THESIS – MASTER'S DEGREE PROGRAMME
SOCIAL SERVICES, HEALTH AND SPORTS

AN INVESTIGATION INTO APPLYING OPEN-SOURCE TECHNOLOGIES FOR HEALTHCARE SOLUTIONS IN REMOTE AND UNDERPRIVILEGED AREAS

An action-based applied research

AUTHOR Pritee Padvi

SAVONIA UNIVERSITY OF APPLIED SCIENCES THESIS
Abstract

Field of Study Social Services, Health and Sports			
Degree Programme Choose Programme			
Author(s) Pritee Padvi			
Title of Thesis An investigation into applying open source technologies for healthcare solutions in remote and under-privileged areas.			
Date	11.1.2024	Pages/Number of appendices	117
Client Organisation /Partners Business Centre of Savonia University of Health Sciences			

Abstract

This thesis aimed to develop electrocardiography (ECG) interpretation and remote monitoring applications to address healthcare challenges in remote areas, particularly low-to-middle-income regions. The intention was to demonstrate how open-source technology can provide healthcare solutions to the client organisation, the Business Centre of Savonia University of Health Sciences. The core objective of this thesis was to evaluate the necessity of such technology in underserved areas, consider legal aspects of medical software, and explore open-source technologies for application development.

The thesis employed a combined action-based and applied research methodology, focusing on cardiovascular healthcare and open-source technology. It involved developing ECG interpretation and remote monitoring prototypes using open-source tools and collaborating with an IT engineer for coding and implementation.

The experimentation with open-source technology in this thesis yielded promising results. The developed prototypes are functional but still in their early developmental stages, needing further refinement and expert collaboration. The study highlights the potential of open-source technology in improving healthcare in remote areas. It suggests ongoing evaluation and development for enhanced functionality and efficiency, opening avenues for future research in technology-driven healthcare solutions.

Keywords
Remote healthcare solutions, opensource software, opensource hardware, opensource technology

PREFACE

I want to express my special thanks to my teacher, Maria Luojus, for your encouragement and all your help throughout the course, for timely feedback on improving my thesis and for allowing me to explore my potential through this thesis. I would also like to thank the Business Centre of Savonia University of Health Sciences for being my parent organisation for this thesis. Furthermore, I would like to thank my better half, Siddhartha Satbhai, for his unwavering support, for providing his expertise as an IT consultant and for guiding me through the technical aspect of the implementation part of this thesis in a simplified manner. Finally, I thank my exceptional children for their patience, understanding, and support.

Espoo 11.1.2024
Pritee Padvi

CONTENTS

LIST OF FIGURES

1 INTRODUCTION

Approximately 2 billion individuals globally reside in rural and remote regions, with one in every three nurses operating in these areas, despite nearly half of the world's population living there (World Health Organisation (WHO) s.a.a.). The primary challenge for healthcare in these regions is the global shortage of well-trained professionals. According to WHO's 2016 estimates, an 18 million health worker shortfall is needed for universal health coverage by 2030, particularly in low- and middle-income areas. Rural and remote areas face acute shortages, leading to uneven distribution and leaving specific populations underserved, especially in communities marked by poverty and poorer health (World Health Organisation (WHO) 2021).

In rural India, where 65% of the population resides (Ministry of Finance, India 2023a), healthcare faces significant challenges despite progress in the past decade. Despite significant strides in enhancing overall health and bridging the rural-urban gap over the past decade, these issues persist, especially in rural areas (Mohan & Kumar 2019; Kumar 2023). Inadequate infrastructure, a shortage of healthcare experts, and transportation obstacles compound the healthcare dilemma in these regions (Akhtar, Haleem, & Javaid 2023).

This research is informed by observed healthcare limitations in India. Inspired by firsthand experiences, it recognises the limitations of working with scarce resources and being overworked. Motivated by a desire to address the healthcare disparities in remote areas, this thesis explores and evaluates the feasibility of leveraging open-source technology to create healthcare solutions, including legal and developmental aspects. This thesis aims to develop an electrocardiography interpretation prototype and remote monitoring system using open-source technology to address the healthcare gaps in rural, low-to-middle-income regions. This study employs action-based and applied research by focusing on the practical application of open-source technology in healthcare. The prototype of an electrocardiography (ECG) interpretation application was developed, driven by personal experiences of losing loved ones to undiagnosed heart conditions. Additionally, the thesis experiments with computer vision and open-source technology to create a remote monitoring system application inspired by a conversation with an elderly friend advocating for remote monitoring, especially when living alone.

2 THEORY BACKGROUND

2.1 The Healthcare System in India

The Indian healthcare system, serving a vast population of 1.4 billion people, is a complex mix of public and private sectors. It grapples with several critical challenges, including insufficient infrastructure, a severe shortage of healthcare professionals, urban-rural disparities, limited health insurance coverage, inadequate public healthcare funding, and a fragmented structure. Notably, the rise of non-communicable diseases adds further strain. To address these issues, the Indian government has introduced significant initiatives. The National Health Mission aims to enhance healthcare accessibility by improving infrastructure and supplies while promoting community involvement. (Kumar 2023.) In the January 2023 Rural Health Statistics report for 2021-22, the Ministry of Health and Family Welfare in India revealed substantial deficiencies in the country's healthcare infrastructure. Community health centres (CHCs) lacked 79.5% of the required specialists. As of March 31, 2022, India had 161,829 sub-centres, 157,935 in rural areas, and 31,053 primary health centres (PHCs), with notable doctor deficits in some states, despite an overall 51% growth in doctors at rural PHCs from 2005 to 2022. (Statistics Division, Ministry of Health and Family Welfare, India 2023.) According to the 2019-20 National Health Accounts Estimates for India, healthcare spending and government investment have significantly shifted. Primary healthcare's share of Current Government Health Expenditure (CGHE) increased from 51.3% in 2014-15 to 55.9% in 2019-20, highlighting a government focus on prioritising primary healthcare. (Ministry of Health and Family Welfare, India 2023b.)

Despite all the efforts, the effective expenditure on public sector healthcare in India is about 2.96% (The World Bank s.a.a) of the gross domestic product (GDP), in stark contrast to the 18.82% (The World Bank s.a.b) spent by the United States. In the Indian healthcare landscape, the private sector holds a prominent position. Compounding this issue is the absence of effective regulation within the private healthcare industry, leading to disparities in the quality and pricing of services (Kasthuri 2018). Around 70% of outpatient visits and 58% of inpatient cases are handled by private providers, including for-profit and not-for-profit entities (Selvaraj, Karan, Srivastava, Bhan, & Mukhopadhyay 2022, 245). On the other hand, the public sector provides healthcare services at minimal or no cost but is often seen as less dependable and offering lower-quality care. Consequently, it is typically not the first choice for individuals unless they cannot afford private healthcare. (Kasthuri 2018.)

The India Health System Review report states that India has made significant progress in health indicators, notably a rise in overall life expectancy, decreased maternal mortality rate, and a drop in infant mortality rate. However, this progress varies among states, and India faces the dual burden of diseases and an ageing population. In 2019, the leading causes of death were ischaemic heart disease, chronic obstructive pulmonary disease, and stroke. (Selvaraj et al. 2022, 25-26.)

Furthermore, India's investment in research and development (R&D) and innovation is notably low compared to many other nations. As per the World Bank data, the Indian government's expenditure on R&D stood at a mere 0.6% of the GDP in 2018 (The World Bank s.a.c), a stark contrast to the

United States, which allocated around 3% for the same purpose in that year (The World Bank s.a.d). India relies heavily on imports in the medical device industry, about 70%, because of limited domestic production (Manu & Anand 2021). Acharya (2006) emphasises that it is essential for low to middle-income countries to invest in science and technology while maintaining essential services like healthcare and sanitation, although it can be challenging. Evidence shows that the rapid development of such countries can lead to economic and health disparities. Science and technology can benefit development in public health by improving diagnosis and healthcare delivery. However, effective government policies are crucial to align health goals with technology priorities, such as training programs, technology transfer, and marketing strategies for health products. (Acharya 2006.)

2.2 The Challenges of Healthcare Services In Remote Areas

As per Karan et al.'s (2021) research, in India, the distribution of healthcare workers across states, rural and urban areas, and between public and private sectors is uneven. Furthermore, a study by Das, Daniels, Ashok, Shim, and Murlidharan (2022) highlighted the intricate configuration of healthcare markets, the significant presence of healthcare providers without formal medical training (informal providers), and notable disparities in care quality and costs within and between rural healthcare markets. (Das et al. 2022). Despite some progress over the years in addressing the critical shortage of medical staff and inadequate infrastructure, they remain a pressing issue to ensure accessible and quality healthcare for rural populations (Akhtar et al. 2023; Kumar 2023; Mohan & Kumar 2019).

In rural healthcare, disparities go beyond staff shortages and are extended to limited access to cardiologists and cardiac care experts in many primary healthcare centres. Rural areas typically have fewer specialised medical services, such as surgery, cardiology, or oncology (Statistics Division, Ministry of Health and Family Welfare, India 2023). Concerning diagnostic delays, primary care doctors may not have the expertise to interpret complex ECGs accurately. As a result, patients may experience delays in receiving a precise diagnosis. The research studies by Rakab et al. (2023) and Amini et al. (2022) indicate that there are challenges in electrocardiogram (ECG) interpretation skills among healthcare professionals and trainee doctors in various regions. While some participants demonstrate competency, significant gaps exist in identifying specific ECG patterns and cardiac conditions. The studies underscore the importance of continuous, standardised training and emphasise the role of education, self-assessment, and experience in shaping ECG interpretation abilities to enhance patient care and outcomes. Another issue is missed opportunities; failure to promptly identify critical cardiac conditions can result in missed opportunities for early intervention and have life-altering consequences for patients (Rakab et al. 2023; Amini et al. 2022). A study by Kwok et al. (2022) discusses how such missed opportunities can affect the diagnosis of heart failure, a complex condition with symptoms similar to other illnesses. These missed chances can happen when patients themselves do not recognise their symptoms as severe or when doctors fail to identify heart failure. Diagnostic delays can harm patients, cause frustration for doctors, and increase healthcare costs. Creating clear pathways for diagnosis and collaboration between specialists and primary care can help identify and treat heart failure more efficiently. (Kwok et al. 2022.)

Rural healthcare facilities often lack essential infrastructure (Kumar 2023; Kasturi 2018), such as well-equipped hospitals, diagnostic laboratories (Jain & Rao 2019), and modern medical equipment. This can lead to delays in diagnosis and treatment. Enhancing the quality and accessibility of services at Primary Health Centres (PHCs) will likely increase people's preference for PHCs as their primary choice for general healthcare (Mustafa & Shekhar 2021). Additionally, patients may need to travel long distances to access these services, causing delays and additional expenses (Chakrabarti & Tatavarthy 2019). Health education and awareness programs may not be as readily available in rural areas. This can lead to lower health literacy, delayed recognition of symptoms, and less preventive care. For instance, a study conducted by Siddique, Rahman, Pakrashi, Islam, and Ahmed (2021, 25-27) amid the covid 19 pandemic found that while disseminating trustworthy health information is crucial and challenging in remote rural regions, how this information is provided to reach the targeted audience also plays a significant role. The issue arises due to communication barriers, such as the inability to read or write, lack of internet connection, or technological barriers; however, personal one-on-one communication, like personal phone calls, has proven more effective in reaching hard-to-reach rural areas. (Siddique et al. 2021.)

Rural populations experience higher levels of poverty and lower socioeconomic status, making it harder for them to afford healthcare costs, including medications and treatments. Adeola Olajide (2023) conducted a study to explore the connection between healthcare access and various socioeconomic factors, revealing that availability, affordability, accessibility, and accommodation are crucial elements. This study found that increased labour hours (across different activities) negatively impact healthcare access, while age and literacy positively influence it. Furthermore, rural areas may have limited access to telehealth services, which can be a valuable resource for remote healthcare consultations. This limitation further isolates rural communities from healthcare options. Some challenges to the successful practical implementation of such services are insufficient medical and technological infrastructure, technological illiteracy, and lack of experts (Rajkumar et al. 2023).

High out-of-pocket expenditure in healthcare serves as a significant deterrent for people in rural areas when seeking healthcare services. The financial burden of paying for medical expenses directly from one's pocket, without substantial insurance coverage or government support, can be overwhelming for individuals with limited resources. This often leads to delayed or avoided healthcare-seeking behaviour, as rural residents may fear the potential financial strain and its long-term consequences on their family's economic stability. As a result, preventable health conditions may worsen, ultimately increasing the overall cost of healthcare and potentially leading to poorer health outcomes among rural populations. In India, where about 12.4% live below the poverty line, heavy reliance on out-of-pocket health expenses, which comprise 62.6% of total healthcare spending, is a significant drawback. (Sriram & Albadrani 2022.) A 2014 National Sample Survey data study reveals that these expenses worsen poverty rates. Before such spending, the poverty headcount was 16.44%, but it jumped to 19.05% afterwards, affecting 6.47 million households.

Factors like larger households, more extended hospital stays, private healthcare use, and chronic illnesses increase the risk of impoverishment due to these costs. (Sriram & Albadrani 2022.)

As mentioned above, rural healthcare faces numerous challenges, from a shortage of medical experts to limited access to specialised services. These hurdles can often lead to delayed diagnoses and treatments. However, in the face of these challenges, technology can play a pivotal role in bridging the gap.

2.3 Electrocardiography (ECG) and Recent Advancements

The electrocardiogram (ECG or EKG) is the graphic representation of the heart's electrical activity (Mehta 2002; Hall & Hall 2021, Chapter 11.) during a cardiac cycle. A cardiac cycle is the sequence of events that take place from one heartbeat to the beginning of the next heartbeat. It consists of two main events called diastole and systole. Diastole refers to the relaxation of the heart muscle and the refilling of blood in the heart chambers, while systole involves the contraction of these muscles, causing the pumping of blood. (Pollock & Makaryus 2019.) ECG is a simple and non-invasive procedure involving placing electrodes on the chest. These electrodes are connected to a machine that measures the heart's electrical activity. The output is typically displayed as a graph on a paper scroll or computer screen.

An initial diagnosis of a heart attack is often made by observing clinical symptoms and specific changes in the ECG. Additionally, an ECG can identify areas of the heart that are not receiving enough oxygen or areas of dead tissue. A baseline ECG is usually conducted before starting cardiovascular medications known to potentially affect heart function, with follow-up tests performed at regular intervals to monitor any changes. (Sattar & Chhabra 2023.)

