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Diagnostic capability of long-term electrocardiographic telemonitoring for detection of heart rhythm disorders

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Abstract: prevalence of cardiac rhythm and conduction disorders is increasing and associated with the growing amount of people of older age groups. The extended use of traditional electrocardiography (ECG) recorders is currently limited due to duration of the investigation, possible skin irritation and withdrawal of consent by the patients. The aim: evaluation of the frequency of arrhythmia incidents in adult patients of different ages by assessing the patch monitoring results, and the impact of the monitoring duration on the possibility of diagnosis. Materials and methods: study included 1123 patients aged from 18 to 99 (599 women and 524 men), data about whom was collected in 2021-2022. ECG was recorded by the «Mawi Heart patch» – a single-use dual-channel device for continuous ECG recording for up to 7 days. Results: the average ECG monitoring time was $81,03 \pm 18,5$ hours or $3,37 \pm 0,7$ days. The majority of the participants (74,35%) received the continuous 3-day ECG monitoring. Most rhythm disorders were recorded in the first 24 hours, but over the next 2 days, atrial fibrillation (AF) was detected in 7,66%, more often in men (48 participants, $p = 0,048$) and with some differences in age groups. Starting above 50 years of age, the frequency of AF diagnosing on the first monitoring days is decreased and it is significantly statistically lower (61,11%, $p < 0,05$). Three-day ECG monitoring is associated with a higher chance of detecting AF (OR = 2,03; 1,53-3,02, $p = 0,031$) regardless of gender, while the 5-day monitoring wasn't as effective. The prolonging of the monitoring time increased the number of diagnosed supraventricular tachycardia (SVT) cases by 5,53% in men and 8,35% in women. The 3 days of monitoring are associated with a higher chance of SVT detection (OR = 4,18; 3,32-4,95, $p = 0,009$). There is a direct correlation between SVT detection and the older age groups ($r = 0,53$, $p < 0,05$). SVT detection is higher in patients of 71-80 years old (OR = 2,71; 2,35-3,75, $p = 0,0041$), and of 81-99 years (OR = 2,92; 2,56-3,49, $p = 0,0039$). Conclusion: The frequency of arrhythmia detection, in patients referred to long-term patch monitoring, is high both for AF and SVT. The sex and age patterns for the prevalence of the described arrhythmias were statistically confirmed. The use of long-term ECG patch monitoring increases the chance of arrhythmia detection, primarily for older patients.

Keywords: [Atrial Fibrillation](#); [Supraventricular Tachycardia](#); [Risk](#); [Cardiac arrhythmias](#); [Tachycardia](#), ECG patch monitoring

Introduction

The disorders of the cardiac rhythm and conduction, which significantly affect life expectancy and severely worsen the patients' quality of life, are common reasons for referring to medical help. The prevalence of these disease groups is increasing, which is associated with the aging of the population. Adverse prognostic disorders of cardiac rhythm and conduction include atrial fibrillation (AF), sustained ventricular tachycardia (VT), supraventricular tachycardia (SVT), sinus bradycardia/arrest, and atrioventricular (AV) blocks (Wilde A. et al., 2020; Yenikomshian M. et al., 2019; Matthew J. et al., 2018). The cardiac arrhythmias are not the only factor increasing the cardiovascular risk – it's also affected by the duration and frequency of non-sinus rhythm episodes. Arrhythmias-associated clinical cases increase the impact on healthcare systems and make up a big part of the economic costs for the treatment and support of patients with the current pathology (Go A. et al., 2018; Qian P. et al., 2020; Mullis A. et al., 2019).

The 12-lead electrocardiography (ECG) is a primary and the most available test for diagnosing cardiac rhythm and conduction disorders, but a part of them remains undetected due to the limited recording time. The continuous ECG monitoring significantly increases the efficiency of the cardiac rhythm and conduction diagnostics (Page R. et al., 2016; Patel U. et al., 2021). Nevertheless, the extended use of traditional ECG recorders is currently limited by the lack of patients' consent, duration of the recording, and possible skin irritation by the electrodes. The skin-implantable loop recorders, which provide continuous ECG recording for up to 3 years, are currently used in clinical practice. Compared to external ECG recorders, the level of arrhythmias detection is increased by the monitoring durability (Gladstone D. et al., 2021). However, considering the high cost of the procedure and the necessity of surgery, it's recommended to use the external recorders, and only consider using the implantable recorders in case of negative result (Heckbert S. et al., 2018).

