HEART RATE CONTROL USING IMPLANTABLE DEVICES. WHAT WE HAVE ACHIEVED AND WHAT ELSE IS WAITING IN MODERN ARHYTHMOLOGY? REVIEW

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The authors declare that they have no conflicts of interest

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Abstract

Ambulatory cardiac monitoring is a rapidly expanding field of functional diagnostics. Today, the main direction of cardiac monitoring is outpatient monitoring of the electrocardiogram, an important diagnostic tool that is used daily by doctors in many specialties. Therefore, both wearable and subcutaneous technologies of electrocardiographic monitoring are now widely used. A number of devices can be placed under the patient's skin and have the ability to wirelessly transmit data to home transmitters, which, in turn, then transmit data to the doctor via cloud interfaces, so that, they allow remote monitoring and monitoring of the patient's condition. Such systems are widely used in various countries of the world, approved in the USA, and are also used for remote monitoring of patients in Europe and Kazakhstan, where their implementation is gaining momentum. This review presents the technical aspects of subcutaneous monitoring, provides a schematic representation of the operation of systems existing on the market, discusses the advantages of this method, as well as the disadvantages of existing implantable cardiac monitors. The issues of the future development of this technology and indications for the use of existing devices approved by the professional cardiological communities are considered.

Имплантацияланатын құрылғылар көмегімен жүрек ырғағын бақылау. Заманауи аритмологияда неге қол жеткіздік және алда не күтіп тұр? Әдебиет шолуы

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Түйін сөздер
амбулаторлық кардиологиялық бақылау, тері астындағы жүрек мониторлары, имплантацияланатын жүрек мониторлары, жүрек соғысы, инсульт, синкопе, жүрекше фибрилляциясы, телемедицина

Аңдатпа

Жүректің амбулаторлық мониторингі - бұл функционалды диагностиканың жылдам дамып келе жатқан саласы. Бүгінгі таңда жүрек мониторингісінің негізгі бағыты - электрокардиограмманы (ЭКГ) амбулаторлық мониторинг жасау - бұл көптеген сала дәрігерлерінің күнделікті қолданатын маңызды диагностикалық құралы. Сондықтан қазіргі кезде электрокардиографиялық бақылаудың тері сыртынан денеге тағатын да, тері асты технологиялары да кеңінен таралған. Бірқатар құрылғыларды науқастың терісінің астына қоюға болады және деректерді үйдегі таратқыштарға сымсыз жіберу мүмкіндігі бар, олар өз кезегінде бұлтты интерфейстер арқылы дәрігерге мәлімет береді, яғни олар науқастың жағдайын қашықтықтан бақылауға және қадағалауға мүмкіндік береді. Мұндай жүйелер АҚШ-та мақұлданған, сондай-ақ әлемнің әр түрлі елдерінде кеңінен қолданылады, сонымен қатар олар Еуропа мен Қазақстанда да науқастарды қашықтықтан бақылау үшін қолданылады.

Әдеби шолу электрокардиограмманы тері астылық бақылаудың техникалық аспектілерін ұсынады, клиникалық қолданыста бар жүйелердің жұмысынан схемалық көрініс береді, осы әдістің артықшылықтарын, сонымен қатар тәжірибелік қолданыстағы имплантацияланатын жүрек мониторларының кемшіліктерін талқылайды. Кәсіби кардиологиялық қауымдастықтар мақұлдаған осы технологияның келешектегі даму мәселелері мен қолданыстағы құрылғыларды қолдануға көрсеткіштер қарастырылады.

Контроль ритма сердца с помощью имплантируемых устройств. Чего мы достигли и что еще предстоит в современной аритмологии? Обзор литературы

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Аннотация

Амбулаторный кардиомониторинг – это быстро расширяющаяся область функциональной диагностики. На сегодняшний день основным направлением кардиомониторинга является амбулаторное мониторирование электрокардиограммы (ЭКГ) – это важный диагностический инструмент, который ежедневно используется врачами многих специальностей. Поэтому в настоящее время широко распространены как носимые, так и подкожные технологии электрокардиографического мониторинга. Ряд устройств могут помещаться под кожу пациента и обладают возможностями беспроводной передачи данных на домашние передатчики, которые, в свою очередь, передают данные врачу через облачные интерфейсы, то есть позволяют дистанционно наблюдать за пациентом и контролировать его состояние. Такие системы широко используются в различных странах мира, одобрены в США, а также применяются для дистанционного наблюдения за больными в Европе и Казахстане, где их внедрение набирает обороты.