In recent times, advancements in technology have enabled electrocardiography devices to surpass clinical settings and find applications in the domestic sphere. A wide range of portable ECG devices are now available for home use. However, such devices are restricted to arrhythmia detection and cannot detect other cardiac disorders. (Zepeda-Echavarria et al. 2022.) Pepplinkhuizen et al. (2022) conducted a study on the accuracy and clinical relevance of the Apple Watch, which is a well-known wearable device brand for its first commercial availability. These watches have a built-in functionality to perform a single-lead ECG to detect atrial fibrillation (AF) and normal sinus rhythm (SR) due to electrodes inside the device. Although the single-lead ECG is accurate for detecting AF and SR, it often produces results that cannot be classified when recording quality is poor. Furthermore, repeating the recording helps to reduce the unclassified results, but if repeated more than once, it can lead to lower accuracy and false-positive results. Physicians' interpretation of single-lead ECGs reduced unclassified results and decreased accuracy. Therefore, the role of the single-lead ECG in diagnosing AF is unclear, and a 12-lead ECG is still necessary for confirming AF diagnosis. (Pepplinkhuizen et al. 2022.) Another potential drawback of smart gadgets offering ECG recording functionality is that they can raise anxiety issues in laypersons or non-medicos. Moreover, there is a need for additional examination of the medico-legal and practical aspects of using smartwatches for ECG recordings. Providing medical advice to untrained consumers based on smartwatch data can also raise ethical questions about how healthcare professionals evaluate smartwatch ECG data. (Zenzes, Seba, & Portocarrero 2023.)

In the medical fraternity, ECGs have been invaluable tools in diagnosing and managing cardiovascular conditions for decades (Sattar & Chhabra 2023). However, the challenge lies in interpreting these intricate patterns, which demand a nuanced understanding of cardiac physiology and a keen eye for anomalies. While experienced cardiologists adeptly decipher these cryptic signals, not all doctors possess the expertise to do so (Rafie et al. 2021; Amini et al. 2022; Kashou et al. 2023; & Rakab et al. 2023). This knowledge gap becomes even more critical in remote and underserved areas with limited access to specialised cardiac care (Nunes et al. 2022).

The PMcardio smartphone application was specifically developed to assist physicians with limited experience interpreting ECGs accurately. A study conducted by Himmelreich and Harskamp in 2023 assessed the validity of this application as a point-of-care tool for interpreting routine primary care 12-lead ECGs, using blinded cardiologist interpretation as the reference standard. This app enables physicians to analyse 12-lead ECGs using an integrated artificial intelligence (AI) algorithm by photographing on Android and iOS platforms. The AI algorithm is trained on existing ECG databases, allowing it to interpret ECGs and diagnose various abnormalities, including arrhythmias, conduction delays, and acute cardiac ischaemia. Additionally, the application offers follow-up advice based on local guidelines and patient-specific information such as age, sex, symptoms, and medical history. Currently, the application is available in Europe and certified as a Class II(b) EU MDR medical device. It boasts a user base of over 10,000 physicians across Europe. Their research revealed robust diagnostic accuracy within the primary care setting and near-perfect performance in diagnosing atrial fibrillation compared to expert readers. However, it is essential to exercise caution when using the app to assess ECGs for indications of prior myocardial infarction in asymptomatic patients and when detecting impulse or conduction abnormalities in ECGs of suboptimal quality. This study provides valuable insights for general practitioners who require an on-the-spot ECG interpretation tool, mainly when they are uncertain about their interpretation skills and when seeking consultation from a cardiologist presents logistical or time-related challenges. (Himmelreich & Harskamp 2023.)

2.4 Ageing Challenges and Remote Monitoring Systems (RMS)

Ageing is an inevitable part of life, impacting everyone with resilience and potential health challenges. According to a United Nations report (2019), the remarkable rise of an ageing global population is leading to the pressing need for innovative solutions to cater to the unique needs and challenges of the elderly. By 2050, one in six people worldwide will be 65 years or older, a significant increase from one in eleven in 2019. Europe and Northern America are on track to see one in four individuals in this age group by mid-century. Perhaps the most telling statistic is the projection that people aged 80 and above will triple, soaring from 143 million in 2019 to an astounding 426 million by 2050. (United Nations 2019.) The implications of this demographic shift are undeniable, for instance, an increase in healthcare costs and age-related health issues.

Innovative technologies hold the power to empower the elderly population. From health technology like wearable monitoring sensors and assistive devices to information technology that enables interoperable electronic medical records, these innovations are already contributing to healthy ageing. (Bloom & Zucker 2023.)

Remote monitoring technology has emerged as an innovative solution, increasingly drawing significant attention. Such systems can be effectively overseen and controlled by a specific designated set of operations across a network, achieving cost-effectiveness and minimising errors. This kind of network may encompass an Internet-of-Things (IoT) infrastructure or a local network incorporating a range of interconnected devices (Rashid et al., 2023). It is being proposed and employed as a proactive care model, particularly in older adults with chronic health conditions and individuals facing physical challenges.

Research conducted by Barrio-Cortes et al. (2021) found the prevalence of disease ailments like hypertension, dyslipidaemia, diabetes and osteoporosis among the geriatric population, highlighting the importance of proactive healthcare management. These chronic conditions entail the regular intake of medications. According to Kim, Koncilja and Nielsen (2018), ensuring the safe and effective administration of medications to elderly individuals is an important facet of caregiving. These people often grapple with polypharmacy, which involves the use of multiple medications, carrying inherent risks such as errors or non-compliance. Managing drug therapy for this demographic demands a systematic and patient-centred approach that considers each patient's unique healthcare goals. (Kim et al. 2018.) Similarly, since medication adherence can be particularly challenging for older people, who face a heightened risk of medication-related side effects, contributing to numerous deaths and hospital admissions, high-risk drugs require regular monitoring. Medications, like those with anticholinergic properties, can exacerbate confusion and dementia symptoms. Over 70% of such medication error-related events are preventable, costing the National Health Services of the United Kingdom a substantial amount annually. (Maidment, Huckerby, & Shukla 2020.) Remote monitoring can provide reminders and alerts for medication schedules, ensuring they take their prescribed medications as directed.

There are several other challenges associated with the ageing population apart from chronic illnesses and medication management. An article by Appeadu & Bordoni (2023) mentions that accidental slips and falls are a prevalent and severe concern, particularly impacting the elderly population by causing disability. These incidents are closely associated with higher mortality rates, increased morbidity, and a decline in overall functionality. Falls are a frequent occurrence, affecting not only older adults but also children and athletes, with the elderly being at a higher risk due to their medical comorbidities. Each year, around 30% of individuals aged 65 and above experience falls; shockingly, nearly half of these cases involve recurring incidents. Among those aged 85 and older, this percentage climbs to approximately 40%. Alarmingly, roughly 10% of these falls result in severe injuries, such as fractures, traumatic brain injuries, or subdural hematomas. It is crucial to note that falls are a leading cause of hospitalisation in this age group, contributing significantly to higher mortality rates. Additionally, using ambulance services, social care, and hospital resources imposes a substantial financial burden. (Appeadu & Bordoni 2023.) Remote monitoring devices, including wearable sensors and smart home technology, can detect falls and alert caregivers or medical professionals for immediate assistance. For those with cognitive decline or dementia, remote monitoring can provide safety measures such as tracking their location, alerting caregivers to unusual behaviours, or ensuring they do not wander into unsafe areas. A study conducted by David et al. (2023) that used IoT technology to remotely monitor physiological measurements in people with dementia at their homes for approximately two years revealed key findings, including a high prevalence of hypertension, lower systolic blood pressure in some cases, and significant weight loss. This study also demonstrated the feasibility of remote monitoring and highlighted its potential for improving the management of health conditions in people with dementia.

The recent COVID-19 pandemic brought focus to the issue of social isolation and loneliness, so much so that it gained attention in the media, NGOs, and government at the national and international levels. The magnitude of this issue was so enormous that in 2018, the United Kingdom appointed a Minister of Loneliness to develop strategies for measuring and reducing loneliness. In response to the notable increase in suicide rate in Japan, the Japanese government appointed a Minister of Loneliness in 2021 to combat isolation and lower suicide rates. (Bouaziz, Brulin, & Campo 2022.) Remote monitoring can include social engagement features, such as video calls or communication apps, to combat social isolation, which can be a significant concern for older adults, especially those living alone.

Remote monitoring can detect subtle changes in health metrics, signalling the onset of health issues. Early detection of such changes allows for prompt intervention and can prevent health conditions from worsening. Furthermore, remote monitoring can aid the transition to home care, especially after hospital stays, by tracking recovery progress, vital signs, and medication adherence. Olivari et al. (2018) showed that remote monitoring for elderly patients following hospitalisation for heart failure does not significantly reduce mortality or heart failure-related hospital readmissions over 12 months. However, it does improve the patient's quality of life both physically and mentally. In an on-treatment analysis, a trend suggested potential improvement in the primary endpoint for patients who ultimately received remote monitoring. (Olivari et al. 2018.)

Older adults often choose to stay at home rather than in care facilities. RMS helps protect their well-being and provides emergency assistance for independent living. The key findings from a study conducted in New Brunswick, Canada, which has a significant ageing population, to explore perceptions of passive remote monitoring technology for supporting older adults who want to continue living independently showed that passive remote monitoring can enable older adults to live at home longer and provide relief to caregivers. This research involved interviews with various stakeholders, including older adults, family caregivers, social workers and government decision-makers. There was a shared commitment among stakeholders to meet the home support needs of this age group. The study emphasises the need for increased awareness of the technology and its benefits among the public and social workers. (Read et al. 2022.) Remote monitoring can provide peace of mind to caregivers by allowing them to keep an eye on their loved ones' health from a distance. Overall, RMS can significantly improve the quality of life for elderly and physically challenged individuals by providing continuous care, early intervention, and the ability to maintain independence and age gracefully at home.

2.5 Software as Medical Device (SaMD) and Regulatory Authorities

According to the WHO, national health plans must include policies, strategies and action plans concerning health technologies, particularly medical devices. When integrated into a robust healthcare system, these frameworks ensure that safe, effective, and high-quality medical devices are readily accessible for the prevention, diagnosis, and treatment of diseases and injuries and for the support of patient rehabilitation. Therefore, the WHO has created a guidance document to emphasise the significance of developing and implementing health technology policies encompassing regulatory health technology management and assessment components. This document highlights the role of medical devices in global healthcare, prioritising needs at the national level and delves into essential elements of effective policies, the organisational systems required for policy implementation, and the methodology for tracking progress. (World Health Organisation (WHO) s.a.b.) However, with constantly evolving technology, many applications have emerged designed to support the general public in their quest for better health and improved lifestyles. While some of these applications may require external hardware for data collection and functionality, it is essential to note that not all of them fall under the category of medical devices.

The concept about medical devices is that a medical device is an instrument, apparatus, machine, software, implant or other similar or related article intended for use in the diagnosis, prevention, monitoring, treatment or alleviation of disease or injury in humans or for investigating, replacing, or modifying the anatomy or physiological processes (Medical Device Coordination Group (MDCG) 2019, 4). The software for ECG applications is intended to assist the healthcare profession in diagnosing health conditions. RMS is intended to serve as a monitoring device designed for medical purposes involving patient data collection, transmission and analysis. Therefore, these applications fall under the medical device category. Furthermore, authorised regulatory bodies in respective countries oversee the regulation of such devices intended for medical purposes. These regulations verify the device's intended purpose, associated risks, quality management, and clinical verification. However, the standard framework for such regulations is based on the International Medical Device Regulators Forum (IMDRF).

To create a solid global foundation based on the Global Harmonization Task Force on Medical Devices and to expedite the process of achieving international harmony and alignment in the regulation of medical devices, the International Medical Device Regulators Forum (IMDRF) was established in October 2011. This collaborative effort extends to regulating software as a medical device, which continues evolving with technological advancements. The IMDRF member countries use their definitions, often aligned with the definition of a medical device provided by the WHO and the IMDRF. However, it is essential to note that the definition of a medical device can vary slightly from one country or regulatory authority to another. (European Commission 2023.)

According to the IMDRF/SaMD WG/N10FINAL:2013 document, SaMD is defined as software designed for one or multiple medical applications that fulfil these functions independently, without being integrated into a medical hardware device. The terms outlined in GHTF/SG1/N71:2012 delineate the medical purpose relevant to SaMD. (International Medical Device Regulators Forum (IMDRF) Software as a Medical Device (SaMD) Working Group 2013, 6.) Software is a compilation of instructions assembled with input data to produce output data (Medical Device Coordination Group (MDCG) 2019, 5). Software typically consists of code, scripts, and programs that enable computers and other devices to perform specific tasks or functions.

While the IMDRF/SaMD WG/N10Final:2013 document of IMDRF provides guidelines on terminology, the possible framework for risk categorisation and corresponding considerations, application of quality management system and clinical evaluation, regulatory approaches can vary among countries and regions since these are not binding, and they consist of voluntary medical device regulators. For instance, within the European Union, SaMD is regulated by the European Medical Device Regulation (EU MDR) authority, and the term used for SaMD is Medical Device Software (MDSW) (Medical Device Coordination Group (MDCG) 2019), whereas, in the United Kingdom and United States of America, the regulatory authorities are Medicines and Healthcare products Regulatory agency (Government of the United Kingdom 2022) and Centre for Devices and Radiological Health (CDRH) (United States Food and Drug Administration (U.S. FDA) 2019), respectively. The CDRH is a branch within the Food and Drug Administration (FDA) that verifies medical devices for public safety (United States Food and Drug Administration (U.S. FDA) 2019). Under the regulations set forth by the EU MDR, an important distinction is that software can be employed independently or in conjunction with other medical devices (Medical Device Coordination Group (MDCG) 2019, 7). Furthermore, it relies on a rule-based system for categorising devices, which is determined by the importance of information supplied by the software in healthcare decision-making scenarios or assessing a patient's condition (Medical Device Coordination Group (MDCG) 2019, 7-16).

The classification of SaMD depends on its medical purpose, setting it apart from general healthcare and wellness software. The medical purpose encompasses diagnostics, treatment, prevention, monitoring and alleviation of disease, disease management, contraception, in-vitro diagnostics, and sterilisation. (International Medical Device Regulators Forum (IMDRF) Software as a Medical Device (SaMD) Working Group 2014, 7-8.) A SaMD, for instance, is a smartphone app that detects and addresses sleep apnea, and an app that tracks healthy sleep patterns is not SaMD. Additionally, SaMD must function independently (IMDRF Software as a Medical Device (SaMD) Working Group, 2014, 7), distinguishing it from Medical Device Software (MDSW) embedded in medical hardware (Medical Device Coordination Group (MDCG) 2019, 5-8). This distinction affects regulatory requirements.

The risk categorisation framework for Software as a Medical Device (SaMD), as defined by the IMDRF/SaMD WG/N12FINAL:2014 document of IMDRF, comprises four categories denoted as I, II, III, and IV. Category 1 (low risk): Collects data for medical supervision, e.g., heart rate monitoring during rehabilitation, Category 2 (low-medium risk): Analyses multiple tests and offers diagnostic recommendations, e.g. providing a 3D image for analysis by incorporating patient's data from computer tomography scan, Category 3 (medium-high risk): Alerts anomalies (e.g., sleep apnea), part of treatment planning (e.g., tumour treatment parameters), and illness monitoring and diagnosis, and Category 4 (high risk): Used in critical, life-and-death situations (e.g., meningitis, acute stroke). (International Medical Device Regulators Forum (IMDRF) Software as a Medical Device (SaMD) Working Group 2014, 14-18.) These categories are determined by the extent of their impact on patient or public health, with specific emphasis on the criticality of accurate information provided by SaMD in the context of treatment, diagnosis, clinical management, and the mitigation of health risks. After the categorisation, the next step for SaMD verification is undergoing the application of quality management systems and clinical evaluation. The documents IMDRF/SaMD WG/N23FINAL: 2015 (International Medical Device Regulators Forum (IMDRF) Software as a Medical Device (SaMD) Working Group 2015) and IMDRF/SaMD WG/N41FINAL:2017 (Software as a Medical Device Working Group 2017) released by IMDRF provide information on the quality management application and clinical evaluation, respectively.