One of the innovations in ECG diagnostics is patch monitors – single-use wireless devices for continuous recording of the heart's electrical activity. This tool improves patients' comfort and increases adherence compared to the traditional

24-hour Holter monitoring. The devices allow to identify a wide range of heart rhythm and conduction disorders (Reimers A. et al., 2018). More than 20 studies based on the results of cardiac arrhythmias diagnostics used patch monitors for patient observation. The current technology can majorly affect our perception of prevalence of arrhythmias and personalized instruction to begin and change the pharmacological treatment, prevent the development of cardiovascular events and reduce the economic effect on healthcare systems (Yenikomshian M. et al., 2019; Eisenberg E., 2014).

According to the research by Evann E. Eisenberg and Steven K. Carlson, in which the patch monitoring was used for patients of a middle age group with palpitations, suspected AF, syncope and pre-syncope, the most prevalent arrhythmia was premature ventricular contraction (93%). Supraventricular tachycardia was recorded in 44% of the patients, and lower rate was observed for atrial fibrillation (AF) /flutter (20%) and non-sustained VT (15%). Over a third of arrhythmias were recorded after 48 hours of monitoring. The average time for the detection of the first arrhythmia episode was 1,2-2,2 days, and the average time for detecting the first arrhythmia accompanied by symptoms was 3,0-2,9 days. The most common rhythm, related to patient-reported symptoms, was normal sinus rhythm (50%). The most precise symptomatic arrhythmia was AF; nevertheless, the majority of AF episodes (62%) were asymptomatic (Antonenko K., 2021).

The AF prevalence among the population grows annually, and it's one of the most significant individual risk factors for ischemic stroke, associated with the decline of positive treatment outcomes, higher mortality or disability risk, and higher probability of hemorrhagic transformation. Patients with AF have five times higher stroke risk compared to the same age group representatives without AF. The stroke risk is furthermore increased from 1,5% in patients aged 50-59 to 23,5% in patients aged 80-89 (Zharinov O., Kuts V., 2022; Steinhubl S. et al., 2018). Due to the high prevalence of the asymptomatic episodes, the outpatient monitoring of cardiac rhythm is an integral component of paroxysmal AF diagnostics. In plenty of cases, the clinical decisions, which include an adjustment of the antiarrhythmic drugs, the necessity

to provide cardioversion, and the possible need to use anticoagulants, are based on the ability to detect and record AF episodes (Kaura A. et al, 2018; Brembilla-Perrot B. et al, 2018).

According to the resolution of the American Heart Association, the prevalence of SVT in the general population is around three cases per 1000. It is noted that women have almost two times higher risk of developing this pathology than men, and elderly patients have 5 times higher risk of developing SVT than young. The statistical data shows that patients with paroxysmal SVT referred to specialized medical facilities to get cardiac ablation are mainly elderly individuals with equal gender distribution and low rate of cardiovascular diseases (Page R. et al, 2016; Waalen J. et al, 2020).

Béatrice Brembilla-Perrot et al. (2018) conducted a big prospective study of the long-term outcomes of 1960 patients with SVT. Among all the participants, 15,4% were older than 70 years old. During the monitoring, the higher risk of AF, stroke, implantation of artificial cardiac pacemaker, and mortality was observed in elderly patients, while the SVT recurrence risk was statistically similar in both groups. By using multifactorial analysis, the age ≥ 70 was independently associated with a higher risk of complications before cardiac ablation, development of conduction disorders, history of AF, high level of procedural complications and failed ablations (Brembilla-Perrot B. et al, 2018).

Aim

To evaluate the frequency of arrhythmia in adult patients of different age groups by the assessment of patch monitoring results, and the impact of the monitoring duration on the probability of diagnosis.

