Application of the Innovative System for e-Health Care and Prevention by the Evaluation and Analysis of ECG Signals

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Abstract **– The study presents a developed and implemented innovative system for electronic health care and prevention, using a complex assessment of momentary disturbances in the electrocardiographic signals, and through reasonable modeling and quantitative digital analyzes to diagnose people after physical, emotional or rehabilitation stress. The priorities of e-health and its main structures are discussed, as well as an analysis of the systemic characteristics of e-health and services. Adapted methods for the evaluation of electrocardiographic signals are proposed, which are statistically studied and applicable in practice for prevention. The developed innovative system for electronic health care and prevention through the analysis of electrocardiographic signals provides quantitative and qualitative assessments of the current state of the heart system in prevention for the purpose of health safety during exercise and training. The electronic health system has been implemented at the University of Ruse in the training of midwives, nurses and electronics engineers.**

Keywords **– e-Health, ECG evaluation and analysis, electronic system, algorithms.**

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1. Introduction

The development and implementation of effective methods in medicine is significant for improving the accuracy of obtained results and medical conclusions. This results in the initiation of activities at national, European and global scale, and a focus on the development of complex scientific methods, models, algorithms and systems [1], [2], [3]. The created innovative system for e-Health and prevention through the application of electronic modeling responds to this dynamic of development, is related to people's health to achieve a better lifestyle and is aimed at prevention of momentary loads.

Two types of the many and diverse diseases with a need for prevention are the basis of development – cardiovascular diseases and problematic skin wounds. The proposed concept of e-Health and prevention, as well as developed innovative system, achieves better health indicators, increases the level of prevention and treatment by introducing personalized medicine and gives the significant positive effect for disease management through the digital tools and provided feedback and data about the condition of the individual.

The e-Health and prevention system aimed at cardiovascular diseases provides a comprehensive assessment of momentary disturbances in electrocardiographic signals. The repeatability of changes in the ECG curve of clinically healthy people in daily life and during exercise is an indicator of temporary risk and the need for consultation with a medical specialist.

The developed system for e-Health and prevention provides an educational character for medical professionals, allowing to study the action and effect of the healing process, as well as enabling the modeling of different states of pathological cases in order to study the general picture of the disease.

The paper presents the application of the innovative system for e-Health and prevention for complex evaluation of momentary disturbances in electrocardiographic signals through quantitative digital and visual evaluations in the diagnosis of people after physical, emotional, or rehabilitation stress through substantiated modeling and analysis methodologies.

The electronic health system has been implemented at the University of Ruse in the training of midwives, nurses, and electronics engineers. For eight years, evidence materials were collected, and the results obtained from the application of proposed e-Health modules were analysed.

2. Methodology

This section presents the vision for the development of electronic health care in Bulgaria and the necessary solutions to support the prevention of diseases and promote a healthy lifestyle, as well as a concept for building the system for electronic health care and prevention by assessing the condition of people in a different review of electrocardiogram parameters.

2.1. e-Health

The vision for the development of health care in Bulgaria until 2030 is defined in the National Health Strategy 2021-2030 as "Health for all – through effective health promotion and disease prevention, conditions for a healthy lifestyle, accessible, and quality health services". In terms of prevention and control, Bulgaria follows the leading documents "Global strategy for the prevention and control of non-communicable diseases" and the World Health Organization (WHO) and European strategy for the prevention and control of non-communicable diseases [4].

Low physical activity is one of the main behavioral risk factors for chronic non-infectious diseases. 25% of the elderly and about 80% of the young have insufficient physical activity. To improve the quality of life and limit the burden of chronic diseases and disabilities, an approach that focuses on health promotion, disease prevention, early diagnosis and better health management needs to be adopted.

The World Health Organization defines primary health care as care for all people of all ages. It should be a whole-of-society approach to health and well-being, focused on the needs and preferences of individuals, families, and communities. This approach focuses on the determinants of health and on the interrelated aspects of physical, mental, and social health and well-being.

The analysis of the state of the health care system in Bulgaria shows that primary outpatient medical care, including specialized and dental care, still cannot fulfill its key role in addressing the main health challenges and the risks of ill health [4].

Innovative solutions in the field of e-health can support the prevention of diseases and the promotion of a healthy lifestyle, lead to improvements in the quality of life of citizens and enable more efficient ways of organizing and providing health services and care. The main priority of e-healthcare is carrying out a digital transformation in the healthcare sector, based on the development of the three technological pillars: cloud technologies, development of wireless communications and networks, mass deployment of high-speed optical networks for data transmission.

The increasing incidence of cardiovascular diseases (CVD) in the population clearly predetermines the need for health prevention strategies. Early identification of cardiovascular risk factors that can be modified and controlled along with timely preventive measures to influence the risk profile plays a crucial role in making this decision. The measures are aimed both at a change in the way of life and at the work, and social environment [5[, [6], [7], [8].

The goal to be achieved by the primary prevention of cardiovascular risk (CSR) is identified by influencing the risk factors before the manifestation of CVD [5], [7]. The process of risk monitoring and control is equally important in the secondary prevention of already established diseases, as part of the rehabilitation program and consistent inclusion of the affected workers in the labor process and social life.