In India, SaMD is regulated under the Drugs and Cosmetics Act 1940, effective from April 2020. The Central Drug Standard Control Organisation (CDSCO), under the Ministry of Health and Family Welfare in India, plays a crucial role in licensing procedures, including import, manufacturing, distribution, and sale (Manu & Anand 2021.).

Medical device classifications may vary from one country to another, reflecting differences in regulatory frameworks and healthcare practices. These variations are typically based on risk level, intended use, and potential impact on patient health. While there is a global effort to harmonise these classifications, stakeholders in the medical device industry need to be aware of the specific requirements in each country where they intend to market their products. Understanding these variations is crucial for compliance with regulatory standards and successful market access.

3 TECHNOLOGICAL SURVEY FOR APPLICATION IMPLEMENTATION OPTIONS

3.1 Knowledge-Based Systems (KBS)

Knowledge-based systems (KBS) are distinct branches of artificial intelligence (AI) that emphasise human knowledge's acquisition, representation, and exploitation for solving complex problems. KBS is a subset of AI technologies that use knowledge representation, reasoning, and problem-solving methodologies to make decisions, solve problems, or assist in undertaking complex tasks. (Russel & Norvig 2003, 22-23.)

Expert systems, classified as KBS, seek to replicate human expertise and decision-making in specific domains. The acquisition of knowledge is necessary for the development and implementation of expert systems. It entails understanding human expertise through a systematic process that makes it understandable to machines, such as codification into rules or facts. Typically, interviews are conducted with domain experts to elicit their insights and produce a knowledge base. A knowledge base is a repository of domain-specific information organised in a structured format. This data can take many forms, including but not limited to rules, facts, frames, semantic networks, and ontologies. An ontology is a formal specification of the concepts and relationships within a given domain. Rule-based reasoning is used through a predetermined set of production rules that outline specific conditions and actions to be taken. These rules serve as guiding principles for an efficient decision-making process within the system, and if-then statements are commonly used. The Inference Engine is essential to applying rules and logic to a knowledge base to draw inferences or make necessary decisions. For this purpose, various reasoning techniques, including Forward Chaining and Backward Chaining, can be used. Forward Chaining is a drill-down approach, starting with simple facts and making inferences based on specified rules until a conclusion is reached. Conversely, Backward Chaining starts with a conclusion and works its way up, trying to find facts that support its particular conclusion. Expert systems frequently include a user interface that allows users to interact with the system. This enables them to enter data, obtain information, or make recommendations as needed. (Giarrantano & Riley 2015, 1-6.)

Expert systems are deployed in medical diagnosis to aid doctors in reaching a diagnosis based on patient symptoms and medical knowledge. For example, the historical expert system MYCIN, developed at Stanford by Ed Feigenbaum, Bruce Buchanan, and Dr. Edware Shortliffe, was used to diagnose blood infections. (Russel & Norvig 2003, 23.) ”With about 450 rules, MYCIN was able to perform as well as some experts, and considerably better than junior doctors.” (Russel & Norvig 2003, 23). Similarly, in financial advisory and troubleshooting, expert systems provide recommendations for risk analysis and assist in identifying and resolving problems based on domain-specific knowledge. In Natural Language Processing (NLP), expert systems implement chatbots and language translation programs. (Giarrantano & Riley 2015, 20-23.)

While expert systems have numerous advantages, they are not without drawbacks. Expert knowledge capture and representation can be a time-consuming and error-prone process. Expert systems must adapt as knowledge evolves, necessitating continuous knowledge base updates. These systems frequently lack common-sense reasoning abilities, making them less robust in dealing with unusual or unexpected situations. Building large, comprehensive expert systems can be difficult and time-consuming. (Russel & Norvig 2003, 23-26.)

3.2 Computer Vision and OpenCV

Computer vision, a subset of artificial intelligence (AI), is concerned with enabling machines to interpret, comprehend, and make sense of visual data from the outside world. Computer vision systems (CVS) have advanced rapidly in recent years, resulting in transformative applications in various industries. These systems use algorithms and deep learning models to process, analyse, and extract meaningful insights from visual data, such as images and videos. (Szeliski 2022, 3-4, & 9; Azure s.a.)

Image preprocessing is the process of improving image quality, resizing, and filtering in order to improve the accuracy of subsequent analysis. Identifying and extracting relevant features from visual data, such as edges, shapes, textures, or objects, is known as feature extraction. Object detection is locating and identifying objects in images or videos using object localisation and classification techniques. Segmentation divides an image into meaningful regions or segments, allowing detailed analysis of specific areas. Convolutional neural networks (CNNs) and other deep learning architectures are used for complex visual recognition tasks in deep learning. (Szeliski 2022, 19-21; Azure s.a.)

Computer vision is a critical technology for self-driving cars, allowing them to perceive and navigate their environment, recognise road signs, pedestrians, and other vehicles, and make real-time decisions for safe driving. Real-time video surveillance employs computer vision to detect unusual activity, track objects, and identify security threats. This CVS technology is used in healthcare for medical image analysis, such as interpreting X-rays, MRIs, and CT scans and tracking patient movement and vital signs. Retailers can use computer vision to optimise inventory management, monitor shopper behaviour, and enable cashier-less checkout experiences. Computer vision systems are used in manufacturing for quality control, identifying product defects, and guiding robotic automation on assembly lines. Lastly, robots use computer vision to navigate, manipulate objects, and interact with their surroundings. (Szeliski 2022, 5-7; Azure s.a.)

OpenCV, or Open Source Computer Vision Library, is a free, open-source software library for computer vision and image processing. It is intended to assist developers in developing applications that can understand, process, and manipulate visual data. OpenCV is well-known for its high performance, extensive algorithm library, and cross-platform compatibility. Since it is open source, anyone can use, modify, and distribute it. This promotes computer vision collaboration and innovation. OpenCV has an extensive library of functions and algorithms for various computer vision tasks, making it a one-stop solution for image and video processing. It is designed for real-time applications and can use hardware acceleration when available. OpenCV is available for Windows, Linux, macOS, and mobile platforms, allowing individuals to create applications for various devices. A large developer community contributes to OpenCV, resulting in continuous improvements and a wealth of resources such as tutorials and forums. OpenCV can enhance and manipulate images, apply filters, and perform operations such as resizing, cropping, and rotation. It is widely used for detecting and tracking objects in images and videos. This is useful in surveillance systems, robotics, and augmented reality. Because it can recognise and identify faces in images and videos, it is helpful for security and authentication. Furthermore, OpenCV integrates with machine learning libraries and tools, enabling tasks like image classification training models. It can overlay digital content in the real world, enhancing interactive experiences and applications. It is also used in the medical field for tasks such as image analysis, tumour detection, and diagnosis assistance. In robotics, OpenCV is used for object navigation, path planning, and obstacle avoidance tasks. (Pajankar 2020, 3-4.)

3.3 Open Source Software and Hardware

Open source software is a term used to describe computer programs whose source code is freely available for anyone to view, modify, and distribute. The "source code" refers to the human-readable instructions that enable a software application to function. Individuals and communities can collaborate and innovate on open-source software, promoting transparency and accessibility. The software is frequently free, removing the need for costly licenses. Individuals, businesses, and organisations can all benefit from this. Because the source code is available for inspection, the program's inner workings can be seen and understood, ensuring trust and security. Global communities of volunteers maintain and improve open-source projects, resulting in constant updates and improvements. Users can modify open-source software to meet their specific requirements, tailoring it to individual or business needs. (Mertic 2023, 3-5.) A small selection of popular open-source software projects can be found in APPENDIX 1.

Paton & Karopka's (2017) study on the role of Free/Libre and Open source Software (FLOSS) in modern healthcare information technology infrastructure found that this technology is increasingly used for electronic patient data collection, including Electronic Health Records (EHRs), and research and quality improvement in healthcare. Additionally, this data is reused under a Learning Health System (LHS) that encompasses data collection, analysis, and health service improvement. This study points out that open-source software is vital in developing such learning systems and emphasises its promotion, collaboration interoperability and data security matters.

The open-source hardware model is analogous to the software variant, except that it deals with physical products, devices, or systems whose designs and specifications are made freely available to the public and are referred to as open-source hardware (OSH). A study by Wenzel (2023) discusses the role of such open hardware in biology laboratories, particularly in low-resource settings. While cost saving is essential, other reasons include faster adoption of new methods, timely feedback, and improved designs through open-source solutions. Furthermore, the availability and reusability of tools like Arduino and Raspberry Pi boards make them popular in settings where resources are limited or low. Open technology is cost-efficient and technically challenging, which contributes to its versatility. However, lack of awareness and institutional support are barriers preventing the adoption of open hardware. (Wenzel 2023.)

Designers make design files, schematics, and specifications available under open licenses (for example, Creative Commons or CERN OHL), allowing anyone to access, modify, and distribute them. Thus, it is a hardware platform that is affordable and non-proprietary, where all design information is open to the public, increasing trust, accountability, and accessibility. A worldwide community of makers, engineers, and hobbyists frequently collaborate to improve and evolve designs. The hardware is accompanied by detailed documentation, making it easier for users to understand and replicate. The community's collective wisdom fosters innovation as people from various backgrounds contribute their expertise and ideas. It democratises technology access by promoting affordability and lowering entry barriers for inventors, startups, and underprivileged communities. Users can customise the designs to meet their requirements, resulting in personalised and locally relevant solutions. (Wenzel 2023.) Open-source hardware is a valuable educational resource that allows students and enthusiasts to explore, learn, and experiment. It promotes sustainability by sharing and reusing designs, reducing electronic waste, and encouraging eco-friendly practices. The practical applications and examples of open-source hardware can be found in APPENDIX 1.

3.4 Unity Engine

The Unity Engine is a powerful and versatile tool for creating 3D, 2D, virtual, and augmented reality experiences. Unity enables developers to create and publish games, simulations, and interactive applications across multiple platforms. It is intended to be user-friendly and accessible to people of all skill levels, from beginners to professionals. With real-time rendering and high-quality graphics, Unity allows one to create stunning 2D and 3D visuals. It includes physics engines that enable the creation of realistic movements and interactions for game objects. (Borromeo 2022, 181-206.) The creations or graphics can be exported to various platforms, including personal computers, mobile devices, consoles, and web browsers (Borromeo 2022, 627-638). The Unity engine also assists in managing and organising assets such as 3D models, textures, and sound files. Individuals can use C# or UnityScript, the company's scripting language, to create game logic and interactivity. (Borromeo 2022, 79-135.) This engine includes a robust animation system that allows bringing characters and objects to life with complex animations and behaviours (Borromeo 2022, 537-587). Therefore, it is widely used for creating virtual reality (VR) and augmented reality (AR) experiences, making it an essential tool for these emerging technologies (Borromeo 2022, 639-672).

Unity's easy-to-use interface and drag-and-drop functionality suit beginner groups who do not have prior coding experience. The Unity community is large and active, with plenty of tutorials, forums, and assets to assist newcomers. Unity's ability to export to multiple platforms makes it a versatile choice for developers. While working on a particular project, one can see the real-time changes, speeding up the development process. Unity includes a large asset store with ready-made assets, scripts, and tools to help with a project. Unity is adaptable to different project sizes because it suits small indie game developers and large studios. Game and interactive application development has traditionally been associated with large budgets, often necessitating large sums of money to access advanced tools and technologies. (Foxman 2019.)

On the other hand, the Unity Game Engine has upended this paradigm by providing an affordable and accessible solution for game developers working on tight budgets. Unity has a Personal Edition free for individuals or small teams earning less than $100,000 annually. It means developers can use Unity's power without incurring any upfront costs, making it an excellent choice for indie developers and startups. This information is provided on the official website of the Unity engine, www.unity.com.

4 PURPOSE AND OBJECTIVES

The purpose of this thesis is to explore the practicality and effectiveness of using innovative open-source technologies to develop applications that address healthcare challenges in remote and underserved areas. The focus is on two key applications - an electrocardiography (ECG) interpretation app and a remote monitoring system. The ECG interpretation app prototype is designed to assist healthcare professionals, especially those lacking expertise in ECG interpretation. The remote monitoring system is aimed at supporting elderly and physically challenged individuals living independently. The overarching goal is to enhance healthcare provision in remote areas by leveraging accessible and cost-effective open-source solutions. This thesis employs an action-based research methodology which is suited for developing and refining practical applications in healthcare.

The primary objectives are:

To assess healthcare challenges:

- in remote and underprivileged areas, with a particular focus on low-middle-income countries, exemplified by India.
- understanding the challenges an ageing population faces and the necessity for effective remote monitoring systems.

To provide healthcare solutions:

- by addressing the lack of ECG interpretation skills and expertise and exploring the recent advancements in ECG interpretation applications.

To understand the legalities:

- investigating the legal frameworks associated with software as a medical device, ensuring compliance and safety in application deployment.

To investigate technologies:

- for exploring the application and integration of open-source technologies and platforms like Unity Engine, OpenCV, Raspberry Pi, and Pi camera in developing the ECG and remote monitoring prototypes.

To evaluate results for deployment:

- by assessing the efficacy and suitability of these technologies for use in remote and underprivileged scenarios.
- to outline potential future research directions in this field, focusing on the scalability and adaptability of solutions.

This thesis aims to harness the potential of open-source technologies to improve healthcare accessibility and affordability, offering innovative solutions to longstanding challenges in remote healthcare delivery.

5 RESEARCH IMPLEMENTATION

Action research addresses social and professional problems through a cycle of action and reflection, focusing on making positive improvements. Unlike more conventional research methods, it stands out for its ability to bring about meaningful changes. The approach emphasises avoiding rigid top-down implementation of unsuitable policies, favouring a flexible and iterative bottom-up approach. This research provides a chance to connect theory with practical application, leading to positive and lasting change. (Hammond & Wellington 2020, 4-5).

Applied research is a systematic and practical investigation to solve problems or address practical questions. Unlike basic or theoretical research, which seeks to enhance understanding or develop theories without immediate application, applied research focuses on the practical application of knowledge to real-world issues. The primary goal of applied research is to generate practical solutions, innovations or interventions that can be directly applied to specific situations or problems. It often involves using existing knowledge and theories in a practical context to solve problems or improve processes. (Brown & Kathleen 2014, 1-2).

For this thesis, a combination of action-based and applied research has been used as it was best suited for implementing such a project. The theory background analyses the challenges in remote healthcare and the ageing population. Through the action research, the plan was made to investigate the available open-source technology that can be used to create the desired application: ECG interpretation and remote monitoring system. These applications are proposed as practical solutions and opportunities to explore new technology to solve problems. However, I collaborated with an IT consultant with experience and knowledge about using open-source technology to proceed with the plan. I understood the requirements and expectations of the application prototypes that I envisioned. This way, action research offered an opportunity to create a bridge between theory and practice that resulted in desirable outcomes. The applied research practically implemented this idea by examining open-source technology and generating innovative prototypes to help with healthcare challenges in remote healthcare.