В обзоре представлены технические аспекты подкожного мониторинга, дано схематичное представление о работе существующих в клинической практике систем, рассматриваются вопросы преимуществ данного метода, а также недостатки существующих в клинической практике имплантируемых кардиомониторов. Рассматриваются вопросы перспективного развития данной технологии и показаний к применению существующих устройств, одобренных профессиональными кардиологическими сообществами.

Ключевые слова
амбулаторный кардиомониторинг, подкожные кардиомониторы, имплантируемые кардиомониторы, сердцебиение, инсульт, обморок, фибрилляция предсердий, телемедицина

Introduction

Currently available ECG monitoring technologies include both “wearable” and subcutaneous ECG recorders and the most successful choice of a device for a particular patient is associated with the frequency with which relapses of the patient's symptoms are expected [1]. Thus, several clinical studies have shown that performing a routine ECG helps to clarify the genesis of syncope only in 2–11% of cases [2]. According to a comparative study, which compared the results of implantable cardiac monitors (ICM) and Holter ECG monitoring technology (HM ECG), modern ICMs transmit up to 98% of arrhythmia episodes during the entire period of their operation, and the loss of single episodes occur only in case of repetition of several arrhythmic episodes during the day [3]. An isolated HM ECG for 24 hours makes it possible to determine the cause of cardiac arrhythmias in 2–20% of cases [2, 4]. To clarify the cause of syncope, the most effective is a rotary table test (tilt test), it allows you to understand the cause of syncope, according to different authors, in 11–87% of cases, and in 76% of cases - to change the therapy in connection with this [2, 5, 6]. At the same time, in only 4% of patients, a complex of neurological examination, including examination by a specialist doctor and computed tomography of the brain, helps in establishing the cause of syncope [6]. Evaluation of ICM data helps in making a diagnosis in 87–90% of patients with syncope and allows a comprehensive assessment of the effectiveness of ablation for atrial fibrillation [2, 5, 7]. Application ICM is also important for patients with syncope not of a cardiogenic nature, but with cardiogenic transient ischemic attacks; the proportion of such patients is up to 58% in the structure of the causes of death from strokes [2, 8, 9]. Semi-annual mortality rate in these patients exceeds 10% [2, 10]. At the same time, it is the genesis of syncope and the difference between cardiogenic and non-cardiogenic syncope that determines the patient's treatment tactics and prognosis [9]. Recording an ECG at the time of rare episodes of syncope is a difficult task, but with longer periods of monitoring it is quite feasible: for example, according to some studies, the number of recorded episodes of arrhythmia reaches 50% only during 365 days of continuous observation with using ICM [11, 12].

Currently, there are complex ICM test systems on the international market that allow for long-term, long-term monitoring and recording of arrhythmia episodes. They have been tested in clinical trials and have been approved by the FDA and EMEA for clinical use. At the moment, such test systems are produced by four manufacturers of medical equipment: St. Jude Medical, Boston Scientific, Medtronic and Biotronik [13]. The data obtained in clinical studies on the use of diagnostic implantable arrhythmia fixation systems in patients at risk of fatal arrhythmias suggest that the instrumental systems of these manufacturers are quite effective in preventing sudden cardiac death [13]. For example, in the ALTITUDE study, it was shown that

the survival rate of patients implanted whose devices transmitted information to remote networks was associated with a relative reduction in the risk of death by 50% [13]. Implantable cardiac devices with remote functionality provide an unprecedented opportunity to ensure daily monitoring of patients and are one of the most advanced medical technologies in cardiology [13].

Outpatient management of patients with ICM, defibrillators and pacemakers, the so-called outpatient cardiac monitoring, provides an innovative solution to the burden of doctors and hospital resources to obtain information about possible deviations in heart rate in patients [13]. Automated and remote transfer of data from the implant to the data control center allows you to quickly respond to the patient's condition: the doctor is informed via messengers, mail and telephone notifications about life-threatening situations in the patient or about violations in the operation of the device [13]. This approach allows you to bring the diagnostic system in arrhythmology to a new level. The trend for the introduction of ICM into widespread clinical practice is redefining the standard of management of patients with arrhythmias [13].

This review focuses on the current state of the art of insertion methods, areas of application and advantages of subcutaneous ICM over HM ECG, the prospects for their use and limitations. The aim is to highlight the diversity of modern ICM technologies and their advantages, to give an idea of the potential of future developments in the field of cardiac monitoring.