Materials and methods

The study was conducted by using the statistical analysis of anonymized data of long-term patch monitoring, provided in 2021-2022. The study included 1123 patients aged from 18 to 99: 599 women and 524 men. The average participants' age was $50,2 \pm 16,65$ years. The durable ECG monitoring was done due to the referral of general practitioners and cardiologists from 30 healthcare facilities according to various medical indications for the current research. The exclusion criteria were age under 18 y.o., previous diagnosis of persistent

atrial fibrillation, and implanted artificial cardiac pacemaker. ECG was recorded by the «Mawi Heart patch» – a single-use dual-channel device for continuous ECG recording for up to 7 days. After the end of the research, the primary analysis of the records was provided by using the Cardio.ai artificial intelligence algorithms, and secondary decoding and validation by certified functional diagnostics physicians. The patch electrode was attached to patients in healthcare facilities by medical staff. In a few cases, patients attached the patch themselves and at the end of the study gave them back to the clinic for further investigation. The statistical analysis was conducted by using the “Stata 12” assessment. The descriptive statistics for detecting the frequency of separate characteristics were presented by the absolute value of observations (patients) and distribution percentage. The statistical validity of the difference between the compared groups was assessed by the Student's t-test, the threshold validity of which was $<0,05$. The correlation between quantitative characteristics was assessed by Spearman's rank correlation coefficient, the distribution of which is different from normal (r). The Chedok scale was used to analyze the correlation results: the relationship was determined by the correlation coefficient value r (0,00-0,29 – very weak, 0,30–0,49 – weak, 0,50–0,69 – moderate, 0,70–0,89 – strong, 0,90-1,0 – very strong). The presence of a causal relationship was assessed by the odds ratio (OR), and with its help, the relationship between the result and causative factor was determined (the risk factor). The 95% confidence limits were calculated to assess the OR relevance. The frequency response and average values were compared by testing the hypothesis for equality of average values of indicators in study groups at a given validity of 0,95, and according to this, the significance of the corresponding indicator was defined.

Results and Discussion

The study enrolled 1123 patients ages from 18 to 99, with the absence of statistically significant differences between gender subgroups. Due to the age distribution, the biggest part was made up of young people and middle-aged patients, which equaled to 76,5% (860 patients); the elderly made up 15,4% (173 patients), and long-livers – 8% (90 patients). The detailed distribution is presented in Table 1.

Table 1. Age distribution of study participants

Age range	Absolute number of patients	Relative number of patients (percent)
18-30 years	141	12,56%
31-40 years	234	20,84%
41-50 years	215	19,15%
51-60 years	187	16,65%
61-70 years	190	16,92%
71-80 years	120	10,69%
81-99 years	36	3,21%

The average ECG monitoring time was $81,03 \pm 18,5$ hours or $3,37 \pm 0,7$ days. The majority of the participants (74,35%) received the continuous 3-day ECG control, 20,75% – the 4-day control, and 2,58% – 5-day control. Fig.1 represents the distribution of ECG monitoring in the study group.

Fig. 1 represents the patients' distribution according to the time of AF detection. In the majority of both men and women, the rhythm disorders were recorded in the first 24 hours of monitoring (489 and 541 respectively, $p > 0,05$), without statistical difference between them. During the following 2 days, AF was detected in 86 patients (7,66%), higher percent was observed in men (48 participants, $p > 0,05$). Only 3 individuals were diagnosed with AF on the 3rd-5th day of monitoring (1 woman and 2 men). It was found that three-day ECG monitoring is associated with a higher chance of

detecting AF (OR = 2,03; 1,53-3,02, $p = 0,031$) regardless of gender, while the 5-day monitoring didn't provide such significant value (OR = 1,63; 1,72–2,96, $p > 0,05$).

More extensive research of the age and gender peculiarities of AF diagnostics in the study group can be found in another article [20]. According to our data, the ages older than 50 are associated with the growing frequency of AF detection, and the indicator reached 12% for the ages of 61-70, though without statistically significant difference between the age subgroups ($p > 0,05$). In the following decade-long gradation, the indicator grew twice (22,5%), which is considered statistically significant ($p = 0,026$) and reached its maximum value in the individuals aged 81-99 (38,8% examined). Overall, the disorder was diagnosed in elderly patients more often than in young and middle-aged (18,5% vs 3,6%, $p < 0,001$). The disorder was the most prevalent in patients older than 75 which shows more statistically significant difference between patients younger than 64 and patients of 65-74 years old (28,8% vs 3,6%; $p < 0,001$; 28,8% vs 18,5% respectively) [Bogomaz V. et al, 2023].