During the development of the ECG interpretation application, it quickly became apparent that defining a proper scope was crucial. For example, it would have been nice to have automatic curve detection. However, this is not a trivial problem to solve. Commercial applications with such features also have a dedicated team of experts working on such features. Additionally, collaboration with an IT consultant presented challenges in aligning project goals with technical capabilities; however, these hurdles were mitigated through iterative feedback and adaptation. After recognising the need to concentrate on our subset of the ECG diagnosis domain due to resource limitations, it was prioritised that the essential features be developed first. However, future iterations would benefit from broader engagement with healthcare professionals to refine the application's clinical accuracy and user interface.

The decision to employ action-based research over other methods was informed by the need for continuous improvement and direct feedback from the practical deployment of the prototypes. The chosen methodologies allowed for a more comprehensive understanding of the challenges and facilitated the development of tailored solutions, which more rigid research frameworks might have constrained.

In designing the ECG interpretation prototype, I employed a creative approach by integrating feedback from multiple iterations, ensuring the application was user-friendly and effectively met clinical needs. My initiative in adapting open-source tools for the remote monitoring system was driven by a commitment to cost-effectiveness and accessibility, which is crucial in resource-limited settings. Collaboration with an IT consultant was orchestrated independently, leveraging their expertise to refine the application prototypes, underscoring my proactive stance in seeking and integrating specialised knowledge.

The open-source technology's information retrieval and analysis process was meticulously documented, from the selection criteria based on features and community support to the testing phases that validated each tool's compatibility with our objectives. I have described the rationale behind choosing Unity engine and OpenCV, considering cost flexibility and the breadth of the existing developer community. The implementation phase was explicit in its description, delineating the steps to develop the ECG interpretation algorithm and the remote monitoring systems' facial recognition feature. By justifying open-source technology, this research ensured practical grounding and demonstrated adaptability to the healthcare context in remote areas. FIGURE 1. depicts the concise overview of my overall research implementation plan. The iterative testing and refining of the prototypes per the feedback obtained is the cyclical process of developing prototypes.

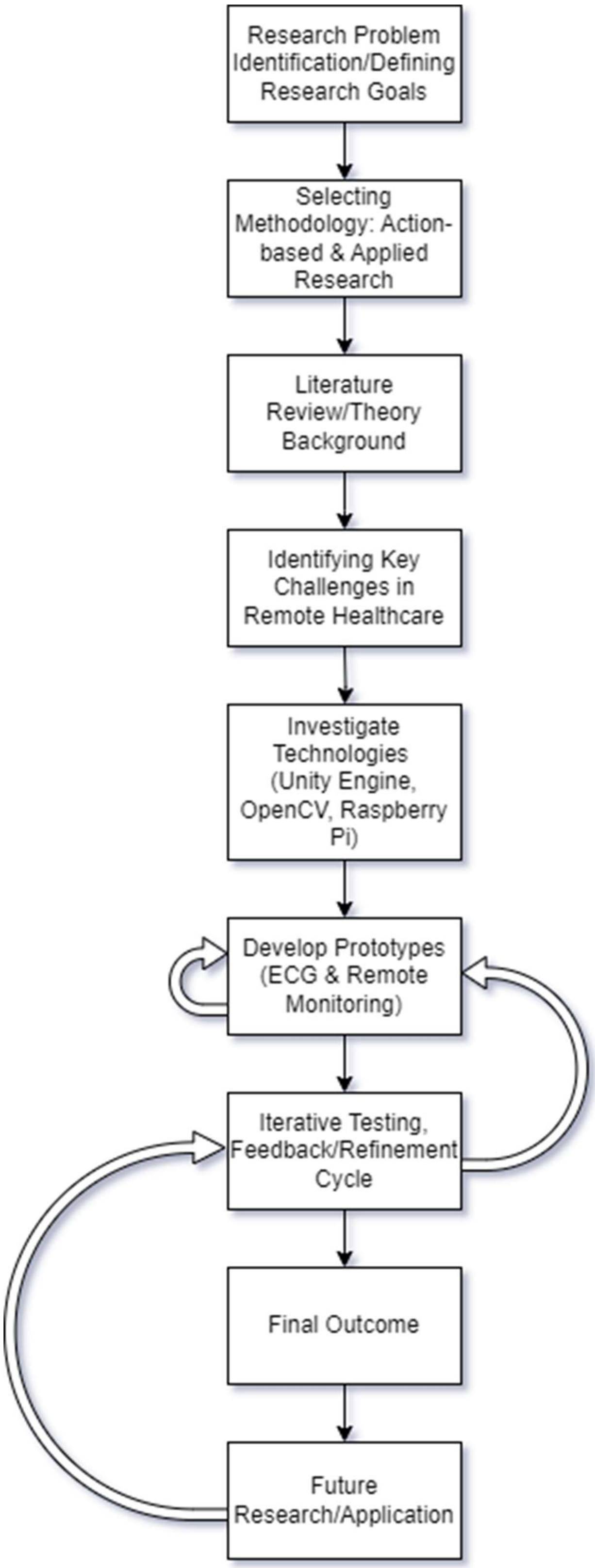


FIGURE 1. Research implementation flowchart

5.1 Design and implementation of the ECG application

In order to design and implement the prototype ECG application, it was first necessary to dive deeper into the theory of knowledge-based systems (KBS) so that the required expert knowledge could be expressed in a way suitable for application implementation. In this case, the expert knowledge took the final form of a flowchart based on propositions. A path through the flowchart can be inferred depending on the value of the propositions and the defined rules. Following this, a software design phase took place in which some fundamental choices were made about application structure, data flow and functionality. Finally, the prototype ECG application was implemented using Unity Engine.

5.1.1 KBS Deeper Dive

Technically, a knowledge base is a set of sentences. In this context, the word sentence is not the same as a sentence in a natural language but rather a technical sentence expressed in a language called a knowledge representation language. Such a sentence expresses some assertion about the world. In this case, the word world denotes the domain under consideration, not the entire world we live in. (Russel & Norvig 2003, 195.) The sentences must be expressed using the syntax of whatever representation language is chosen. The syntax specifies whether a particular sentence is well-formed or not. Furthermore, the semantics of the language must also be defined. While syntax specifies the form, semantics specifies meaning. A commonly used representation language in KBS is logic. In logic, semantics is exact. In this case, the semantics defines each sentence's truth (true or false) concerning each possible world. (Russel & Norvig 2003, 201.) The framework of KBS for the ECG prototype application is shown in FIGURE 2.

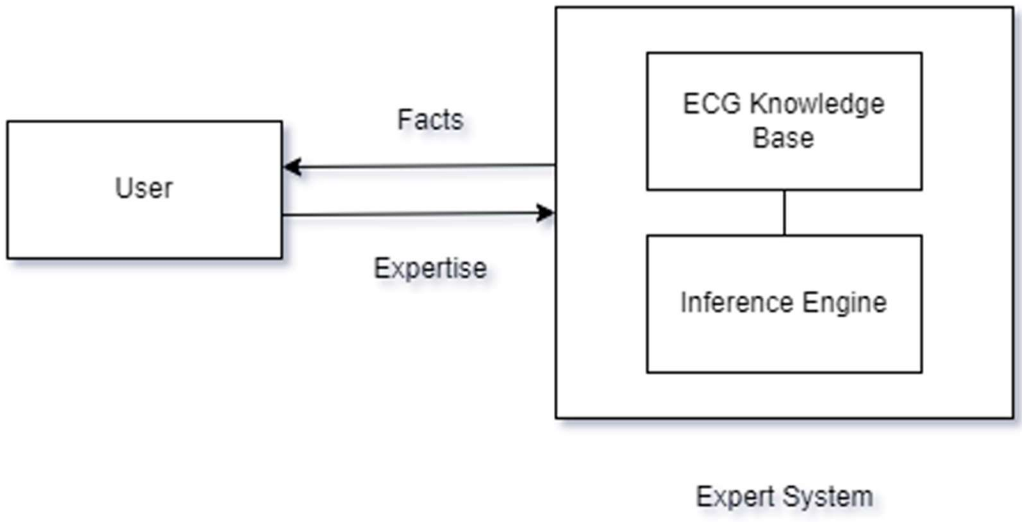


FIGURE 2. Knowledge-based system framework for the ECG prototype application

A straightforward propositional logic defined expert knowledge for the ECG prototype application. The syntax of propositional logic defines the structurally correct sentences. The atomic sentences, essential elements that cannot be further split, consist of a single proposition symbol. Each symbol thus represents a proposition that can be either true or false. Complex sentences are constructed from more straightforward sentences using logical connectives. There are five standard connectives:

negation (¬), conjunction (∧), disjunction (∨), implication (→) and biconditional (↔). (Russel & Norvig 2003, 204-205.)

Using propositional logic, a simple knowledge base can be defined. To illustrate this, consider the following simple set of questions taken from the ECG knowledge base or ECG interpretation questionnaire or flowchart from APPENDIX 4 as a simple example of the ECG diagnosis domain in an expert system:

1. Does the ECG have a standard calibration mark?
2. Do the waves in aVR show negative deflection?
3. Do waves in Lead I and Lead II show positive deflection?

Three propositions, A, B and C, can be defined from these questions. The following rules can then be defined based on the given questions:

1. A is true if the ECG has a standard calibration mark.
2. B is true if the waves in aVR show negative deflection.
3. C is true if the waves in Lead 1 and Lead II show positive deflection.

Then, any sentence composed of these propositions can be evaluated. For example:

R: A ∧ B ∧ ¬C

In this case, sentence R evaluates to be false. Given more propositions that express questions and more sentences using those propositions, an inference algorithm could be used to query the knowledge base on the truth of any given sentence. An example of a simple inference algorithm is given in the following FIGURE 3.

```
function TT-ENTAILS?(KB, α) returns true or false
        inputs: KB, the knowledge base, a sentence in propositional logic
                α, the query, a sentence in propositional logic
        symbols ← a list of the proposition symbols in KB and α
        return TT-CHECK-ALL(KB, α, symbols,{ })

function TT-CHECK-ALL(KB, α, symbols, model) returns true or false
        if EMPTY?(symbols) then
                if PL-TRUE?(KB, model) then return PL-TRUE?(α, model)
                else return true || when KB is false, always return true
        else do
                P ← FIRST(symbols)
                rest ← REST(symbols)
                return (TT-CHECK-ALL(KB, α, rest, model ∪ {P = true})
                and
                TT-CHECK-ALL(KB, α, rest, model ∪ {P = false}))
```

FIGURE 3. Simple inference algorithm (Russel & Norvig 2003, 209)

5.1.2 Expert Knowledge

Expert knowledge is an explicit source of knowledge or information from any particular domain obtained via in-depth understanding, experience, critical thinking, and problem-solving within that particular field. Such expertise is gained from applying that specific knowledge in various challenging scenarios where one has to analyse complex problems, find solutions, and make informed decisions based on knowledge and experience. (Caley et al. 2014; Hetmanski 2018.) Maintaining expert knowledge is critical to continuous learning and keeping up with the latest developments as the field evolves. Additionally, experts are those their peers recognise in the same field, which comes through publications or achievements within the profession (Hetmanski 2018). Knowledge acquisition is the most crucial element of building knowledge-based systems, and this knowledge is obtained from experts to create a knowledge base to be processed through an inference engine.

Ideally, the knowledge from experts is acquired via questionnaires, interviews and analysing protocol (Edwards & Cooley 1993, 660); however, for this thesis, the expert knowledge required to implement the ECG prototype app was distilled by studying various professional literature on ECG interpretation. This decision was made after acknowledging that it was not feasible to approach experts unless it was a funded project where access to experts' time and effort would not be an issue in acquiring the knowledge. Therefore, three books were shortlisted to obtain the required knowledge for the ECG prototype app. These books were 'P. J. Mehta's Understanding ECG Electrocardiography', 'Guyton and Hall Text Book of Medical Physiology', and 'The ECG Made Easy by John Hampton'. In order to understand ECG, it is vital to have a good understanding of normal heart anatomy and its electrophysiology. A brief synopsis related to this topic can be found in APPENDIX 2. The next step was to understand the basic concepts of electrocardiography. APPENDIX 3 provides a concise overview of this subject matter. Thus, given the vast scope of the subject, the choice was soon made to focus on creating a prototype design and defining rules for a subset of the ECG diagnosis domain.

An ECG investigation is always recommended whenever a patient presents with cardinal symptoms suggesting issues related to the cardiovascular system. These cardinal symptoms include chest pain, dyspnea or breathlessness on exertion, palpitations, vomiting, sweating, and syncopal attacks. The flowchart created as a knowledge base found in APPENDIX 4 begins with basic concepts of ECG followed by filling in the patient information such as name, age, sex, pre-existing medical conditions like hypertension, diabetes mellitus, stroke, hyperlipidemia, and current complaints. Understanding intricate and complex ECG patterns is a skill acquired through experience and a deep understanding of the subject. However, at the fundamental level, a general physician is expected to be acquainted with common ECG findings. Therefore, the most common ailments related to possible ECG findings concerning cardiovascular disorders were short-listed to implement the prototype ECG app. (see FIGURE 4.) The standard calibration of ECG paper, normal rhythm and rate, methods to calculate heart rate in regular and irregular heartbeats, and lead-specific ST segment pattern changes indicating specific myocardial wall or area involvement in myocardial infarction were also studied and included in the flowchart. The idea was to cover the most common probable findings on ECG, which are suggestive of issues concerning cardiac illnesses. The step-by-step progression of how to approach reading an ECG, from calibration details to peculiar wave patterns, was created using YES and NO flowcharts. This was done because it was easier to deduce rules based on the flowchart for the prototype app. The images to point out details of ECG wave patterns in various cardiac conditions were obtained from personal collection and #FOAMed Medical Education Resources by LITFL, which is licensed under a Creative Commons Attribution -NonCommercial -ShareAlike 4.0 International license. Please refer to Appendix 2, Appendix 3, and Appendix 4 for the flowchart produced in this phase of expert knowledge acquisition.

Interpretation of ECG corresponding to a component	**ECG patterns studied and included in creating the flowchart for the app prototype**
Rhythm and rate	Normal sinus rhythm, sinus bradycardia, sinus tachycardia, and sinus arrhythmia Ventricular premature beats/premature ventricular complexes, ventricular tachycardia, ventricular fibrillation, Torsade de Pointes, atrial fibrillation, and atrial flutter
Axis of heart	Normal cardiac axis, right axis deviation, and left axis deviation
Chamber hypertrophy	Right atrial hypertrophy, left atrial hypertrophy, right ventricular hypertrophy, and left ventricular hypertrophy
Conduction defects	First-degree heart block, second-degree heart block/Mobitz Type 1, second-degree heart block/Mobitz Type 2, third-degree or complete heart block, right bundle branch block, and left bundle branch block
ST segment changes and T wave abnormalities	Myocardial infarction, myocardial ischaemic, and hyperkalaemia

FIGURE 4. The basic components of ECG are included in the ECG app prototype.