The quality of care for people with cardiovascular diseases is greatly improved through e-Health. The action plan and mission of the European Society of Cardiology is to have a significant role in all aspects of e-Health to support cardiovascular health in Europe [9], [10]. The long-term benefits of these treatments are often disappointing due to the low health culture of the population, despite the availability of effective treatment methods [10], [11], [12]. The European Society of Cardiology recommends continuous prevention programs in cardiac rehabilitation, ischemic heart disease, prevention of disease recurrence to improve people's condition [13], [14], [15]. Summary data on participation in and adherence to cardiac rehabilitation programs have been reported, showing potential to improve general health status [15], [16].

Innovations in ICT technologies and the digital delivery of healthcare provide the opportunity to improve post-diagnosis care and follow-up in the outpatient setting [17], [18].

A promising way to address the challenges of conventional cardiac care is the care delivery strategy identified by the European Association of Preventive Cardiology (EAPC) in collaboration with the Acute Cardiovascular Association (ACCA) and the Association of Cardiovascular Nurses and Allied Professions (ACNAP) such as [9], [18]. The use of e-Health would also be useful in other cardiovascular diseases.

Electronic health care is primary prevention, as technological systems and methodological solutions – mobile applications, text messages and sensors for self-monitoring, remote behavioral consultations, etc., improve the way of life by changing behavior [19], [20].

e-Health uses information and communication technologies for diagnosing and treating patients and promoting a healthy lifestyle (primary prevention), conducting research, training health professionals, tracking diseases and monitoring public health to improve or create conditions for provision of health services and health care [21], [22], [23].

The latest innovations in the field of information and communication technologies provide guidance for overcoming current barriers and are the initial step to achieve successful electronic and digital healthcare in everyday life and clinical practice [24].

Figure 1 presents challenges for e-Health care in cardiovascular medicine [9].

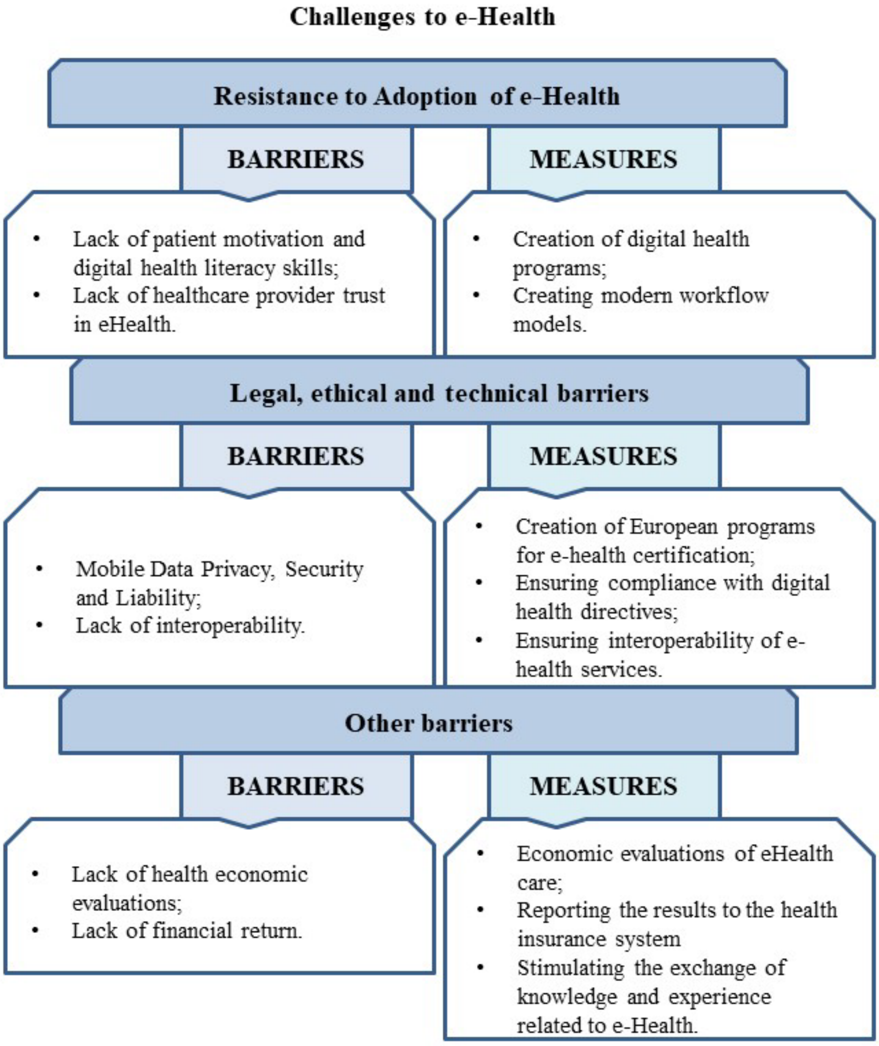


Figure 1. Challenges to e-Health care

The challenges of e-Health in cardiology should be addressed with the help of science and research by combining the results of clinical and socio-economic analyses, be stimulated and supported to increase the database in the field of e-Health.

2.2. Approach to building the e-Health and Prevention System

The developed eHealth and prevention system is based on information, medical technologies, and software. Figure 2, illustrates a prerequisite for improved dialogue and innovative exchange and analysis of health data and information.

