 4%), who also more frequently required inotropic agents and anticholinergics [23].

Deep sedation may be necessary during CRT implantation in restless or agitated patients, in those who continue to experience pain despite local anaesthesia, or in cases where patients cannot tolerate prolonged supine positioning due to comorbidities. In such situations, midazolam or fentanyl may be administered to alleviate symptoms and improve patient comfort. Importantly, no significant differences in the length of hospital stay were observed with respect to the anaesthetic technique used [24].

ANAESTHETIC MANAGEMENT DURING SUBCUTANEOUS CARDIOVERTER-DEFIBRILLATOR IMPLANTATION

In the 1970s, Mieczysław Mirowski and colleagues developed the first implantable defibrillator which, despite numerous design limitations, successfully fulfilled its intended function in 97% of cases. In 1980, the first human implantation of an ICD was performed [25].

Anaesthetic management for ICD implantation is generally similar to that for pacemaker or CRT device implantation. When intraoperative ICD testing is required, deep sedation with propofol combined with fentanyl is typically used [16, 26].

Implantation of a subcutaneous ICD (S-ICD) requires different anaesthetic management, as the device is positioned subcutaneously along the left anterior axillary line. Placement of the shock electrode involves creating a subcutaneous tunnel parallel to the left sternal border. Extensive tunnelling and defibrillator testing with determination of the shock threshold necessitate either a deep level of sedation or GA [27]. However, anaesthetic management has received limited attention in the published results of two large clinical trials [28]. According to some authors, patients undergoing the procedure under moderate or deep PS experienced pain and discomfort during tunnelling and ICD testing, which required deepening of anaesthesia but without the use of muscle relaxants or mechanical ventilation. To relieve postoperative pain, local anaesthetics were infiltrated subcutaneously at the end of the procedure [29].

The standard approach to S-ICD implantation often requires GA or deep sedation under the supervision of an anaesthesiologist. More recently, serratus anterior plane block under ultrasound guidance, in combination with parasternal blockade, has been employed to provide anaesthesia/analgesia and reduce the need for sedation during S-ICD implantation [10-13].

Thus, most procedures for the implantation of electronic antiarrhythmic devices can today be performed under local anaesthesia with varying levels of PS, without the need for GA with muscle relaxation and mechanical ventilation. In certain patients (particularly undergoing CRT or ICD implantation), administration of 1% propofol as part of anaesthetic management may lead to intraoperative hypotension and/or depression of spontaneous respiration. Such cases necessitate continuous, careful monitoring of the patient's condition by the attending anaesthesiologist and represent an additional psychological burden for the medical staff.

ANAESTHETIC MANAGEMENT DURING CATHETER ABLATION OF ARRHYTHMIAS

Anaesthesia for catheter ablation of atrial fibrillation

over time, catheter ablation (CA) of atrial fibrillation (AF) has evolved from an experimental procedure into a first-line therapy, as evidenced by numerous publications [30]. During CA, electrical isolation of the pulmonary veins from the left atrium is achieved using either radiofrequency current or cryothermal energy [31]. Since AF ablation is associated with painful sensations and requires the patient to remain supine and immobile for an extended period, it is considered appropriate to perform this procedure under GA with mechanical ventilation (MV) or under total intravenous anaesthesia (TIVA) with spontaneous respiration. An ideal anaesthetic technique that fully satisfies both operator and patient has yet to be established.

Several publications, based on large clinical datasets, have shown that GA with MV is associated with higher procedural success rates and shorter procedural duration compared with moderate sedation using midazolam (Dormicum) and fentanyl (88% versus 69%, $p<0.001$; and 2.4±1.4 versus 3.6±1.1 hours, $p<0.001$) [32]. The authors suggested that the absence of muscular contractions and controlled ventilation during GA + MV facilitated more stable positioning of the ablation catheter during energy delivery. With respect to complication rates, these were low and comparable between AF ablation performed under GA with MV and that performed under moderate or deep pharmacological sedation (PS) in combination with opioids.