5.1.3 Software Design

A fundamental desire expressed from the start was that the prototype ECG application, despite being a prototype, should not be a quick and dirty hack but follow some general software development best practices. This ensures that maintenance and further extension of the application will not require starting from scratch. An event-driven application architecture was chosen to keep critical modules loosely coupled, making separating concerns easier. Furthermore, instead of hardcoding rules and questions, it was chosen to use JSON to ingest all the required data into the system. For example, they were building on the example questions from the previous section. This illustration is shown in FIGURE 5.

```json
{
  "propositions": [
    {
      "name": "1A",
      "question": "Does the ECG have a standard calibration mark?"
    },
    {
      "name": "1B",
      "question": "Do the waves in aVR show negative deflection? (see Figure 5)"
    },
    {
      "name": "1C",
      "question": "Do waves in Lead I and Lead II show positive deflection? (see Figure 5)"
    }
  ]
}
```

FIGURE 5. JSON structure for defining propositions (Padvi 2023, CC BY -NC-SA)

It was decided to employ finite state machines (FSM) to navigate the user through the knowledge flowchart via forms defined in the user interface. The key modules were identified as follows:

1. AppManager: Responsible for the application lifecycle, UI (user interface) transitions, positioning and miscellaneous tasks.
2. FSM Manager: Responsible for keeping track of all active FSMs in the system and reacting to events fired by every FSM. These events could be user input, FSM completion, branching, etc.
3. InferenceEngine: Responsible for maintaining the knowledge base and answering queries given to it.

These modules would be defined as singletons and be primarily responsible for the correct operation of the application.

5.1.4 Implementation Using Unity Engine

Given the global design ideas and requirements, several supporting data structures and components were defined in Unity during the implementation phase. Further elaborating on the example questions from the previous sections, FIGURE 6 shows a snippet of the user interface in the following figure:

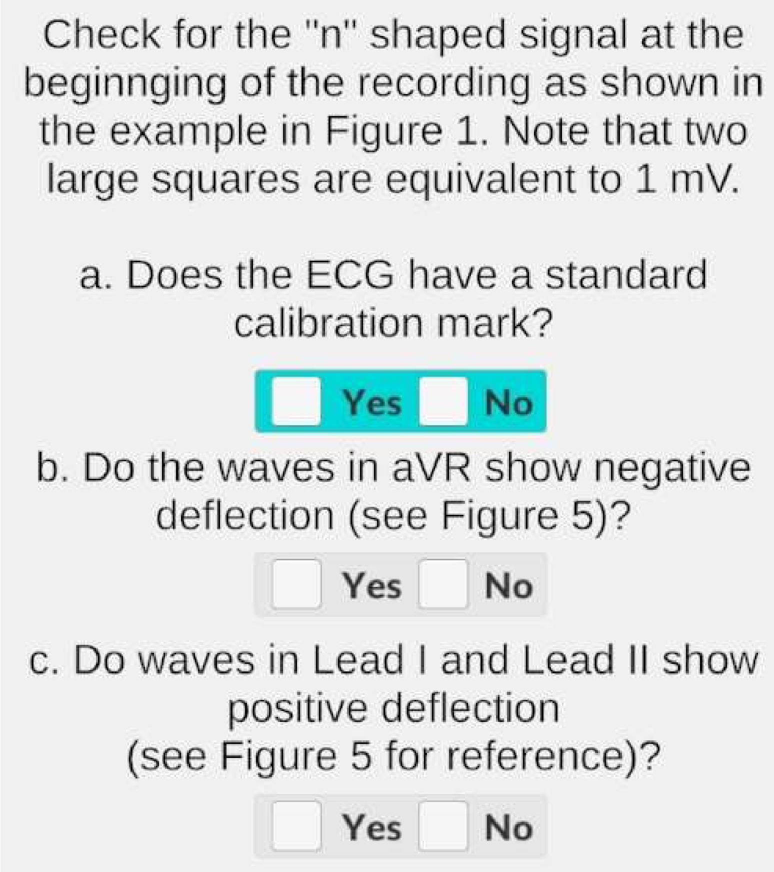


FIGURE 6. Part of the user interface for the ECG prototype application (Padvi 2023, CC BY -NC-SA)

An interface called FormInput was defined, laying the basis for all form-related elements required for the operation's proper operation. Three classes implementing the FormInput interface were defined: YesNoToggle, InputField, and FormCondition. The YesNoToggle class defines the Yes/No checkboxes as depicted in FIGURE 6 and implements their proper execution. A YesNoToggle can be a standard toggle or define special conditions depending on whether "Yes" or "No" is chosen. Those special conditions include a terminal "Yes" or "No", meaning that the flow ends then and there. For example, if one answered "No" to the first question in the example, the flow would end then and there, as the ECG prototype app's knowledge base does not have the knowledge to interpret ECGs without a standard calibration mark. Another noteworthy condition is a branching operation to an entirely different flowchart section. The InputField FormInput allows a user to enter data manually, and the FormCondition FormInput imposes a condition on the current form before letting the user move ahead. For example, an ECG screenshot must be loaded early in the flowchart. There is a FormCondition for this. The user cannot proceed without loading an ECG, as there would be nothing to interpret.

Proposition and FSMComponent (finite state machine component) are the critical data structures.

```
[System.Serializable]
10 references
public class Proposition
{
    public string name;
    public string question;
    public bool? value = null;

    3 references
    public Proposition(string name, string question)
    {
        this.name = name;
        this.question = question;
    }
}
```

FIGURE 7. Proposition Class (Padvi 2023, CC BY -NC-SA)

The proposition contains a proposition in the sense of a logical proposition, as defined in section 5.1.1, and a related question for convenience. (see FIGURE 7.)

```
public class FSMComponent
{
    public FormInput formInput;
    public ComponentType type;
    public Proposition proposition;

    public string conclusionOnTermination;
    public string subConclusion;

    public int? nextScreenOnBranchingYes = null;
    public int? nextScreenOnBranchingNo = null;
    public int? nextScreen = null;

    3 references
    public FSMComponent(FormInput formInput)
    {
        this.formInput = formInput;
    }
}

7 references
public enum ComponentType
{
    YesNoToggle,
    TextField,
    FormCondition
}
```

FIGURE 8. FSMComponent Class (Padvi 2023, CC BY -NC-SA)

The FSMComponent, as seen in FIGURE 8, is the essential component on which all FSMs (finite state machines) are built. Each FSM holds a list of FSM components. The FSMComponent contains a FormInput, a proposition, information about conclusions, terminal conditions, branching conditions, and screen flow. Each FSM initialises itself by reading out its FSM components and keeping track of an internal state until, depending on user input, it fires a completion event. This can mean that it needs all questions to be filled in (either sequentially or simultaneously – each FSM has an enum specifying an FSMInputType), or it could mean that one of the questions leads to a branch condition, in which case the FSM will still first fire a completion event because branching will take the user to another FSM.

Each FSM is related to one specific user input screen or form. For example, the ECG Setup screen is shown in FIGURE 9. There is one FSM associated with this screen. It contains one FormInput, namely a FormCondition. The condition is that an ECG image has to be loaded; otherwise, the user cannot proceed. The FSM only fires a completion event once the FormCondition is satisfied. Once the completion event is fired, the user can proceed to the next screen. Of course, the user can still edit the photo in this particular case. The FSM will still be complete because the ECG has been loaded.

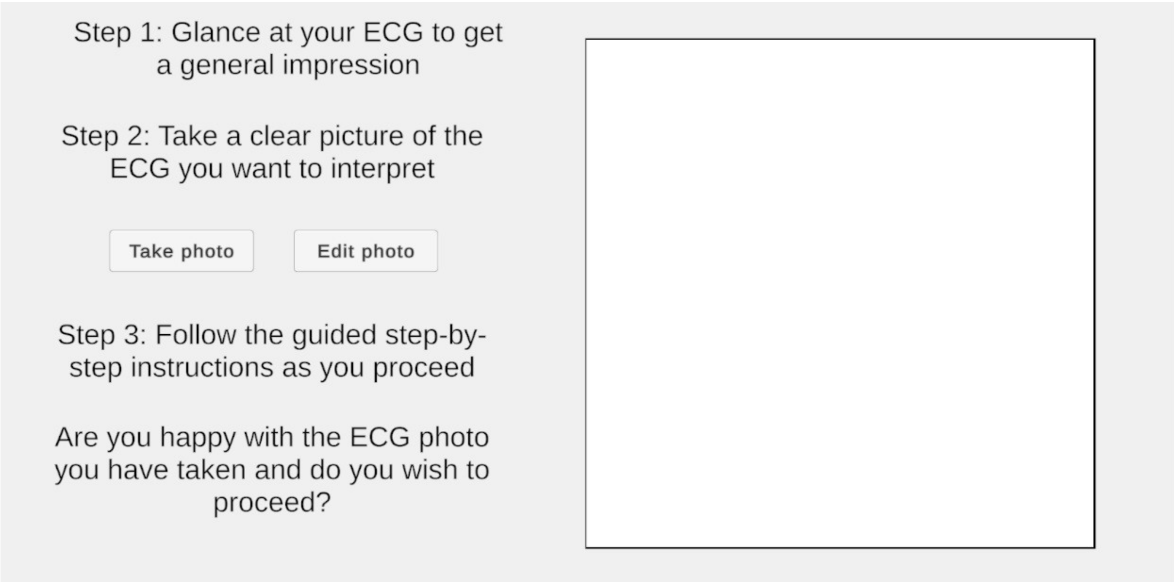


FIGURE 9. The ECG Setup screen (Padvi 2023, CC BY-NC-ND 4.0.)

FIGURE 10 and FIGURE 11 are the flow samples through the implemented application. However, a demonstration of the complete sample flow from start to finish can be found in APPENDIX 6.

FIGURE 10. A sample of the title screen of the app. (Padvi 2023, CC BY-NC-ND 4.0.)

The app starts with the title screen. There is also a disclaimer here since this app is a SaMD prototype and should not be used for medical diagnosis.

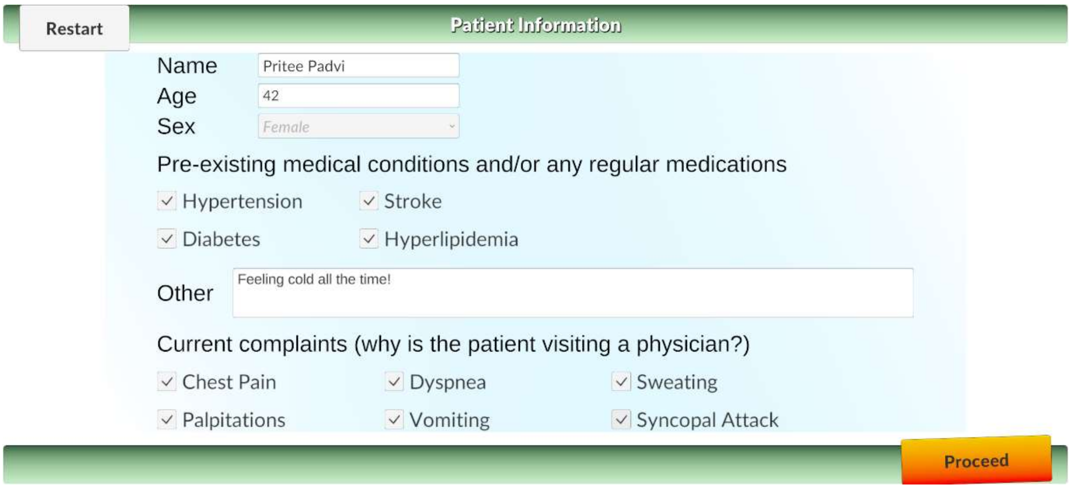


FIGURE 11. A sample of patient information must be filled in the app. (Padvi 2023, CC BY-NC-ND 4.0.)

5.2 Design and experimentation of remote monitoring application

The inspiration for a remote monitoring application came from Morreira, Soares, Torres, and Sobral's paper (2020), which discusses the various possibilities for using IoT (Internet of Things) in healthcare systems. This simple and elegant design illustrated in FIGURE 12 depicts a straightforward approach to analysing images for a remote monitoring system.

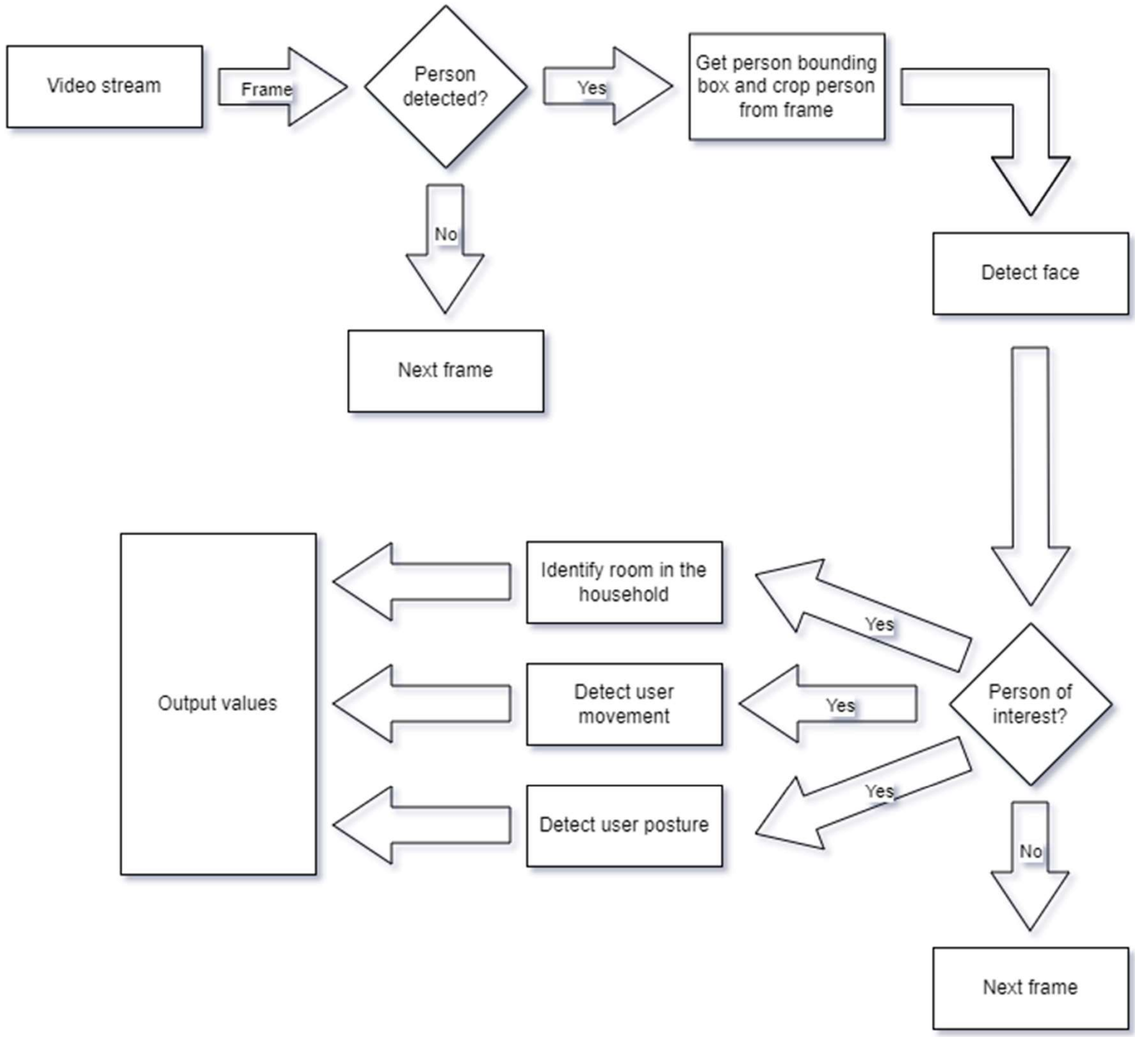


FIGURE 12. Remote monitoring system design

In a nutshell, the proposed system analyses video on a frame-by-frame basis. For each frame, if no person is detected in that frame, it is discarded, and the system moves on to the next frame. If a person is detected in a frame, the system moves on to the next step, establishes a bounding box around the person in the image and crops that section out of the frame as new image data. After this, from this specific image data, it detects the face of the person. Next, it is determined if this is a person of interest, such as a patient being monitored. It would not be beneficial for the system to monitor a guest or any other person not of interest in the specific scenario. If a person of interest is not identified, the system discards the data and moves on to the next frame. If it is a person of interest, then the system can carry out any further processing that may be desired, such as identifying which room the person is in, what type of posture the person is in, the type of movement he or she is making, and so on. This system can very well be implemented with existing open-source software and hardware. By choosing this route, it would become possible to bridge the gap of limited access to healthcare facilities in remote areas by making it an affordable and scalable solution for remote patient care, particularly in areas where monitoring patients' health remotely is crucial.