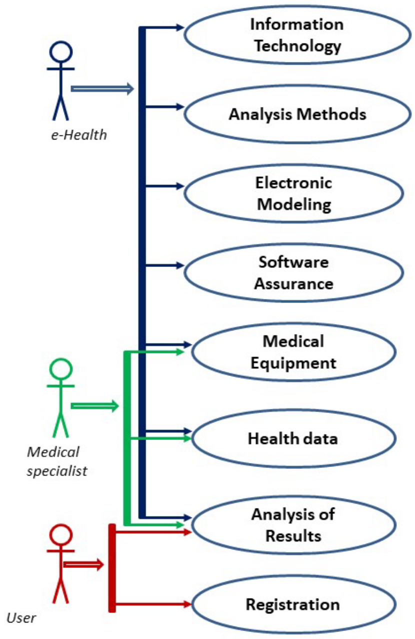
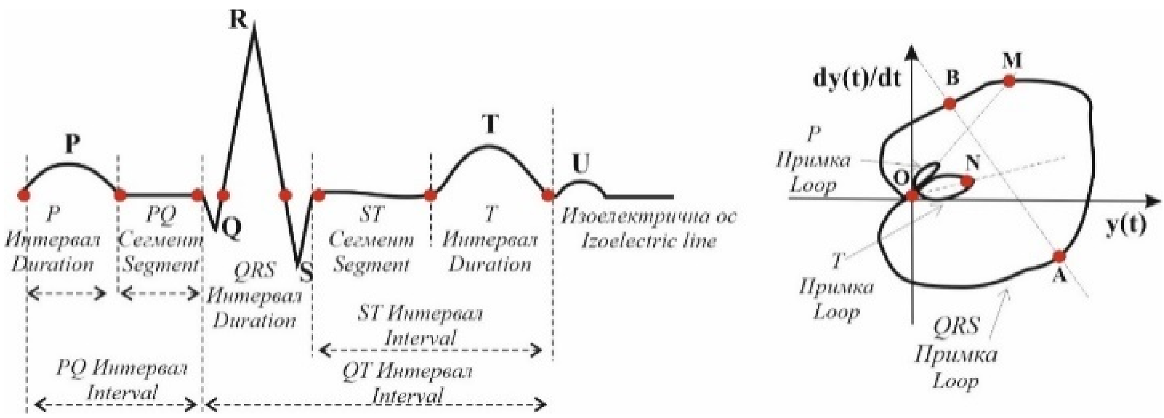


Figure 2. e-Health system and its main substructures

In the developed e-Health and prevention system, the individual parameters of an ECG signal are labeled as shown in Figure 3 and are aligned with the medical cardiographic reports [25].



а) linear *б) vector*

Figure 3. General view of linear and vector electrocardiogram

The e-Health and prevention system evaluates the interests of all users – both sick and healthy, which also determines the different view of the parameters of their electrocardiograms and assessment in prevention.

In the prevention methods of a healthy person, quantitative information about the time, amplitude, dynamic intervals, segments, waves of the ECG, the frequency and character of the heart rhythm, allow assessment and the necessary prevention, leading to the analysis of the electrocardiogram. For this type of analysis, only one lead provided by portable electrocardiographs operating by electrodermal activity is sufficient.

The research method is based on accessible and reliable means of diagnosis in order to evaluate deviations in the work of the heart under the influence of physical and emotional stress or kinesirehabilitation therapy [26], [27].

Figure 4 shows the block diagram of the complex approach in building a concept for an e-Health and prevention system through the evaluation and analysis of an ECG signal. The applicability of the electronic health and prevention in people's daily life for a quick assessment of their current condition was evaluated. Each separate part of the structure works independently, but together they provide a complex assessment.