During the result analysis, we assessed the relationship between the age groups and the time of AF diagnosis (tab. 2). The absolute majority (1034 individuals, 92%), was diagnosed with AF on the first day of ECG monitoring without statistical difference in the age groups ($p > 0,05$). During the following two days, the arrhythmia was also diagnosed in 7,6% of the patients, though, with

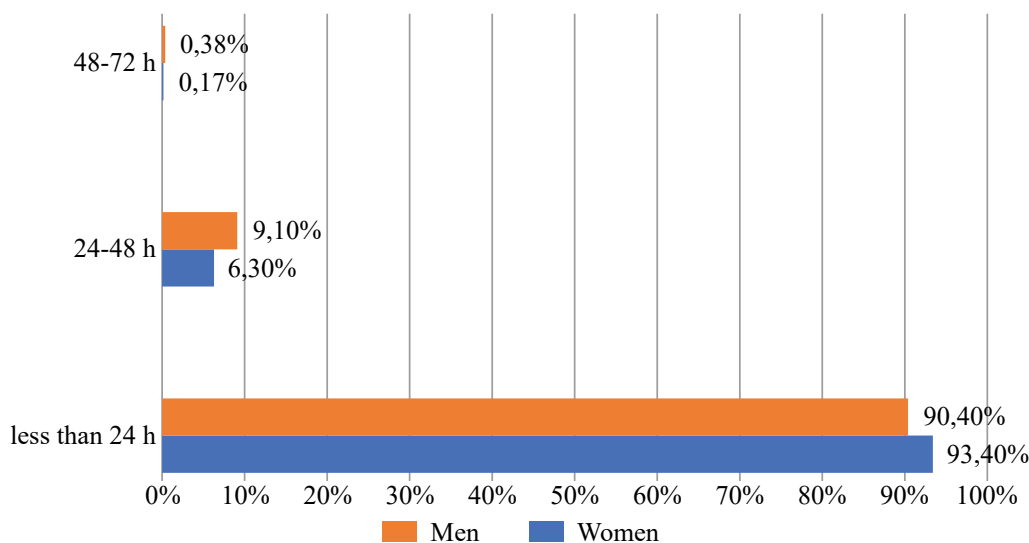


Fig. 1. Distribution of participants according to the time of AF detection

Table 2. Distribution of participants according to age groups and the time of AF development

Age groups	First day of monitoring (absolute number of participants, %)	1-2 day of monitoring (absolute number of participants, %)	3-5 day of monitoring (absolute number of participants, %)
18-64	829 (96,4%)	30 (3,5%)	1 (0,12%)
65-74	141 (81,5%)	32 (18,5%)	0 (0%)
75-99	64 (71,1%)	24 (26,6%)	2 (2,2%)
Total	1034 (92%)	86 (7,6%)	3 (0,27%)

several differences in age groups: the rhythm disorder was validly often diagnosed in patients of 65-74 years (18,5% vs 3,5%, $p < 0,05$) and in patients after 70 (26,6% vs 3,5%, $p < 0,05$). This indicator was observed significantly more often in long-livers than in elderly patients ($p < 0,05$). Over the 3-5 days of monitoring only 3 patients were diagnosed with AF, and 2 of them were older than 75. During the risk assessment, it was revealed that age is independently associated with AF development in patients of 65-74 (OR = 3,02; 2,72-3,95, $p < 0,001$) and after 75 years (OR = 2,78; 2,68-3,05, $p = 0,021$).

As shown in the trend line on Fig. 2, starting from 50 years of age, the frequency of AF diagnosing on the first monitoring days is decreasing and patients have this indicator statistically lower (61,11%, $p < 0,05$).

SVT of different durations was detected in 429 patients (38,2% of the general number of partic-

ipants) with the following gender distribution: 264 women and 165 men ($p < 0,05$). The prevalence of SVT diagnostics in the women subgroup corresponds to the literary evidence of gender peculiarities of detecting this arrhythmia type [4,9].