Other investigators have likewise reported that AF ablation under GA + MV demonstrated better tolerability, more positive patient perception of the procedure, higher therapeutic efficacy, and improved quality of life compared with moderate or deep sedation with spontaneous respiration [31]. Another small randomised study indicated that patients undergoing AF ablation under intravenous anaesthesia with spontaneous respiration had higher arterial $PaCO_2$ levels on blood gas analysis, whereas complication and recurrence rates did not differ compared with GA + MV [34].

A meta-analysis and systematic review of studies comparing AF ablation outcomes under GA + MV versus intravenous anaesthesia with spontaneous respiration concluded that CA performed with GA + MV yielded superior procedural results. However, no significant differences were observed between the two groups in terms of procedural duration or fluoroscopy time [35].

Nevertheless, alongside its advantages, GA also has drawbacks. Potential limitations of GA during AF ablation include the absence of intraoperative patient feedback, the need for inotropic support in certain patients, an increased risk of phrenic nerve injury, and higher costs [36]. An interesting study conducted by J. S. Goode Jr. and colleagues (2006) compared methods of ventilatory support between controlled MV and high-frequency jet ventilation (HFJV), demonstrating that HFJV provided greater stability of the posterior left atrial wall, thereby facilitating catheter ablation [37].

Among pharmacological agents used during AF ablation, propofol and the combination of midazolam with fentanyl are most frequently employed. The most commonly administered opioids are remifentanil and fentanyl [35].

The principal drawbacks of propofol include respiratory depression and hypotension, difficulty in maintaining optimal catheter stability due to disturbances in spontaneous respiration, longer procedural and fluoroscopy times, and a higher incidence of arrhythmia recurrence. In 2011, H. Kottkamp and colleagues conducted a prospective observational study of 650 patients who underwent AF ablation under deep sedation with midazolam and fentanyl followed by propofol infusion. In this cohort, severe hypotension occurred in 2.3% of patients, 15% required vasopressors, 1.5% developed severe hypoxia, and 1.2% required mechanical ventilation with positive end-expiratory pressure [38].

Q. Liu and colleagues (2011) reported a dose-dependent relationship between propofol and arrhythmia inducibility. Their study documented cases of supraventricular tachycardia transforming into ventricular tachycardia, as well as suppression of the electrophysiological properties of the cardiac conduction system under the influence of propofol. Furthermore, clinically relevant doses of propofol were shown to suppress potassium, sodium, and calcium channels in cardiomyocytes and to shorten action potential duration. The authors concluded that propofol exerts a cumulative negative effect on the cardiac conduction system [39].

Improved respiratory homeostasis and favourable long-term procedural outcomes have been associated with the use of non-invasive ventilation (NIV) during deep sedation with propofol in high-risk patients, such as those with obstructive sleep apnoea, elevated body mass index, or prolonged procedural duration [40]. The methods of respiratory support in the anaesthetic management of such interventions warrant a separate review due to their complexity and specific requirements.

A relatively new sedative agent, dexmedetomidine (an α_2-adrenoceptor agonist with a short half-life), is characterised by dose-dependent sedative effects, mild analgesia, and less pronounced respiratory depression compared with propofol [41]. In a 2014 study, J. S. Cho and colleagues concluded that dexmedetomidine combined with remifentanil, compared with midazolam plus remifentanil, provided deeper sedation, less respiratory depression, superior analgesia, and greater operator satisfaction during AF ablation - even at lower therapeutic doses of remifentanil [42]. However, the potential adverse effects of dexmedetomidine include bradycardia, conduction disturbances, and hypotension.

Taken together, these studies indicate that the optimal anaesthetic approach for AF ablation remains unresolved. In most investigations, the choice has been between GA with mechanical ventilation, TIVA, or superficial to moderate pharmacological sedation of varying depth with spontaneous respiration, sometimes combined with non-invasive ventilatory support.

GA with mechanical ventilation necessitates tracheal intubation, use of advanced equipment for continuous monitoring of vital parameters, and administration of muscle relaxants. By contrast, TIVA with preserved spontaneous respiration does not necessarily require intubation and mechanical ventilation as obligatory components. However, given the duration and invasiveness of AF ablation, the accumulation of sedative and analgesic agents, and the comorbidity of patients, this possibility cannot be entirely excluded. Nevertheless, patients may remain able to purposefully respond to verbal commands during CA. In all cases, the marked depression of consciousness associated with sedative use mandates continuous monitoring of respiratory parameters, haemodynamics, and depth of sedation [7].