Technical capabilities of receiving and storing heart rate data

The basis for the transition from ECG monitoring with cutaneous electrodes to monitoring implantable devices were studies that showed that the ECG voltage measured by electrodes on the skin should be identical to the ECG voltage in the underlying subcutaneous areas [14]. So, R. Arzbaecher et al. showed that cutaneous and subcutaneous ECGs coincided in amplitude and morphology [14]. Typically, potential maps of the body surface show gradients of several hundred microvolts per centimeter in the areas of the chest just above the heart; in this way, a pair of electrodes with a distance of 3 or 4 cm, if correctly positioned and oriented to the chest, can easily record 1 MV R-waves during sinus rhythm [14]. The potential gradients on the chest form a two-dimensional vector field, and two pairs of electrodes at the corners of the sensor form two ECG outputs, which measure two orthogonal components of this vector [14]. An example of a suitable combination of two conclusions: the sum of squares is independent of the direction of the surface potential gradient vector and allows automatic detection of the R-wave, regardless of the orientation of the device, a change in the patient's posture, or even a change in the direction of cardiac activation [14]. To demonstrate that high quality ECG recordings can be obtained from closely spaced bipolar pairs, R. Arzbaecher et al. studied 60 patients with ICD implanted and recordings from multielectrode precordial matrices during sinus rhythm and during induced episodes of ventricular fibrillation as part of a standard defibrillator testing protocol [14]. In these patients, the mean R-wave amplitude was 1.4 mV (range 0.3–2.7) in sinus rhythm and 0.8 mV (range 0.3–2.0) with ventricular fibrillation [14]. Arzbaecher R. et al. observed in these experiments that precordial locations, which are reflected by large R-waves during sinus rhythm, as a rule, give large deviations in ventricular fibrillation [14]. This is an important observation, since the optimal implantation site can be determined by simply displaying R-waves against the background of sinus rhythm, without the need to induce ventricular fibrillation [14]. In this study, the clarity and amplitude of deviations in both sinus rhythm and episodes of ventricular fibrillation were such that the proper level of reliability could be expected from most of the processing algorithms [14]. In modern ICM, R-waves are identified using an adaptive threshold detector, and R-R interval series are compared to programmed detection thresholds. If the sequence of interval measurements satisfies the trigger criteria, then the contents of the circular buffer are selected as significant for storage and transferred to permanent storage [14]. Further development of technologies for installing ICM made it possible to achieve their stable position, in which a week after implantation the amplitude of the R wave of 0.75 ± 0.39 mV is recorded, and it remains stable throughout the observation period [15].

Diagram of the device of modern instrument complexes of various devices implantable heart monitors

The system usually consists of 4 main components [16]:

1. An implantable cardiac monitor is an implant, in fact, a disposable electronic sensor, implanted into the subcutaneous tissue in the area above the heart. The device is equipped with contacts, for most monitors - two, which are electrodes-detectors of electromagnetic waves recorded as an ECG curve - “subcutaneous ECG” of the patient. The data are recorded continuously, however, only up to 55 minutes of records are stored in the device's memory, while modern devices store only “fragments” of ECG curves that correspond to the device's settings for storing anomalous episodes.

These are either automatically saved episodes, or several minutes of ECG recorded after activation of the recording by the patient himself through the PCM remote control (provided that such a remote control is available in the manufacturer's instrument complex). The parameters of the start of the recording of an arrhythmia episode in the device memory are determined by the physician adjusting the implanted sensor through a special part of the device complex - the programmer.

2. Programmer is a stationary device that is used to set the operating parameters of a sensor implanted in a patient using wireless communication [13]. The programmer has a screen for displaying image of the patient's ECG data coming from the implanted sensor directly or through the transmitter (depends on the manufacturer's instrumentation). It is possible to print ECGs from it, information about the patient's ECG episodes can be stored in the memory of the programmer. The programmer is a part of the instrumentation system used by medical personnel in a medical hospital. One programmer serves several patients of a given hospital. The programmer is also used to adjust the location and orientation of the implant, optimize the signal amplitude, as well as to set the parameters of the event trigger and data storage for each device [14].

3. Patient assistant - remote control for the implant, which is also called the activation unit. This is a device with replaceable batteries for wireless communication with the implant. It allows a short segment of data to be captured at the press of a button, which is useful for documenting rhythms associated with dizziness or chest flutter [14]. Some PCMs contain a uniaxial accelerometer, which perceives the characteristic signature of a patient falling and can transmit data based on this trigger [14].