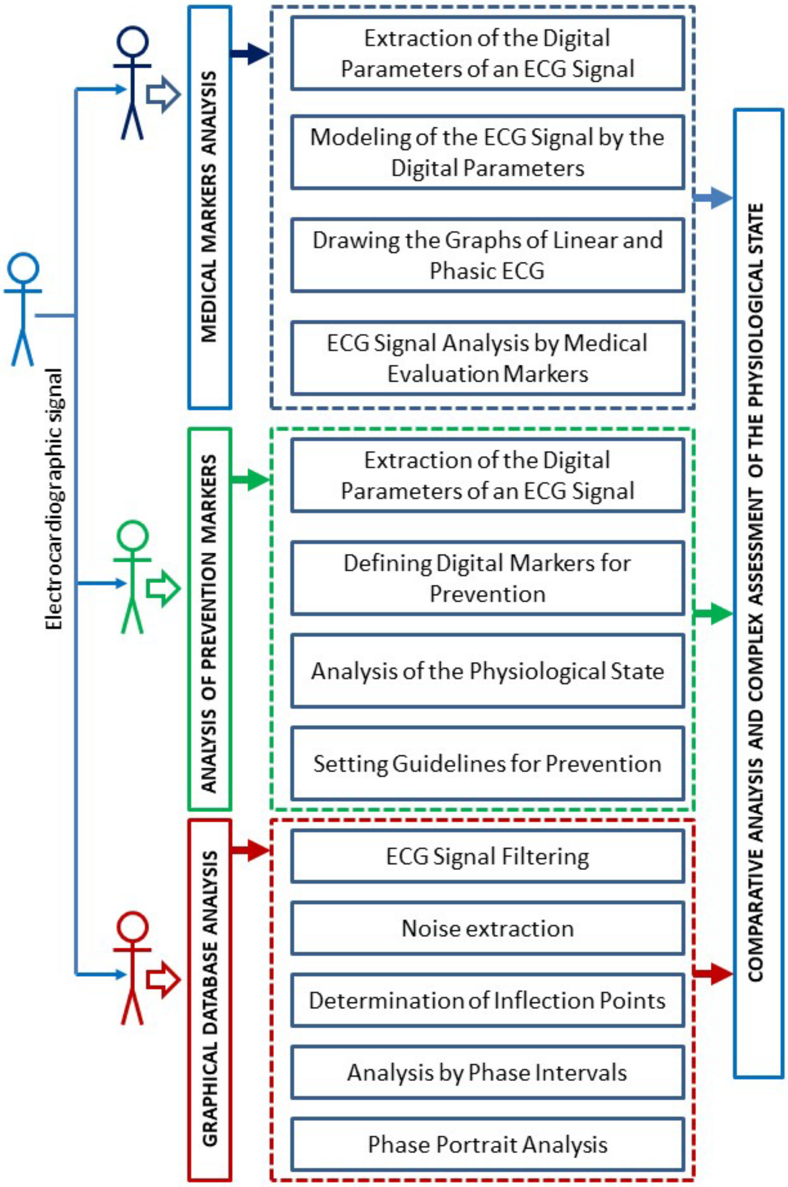


Figure 4. A complex approach to building a system for e-Health and prevention through an ECG signal

The analysis of the electrocardiogram gives an assessment of the physiology of cardiac activity with the identification of the risks of cardiopathology, an assessment of the heart's ability to perform various vital loads, and others. This analysis in the development of the e-Health and prevention system is carried out not only from the point of view of revealing a pathology that has already occurred, but from the point of view of prevention.

Each fragment of an ECG signal is associated with a specific cardiac activity and needs to be analyzed for deviations for the purpose of prevention.

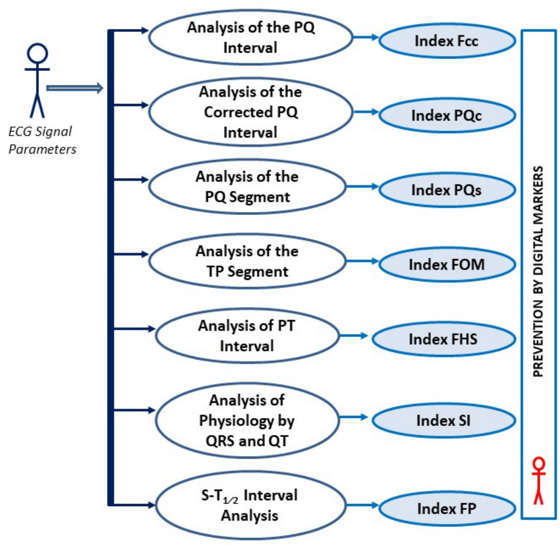


Figure 5. A complex approach to the evaluation of an ECG signal using markers in the e-Health and prevention system

Table 1. Description of prevention markers

PQ interval status marker in prevention $$Index\ F_{CC} = \frac{PQ_{int}}{PT_{int}}.100\%$$
Corrected PQc interval for a given heart rate $$PQ_C = \frac{0{,}3.QT_C}{0{,}7}, s$$
A marker for prevention through assessment of AV conduction quality and the risk of cardiac arrhythmias $$Index\ PQ_S = \frac{PQ_{seg}}{PQ_{int}}.100, \%$$
Myocardial resting phase index $$Index\ FOM = \frac{TP_{seg}}{RR}.100, \%$$
Physiological capacity of the heart and maximum heart rate threshold $$Max\ FHS = \frac{90}{PT_{int}}$$
Status and dynamics assessment of the ventricular systole of the heart $$Index\ SI = \frac{QT_{int}}{RR}.100, \%$$
State of contractile function of the myocardium $$Index\ FP = \left(1 - \frac{S - T_{0.5}}{QT_{int}}\right).100, \%$$

The complex approach and methodology for the analysis of electrocardiographic signals using markers for the prevention of cardiovascular diseases is presented in Figure 5, and the description of the markers is given in Table 1.

3. Results and Discussion

This section presents the operation of the built electronic healthcare system, as well as the results obtained from its testing in real conditions. The dialog interface of the system, the summary results for the individual prevention markers and the statistical study by analysis of variance of the proposed markers for groups and status are presented.

3.1. Structure of an e-Health and Prevention System

The e-Health and prevention system is made up of two parts – for prevention based on ECG signals and for prevention of problematic skin wounds. Figure 6 presents the developed system for e-Health and prevention in the analysis part through ECG signals.

The recorded ECG signals are transferred to computer processing. The analysis and evaluation of ECG signals require appropriate representation to give the diagnostic information through criteria in the prevention of the current state of an object.

After processing the analyzed signals, the system creates a database and visualizes the health status assessment with text and emoticons. Based on the criteria for the prevention of people under various emotional and physical stresses, an assessment of the current state and a prescription for prevention is given.

Input data for the electronic prevention system by electrocardiological signals are the electrode leads made with two medical devices – a standard 12-lead ECG device and eight-channel recording of the result, and a device for rapid recording of one-channel recording by electrodermal activity (EDA).