Recent data from a meta-analysis and systematic review by N. Pang and colleagues (2022) compared GA with mechanical ventilation/deep sedation (DS) with TIVA or superficial to moderate sedation with spontaneous respiration in AF ablation, analysing procedural and clinical outcomes [43]. Notably, the authors grouped together patients who underwent GA with mechanical ventilation and those who received DS (defined in domestic practice as TIVA with preserved spontaneous respiration). They emphasised that GA with mechanical ventilation and DS achieve a similar depth of sedation, sufficient to maintain patient immobility. The main distinctions lay in airway management and anaesthetic dosing; however, when airway reflexes were not preserved during DS, the same level of respiratory support was provided as under GA with mechanical ventilation. Therefore, these patients were included within a single analytical group.

It is important to note that this meta-analysis was conducted in accordance with the Cochrane standards of evidence-based medicine: heterogeneity between studies was assessed using the I^2 statistic and Cochran's Q test; sensitivity analyses, including meta-regression, were performed in cases of high heterogeneity; and publication bias was evaluated using funnel plots and Egger's test. These methodological considerations warrant a more detailed review of the findings.

In this study, the authors analysed trials including 2,418 patients conducted across centres in China, the United Kingdom, and other countries. The mean age of participants, predominantly male (70.5%), was 61.2 years. In all studies, radiofrequency energy was used to achieve pulmonary vein isolation, with additional ablation performed where necessary.

The meta-analysis demonstrated that GA with MV or DS was associated with a lower recurrence rate following AF ablation ($p = 0.03$) compared with superficial or moderate sedation with spontaneous respiration.

The study also examined costs and complications according to anaesthetic modality. No significant differences were found between the two groups in procedural duration ($p = 0.35$) or fluoroscopy time ($p = 0.60$), whereas ablation time was shorter in the GA + MV/DS group ($p = 0.008$). The overall complication rate and the incidence of serious adverse events were not statistically different between the two groups ($p = 0.07$ and $p = 0.94$, respectively).

On the basis of their findings, the authors concluded that GA + MV/DS may reduce the risk of AF recurrence after ablation without increasing complication rates, and may shorten ablation time, although no statistical differences were observed in other procedural parameters compared with light/moderate sedation with spontaneous respiration. Summarising the findings of the reviewed studies, the authors emphasised the significant role of anaesthesiologists in electrophysiology laboratory procedures [44].

Similar conclusions are supported by the results of a survey of 479 anaesthesiologists and cardiologists on the topic of anaesthetic support for minimally invasive cardiac procedures. In this survey, 92% of respondents indicated that the involvement of anaesthesiologists increases patient satisfaction with the procedure. However, integration of anaesthesiologists into cardiology practice remains slow: only 66% of respondents reported increased participation of anaesthesiologists in minimally invasive procedures [45].

In our view, GA and DS with mechanical ventilation or non-invasive ventilatory support are the preferred anaesthetic strategies during AF ablation, particularly in cases where prolonged procedures are anticipated in elderly and/or comorbid patients. The involvement of anaesthesiologists in minimally invasive cardiac procedures enhances safety and improves the quality of care.

More recently, inhalational anaesthesia (inhalational sedation) has been increasingly applied during radiofrequency AF ablation. The principal advantage of inhalational anaesthesia is its reliable hypnotic effect, provided by effective and safe halogenated anaesthetics such as isoflurane and sevoflurane. Inhalational anaesthesia may be administered either via a laryngeal mask or tracheal intubation [44]. Its advantages include controllability (stable concentrations without haemodynamic instability, and the ability to increase, reduce, or discontinue gas administration within seconds), the low toxicity of isoflurane (not metabolised in the body and excreted via the lungs), and rapid recovery. The principal drawback of inhalational anaesthesia is the high cost of technical maintenance and its insufficient analgesic effect, often requiring the administration of supplementary agents.