4. Patient monitor - a device designed to receive information from the implant, temporarily store it in a limited volume and transmit data to the dedicated servers of the company-developer of the instrument complex. Depending on the manufacturer and device settings, transmission from the implant to the monitor can be automatic or can be induced from the control panel by the patient. The data transmission channels from the monitor itself to the servers of the developer company differ for the instrument complexes existing on the market. This can be a wired telephone or cellular connection, and the storage servers can be cloud-based or fixed. Usually this part of the system is located in the patient's bedroom, since wireless data transmission requires a distance between the implant and the monitor no more than 3-10 m. The interaction of the patient with the monitor includes the initial setup procedure, performing the data collection requested by the doctor and responses to the doctor-specified notifications displayed on the monitor screen.

Modern technology of data transmission in systems implantable heart monitors for medical monitoring

When the ICM is working, the perceived ECG is cycled through a circular buffer (memory circuit) for about 10 minutes [14]. Episodes identified by the CM as arrhythmic can be transferred wirelessly (Wi-Fi or Bluetooth) to a large memory storage, patient monitor. Setting of data transmission parameters is possible for devices existing on the market only with the help of an external programmer supplied by the manufacturer [14]. Among the systems existing on the market, there are those in which the transfer of data from the implant to the patient's bedside monitor can occur only through the implementation of a number of actions by the patient - this is called “inductive monitoring” [13]. A significant barrier in the provision of medical care, both for clinicians and patients, is non-compliance by patients with the requirements for their participation in the daily process of data transfer [13]. In instrument complexes with a more modern model of data transfer, automated, no special actions from the patient are required for data transfer. This fact increases the diagnostic value of these instrumental models [13]. But even such systems of cardiac monitoring, in which the transmission, collection, safety of data depend on the patient's compliance, nevertheless have advantages over the absence of such a diagnostic capability and standard HM, as shown in a number of studies [13]. Currently released ICMs have up to 55 min of working memory before events begin to be overwritten or lost [14]. It is obvious that ICM with automatic remote transmission of key results have a significant advantage over HM ECG technology, while the patient lives in a region that allows remote data download [10]. Most of the ICMs existing in clinical practice transfer data to their processing center, but the system for tracking the accumulated data is organized differently for different manufacturing companies. Data processing is carried out, as a rule, once, and the information received is analyzed for a certain, sometimes quite long, a period of time, which allows a time pause between the recorded and transmitted arrhythmic episode and the adoption of a medical decision in relation to the patient. Remote control of actual patient data with timely data transmission to the doctor is possible and has already been partially implemented, and in this sense, the leading monitors on the market are ICM St. Jude Medical, which uses the system of wireless data collection, cloud storage and automated data analysis - Merlin.net® [13]. This approach, as shown by the study

of S.-Y. Ooi et al., Allows the transmission of up to 93% of the ECG episodes of each patient daily [15]. Clinical studies have already confirmed that the transition to such a model of "remote" observation from the model

"Per visit" assessment of patient data when visiting a clinic is justified both from the point of view of the benefit for the patient and from the point of view of health care economics [13, 15–18]. However, the limitation of devices existing on the market is the delay in data transmission up to a day when the episodes are recognized as non-threatening, and from 3–10 to 5 minutes - when the life-threatening episodes are detected. A prospect for the further development of the technical capabilities of the ICM is the mode of transferring data on life-threatening episodes in real time, with the possibility of an ambulance leaving at the location of the patient when he develops life-threatening arrhythmias.

Method of implantation of cardiac monitors

The procedure for implantation of most ICMs existing in practice is quite simple and can be performed on an outpatient basis, in about 9-15 minutes with local anesthesia [2, 14, 19–21]. The introduction of the Reveal® LINQ™ ICM is permissible in the patient's bed, which eliminates the cost of carrying out the procedure in the operating room [10, 19].

The conditions of asepsis must be observed, and local anesthesia is preliminarily performed [2]. Usually, the implant is placed in the subcutaneous tissue above the heart region. The guidelines for installation in the normal position of the heart (left) are: the upper border - the first rib on the left, the lower one - the fourth rib on the left, the right extreme border - the parasternal line, the left border - the left midclavicular line [2]. Searching for the right one the position of the implant is aimed at achieving the greatest amplitude of the R wave or the QRS complex of the cardiogram, which from peak to peak should be at least 0.3–10 mV, while the P and T waves should differ as much as possible in amplitude from R wave [2].