The open-source implementation of such a system could be done using the following hardware and software components:

Raspberry Pi: The low-cost and versatile core computing device or a single-board computer.
Raspberry Pi Camera: An affordable, cost-effective camera capturing images for analysis.
OpenCV Library: An open-source computer vision library for image processing.
Internet Connection: Facilitates data transmission, enabling remote monitoring.

The system continuously captures images through the Raspberry Pi Camera. The images are processed using OpenCV, allowing the system to perform essential functionalities, including motion, face recognition and fall detection. Motions are detected by identifying the changes in the camera feed, ensuring attention to significant events. The face is recognised when the patient's face is captured within frames, and the fall is detected by analysing the patient's motion patterns. Alerts are generated only when both face recognition and fall detection occur. This design, utilising affordable open-source hardware and open-source software, aims to bridge healthcare gaps in remote areas, offering a scalable solution for remote patient care. It can ensure that doctors are notified only when a recognised patient is in distress, enhancing the system's specificity and reducing false alarms.

Raspberry Pi and open-source software are affordable, making the system accessible in resource-constrained areas. The modular design allows for easy scalability to monitor multiple patients or rooms. Overall, the system enables healthcare professionals to monitor patients' well-being remotely, reducing the need for frequent physical checkups. The cost-effective nature of Raspberry Pi and open-source software makes the system financially viable in low-resource settings. The open-source approach allows communities to access and modify the system to suit local needs and simultaneously decreases dependence on expensive, proprietary healthcare solutions, making healthcare monitoring more sustainable in remote and underprivileged areas. Potential future enhancements include integrating additional sensors for vital sign monitoring, optimising the system for low-bandwidth environments, and further customisation for diverse healthcare needs in different regions. This system represents a step towards democratising healthcare, making remote patient monitoring a reality even in remote and underprivileged areas.

The following open-source Facial Recognition API, written in Python, was used for this experiment: https://github.com/ageitgey/face_recognition/tree/master.
The training set, as seen in FIGURE 13, was offered using this software. Then, using Raspberry Pi, Raspberry Pi camera, and the software, the system could recognise me, as depicted in FIGURE 14.

The GitHub repository of the Facial Recognition API also provides a good collection of ready-made demos and code examples that can be used to test the API and can be modified as required. For recognition of faces in a live video stream, Facial Recognition API uses OpenCV.

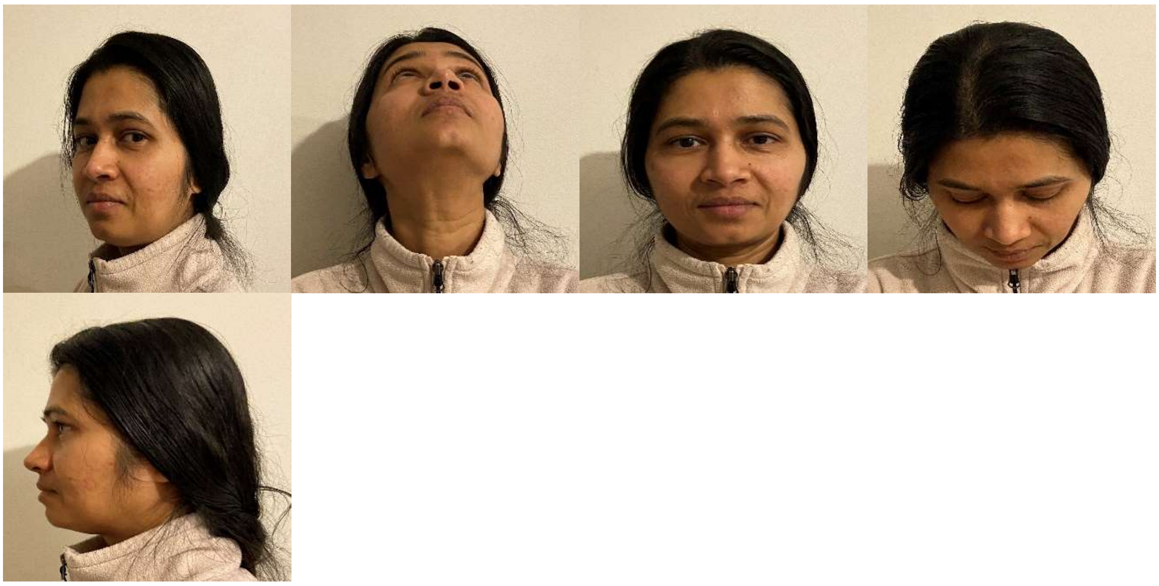


FIGURE 13. The training set (Padvi 2023, CC BY-NC-ND 4.0.)

FIGURE 14. Face recognition (Padvi 2023, CC BY-NC-ND 4.0.)

6 RESULTS

6.1 ECG interpretation prototype application

The knowledge base system for the ECG prototype application was successfully created using propositional logic, which helped create a step-by-step guide for making decisions that helped navigate different possibilities based on specific facts and rules. This explicit representation of expert knowledge in the form of propositions and rules provided clarity in the decision-making process. It directed an efficient and structured implementation of the ECG prototype application. Expert knowledge for this prototype was acquired through an in-depth study of professional literature on ECG interpretation and outcome, encompassing normal heart anatomy, electrophysiology, and ECG patterns in selected cardiac conditions. It was distilled to form the basis for the application as a knowledge base. A detailed overview of this study can be found in APPENDIX 2, APPENDIX 3, and APPENDIX 4. The expert knowledge from APPENDIX 4 was used to create and define propositional logic or inference algorithms for the inference engine part of the knowledge-based system framework. Furthermore, JSON was employed for defining propositions (see FIGURE 5), which allowed flexibility and ease of data ingestion. Finite state machines (FSM) guide users through the knowledge flowchart via user interface forms. The key modules, including AppManager, FSM Manager, and Inference engine, were identified to ensure the proper functioning of the application.

Implementing the ECG prototype application using the UNITY engine involved creating supporting data structures and components. The user interface focused on user interaction (see FIGURE 6), featuring elements like YesNo Toggle, InputField, and FormCondition. Proposition (FIGURE 7) and FSMComponent (FIGURE 8) were identified as critical data structures with propositions encapsulating logical statements and FSMComponent serving as the foundation for finite state machines. This was applied to all the information provided in APPENDIX 4.

The implemented application follows a structured flow, starting with a title screen and incorporating a disclaimer due to its prototype nature (FIGURE 10). A sample flow was demonstrated, showcasing the navigation through screens such as the ECG Setup screen, where conditions such as loading an ECG image were enforced (see FIGURE 9, FIGURE 10, and FIGURE 11). The user interface facilitated a step-by-step progression, adhering to the defined rules and propositions. See APPENDIX 6 for a complete sample flow from beginning to end. In order to have a complete experience of this research project, the created application prototype should be used. The link to download this application is -
https://www.dropbox.com/scl/fi/kcyyycw8gv8tlwtekbawv/ECG.apk?rlkey=va7tz9pmz29hxlthhuwht693h&dl=0

However, please note that this prototype should not be used for medical diagnosis.

6.1.1 Evaluation and validation

The prototype application underwent a demonstration phase, and preliminary user feedback was obtained to assess its usability and effectiveness. The application's responses to user inputs were evaluated, and any identified issues were addressed to enhance the overall user experience. Additional user feedback should be obtained from outside parties to increase the effectiveness of this application. The created prototype guides the user in interpreting an electrocardiogram.

6.1.2 Challenges and limitations

Several challenges were encountered during the development and implementation phases. These included technical constraints, resource limitations, and the need to focus on a subset of the ECG diagnosis domain. Acknowledging these challenges is crucial for understanding the scope and potential improvements of the prototype.

6.2 Results from the remote monitoring application

The remote monitoring application prototype system proved effective in capturing, processing, and analysing video frames for remote patient monitoring. The system successfully recognised the test subject using the open-source Facial Recognition API, as demonstrated in Figure 14. The modular design allowed for easy scalability, allowing it to monitor multiple patients or rooms. The system's key features include motion detection, face recognition, and fall detection. Motions are detected by identifying the changes in the camera feed, ensuring attention to significant events. The face is recognised when the patient’s face is captured within frames, and the fall is detected by analysing the patient’s motion patterns. Furthermore, when face recognition and fall detection occur, alerts are generated.

The cost-effective nature of Raspberry Pi and open-source software makes the system accessible in resource-constrained areas. The system represents a significant step in democratising healthcare by enabling remote patient monitoring, even in remote and underprivileged areas. Future enhancements could involve integrating additional sensors for vital sign monitoring, optimising for low-bandwidth environments, and further customisation for diverse healthcare needs in different regions.

6.2.1 Challenges and limitations

The accuracy of face recognition algorithms may be affected by varying lighting conditions, facial expressions or obstructions.

The system may generate false positives or false negatives in detecting faces and falls. Fine-tuning the algorithms is crucial to minimise such errors and increase the system’s reliability.

Remote monitoring relies on a stable internet connection. In areas with poor connectivity, delays or interruptions in data transmission can affect the real-time monitoring capabilities.

Continuous video monitoring raises privacy concerns. Striking a balance between effective monitoring and respecting an individual’s privacy rights poses a challenge. Implementing robust privacy measures is essential.

7 DISCUSSION AND CONCLUSION

The purpose of this thesis is to offer healthcare solutions to assist healthcare staff working in remote areas. This thesis explores reasons for choosing open-source technologies to create these applications and explains their implementation process. Based on the reviewed literature as a part of action research, one issue identified through action research among various challenges was the availability of expert physicians, such as cardiologists, in remote areas. Healthcare units in rural areas often rely on less experienced or less qualified professionals to provide medical care. An ECG investigation is the most common investigation often advised or performed whenever patients present with acute chest pain or have a history suggestive of cardiovascular illnesses. Medical graduates are expected to read ECG accurately, but this skill needs to be improved in some medical professionals despite being an essential part of their final medical examination. A rural health centre's doctor or healthcare staff must work with limited resources and deal with other challenges. Therefore, the primary goal of this thesis is to assist healthcare professionals, especially those lacking expertise and provide support in situations with staff shortages. Like the implemented prototype, ECG interpretation apps can save lives by facilitating timely diagnosis. This application is designed for novice practitioners who require assistance or lack advanced proficiency. The application design emphasises simplicity, offering a systematic walkthrough for interpreting electrocardiograms (ECGs) and deriving informed conclusions. Notably, the application has functionality that captures an ECG image that must be interpreted. Subsequently, the application facilitates a comparative analysis between the captured ECG image and exemplar ECGs, guiding users towards conclusive interpretations. Once the picture is taken, the app compares the recorded ECG to the example ECG. This dual interpretation and simultaneous learning process distinguishes the application's educational approach.

The ethical issues regarding such software for medical diagnosis are supervised by regulatory authorities such as the International Medical Device Regulators Forum (IMDRF). Therefore, it is essential to note that the ECG interpretation prototype application developed in this thesis has yet to be a final version ready for the market. This app, currently in its prototype stage, begins with a crucial disclaimer informing users that it is in the initial stage of development and should not be relied upon as a means to diagnose cardiac conditions. This disclaimer is a vital ethical consideration, emphasising that while the app aims to assist healthcare professionals, it is not yet a substitute for professional medical judgment. It reflects the responsibility towards users, ensuring that the technology aids but does not overshadow clinical judgment. Furthermore, this prototype has to undergo a rigorous refinement, testing, and evaluation process according to user feedback from the domain experts and as directed by the regulatory authority associated with SaMD in the respective country of deployment.

At the current stage, the lack of extensive field testing as per the regulatory guidelines impacts the reliability of this application. Feedback from healthcare professionals or potential end-users will be integrated into future development phases. Additionally, if the database of ECG knowledge is expanded, artificial intelligence-based algorithms can be applied in the future. Furthermore, as the technology evolves, the application should be customised and updated accordingly. It is crucial to ensure safety, effectiveness and compliance with regulations.

Although ECG interpretation apps already exist, they have yet to find their way to remote and underprivileged areas. This constraint arises from the intricate regulatory frameworks governing Software as a Medical Device (SaMD), which vary across jurisdictions; coupled with the commercial nature of prevailing applications that render them economically unviable in resource-constrained environments, a vacuum remains to fill. Furthermore, the applications currently on the market integrate Artificial Intelligence (AI), which has enhanced the accuracy and efficiency of diagnosing cardiac abnormalities (Martínez-Sellés & Marina-Breysse). Such sophisticated applications are typically developed by large teams comprising professionals from the medical and IT domains, for instance, PMcardio. Such research project ventures require substantial funding, contributing to their elevated costs and rendering them impractical for deployment in economically constrained regions. In this context, the prospect of implementing applications founded on open-source technology emerges as a viable alternative, promising to mitigate financial burdens significantly. Securing appropriate funding is essential to realise the potential of open-source technology in this regard. A collaborative effort towards this arena could result in developing and deploying cost-effective applications that can significantly diminish the financial barriers associated with existing commercial solutions. Notably, many countries grappling with healthcare challenges in remote and underprivileged regions confront a paucity of government-sponsored research and development funding. A new business model would have to be devised for these countries that use open-source technologies to provide healthcare solutions.

Open-source technology, with its collaborative and cost-effective nature, has the potential to alleviate financial limitations, offering a potent avenue for research and development initiatives operating within constrained financial parameters. Ahmad (2023) mentions in his research that many startup companies use open-source technology for its advantages, such as product efficiency, cost-effectiveness, scalability, and flexibility. Although it can be challenging and time-consuming to learn about this technology, update and integrate software, and go through the regulatory requirements and security concerns, it is still crucial in improving the product's efficiency, especially in the healthcare sector. The studies by Paton and Karopka (2017) and Wenzel (2023) mention the use of open-source technology in their research and its effectiveness. These technologies have enhanced health IT infrastructure, enabling more functionality and user-friendly solutions. The shift towards open hardware, as discussed in Wenzel’s, has particularly aided in overcoming resource constraints, making advanced tools more accessible and cost-effective.