Anaesthetic management during catheter ablation of supraventricular tachycardia

the primary objective of sedation during electrophysiological study (EPS) and ablation for supraventricular tachycardia (SVT) is to achieve an appropriate balance between patient comfort and a level of sedation that still permits arrhythmia induction. CA for SVT is generally performed under TIVA with mild to moderate sedation, using benzodiazepines and opioids while maintaining spontaneous respiration. In particular clinical situations - such as in agitated patients, those who continue to report pain despite local anaesthesia, patients unable to tolerate prolonged supine positioning, or those with significant comorbidities - the procedure may be carried out under GA with MV or DS.

It should be noted that any degree of sedation reduces arrhythmia inducibility. Unlike propofol and dexmedetomidine, benzodiazepines combined with opioids exert less influence on the electrophysiological properties of the conduction system, including those of the accessory pathway [44-46]. Dexmedetomidine suppresses the automaticity of the sinoatrial node and has a negative dromotropic effect on AV conduction. These actions account for the reduced inducibility of SVT during EPS and CA [47]. For this reason, the use of dexmedetomidine in this patient category within the electrophysiology laboratory is not recommended.

Anaesthetic management during catheter ablation of ventricular arrhythmias

when selecting sedation strategies for CA of ventricular arrhythmias (VA), several factors must be considered, including patient age, comorbidities, access approach (endocardial and/or epicardial ablation), risk of airway obstruction, and patient preference. GA or DS provides patient comfort, facilitates epicardial access, and creates optimal conditions for catheter manipulation during mapping and ablation, particularly in prolonged procedures. However, the main drawback of GA/DS is the potential suppression of VA. The elimination of psychological stress and the associated changes in autonomic tone under GA/DS may reduce the spontaneous manifestation of catecholamine-dependent VA and the inducibility of re-entrant VT. Inhalational anaesthetics (sevoflurane, isoflurane) prolong action potential duration and ventricular refractoriness, while dexmedetomidine decreases sympathetic tone [44]. For these reasons, the use of such agents during CA should be avoided [48].

As noted previously, patients receiving dexmedetomidine demonstrated a significant reduction in the overall frequency of ventricular arrhythmias (OR 0.35, 95% CI 0.16-0.76) and a marked reduction in VT risk compared with controls (OR 0.25, 95% CI 0.08-0.80, $I^2 = 20\%$) [49].

Moreover, most anaesthetic agents used for sedation and analgesia reduce myocardial contractility and blood pressure, with the risk of worsening haemodynamic instability during VT, sometimes necessitating vasopressor support. Notably, the use of agents such as propofol in VA patients with severe left ventricular dysfunction may cause profound hypotension during CA. The use of such anaesthetics must therefore be strictly justified. Nevertheless, the effects of propofol on the electrophysiological properties of the heart are complex, and in some cases suppression of VA may be beneficial - for example, in terminating ventricular tachycardia or suppressing ventricular electrical storm [50].

Another disadvantage of GA/DS with muscle relaxants is the increased risk of phrenic nerve injury, since pharmacological muscle relaxation hampers identification of the phrenic nerve during epicardial ablation [51].

No definitive consensus has been reached regarding the optimal sedation strategy during CA in patients with idiopathic VA (premature ventricular contractions and/or ventricular tachycardia). In many centres, CA in this setting is performed under mild sedation with benzodiazepines. In some patients with idiopathic VT, however, administration of these agents negatively affects arrhythmia inducibility.

For this reason, in our practice we endeavour to avoid their use and resort to mild or moderate sedation only in selected clinical situations [52].

CONCLUSION

Thus, during pacemaker implantation and CA for AF, supraventricular arrhythmias, and ventricular arrhythmias, the following principles should be observed: the involvement of anaesthesiologists in minimally invasive cardiac procedures enhances the quality and safety of care. Patients undergoing arrhythmia-related interventions require thorough preoperative assessment to determine the optimal sedation and analgesia strategy, with an anaesthetic plan tailored to the individual. Comorbidities (such as morbid obesity, chronic respiratory disease), chronic use of psychoactive drugs and/or opioid analgesics for pain management, and similar factors should be decisive in favour of GA with mechanical ventilation (GA + MV).