Early ICM required a surgical pocket between the cutaneous and muscle layers of the same size and shape as the device, about 2 cm [10, 14]. The operation itself to install the implant was performed through a two-centimeter skin incision, and the sensor was sutured to the underlying tissues [2]. An excessively large pocket disrupted tissue-PCM contact and decreased signal detection [10]. More modern devices are introduced using the "injection" technique. The advantages of "injectable" ICM are that this method of administration not only reduces the volume of trauma, but also provides better contact of the ICM with tissues. The Reveal® LINQ ч device (Medtronic, USA) is preloaded into an insertion instrument that is used to deliver it subcutaneously through a small puncture (less than 1 cm), which can then be closed with surgical glue, surgical tape, sutures or staples [19]. The BioMonitor 2® device (Biotronik, Germany) is introduced in a similar way [10]. But even with newer PCMs, the operator must take care not to rotate the insert tool, thereby inadvertently creating a pocket larger than necessary and impairing tissue contact [10].

The miniaturization of the device and the simplification of the implantation procedure contribute to an increase in the use of ICM [10, 19–23]. After the device is inserted and sewn into the "pocket", the parameters of the arrhythmia trigger and recording are programmed on the programmer by the doctor, and the data download from the ICM usually begins after a period of "settling" of the implant for several weeks, when the "pocket" "Around the monitor heals [14].

Overall Clinical Value of Cardiac Monitoring with an Implantable Cardiac Monitor

The clinical benefit of such a diagnostic intervention as ICM placement can be determined not only by whether an anomaly is detected, but also by whether ICM placement has a positive effect on patient treatment and prognosis, quality and duration of life [10, 22– 25]. One example is the documentation of paroxysmal AF in a patient with cryptogenic stroke, which led to the initiation of oral anticoagulant therapy [10, 24, 25]. In addition, the results of ICM work can be "expected" (for example, search for the cause of fainting based on the correlation of symptoms with arrhythmia) or "unexpected" (for example, detection of a previously unknown paroxysmal form of AF in a patient under observation for any other reason that triggers the onset of prophylactic anticoagulation) [10, 22, 26]. In any case, it can be argued that patients only benefit from the intervention - setting the ICM [10, 22, 23–27].

Despite some drawbacks, subcutaneous monitors are quite effective for detecting negative nonperfusion phenomena (asystole, brady- or tachycardia) affecting the ECG. However, such devices have begun to appear that make it possible to determine ST segment deviations, which is undoubtedly important for patients with high risks of recurrent acute coronary events [27]. As described above, the subcutaneous ECG signal recorded by the electrodes facing the skin surface is similar to those recorded from the body surface above the electrodes, both in morphology and in amplitude [10]. ICM, in comparison with devices for HM, do not cause discomfort to the patient in the process of diagnosis, meet the requirements for sensitivity and specificity in the diagnosis of arrhythmias, but the existing

devices do not have 100% sensitivity and specificity [14]. On the other hand, current generation built-in PCMs provide 3-year monitoring and rarely give skin irritations [1, 19, 20]. To minimize the negative cosmetic consequences when installing the device along the left axillary line, a group of scientists (G. Miracapillo et al.) Successfully tested the placement of ICM in the left axillary region [28].

Automatic remote loading of data - a valuable feature in many cases - is present in some wearable devices, but they have been compared with ICM for sensitivity and specificity of arrhythmia detections only with traditional approaches, including HM ECG rather than ICM [29, 30].

Disadvantages and limitations of using an implantable cardiac monitor

Certain technical features can reduce the efficiency of ICM data collection. Important among them are the problems of oversensing and undersensing [10]. In order to minimize the overall volume of the device, and hence the surgical problems with implantation and scar size, modern monitors have only two electrodes and an elongated shape that provides maximum separation of the electrodes [14]. Unfortunately, this makes the ECG signal very sensitive to the position of the device in the chest, changes in the patient's posture and changes in the direction of cardiac activation that can occur during an arrhythmic episode [14]. Therefore, subcutaneous ICMs are characterized by “false alarms” caused by both signal loss and external interference [14].