SVT was diagnosed in 350 patients monitored for 3 days (81,6% of all cases of diagnosis), and in 79 (18,4%) monitored for 5 days. The 3 days of monitoring are associated with a higher risk of SVT detection (OR = 4,18; 3,32-4,95, $p = 0,009$). Among women, the most cases were registered during the first 3 monitoring days. That was 81% (214 patients), and 19% (50 patients) – during the following 2 days. In men, the same indicator was 82% (136 patients) and 18% (29 patients) respectively. The prolonging of the monitoring time increased the number of diagnosed SVT cases by 5,53% in men and 8,35% in women, without a statistically significant difference between them (in 50 and 29 participants respectively, $p < 0,05$). At

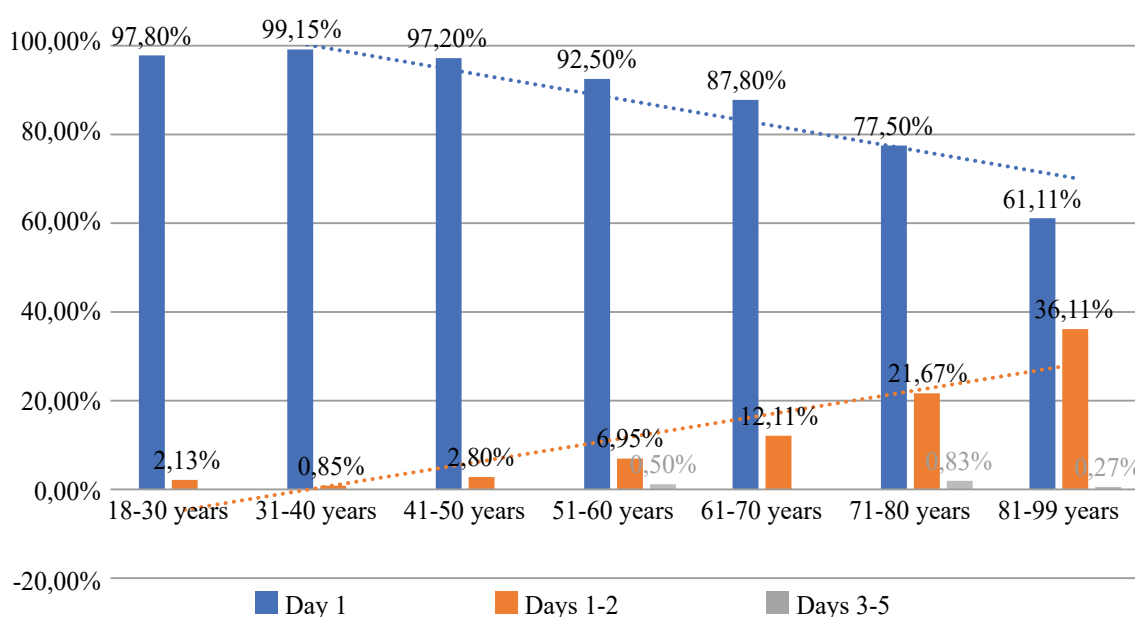


Fig. 2. Dynamics of AF diagnosis depending on the monitoring time and the age distribution

the same time, we detected the direct correlation between the monitoring duration of ≤ 3 days and SVT diagnosing ($r = 0,57, p < 0,05$).

The same tendency was observed during the analysis of frequency of SVT diagnostics depending on the monitoring duration in different age groups. This pathology during the first 3 days of monitoring was observed in all age groups in the range from 78% to 87,7% and the clear connection with the specific age range was not found ($p > 0,05$ between all groups). During the 4-5 days of monitoring the SVT was found in patients of 51-60 years old, though, without statistically significant difference among the participants of different ages ($p > 0,05$). It was determined that the 3-day ECG monitoring isn't associated with the higher chance of SVT diagnosis ($OR = 3,78; 3,21-4,95, p < 0,001$).