It is prudent to avoid GA and deeper levels of sedation in patients undergoing pacemaker implantation (with the exception of subcutaneous implantable cardioverter-defibrillators [S-ICDs]); adequate local or regional anaesthesia is critical for patient comfort. CA for supraventricular arrhythmias or idiopathic ventricular tachycardia, particularly when the arrhythmia is suspected to be catecholamine-sensitive or was non-inducible during a prior procedure, should likewise be performed with minimal anaesthesia.

In the absence of formal indications for GA + MV, moderate or deep sedation (e.g. propofol infusion, midazolam, fentanyl) combined with non-invasive ventilatory support and intensive monitoring of vital functions may be used in haemodynamically stable patients with various arrhythmias when a prolonged procedure or more invasive approaches (such as epicardial access) are anticipated. GA + MV or DS with ventilatory support remain the preferred anaesthetic strategies during CA for AF and epicardial ablation of ventricular arrhythmias, particularly when lengthy procedures are expected in elderly and/or comorbid patients.

It should also be noted that, according to recent studies, anaesthetic choice is determined primarily by patient characteristics and institutional factors, without significant impact on long-term outcomes such as AF recurrence or complication rates.

REFERENCES

1. Bokeria LA, Revishvili ASh. Interventsionnaya i khirurgicheskaya aritmologiya: sovremennoe sostoyanie, problemy i perspektivy razvitiya. *Meditsinskaya tekhnika*. 2002;6: 7-8. (In Russ.)
2. Palmisano P, Ziacchi M, Angeletti A, et al. The Practice of Deep Sedation in Electrophysiology and Cardiac Pacing Laboratories: Results of an Italian Survey Promoted by the AIAC (Italian Association of Arrhythmology and Cardiac Pacing). *J Clin Med*. 2021;10(21): 5035. https://doi.org/10.3390/jcm10215035.
3. Potievskaya VI, Zabolotskikh IB, Gridchik IE, et al. Sedation of patients in intensive care units. Guidelines. *Russian Journal of Anesthesiology and Reanimatology*. 2023;(5): 624. (In Russ.). https://doi.org/10.17116/anaesthesiology20230516.
4. Lü F, Lin J, Benditt DG. Conscious sedation and anesthesia in the cardiac electrophysiology laboratory. *J Cardiovasc Electrophysiol*. 2013;24(2): 237-245. https://doi.org/10.1111/jce.12001.
5. Essandoh MK, Mark GE, Aasbo JD, et al. Anesthesia for subcutaneous implantable cardioverter-defibrillator implantation: Perspectives from the clinical experience of a U.S. panel of physicians. *Pacing Clin Electrophysiol.* 2018;41(7): 807-816. https://doi.org/10.1111/pace.13364.
6. Anesthesiology: national guidelines: a short edition / edited by A.A. Bunyatyan, V.M. Mizikov. Moscow: GEOTAR-Media, 2020. 656 p. (In Russ.). ISBN 978-5-9704-5709-2.
7. Walsh TS, Kydonaki K, Antonelli J, et al. Staff education, regular sedation and analgesia quality feedback, and a sedation monitoring technology for improving sedation and analgesia quality for critically ill, mechanically ventilated patients: a cluster randomised trial. *Lancet Respir Med*. 2016;4(10):807-817. https://doi.org/10.1016/S2213-2600(16)30178-3.
8. Kozlov IA. Modern approaches to sedation in intensive care units. *Meditsinskij alfavit.* 2013;1(38): 2232. (In Russ.).
9. Fitzpatrick AP, Lesh MD, Epstein LM, et al. Electrophysiological laboratory, electrophysiologist-implanted, nonthoracotomy-implantable cardioverter/defibrillators. *Circulation*. 1994;89(6): 2503-2508. https://doi.org/10.1161/01.cir.89.6.2503.
10. Zhang Y, Min J, Chen S. Analgesic Efficacy of Regional Anesthesia of the Hemithorax in Patients Undergoing Subcutaneous Implantable Cardioverter-Defibrillator Placement. *J Cardiothorac Vasc Anesth*. 2021;35(11): 3288-3293. https://doi.org/10.1053/j.jvca.2021.02.052.
11. Szamborski M, Janc J, Leśnik P, et al. Ultrasound-Guided Pectoserratus Plane Block and Superficial Serratus Anterior Plane Block for Subcutaneous Implantable Cardioverter-Defibrillator Implantation: A Comparative Study. *Med Sci Monit*. 2023;29: e940541. Published 2023 Jul 21. https://doi.org/10.12659/MSM.940541.
12. Uran C, Giojelli A, Borgogna DA, et al. Ultrasound-guided serratus anterior plane block combined with parasternal block in subcutaneous implantable cardioverter defibrillator implantation: Results of a pilot study. *Pacing Clin Electrophysiol*. 2020;43(7): 705-712. https://doi.org/10.1111/pace.13944.
13. Ziacchi M, Bisignani G, Palmisano P, et al. Serratus anterior plane block in subcutaneous implantable cardioverter defibrillator implantation: A case-control analysis. *J Cardiovasc Electrophysiol.* 2019;31: 144-149. https://doi.org/10.1111/jce.14293.
14. Sumin SA. Midazolam: opportunities and prospects for use in intensive care. *Medical alphabet*. 2017;3(29): 47-52. (In Russ.).
15. Miśkowiec D, Kasprzak JD, Wejner-Mik P, et al. Conscious sedation during cryoballoon ablation of atrial fibrillation: a feasibility and safety study. *Minerva Cardioangiol*. 2018;66(2): 143-151. https://doi.org/10.23736/