Inadequate detection of arrhythmias due to physiological and nonphysiological circumstances increases the time it takes to view episodes by the doctor and can reduce the effectiveness of diagnosis due to the limited storage time of episodes in the device, since in this case less important events or “noise” can be recorded in place of more important data [10]. Primary nonphysiological reasons for inadequate detection of bradycardia and pauses include lack of sensitivity due to loss of electrode contact with surrounding tissues or sudden drop in R-wave amplitude (eg, pericardial effusion) or oversensitivity due to myopotential noise or electromagnetic interference [10]. Physiological reasons for inadequate detection of bradycardia and pauses may be associated with insufficient sensitivity of the ICM to such arrhythmias [10]. In the latter case, the problem is most likely associated with a change in the R-wave vector [10]. Currently available subcutaneous monitors record data from one pair of electrodes and cannot provide a reliable signal during normal postural changes or changes in the direction of cardiac activation, such as the development of polymorphic ventricular tachycardia or ventricular fibrillation [14]. The narrow bandwidth of the recording prevents detailed analysis of the waveform morphology to assess ischemia; there is no scheme for detecting or eliminating rhythm peaks or defibrillation artifact, and a single ECG channel limits diagnostic capabilities [14]. In syncope, when the patient is unconscious after a fall, activation of the data recording by the user (patient) is not possible [14]. Therefore, unfortunately, modern ICM cannot be considered absolutely reliable devices for detecting episodes of cardiac arrest [14].

Finally, ICM, in contrast to externally wearable loop recorders, require an invasive procedure, which inevitably increases the risk of infection, hematoma, and pain associated with the procedure [10, 19–21]. For example, in the controlled trial Cryptogenic Stroke and Underground AF (CRYSTAL AF), which evaluated long-term ICM monitoring for AF after cryptogenic stroke using Reveal® XT™ ICM (Medtronic, Minneapolis, Minnesota, USA), 5 of 208 (2.4%) ICMs were removed due to infection at the injection site or pocket erosion [10]. Unfortunately, local inflammatory reactions caused by the implantation procedure, even when miniature devices are installed, are observed in 0.8-1.6% of patients, and serious adverse events - in 0.7-1.7% of patients from 100 [19–21]. In this regard, an interesting solution proposed by Medtronic and tested in a clinical trial by K.G. Tarakji et al., - insertion of the ICM into a special absorbable antibacterial “pocket” [23].

The small size of the ICM facilitates implantation, but complicates the removal of the device: years after implantation, very small devices are difficult to detect and release from the surrounding tissues [10, 20, 21]. As a consequence, the explantation procedure may take longer than the implantation procedure, and the wound after removal of the ICM may be larger than that required for implantation. Finally, a cosmetic defect associated with the implantation and explantation procedure can become a problem for the patient [10]. It is especially important to take this into account when a patient has a tendency to form keloid scars.

Economic problems that remain in some regions can adversely affect the development of ICM technology and at the same at the same time, some technological factors can also negatively affect the enthusiasm for the use of ICM among healthcare providers [10]. For example, the availability of the data transmission network in the patient's place of residence, the fear of exposure to the patient's body of magnetic fields, or restrictions on patients undergoing examinations on magnetic tomographs of a certain power after the installation of a ICM that does not have the appropriate technical characteristics. Although most of the latest models of ICM are allowed to be used for MRI on devices with a power of up to 3 Tesla (T) and even for individual

devices - up to 10 T, the old-style ICM is not recommended for patients exposed to strong magnetic fields (more than 3 –10 T) or high-frequency electrical systems [3, 5, 20].

A limitation for some ICM systems is the requirement for the patient's cognitive functions, which must be sufficiently preserved mentally, educated and motivated to use the remote monitoring function and the bedside monitor, as well as the ICM remote control - "patient assistant" [10].

Implantable cardiac monitors have another serious drawback - their functions are limited to diagnostic purposes. Thus, the development of remote monitoring applications for pacemakers and especially implantable cardioverter defibrillators may reduce the role of monitoring devices exclusively in the future.

Conclusions

Ambulatory cardiac monitoring is an expanding field of cardiology, which in the coming years is likely to go beyond conventional ECG and blood pressure recordings, including going beyond the capabilities of HM ECG and will include the assessment of other potentially valuable clinical parameters (for example, assessment of hemodynamics, recognition of ischemia, metabolic changes, assessment of the risk of arrhythmia). ICM is a time-tested technology that has shown positive results of application and has further development prospects, improving the technical characteristics of devices and, at the same time, expanding the indications for their use, worthy of widespread introduction into clinical practice.

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