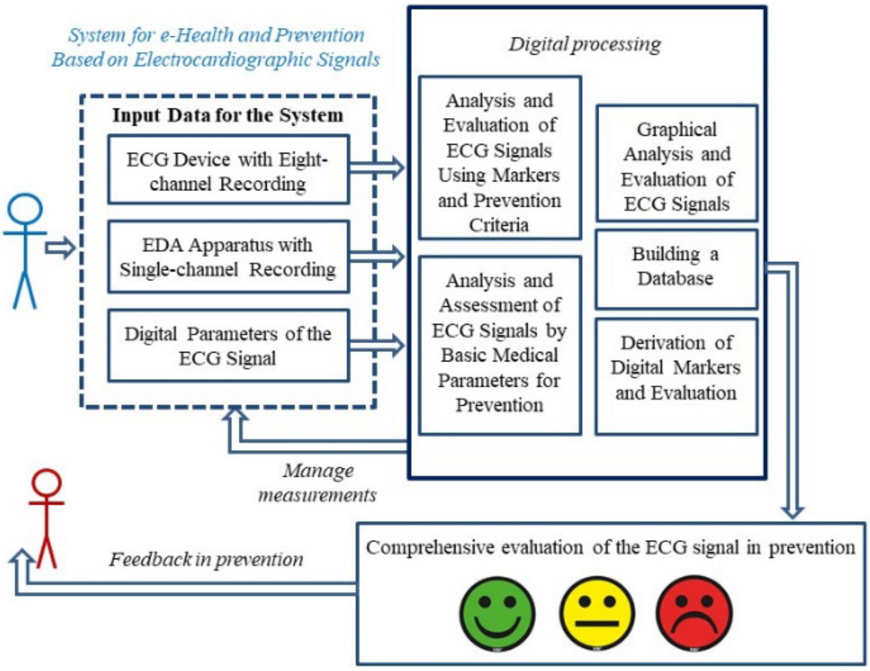
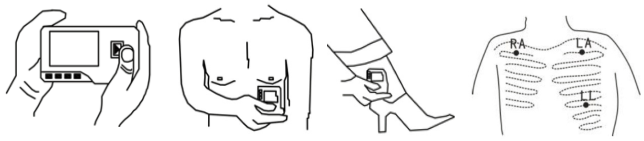


Figure 6. Structural diagram for building an e-Health and prevention system

For the purposes of the research, a Prince 180B electronic module was used, which registers the electrical conductivity of the heart through electrodermal activity. The electrical pulses generated by the polarization and depolarization of the myocardium are captured as shown in Figure 7. A 30-second single-channel recording is recorded and digitally processed with noise reduction filters [28], [29], [30].

The ECG signal recorded when measuring with the palms (Figure 7a) is equivalent to I lead. The measurement at one point on the chest (Figure 7b) is equivalent to the V chest lead of the ECG signal. The measurement at the ankle (Figure 7c) is equivalent to the ECG signal of lead II. Through the system of three leads (Figure 7d), monitoring studies are carried out.



a) b) c) d)

Figure 7. Prince 180B measurement methods in the e-Health and prevention system

The received data is converted for processing and analysis by the developed e-Health and prevention system.

3.2. Stages of Experimental Research

To obtain objective information about the accessibility of the proposed research methods and the effectiveness of the developed methods, numerous experiments have been organized and conducted to create a database and knowledge for the purpose of prevention. The impact of the living environment and emotional stress are essential factors for the appearance of cardiovascular pathological changes. The increased morbidity of the cardiovascular system among the population creates the need for a thorough study of the factors affecting the functional state of the cardiovascular system in a normal living environment.

Studies include the impact of emotional and physical stress on electrocardiogram parameters and assessment by prevention markers. In the early stage of diseases of the cardiovascular system, prevention remains one of the most urgent tasks of modern cardiology.

During the research stages, all obtained data, graphical and quantitative indicators and evaluations are stored or retrieved in an organized database.

In the e-Health and prevention system, modeling of ECG signals based on entered input data is provided.

The phase portrait is an estimate of the shape of the individual fragments in the ECG signal, as well as its deviations outside the time domain. The developed models provide an opportunity to evaluate the activity of the heart under certain risk loads, which determines the importance of the system in prevention.

The studies were conducted with different ECG signals: (i) Patients examined in leading world medical centers, with results recorded in authorized databases – European ST-T Database, BIDMC Congestive Heart Failure Database and MIT-BIH Arrhythmia database, as benchmarks for a specific disease and/or treatment that are certified. These cardiographic signals are in digitized form and contain information about the ECG signal, gender, age and received medical assessment of the patient's condition; (ii) Virtual patients simulated with an ECG simulator for research in the Medical Electronics Laboratory of the Department of Electronics; (iii) Patients tested by EDA ECG machine.

3.3. Results of the work of the System for e-Health and Prevention through ECG Signals

Figure 8 presents the developed dialog interfaces of a system for e-Health and prevention through electrocardiographic signals, built on the basis of the developed algorithms.

In the system for electronic health care and prevention, a file database for the studied objects is organized and the object is retrieved by keywords.

The dialog interface is divided into three areas. In the left part, 18 parameters are entered or visualized for each fragment of the ECG curve and the control buttons are located. In the middle part is the graphic field (linear or phase portrait of the ECG) and below it is written a text with the analysis according to medical criteria. On the right, the markers are calculated according to the prevention methodology.