S0026-4725.17.04505-4
16. Fox DJ, Davidson NC, Bennett DH, et al. Safety and acceptability of implantation of internal cardioverter-defibrillators under local anesthetic and conscious sedation. *Pacing Clin Electrophysiol.* 2007;30: 992-997. https://doi.org/10.1111/j.1540-8159.2007.00816.x.
17. Marquié C, Duchemin A, Klug D, et al. Can we implant cardioverter defibrillator under minimal sedation?. *Europace*. 2007;9(7): 545-550. https://doi.org/10.1093/europace/eum060.
18. Kaya E, Südkamp H, Lortz J, et al. Feasibility and safety of using local anaesthesia with conscious sedation during complex cardiac implantable electronic device procedures. *Sci Rep.* 2018;8(1): 7103. https://doi.org/10.1038/s41598-018-25457-x.
19. Trouvé-Buisson T, Arvieux L, Bedague D, et al. Anaesthesiological support in a cardiac electrophysiology laboratory: a single-centre prospective observational study. *Eur J Anaesthesiol.* 2013 Nov;30(11): 658-63. https://doi.org/10.1097/EJA.0b013e3283626095.
20. Pandya K, Patel MB, Natla J, et al. Predictors of hemodynamic compromise with propofol during defibrillator implantation: a single center experience. *J Interv Card Electrophysiol.* 2009;25(2): 145-151. https://doi.org/10.1007/s10840-008-9355-6.
21. Shatalov KV, Serguladze SY, Abdurazakov MA, et al. Cardiac resynchronization therapy: alternative methods of left ventricular electrode implantation. *Minimally Invasive Cardiovascular Surgery*. 2024;3(3): 39-49. (In Russ.).
22. Pfau G, Schilling T, Kozian A, et al. Outcome after implantation of cardiac resynchronization/defibrillation systems in patients with congestive heart failure and left bundle-branch block. *J Cardiothorac Vasc Anesth*. 2010;24(1): 30-36. https://doi.org/10.1053/j.jvca.2009.07.009
23. Theron P, Guha K, Mantziari L, et al. General anesthesia versus sedation for implantation of a biventricular pacing device for cardiac resynchronization therapy. *J Cardiothorac Vasc Anesth.* 2014;28: 280-284. https://doi.org/10.1053/j.jvca.2013.07.008.
24. Looi KL, Lee AS, Cole K, et al. Conscious sedation and analgesia use in cardiac device implantation. *Int J Cardiol.* 2013;168(1): 561-563. https://doi.org/10.1016/j.ijcard.2013.01.167.
25. Ladeev AYu, Marochkov AV, Dmitrieva VN. The history of the creation and development of implantable cardioverter defibrillators. *Surgery news.* 2016;24(4): 317-327. (In Russ) https://doi.org/10.18484/2305-0047.2016.4.317.
26. Sayfo S, Vakil KP, Alqaqa'a A, et al. A retrospective analysis of proceduralist-directed, nurse-administered propofol sedation for implantable cardioverter-defibrillator procedures. *Heart Rhythm*. 2012;9(3): 342-346. https://doi.org/10.1016/j.hrthm.2011.10.009.
27. Cappato R, Smith WM, Hood MA, et al. Subcutaneous chronic implantable defibrillation systems in humans. *J Interv Card Electrophysiol.* 2012;34(3): 325-332. https://doi.org/10.1007/s10840-012-9665-6.
28. Burke MC, Gold MR, Knight BP, et al. Safety and Efficacy of the Totally Subcutaneous Implantable Defibrillator: 2-Year Results From a Pooled Analysis of the IDE Study and EFFORTLESS Registry. *J Am Coll Cardiol.* 2015;65(16): 1605-1615. https://doi.org/10.1016/j.jacc.2015.02.047.