Reflecting on the findings from Msiska & Nielsen's (2017) study, my thesis emphasises the necessity of diverse human resource capacities for the successful deployment and operation of open-source health information systems, especially in developing countries. Drawing from the case study of DHIS2 in Malawi, this thesis also underscores the necessity of continuous capacity building to adapt to rapid innovations in open-source health information platforms, a critical aspect highlighted in the paper. The paper's analysis of the challenges in deploying and maintaining health information systems in developing countries offers a valuable perspective for this thesis, especially regarding the need for a holistic approach to capacity building beyond end-user training.

This thesis highlights similar demands in rural healthcare facilities by echoing the systematic review from Syzdykova, Malta, Zolfo, and Diro (2017), emphasising the need for flexible and reliable open-source EHR systems in low-resource settings. It proposes tailored open-source solutions to address these challenges. Using open-source software in the Kenyan case (Muinga et al. 2018) study aligns with my research's approach, highlighting the benefits of community support and cost-effectiveness in developing healthcare solutions.

It was possible to create these prototypes with collaboration and support from an Information Technology software engineer. This action demonstrates that interdisciplinary collaboration is vital to developing innovative healthcare solutions, just as the study by Amjad, Kordel, and Fernandes (2023) emphasises the need for interdisciplinary collaboration between healthcare providers, data scientists, and other stakeholders in developing AI applications in telehealth. Although AI is not used for this thesis, the interdisciplinary collaboration stands true given the technical aspects of this research.

During this process, I took a brief dive into understanding about this technology. It was like scratching the surface. Part of the learning process involved conducting a technological survey on various open-source technologies and their potential applications. As mentioned earlier, most current applications use AI algorithms, which are readily available. However, the prototype for this thesis work is based on using an actual ECG recordings database for interpretation, which was challenging to obtain. Although I had a physical collection of some ECGs, they were not used because the paper quality degraded, and wave patterns needed to be visible. The digital version of ECG samples is preferable for future research. Furthermore, access to experts like cardiologists would have been genuinely beneficial in extracting and using the expert data for this prototype. This part was dropped due to time and financial constraints. Also, it is worth noting that this ECG interpreting prototype is made using the Unity engine, and there is limited literature on such applications.

About designing and experimenting with remote monitoring applications, the prototype inspiration came from Moreira, Soares, Torres and Sobral's (2020) article and an interview with an elderly individual, Mr Blietz, who has experience using the remote monitoring application for two of his family members. The transcript of this interview is provided in APPENDIX 5. Mr Blietz's son had Down's syndrome, and his wife suffered from chronic respiratory illness and frequent falls and, therefore, needed remote monitoring. However, in both cases, camera or face detection was not part of their remote monitoring system. A discussion with Mr Blietz shed light on his perspectives and experiences, which were pertinent to understanding the impact of technology on people's lives, particularly in the context of safety and well-being where privacy concerns were not a hindrance. The interview offered valuable insights into the evolving relationship between technology and healthcare, as well as the willingness of individuals to embrace monitoring technologies. This information initiated the idea to investigate and experiment with open-source technology, Raspberry Pi, Raspberry Pi camera, open-source software, and wireless connection to recreate a remote monitoring application that could detect faces, motions and falls. Such technology can, of course, also be deployed in remote areas. The results obtained from the experimentation in this thesis prove that face detection functionality can be obtained via open-source technology as a remote monitoring tool. If this application is taken seriously, the next step would be to comply with GDPR and HIPAA regulations to protect patient data or data privacy. The EU's General Data Protection Regulation (GDPR) is the most robust privacy and security law, updated based on the 1995 Data Protection Directive (European Council 2023). Health Insurance Portability and Accountability Act is a federal law in the US that protects sensitive patient information from being disclosed without the patient's consent or knowledge (Centers for Disease Control and Prevention (CDC) 2022).

The outcome of this thesis demonstrates that open-source technology can be utilised to implement healthcare solutions in remote and underprivileged areas despite limited literature due to proprietary issues with existing commercial applications. It is a realistic, feasible, cost-effective and practical solution. To summarise, the Unity Game Engine was used to implement a prototype application for ECG interpretation successfully. Additionally, the remote monitoring system prototype was designed using open-source technology, which practically demonstrates that such innovations can offer sustainable, affordable, and viable solutions to the problems faced by healthcare workers in underserved areas. The ECG interpretation application can help physicians lacking expertise in reading ECGs to reach conclusions while simultaneously learning. Remote monitoring systems can prove helpful in regularly monitoring patients. These elderly or physically challenged individuals want to live independently in remote areas, obliterating their frequent need to visit health centres.

In the process of this research, it became clear and relevant that there is much scope for ongoing research based on the results of this thesis. To name a few: refining the process of eliciting expert knowledge, improving the technical solutions themselves, investigating business models for specific regions based on open-source technology, and digging into each region's regulatory requirements.

7.1 Reliability of this research

The systematic approach and practical implementation determine the reliability of the research. The focus was to create prototypes for ECG interpretation and remote monitoring applications with open-source tools using applied and action-based research. Given the limited time and resources, collaboration with an IT engineer for coding and implementation ensured that the solutions were theoretically sound, practically feasible, and efficient.

The iterative development and refinement process closely tie the dependability of the research. When working with open-source tools, carefully selecting and testing is crucial to ensure compatibility and functionality. This action highlights the adaptability and responsiveness of the research to real-world challenges. Instead of more conventional methods, opting for action-based applied research was motivated by the desire for ongoing improvement and direct feedback from deploying the prototypes in practice. This approach enabled a thorough comprehension of challenges, facilitating the creation of solutions tailored to the specific needs of remote healthcare settings.

Furthermore, the retrieval and analysis of information for open-source technology were meticulously recorded. The criteria for selection, based on features and community support, along with the validation of each tool's compatibility with our objectives during testing phases, contributed to the strength and reliability of the research. The rationale for opting for specific technologies, such as the Unity engine and OpenCV, was clearly explained, considering factors like cost, flexibility, and the extent of the existing developer community. This thorough documentation of the implementation phase emphasised the research's practical foundation and ability to adapt to healthcare contexts in remote areas.

7.2 Future research and development work concerning ECG prototype

Future work could involve expanding the knowledge base, refining the user interface based on user feedback, and addressing any identified limitations. The development team could expand the prototype to cover a broader range of ECG diagnosis scenarios, creating a more comprehensive tool.

7.3 Future research and development work concerning remote monitoring application

Scope for enhancing the face recognition algorithms to enhance and improve the system's ability to recognise faces accurately.

Extending the system's capabilities is possible by integrating additional sensors for vital sign monitoring, such as heart rate and body temperature, which can provide more comprehensive health insights.

The system can be customised to cater to diverse healthcare needs in different regions by adapting the system to local medical practices, languages, and specific patient monitoring.

Implementing machine learning algorithms to analyse patient behaviour, such as detecting patterns in movement, identifying deviations from routines, and predicting potential health issues over some time.

Implementing robust security measures to protect patient data and ensure compliance with privacy regulations. Exploring encryption methods and authentication protocols to safeguard sensitive information would be vital.

Developing mechanisms to maximise the system for low-bandwidth environments to ensure effective remote monitoring even in areas with limited internet connection.

REFERENCES

Acharya, Tara 2006. Science and technology for wealth and health in developing countries. Global Public Health - An International Journal for Research, Policy and Practice Volume 2 (1), 53-63. Abstract retrieved from https://doi.org/10.1080/17441690600673833. Accessed 5.11.2023.

Adeola Olajide, Oluwafunmiso 2023. Examining the Relationship between Access to Health Care and Socio-Economic Characteristics. In Rusangwa, Christian (Ed.) Rural Health - Investment, Research and Implications. IntechOpen EBooks. https://doi.org/10.5772/intechopen.109884. Accessed 5.11.2023.

Ahmad, Norman 2023. The effect of open-source software technologies in Health-tech Startups. Master's thesis. Degree programme in information processing science. University of Oulu. PDF file. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/http://jultika.oulu.fi/files/nbnfioulu-202306212720.pdf. Accessed 4.12.2023.

Akhtar, Md Nahid, Haleem, Abid, & Javaid, Mohd 2023. Scope of health care system in rural areas under Medical 4.0 environment. Intelligent Pharmacy, Volume 1 (Issue 4), 217-223. https://doi.org/10.1016/j.ipha.2023.07.003. (https://www.sciencedirect.com/science/article/pii/S2949866X23000576). Accessed on 12.10.2023.

Amini, Keyvan, Mirzaei, Alireza, Hosseini, Mirtohid, Zandian, Hamed, Azizpour, Islam, & Haghi, Yagoob 2022. Assessment of electrocardiogram interpretation competency among healthcare professionals and students of Ardabil University of Medical Sciences: a multidisciplinary study. BMC Medical Education, 22(1). https://doi.org/10.1186/s12909-022-03518-0. Accessed 5.6.2023.

Amjad, Ayesha, Kordel, Piotr,& Fernandes, Gabriela 2023. A Review on Innovation in Healthcare Sector (Telehealth) through Artificial Intelligence. Sustainability 2023, 15, 6655. https://doi.org/10.3390/su15086655. Accessed 8.1.2024.

Anesthesia Key 2020. Cardiac cycle image. https://aneskey.com/chapter-28-cardiac-cycle/#/core/product/identifier/9781108565011%23CN-bp-57/type/BOOK_PART/core-reader#CN-bp-57. Accessed 30.8.2023.

Appeadu, Michael, & Bordoni, Bruno 2023. Falls and Fall Prevention in the Elderly. In StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK560761/. Accessed 10.9.2023.

Azure s.a. What Is Computer Vision? Internet publication. Microsoft Azure website. https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-computer-vision#object-classification. Accessed 25.11.2023.

Barrio-Cortes, Jaime, Castaño-Reguillo, Almudena, Beca-Martínez, María Teresa, Bandeira-de Oliveira, Mariana, López-Rodríguez, Carmen, & Jaime-Sisó, María Ángeles 2021. Chronic diseases in the geriatric population: morbidity and use of primary care services according to risk level. BMC Geriatrics, 21. https://doi.org/10.1186/s12877-021-02217-7. Accessed 10.9.2023.

Bloom, David, & Zucker, Leo 2023. Aging Is the Real Population Bomb. Internet publication. International Monetary Fund website. 11.7.2023. https://www.imf.org/en/Publications/fandd/issues/Series/Analytical-Series/aging-is-the-real-population-bomb-bloom-zucker. Accessed 10.9.2023.

Borromeo, Nicolas Alejandro 2022. Hands-On Unity 2022 Game Development. Third edition. United Kingdom: Packt Publishing Ltd.

Bouaziz, Ghazi, Brulin, Damien, & Campo, Eric (2022). Technological Solutions for Social Isolation Monitoring of the Elderly: A Survey of Selected Projects from Academia and Industry. Sensors, 22(22), 8802. https://doi.org/10.3390/s22228802. Accessed 11.9.2023.

Brown, Mitchell, & Kathleen Hale 2014. Applied Research Methods in Public and Nonprofit Organizations, John Wiley & Sons, Incorporated, 2014. ProQuest Ebook Central, https://ebookcentral-proquest-com.ezproxy.savonia.fi/lib/savoniafi/detail.action?docID=1767442. Accessed 9.1.2024.

Burns, Ed, & Buttner, Robert 2021a. Normal Sinus Rhythm. ECG library by LITFL - Life in the FastLane. 11.3.2021. https://litfl.com/normal-sinus-rhythm-ecg-library/. Accessed 11.7.2023.

Burns, Ed, & Buttner, Robert 2021b. Normal Sinus Rhythm. ECG library by LITFL - Life in the FastLane. 11.3.2021. https://litfl.com/normal-sinus-rhythm-ecg-library/. Accessed 11.7.2023.

Burns, Ed, & Buttner, Robert 2021h. Right Atrial Enlargement. ECG library by LITFL - Life in the FastLane. 7.7.2021. https://litfl.com/right-atrial-enlargement-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2021i. Left Atrial Enlargement. ECG library by LITFL - Life in the FastLane. 4.6.2021. https://litfl.com/left-atrial-enlargement-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2021j. Right Atrial Enlargement. ECG library by LITFL - Life in the FastLane. 7.7.2021. https://litfl.com/right-atrial-enlargement-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2021m. Right Ventricular Hypertrophy (RVH). ECG library by LITFL - Life in the FastLane. 4.6.2021. https://litfl.com/right-ventricular-hypertrophy-rvh-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2021q. AV Block: 2nd degree, Mobitz I (Wenckebach Phenomenon). ECG library by LITFL - Life in the FastLane. 8.2.2021. https://litfl.com/av-block-2nd-degree-mobitz-i-wenckebach-phenomenon/. Accessed 18.10.2023.

Burns, Ed, & Buttner, Robert 2021t. T wave. ECG library by LITFL - Life in the FastLane. 11.3.2021. https://litfl.com/t-wave-ecg-library/. Accessed 15.7.2023.

Burns, Ed, & Buttner, Robert 2022e. Ventricular Fibrillation (VF). ECG library by LITFL - Life in the FastLane. 24.3.2022. https://litfl.com/ventricular-fibrillation-vf-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2022f. Ventricular Fibrillation (VF). ECG library by LITFL - Life in the FastLane. 24.3.2022. https://litfl.com/ventricular-fibrillation-vf-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2022l. Atrial Flutter. ECG library by LITFL - Life in the FastLane. 11.2.2022. https://litfl.com/atrial-flutter-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2022n. Right Bundle Branch Block (RBBB). ECG library by LITFL - Life in the FastLane. 13.7.2022 https://litfl.com/right-bundle-branch-block-rbbb-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2022o. Left Ventricular Hypertrophy (LVH). ECG library by LITFL - Life in the FastLane. 2.4.2021. https://litfl.com/left-ventricular-hypertrophy-lvh-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2022r. AV Block: 2nd degree, Mobitz II (Hay block). ECG library by LITFL - Life in the FastLane. 4.2.2022. https://litfl.com/av-block-2nd-degree-mobitz-ii-hay-block/. Accessed 18.10.2023.

Burns, Ed, & Buttner, Robert 2023c. Ventricular Tachycardia- Monomorphic VT. ECG library by LITFL - Life in the FastLane. 19.3.2023. https://litfl.com/ventricular-tachycardia-monomorphic-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2023d. Ventricular Tachycardia- Monomorphic VT. ECG library by LITFL - Life in the FastLane.19.3.2023. https://litfl.com/ventricular-tachycardia-monomorphic-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2023g. Polymorphic VT and Torsades de Pointes (TdP). ECG library by LITFL - Life in the FastLane. 15.4.2023. https://litfl.com/polymorphic-vt-and-torsades-de-pointes-tdp/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2023k. Atrial Fibrillation. ECG library by LITFL - Life in the FastLane. 31.1.2023. https://litfl.com/atrial-fibrillation-ecg-library/. Accessed 14.7.2023.