In the right part of the dialog interface, the analysis of the ECG signal is visualized in tabular form according to the proposed markers and evaluation criteria for prevention through their quantitative values, the qualitative assessment made according to the corresponding index is written and the limits of change of this marker are given (Norm).

From the presented modeling data, Figure 8a, it can be seen that the assessment of a clinically healthy person assessed by medical criteria is not always sufficient to assess the current state of the subject and his ECG signal – prevention markers provide an additional assessment.

According to the assessment of prevention markers at the given moment there is a prerequisite for rhythm disorders expressed by Index PQs and temporary risk in AV conduction.

These indices and assessment should be refined for a longer time interval in the given subject and cardiac activity should be assessed by a medical specialist.

a) Modeled signal in the norm

b) ECG signal in stress mode – before final exam procedure

Figure 8. Dialog interface when evaluating markers for prevention.

The performance of the e-Health and prevention system is represented by randomly selected patients with clinical indicators. The uniformity of temporal electrocardiographic fragments and the area of abnormal areas are visualized and highlighted clearly by the phase portrait of the signal.

The e-Health system allows modeling of many different objects with changes in individual fragments of the ECG signal, giving a visual, qualitative and quantitative assessment of the specific condition.

This capability is extremely useful for training medical professionals because it allows role-play of real-world situations with advanced prevention marker analysis. The system was tested in 2020 by 2nd year medical students who expressed the usefulness of this mode of operation for learning.

Figure 9 shows the result of ECG signal V1, QRS complex finding and phase portrait.

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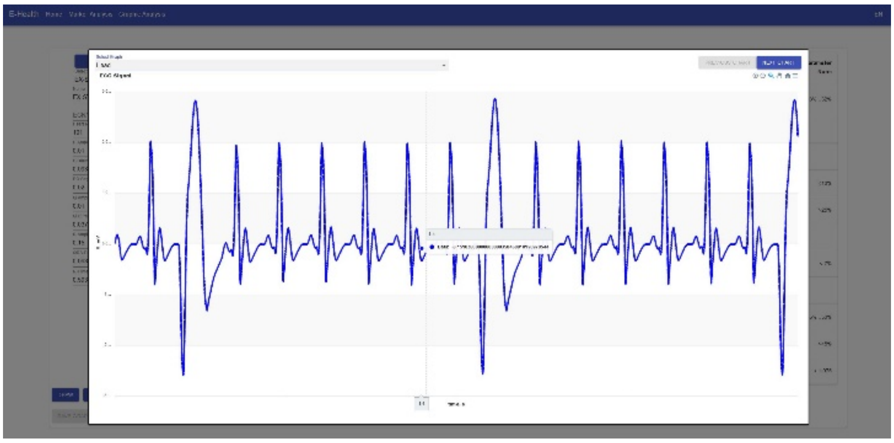
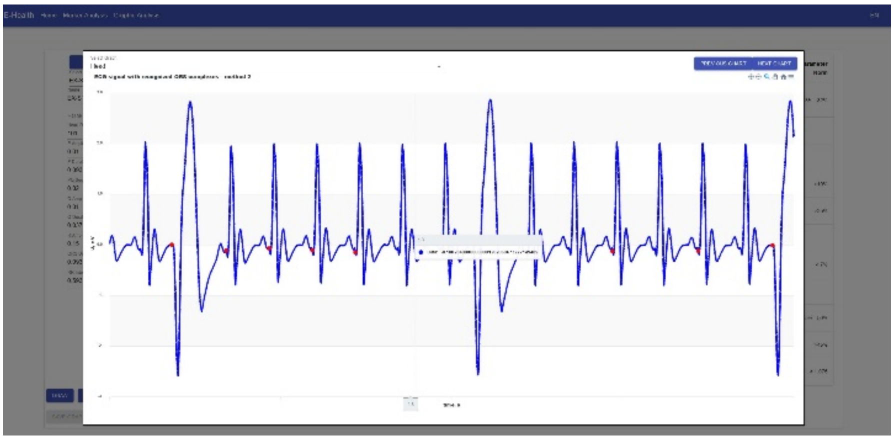
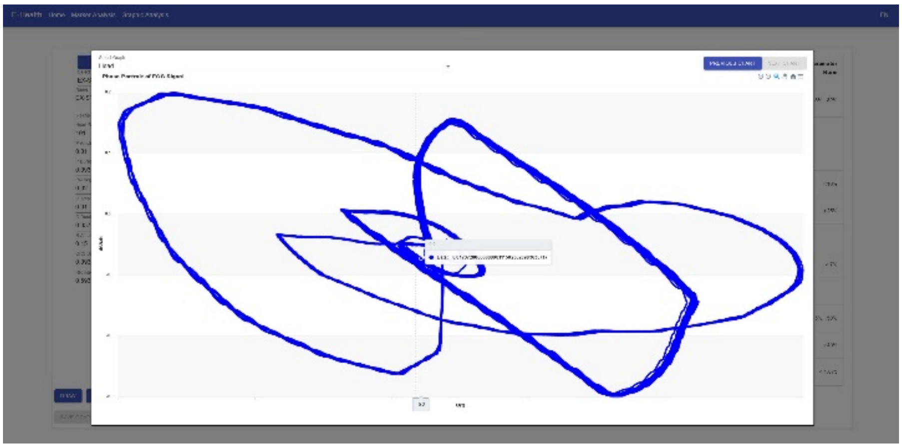


a) ECG signal, V1



b) Finding the QRS complex



c) Phase portrait

Figure 9. Experimental data for a patient, I lead, premature ventricular contraction

Experimental research was carried out in the period from 2016 to 2022 as follows: (i) In period 2016…2021 – in laboratory conditions in the Medical Electronics Laboratory of University of Ruse and Ruse: field, fitness, sports hall, and in the city swimming pool, examination procedure; (ii) (ii) In 2022 – in the Rehabilitation Center at UMBAL Medica Ruse.