29. Essandoh MK, Portillo JG, Weiss R, et al. Anesthesia care for subcutaneous implantable. *J Clin Anesth.* 2016;31: 53-59. https://doi.org/10.1016/j.jclinane.2015.11.009.
30. Blomström-Lundqvist C, Gizurarson S, Schwieler J, et al. Effect of Catheter Ablation vs Antiarrhythmic Medication on Quality of Life in Patients With Atrial Fibrillation: The CAPTAF Randomized Clinical Trial. *JAMA*. 2019;321(11): 1059-1068. https://doi.org/10.1001/jama.2019.0335.
31. Hoffmann E, Straube F, Wegscheider K, et al. Outcomes of cryoballoon or radiofrequency ablation in symptomatic paroxysmal or persistent atrial fibrillation. *Europace*. 2019;21(9): 1313-1324. https://doi.org/10.1093/europace/euz155.
32. Di Biase L, Conti S, Mohanty P, et al. General anesthesia reduces the prevalence of pulmonary vein reconnection during repeat ablation when compared with conscious sedation: results from a randomized study. *Heart Rhythm.* 2011;8(3): 368-372. https://doi.org/10.1016/j.hrthm.2010.10.043.
33. Stašková K, Bulava A, Tesařík R, et al. Radiofrequency catheter ablation of atrial fibrillation performed under general anesthesia: results of a unicentric randomized trial. *Vnitr Lek.* 2017;63(3): 163-169.
34. Firme EB, Cavalcanti IL, Barrucand L, et.al. Curative ablation of atrial fibrillation: comparison between deep sedation and general anesthesia. *Rev Col Bras Cir*. 2012;39(6): 462-468. https://doi.org/10.1590/s0100-69912012000600004.
35. Li Ka Hou C, Sang T, Chan C, et al. Anesthesia use in catheter ablation for atrial fibrillation: a systematic review and meta-analysis of observational studies. *Heart Asia*. 2019;11(2): e011155. https://doi.org/10.1136/heartasia-2018-011155.
36. Gerstein NS, Young A, Schulman PM, et al. Sedation in the Electrophysiology Laboratory: A Multidisciplinary Review. *J Am Heart Assoc.* 2016;5(6): e003629. https://doi.org/10.1161/JAHA.116.003629.
37. Goode JS Jr, Taylor RL, Buffington CW, et al. High-frequency jet ventilation: utility in posterior left atrial catheter ablation. *Heart Rhythm.* 2006;3(1): 13-19. https://doi.org/10.1016/j.hrthm.2005.09.013.
38. Kottkamp H, Hindricks G, Eitel C, et al. Deep sedation for catheter ablation of atrial fibrillation: a prospective study in 650 consecutive patients. *J Cardiovasc Electrophysiol.* 2011;22(12): 1339-1343. https://doi.org/10.1111/j.1540-8167.2011.02120.x.
39. Liu Q, Kong AL, Chen R, et al. Propofol and arrhythmias: two sides of the coin. *Acta Pharmacol Sin.* 2011 Jun;32(6): 817-23. https://doi.org/10.1038/aps.2011.42
40. Vevecka A, Schwab C, Forkmann M, et al. Predictive Factors and safety of noninvasive mechanical ventilation in combination with propofol deep sedation in left atrial ablation procedures. *Am J Cardiol.* 2019;124(2): 233-238. https://doi.org/10.1016/j.amjcard.2019.04.013.
41. Sairaku A, Yoshida Y, Hirayama H, et al. Procedural sedation with dexmedetomidine during ablation of atrial fibrillation: a randomized controlled trial. *Europace*. 2014;16(7): 994-999. https://doi.org/10.1093/europace/eut363.