Table 3. Results of SVT detection depending on the monitoring duration and patient age

Age (years)	Amount and % of SVT detection depending on the monitoring duration	
	3 days	4-5 days
18-30	9 (81,8%)	2 (18,2%)
31-40	29 (80,6%)	7 (19,4%)
41-50	54 (79,4%)	14 (20,6%)
51-60	72 (78,3%)	20 (21,3%)
61-70	100 (81,3%)	23 (18,7%)
71-80	71 (87,7%)	10 (12,3%)
81-99	15 (83,3%)	3 (16,7%)

SVT was most frequently diagnosed in patients of 51-70 years, which is 50% of all diagnosed SVT cases (the detailed distribution is presented

in Fig.4). Remarkably, the significant growth of the current rhythm disorder starts at the age of 50 and grows 1,6 times during the following decade (though, without a significant difference), and statistically higher incident rates were registered in the groups of 71-80 and 81-99 years (22,5% and 38,9% respectively, $p < 0,05$ in both cases). Overall, we observed the tendency of more frequent SVT diagnosing with the age increase (the ratio of detected SVT cases to the general number of examined patients of the specific age group). At the same time, there is a direct correlation between SVT detection and the older age groups ($r = 0,53, p < 0,05$), and the fact that SVT risk is associated with patients of 71-80 years ($OR = 2,71; 2,35-3,75, p = 0,0041$), and of 81-99 years ($OR = 2,92; 2,56-3,49, p = 0,0039$).

The current multicenter clinical implementation of patch monitoring demonstrated the obvious benefit of the technology – the maximum conservation of the patients' common lifestyle.

The limitation of the current study is the assessment of the monitoring results in patients without the analysis of the clinical causes, which was the reason for conducting the research. Increasing the number of observed cases in patients of the eldest age groups with a deep study of the clinical signs of the pathology would be reasonable for future studies.

Conclusion

In the vast majority of participants of both sexes, AF was recorded in the first 24 hours of monitoring (77.3%), but, during the next 2 days, AF was detected in another 7.66% of participants. Therefore, three-day ECG monitoring is associated with a higher chance of detecting AF ($OR = 2.03;$

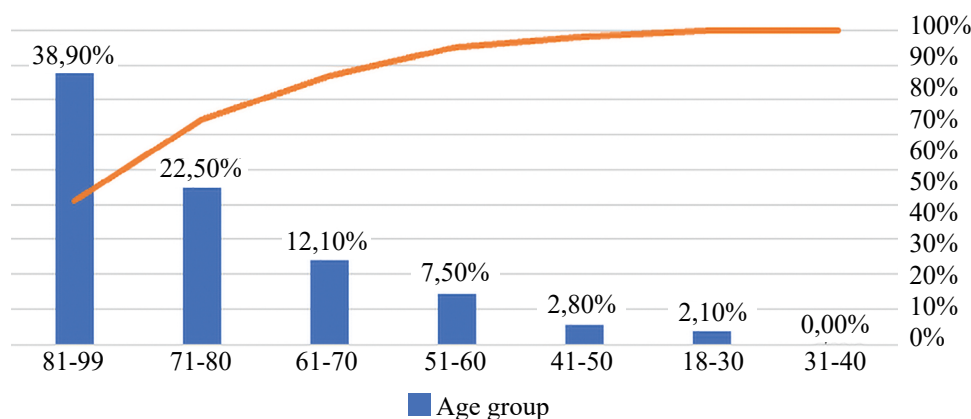


Fig. 3. Distribution of participants with SVT in different age groups

1.53–3.02, $p = 0.031$) regardless of sex, while five-day monitoring does not have such a significant value (OR = 1.63; 1.72–2.96, $p > 0.05$).

Evaluating data about SVT, we found that monitoring duration of three days is associated with a higher chance of detecting SVT (OR = 4.18; 3.32–4.95, $p = 0.009$), which is also confirmed by a direct high correlation between the duration of monitoring of up to 3 days and diagnosis of SVT ($r = 0.57$, $p < 0.05$).

It was found that age is independently associated with the risk of AF: in patients 65–74 years old (OR = 3.02; 2.72–3.95, $p < 0.001$) and after 75 years (OR = 2.78; 2.68–3.05, $p = 0.021$). Instead, 3-day ECG monitoring, regardless of age, is associated with a higher chance of SVT diagnosis (OR = 3.78; 3.21–4.95, $p < 0.001$).

In general, long-term patch monitoring is a highly effective method of detection both for AF and SVT. The use of long-term ECG patch monitoring increases the chance of arrhythmia detection, primarily for older patients, and allows to provide personalized pharmacotherapy and prevention strategies.