Figure 10 and Figure 11 present the results obtained by markers for the state of the PQ interval (Index Fcc) and for assessing the quality of AV conduction and the risk of cardiac arrhythmias (Index PQs) in rest (CA) and stress (ST) mode for seven from the subjects of the group of people under extreme driving conditions (AU – driving in snowy conditions) and the group of people under emotional load during the test procedure (EX – exam).

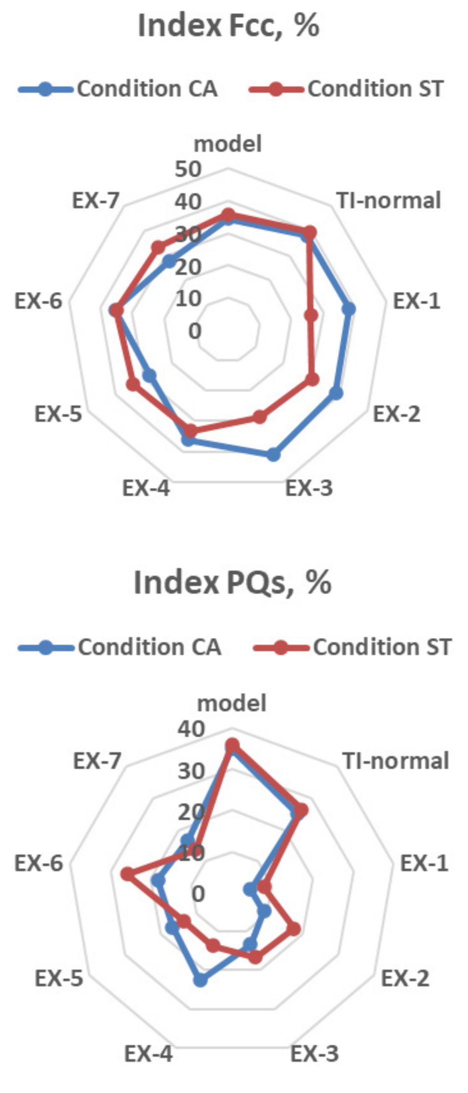
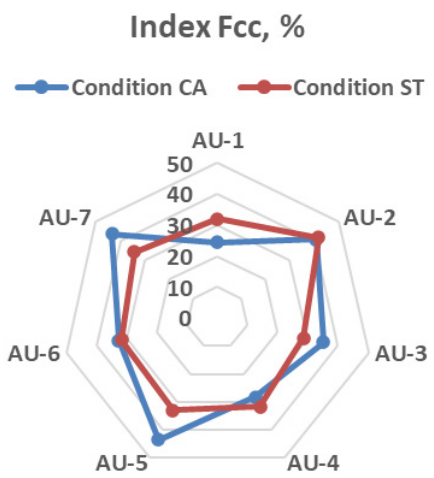


Figure 10. Experimental data for group EX

In Figure 10, the indicators of a modeled object based on the average statistical parameters of an electrocardiographic signal are depicted in gray, along with those of an object obtained using the CARDIOSIM II ECG simulator.



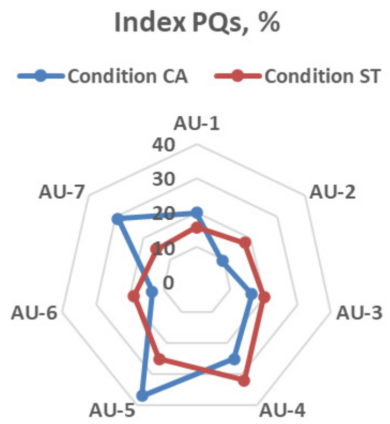


Figure 11. Experimental data for group AU

Figure 12 illustrates the presentation of prevention markers for four of the significant markers based on the measured results of one of the subjects investigated in the KRM group (kinesirehabilitation procedure).

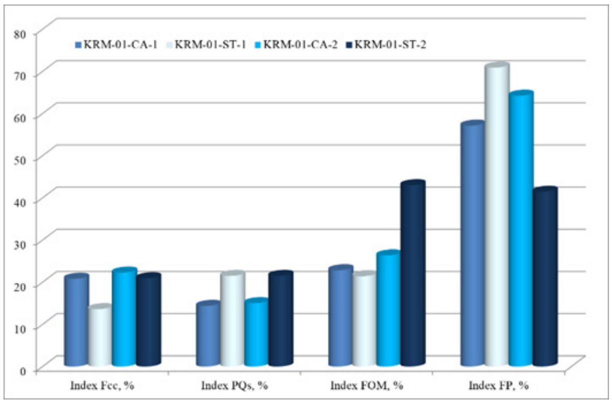


Figure 12. Visual interpretation of the results for one investigated object from the KRM group

The subject was tested for two different procedures both before and after the procedures. The graph shows that the markers Index FP and Index FOM are significant in terms of expressed pathology – their values vary widely and can express a strong change in the current state. The remaining two markers change within narrower limits.