42. Cho JS, Shim JK, Na S, et al. Improved sedation with dexmedetomidine-remifentanil compared with midazolam-remifentanil during catheter ablation of atrial fibrillation: a randomized, controlled trial. *Europace*. 2014;16(7): 1000-6. https://doi.org/10.1093/europace/eut365.
43. Pang N, Gao J, Zhang N, et al. Comparison of the Different Anesthesia Strategies for Atrial Fibrillation Catheter Ablation: A Systematic Review and Meta-Analysis. *Cardiol Res Pract*. 2022;2022: 1124372. https://doi.org/10.1155/2022/1124372.
44. Yildiz M, Yilmaz Ak H, Oksen D, et al. Anesthetic Management In Electrophysiology Laboratory: A Multidisciplinary Review. *J Atr Fibrillation*. 2018;10(5):1775. https://doi.org/10.4022/jafib.1775.
45. Nelson EW, Woltz EM, Wolf BJ, et al. A Survey of Current Anesthesia Trends for Electrophysiology Procedures. *Anesth Analg*. 2018;127(1): 46-53. https://doi.org/10.1213/ANE.0000000000003376.
46. Kovoor P, Porter R, Uther JB, Ross DL. Efficacy and safety of a new protocol for continuous infusion of midazolam and fentanyl and its effects on patient distress during electrophysiological studies. *Pacing Clin Electrophysiol*. 1997;20(11): 2765-2774. https://doi.org/10.1111/j.1540-8159.1997.tb05434.x
47. Khan ZP, Ferguson CN, Jones RM. alpha-2 and imidazoline receptor agonists. Their pharmacology and therapeutic role. *Anaesthesia*. 1999;54(2): 146-165. https://doi.org/10.1046/j.1365-2044.1999.00659.x
48. Terao Y, Higashijima U, Toyoda T, et al. The effects of intravenous anesthetics on QT interval during anesthetic induction with sevoflurane. *J Anesth*. 2016;30(6): 929-934. https://doi.org/10.1007/s00540-016-2252-8.
49. Zhong Q, Kumar A, Deshmukh A, Bennett C. Dexmedetomidine Reduces Incidences of Ventricular Arrhythmias in Adult Patients: A Meta-Analysis. *Cardiol Res Pract*. 2022;2022: 5158362. https://doi.org/10.1155/2022/5158362.
50. Shannon K, Saltzman D, Li I, et al. Ventricular tachycardia converts to sinus rhythm after administration of propofol. *Am J Emerg Med.* 2021;48: 377.e1-377.e3. https://doi.org/10.1016/j.ajem.2021.04.028.
51. Patel S, Deng J, Zubair A, et al. Sedation Versus General Anesthesia for Ablation of Ventricular Arrhythmias: A Systematic Review and Meta-Analysis. *Ann Card Anaesth*. 2025;28(2):119-127. https://doi.org/10.4103/aca.aca_229_24.
52. Polovinka VS, Demyanenko AV, Steklov VI, et al. Innovative methods of treatment of ventricular arrhythmias of the heart. *Military Medical Journal*. 2014;335(11): 44-52. (In Russ). https://doi.org/10.17816/RMMJ74301.