Perspectives of subsequent scientific research

In the future, we plan to investigate arrhythmias and conduction disturbances in patients of different age groups and sexes, and to analyze the presence of comorbid pathology and its influence

on the appearance or manifestations of arrhythmia in order to develop an algorithm for the early diagnosis of AF in elderly people without pronounced symptoms based on risk factors. In addition, we are interested in pharmacological therapy in asymptomatic patients: its feasibility, indications and possible risks.

Financing

There is no external financing.

Conflict of interest

The researchers declare no conflict of interest.

Consent to publication

The study was conducted in compliance with the principles of the Helsinki declaration of the World Medical Association (WMA) "Ethical principles of medical research involving human subjects". Informed consent was obtained from all subjects according to the Ukrainian law.

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A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of article

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Діагностичні можливості довготривалого електрокардіографічного телемоніторингу для виявлення порушень ритму

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Анотація: поширеність порушень серцевого ритму і провідності зростає з часом та пов'язана зі збільшенням кількості людей старших вікових груп. Аритмії часті причини звернення за медичною допомогою, а також суттєво впливають на тривалість життя та значно погіршують якість життя пацієнтів. Широке застосування традиційної електрокардіографії (ЕКГ) наразі обмежене через лімітовану тривалість дослідження, можливе подразнення шкіри та погіршення комплаєнсу пацієнта. Мета дослідження: оцінити частоту випадків аритмій у дорослих пацієнтів різних вікових груп за результатами патч-моніторингу та впливу тривалості моніторингу на можливість їх діагностування. Матеріали і методи: протягом 2021-2022 років було обстежено 1123 пацієнти віком від 18 до 99 років: 599 жінок і 524 чоловіків. Фіксація ЕКГ відбувалась за допомогою «Mawi Heart patch» – одноразового двоканального пристрою для безперервної реєстрації ЕКГ до 7 днів. Результати дослідження: середній час моніторингу ЕКГ становив $81,03 \pm 18,5$ години або $3,37 \pm 0,7$ доби. Більшість учасників (74,35%) отримували безперервний 3-денний ЕКГ-контроль. Більшість порушень ритму реєстрували у перші 24 години, але протягом наступних 2 діб фібриляція передсердь (ФП) була виявлена у 7,66%, частіше у чоловіків (48 учасників, $p = 0,048$) та мала наступні відмінності у вікових групах: частіше спостерігалась у пацієнтів 65-74 років (18,5% vs 3,5%, $p < 0,05$) та у пацієнтів після 70 років (26,6% vs 3,5%, $p < 0,05$). Починаючи з 50 років частота діагностики ФП у перші дні моніторингу знижується і показник статистично нижчий (61,11%, $p < 0,05$). Триденний ЕКГ-моніторинг асоціюється з вищим ризиком виявлення ФП ($OR = 2,03$; 1,53-3,02, $p = 0,031$) незалежно від статі, тоді як 5-денний моніторинг не мав достовірної різниці. Подовження часу моніторингу призвело до збільшення кількості виявлених випадків суправентрикулярної тахікардії (СВТ) на 5,53% у чоловіків та на 8,35% у жінок. Трьох денний моніторинг асоціюється з вищим ризиком виявлення СВТ ($OR = 4,18$; 3,32-4,95, $p = 0,009$). Наявний прямий кореляційний зв'язок між виявленням СВТ та старшими віковими групами ($r = 0,53$, $p < 0,05$), а саме: виявлення СВТ асоціюється з пацієнтами 71-80 років ($OR = 2,71$; 2,35-3,75, $p = 0,0041$), та 81-99 років ($OR = 2,92$; 2,56-3,49, $p = 0,0039$). Висновок: при використанні тривалого патч-моніторингу збільшується частота виявлення порушень ритму як і ФП, так і СВТ. Підтверджено статево-вікові закономірності поширеності описаних аритмій. Використання тривалого патч-моніторингу ЕКГ підвищує ймовірність виявлення аритмії, насамперед у літніх пацієнтів.

Ключові слова: фібриляція передсердь, суправентрикулярна тахікардія, серцеві аритмії, ЕКГ патч-моніторинг



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