After the tests, the following changes associated with an increase in heart rate are summarized:

- Decreases the mean RR interval.
- The PR segment is shortened.
- The amplitude of the P wave increases.
- At a very high heart rate, the Q wave becomes more negative.
- Decreases the width of the QRS complex.
- Reduces the amplitude of the R wave in the peripheral leads (V5).
- The amplitude of the R wave decreases and the depth of the S wave increases, resulting in a more negative S wave.

• Decreases ST level.
• The amplitude of the T wave increases and becomes more symmetrical.
• The QT interval shortens depending on the vegetative tone.
• The U wave changes and becomes more difficult to identify at a high heart rate.

3.4. Summary of the Results after the Analyzes of the Prevention Markers

The resulting numerical measurements of the detected dependencies prove that the selected markers according to medical criteria correspond to each other and have a significant strong relationship, which determines their selection for the analysis of the ECG signal and proves the significance of the proposed model.

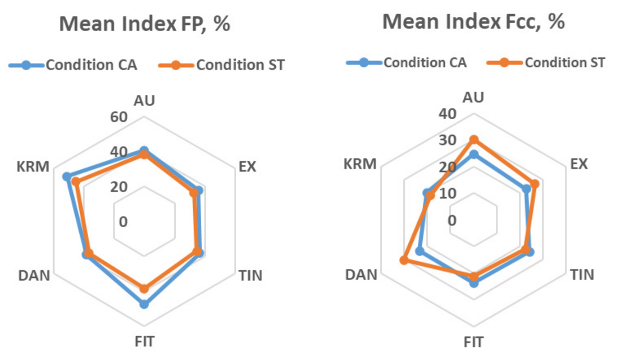
Analysis of variance studies across markers, groups, and condition are presented with their numerical characteristics in Figure 13.

The change in the SI Index informs about a prolonged or shortened QT interval, with a lower level being registered in a relaxed state. In a state of stress, the assessment of the electrical systole of the chambers is of a higher level. Group EX, for whom the stress mode is emotional, is an exception.

The clinically significant pathology of the ventricular systole is expressed by the FOM Index, and in a relaxed mode the index expresses the expansion of the QRS complex and the QT interval above a certain threshold. In a state of stress, the FOM index reflects the resting phase of the myocardium, which decreases with exercise.

The S-T$_{0.5}$ interval is related to the strength and quality of myocardial contraction and indicates the main repolarization phase of the action potential of cardiomyocytes.

A decrease in the FP Index below the limit values indicates problems in myocardial contraction and it is necessary to monitor both modes – rest and exercise. In the studied groups, Index FR decreases during exercise and increases during rest. After correcting for cardiomyocyte cellular metabolism, the plateau phase of the ECG was normalized to normal ranges.



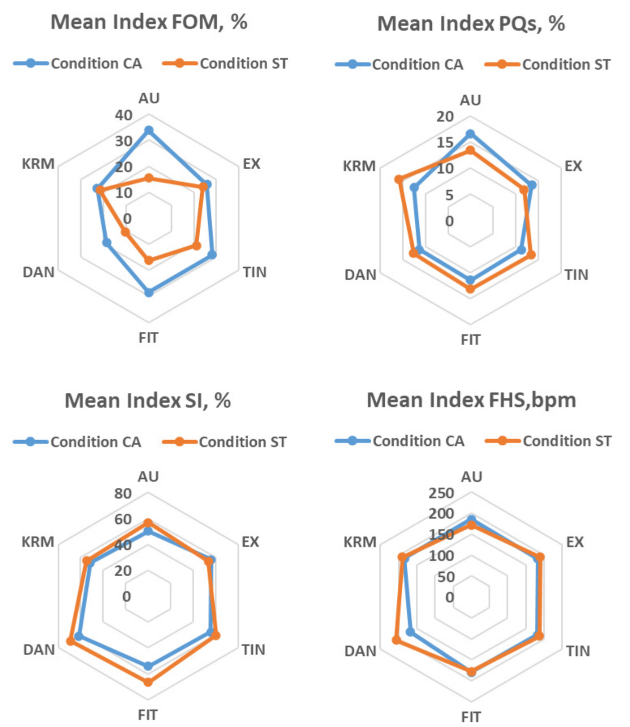


Figure 13. Variance analysis of markers by group and condition, in percentages

4. Conclusion

The study aimed to examine the impact of implementing e-Health in cardiovascular system prevention and assess the challenges associated with its implementation through scientific research: technical, clinical, psychological, and social analyses. Building an e-Health system provides guidelines for better prevention ensuring a normal social and work environment for people.

The priorities of e-Health and its main system structures are defined and an analysis of the system characteristics of e-Health and services is carried out.

The proposed concept for the application of modelling in the system for electronic health care and prevention ensures the optimization of the quality of treatment and the formation of quantitative and qualitative characteristics of the current state of health of people.

Methods for the evaluation of electrocardiographic signals have been adapted, which have been statistically studied with the proposed methods for prevention markers.

An innovative system for e-Health and prevention was developed and created through the analysis of electrocardiographic signals to provide real quantitative and qualitative assessments of the current state of the heart system in prevention with the aim of: (i) Health safety during exercise; (ii) Training of engineering and medical professionals.

The developed system is open and can be upgraded to expand both its application areas and functionalities.

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