Burns, Ed, & Buttner, Robert 2023p. Left Bundle Branch Block (LBBB). ECG library by LITFL - Life in the FastLane. 3.10.2023. https://litfl.com/left-bundle-branch-block-lbbb-ecg-library/. Accessed 18.10.2023.

Burns, Ed, & Buttner, Robert 2023s. Anterior Myocardial Infarction. ECG library by LITFL - Life in the FastLane. 8.6.2023. https://litfl.com/anterior-myocardial-infarction-ecg-library/. Accessed 18.8.2023.

Burns, Ed, & Cadogan, Mike 2022a. Myocardial Ischaemia. ECG library by LITFL - Life in the FastLane. 16.3.2022. https://litfl.com/myocardial-ischaemia-ecg-library/. Accessed 15.7.2023.

Burns, Ed, & Cadogan, Mike 2022b. Myocardial Ischaemia. ECG library by LITFL - Life in the FastLane. 16.3.2022. https://litfl.com/myocardial-ischaemia-ecg-library/. Accessed 15.7.2023.

Burns, Ed, & Cadogan, Mike 2022c. Myocardial Ischaemia. ECG library by LITFL - Life in the FastLane. 16.3.2022. https://litfl.com/myocardial-ischaemia-ecg-library/. Accessed 15.7.2023.

Cadogan, Mike, & Buttner, Robert 2022a. P wave. ECG library by LITFL - Life in the FastLane. 29.1.2022. https://litfl.com/p-wave-ecg-library/. Accessed 11.7.2023.

Cadogan, Mike, & Buttner, Robert 2022b. ECG Axis Interpretation. ECG library by LITFL - Life in the FastLane. 27.4.2022. https://litfl.com/ecg-axis-interpretation/. Accessed 15.7.2023.

Cadogan, Mike, & Buttner, Robert 2022c. ECG Axis Interpretation. ECG library by LITFL - Life in the FastLane. 27.4.2022. https://litfl.com/ecg-axis-interpretation/. Accessed 15.7.2023.

Cadogan, Mike, & Buttner, Robert 2022d. ECG Axis Interpretation. ECG library by LITFL - Life in the FastLane. 27.4.2022. https://litfl.com/ecg-axis-interpretation/. Accessed 15.7.2023.

Caley, Michael Julian, O'Leary, Rebecca, Fisher, Rebecca, Low-Choy, Samantha, Johnson, Sandra, & Mengersen, Kerrie 2014. What is an expert? A systems perspective on expertise. Ecology and evolution, 4(3), 231–242. https://doi.org/10.1002/ece3.926. Accessed 30.11.2023.

Centers for Disease Control and Prevention (CDC) 2022. Health Insurance Portability and Accountability Act (HIPAA)." Internet publication. Last reviewed June 27.6.2022. https://www.cdc.gov/phlp/publications/topic/hipaa.html. Accessed 6.1.2024.

Central Drugs Standard Control Organisation, Directorate General Of Health Services, Ministry of Health & Family Welfare, Government of India n.d. Online System for Medical Devices. Internet publication. The Ministry of Health & Family Welfare, India, website. https://cdscomdonline.gov.in/NewMedDev/Homepage. Accessed 2.11. 2023.

Chakrabarti, Sandip, & Tatavarthy, Aruna Divya 2019. The geography of medical travel in India: Differences across states, and the urban-rural divide. Applied Geography, 107, 12–25. https://doi.org/10.1016/j.apgeog.2019.04.003. Accessed 8.5.2023.

Das, Jishnu, Daniels, Benjamin, Ashok, Monisha, Shim, Eun-Young, & Muralidharan, Karthik 2022. Two Indias: The structure of primary health care markets in rural Indian villages with implications for policy. Social Science & Medicine 301, 112799. https://doi.org/10.1016/j.socscimed.2020.112799. Accessed 2.5.2023.

David, Michael, Kolanko, Magdalena, Giovane, Martina Del, Lai, Helen, True, Jessica, Beal, Emily, Li, Lucia, Nilforooshan, Ramin, Barnaghi, Payam, Malhotra, Paresh, Rostill, Helen, Wingfield, David, Wilson, Danielle, Daniels, Sarah, Sharp, David, & Scott, Gregory 2023. Remote Monitoring of Physiology in People Living With Dementia: An Observational Cohort Study. JMIR Aging 6(1), e43777. https://doi.org/10.2196/43777. Accessed 11.9.2023.

Edwards, Marion, & Cooley, Roger 1993. Expertise in expert systems: knowledge acquisition for biological expert systems. Computer applications in the biosciences: CABIOS, 9(6), 657–665. https://doi.org/10.1093/bioinformatics/9.6.657. Accessed 30.11.2023.

European Commission 2023. International Cooperation. Internet publication. The European Union website. 24.5.2023. https://health.ec.europa.eu/medical-devices-dialogue-between-interested-parties/international-cooperation_en#:~:text=I%2D235965%26language%3DEN-. Accessed 12.9.2023.

European Council 2023. The general data protection regulation. Internet publication. Last reviewed 11.11.2023. https://www.consilium.europa.eu/en/policies/data-protection/data-protection-regulation/. Accessed 6.1.2024.

Foxman, Maxwell 2019. United We Stand: Platforms, Tools and Innovation With the Unity Game Engine. Sage Journals, Social Media + Society, 5(4). https://doi.org/10.1177/2056305119880177. Accessed 27.11.2023.

Giarratano, Joseph, & Riley, Gary 2015. Expert Systems: Principles and Programming Fourth Edition. India: Cengage Learning India Private Limited.

Gohel, Bakul, & Tiwary, Uma Shanker 2010. Automated Risk Identification of Myocardial Infarction Using Relative Frequency Band Coefficient (RFBC) Features from ECG. The Open Biomedical Engineering Journal 4(1), ResearchGate. https://www.researchgate.net/figure/a-Cardiac-vector-black-arrow-in-centre-b-electrode-connectivity-of-I-II-III-lead_fig2_51177719. Accessed 31.10.2023.

Gonzalez-Barahona, Jesus M. 2021. A Brief History of Free, Open Source Software and Its Communities. Computer, vol. 54 (2),75-79. DOI: 10.1109/MC.2020.3041887. Accessed 4.11.2023

Government of the United Kingdom 2022. Consultation outcome, Chapter 10: Software as a Medical Device. Internet publication. The Government of United Kingdom website. Updated 26.6.2022. https://www.gov.uk/government/consultations/consultation-on-the-future-regulation-of-medical-devices-in-the-united-kingdom/chapter-10-software-as-a-medical-device. Accessed 12.9.2023.

Hall, John & Hall, Michael 2021. Guyton and Hall Textbook of Medical Physiology. 14th Edition, International Edition. Philadelphia: Elsevier.

Hammond, Michael, & Jerry Wellington 2020. Research Methods : The Key Concepts, Taylor & Francis Group, 2020. ProQuest Ebook Central, https://ebookcentral-proquest-com.ezproxy.savonia.fi/lib/savoniafi/detail.action?docID=6284519. Accessed 9.1.2024.

Hetmanski, Marek 2018. Expert Knowledge: Its Structure, Functions and Limits. Studia Humana Volume 7:3, 11-20. DOI: 10.2478/sh-2018-0014. Accessed 7.11.2023.

Himmelreich, Jelle, & Harskamp, Ralf 2023. Diagnostic accuracy of the PMcardio smartphone application for artificial intelligence–based interpretation of electrocardiograms in primary care (AMSTELHEART-1). Cardiovascular Digital Health Journal, 4(3), 80–90. https://doi.org/10.1016/j.cvdhj.2023.03.002. Accessed 4.11.2023.

International Medical Device Regulators Forum (IMDRF) Software as a Medical Device (SaMD) Working Group 2013. Software as a Medical Device (SaMD): Key Definitions. PDF file. 9.12.2013. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.imdrf.org/sites/default/files/docs/imdrf/final/technical/imdrf-tech-131209-samd-key-definitions-140901.pdf. Accessed 12.9.2023.

International Medical Device Regulators Forum (IMDRF) Software as a Medical Device (SaMD) Working Group 2014. "Software as a Medical Device": Possible Framework for Risk Categorization and Corresponding Considerations. PDF file. 18.9.2014. https://www.imdrf.org/sites/default/files/docs/imdrf/final/technical/imdrf-tech-140918-samd-framework-risk-categorization-141013.pdf. Accessed 12.9.2023.

International Medical Device Regulators Forum (IMDRF) Software as a Medical Device (SaMD) Working Group 2015. Software as a Medical Device (SaMD): Application of Quality Management System. PDF file. 2.10.2015. https://www.imdrf.org/sites/default/files/docs/imdrf/final/technical/imdrf-tech-151002-samd-qms.pdf. Accessed 10.9.2023

Jain, Rahi, & Rao, Bakul 2019. Role of laboratory services in primary health center (PHC) outpatient department performance: an Indian case study. Primary Health Care Research & Development, 20. https://doi.org/10.1017/s1463423619000537. Accessed 8.5.2023.

Karan, Anup, Negandhi, Himanshu, Hussain, Suhaib, Zapata, Tomas, Mairembam, Dilip, De Graeve, Hilde, Buchan, James, & Zodpey, Sanjay 2021. Size, composition and distribution of health workforce in India: why, and where to invest? Human Resources for Health, 19(1). https://doi.org/10.1186/s12960-021-00575-2. Accessed 2.5.2023.

Kashou, Anthony, Noseworthy, Peter, Beckman, Thomas, Anavekar, Nandan, Cullen, Michael, Angstman, Kurt, Sandefur, Benjamin, Shapiro, Brian, Wiley, Brandon, Kates, Andrew, Huneycutt, David, Braisted, Andrew, Smith, Stephen, Baranchuk, Adrian, Grauer, Ken, O'Brien, Kevin, Kaul, Viren, Gambhir, Harvir, Knohl, Stephen, & Albert, David 2023. ECG Interpretation Proficiency of Healthcare Professionals. Current Problems in Cardiology, 48(10), 101924. https://doi.org/10.1016/j.cpcardiol.2023.101924. Accessed 6.11.2023.

Kasthuri , Arvind 2018. Challenges to Healthcare in India. Indian Journal of Community Medicine Volume 43(3), 141-143. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6166510/. Accessed 4.5.2023.

Kim, Luke, Koncilja, Kenneth, & Nielsen, Craig 2018. Medication management in older adults. Cleveland Clinic Journal of Medicine, 85(2), 129–135. https://doi.org/10.3949/ccjm.85a.16109. Accessed 10.9.2023.

Klabunde, Richard 2023. Normal and Abnormal Electrical Conduction. Internet publication. Cardio-vascular physiology concepts. Updated 27.10.2023. https://cvphysiology.com/arrhythmias/a003. Accessed 9.11.2023.

Kumar, Aniket 2023. The Transformation of The Indian Healthcare System. *Cureus*, *15*(5). https://doi.org/10.7759/cureus.39079. Accessed on 6.5.2023.

Kurian, Thomas, Ambrosi, Christina, Hucker, William, Fedorov, Vadim, & Efimov, Igor 2010. Anatomy and Electrophysiology of the Human AV Node. Pacing and Clinical Electrophysiology, *33*(6), 754–762. https://doi.org/10.1111/j.1540-8159.2010.02699.x. Accessed 13.8.2023.

Kwok, Chun Shing, Burke, Hayley, McDermott, Sarah, Welsh, Vicky, Barker, Diane, Patwala, Ashish, Duckett, Simon, Satchithananda, Duwarakan, & Mallen, Christian 2022. Missed Opportunities in the Diagnosis of Heart Failure: Evaluation of Pathways to Determine Sources of Delay to Specialist

Evaluation. Current Heart Failure Reports, 19(4), 247–253. https://doi.org/10.1007/s11897-022-00551-4. Accessed 5.6.2023.

Larkin, John, & Buttner, Robert 2021a. First Degree Heart Block. ECG library by LITFL - Life in the FastLane. 6.2.2021. https://litfl.com/first-degree-heart-block-ecg-library/. Accessed 15.7.2023.

Larkin, John, & Buttner, Robert 2023b. AV block: 3rd degree (complete heart block). ECG library by LITFL - Life in the FastLane. 15.11.2023. https://litfl.com/av-block-3rd-degree-complete-heart-block/. Accessed 18.11.2023.

Maidment, Ian, Huckerby, Clair, & Shukla, David 2020. Medication management in older people – a hidden burden. Prescriber, 31(11-12), 30–33. https://doi.org/10.1002/psb.1881. Accessed 10.9.2023.

Manu, Manas, & Anand, Gaurav 2021. A review of medical device regulations in India, comparison with European Union and way-ahead. Perspectives in Clinical Research 13(1), 3-11. https://doi.org/10.4103/picr.picr_222_20. Accessed 2.11.2023.

Martínez-Sellés, Manuel, & Marina-Breysse, Manuel 2023. Current and Future Use of Artificial Intelligence in Electrocardiography. J. Cardiovasc.Dev. Dis. 2023, 10, 175. https://doi.org/10.3390/jcdd10040175. Accessed 9.1.2024.

Medical Device Coordination Group (MDCG) 2019. MDCG 2019-11 Guidance on Qualification and Classification of Software in Regulation (EU) 2017/745 – MDR and Regulation (EU) 2017/746 – IVDR . PDF file. October 2019. https://health.ec.europa.eu/system/files/2020-09/md_mdcg_2019_11_guidance_qualification_classification_software_en_0.pdf. Accessed 12.9.2023.

Mehta, Pradip 2002. Understanding ECG Electrocardiography. Sixth Edition. Mumbai: Mesh Publishing House PVT LTD., Mumbai 400026

Mertic, John 2023. Open Source Projects - Beyond Code: A Blueprint For Scalable and Sustainable Open Source Projects. United Kingdom: Packt Publishing Ltd.

Ministry of Finance, India 2023a. Economic survey highlights thrust on rural development. Internet publication. The Press Information Bureau of Government of India. 31.1.2023. https://pib.gov.in/PressReleasePage.aspx?PRID=1894901#:~:text=The%20Survey%20notes%20that%2065. Accessed 2.5.2023.

Ministry of Health and Family Welfare, India 2023b. National Health Accounts Estimates for India (2019-20) released. Internet Publication. The Press Information Bureau of Government of India. 25.4.2023. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1919582. Accessed 2.5.2023.

Mohan, Pavitra, & Kumar, Raman 2019. Strengthening primary care in rural India: Lessons from Indian and global evidence and experience. Journal of Family Medicine and Primary Care 8(7): 2169-2172. https://doi.org/10.4103/jfmpc.jfmpc_426_19. Accessed 10.5.2023.

Moreira, Rui, Soares, Christophe, Torres, Jose Manuel, and Sobral, Pedro 2020. Combining IoT architectures in next generation healthcare computing systems. In Sangaiah, Arun Kumar, & Mukhopadhyay, Subhas Chandra (Eds.) Intelligent IoT systems in personalized health care. Elsevier Science & Technology. ProQuest Ebook Central, https://ebookcentral-proquest-com.ezproxy.savonia.fi/lib/savoniafi/detail.action?docID=6388639.

Msiska, Brown, & Nielsen, Petter 2017. A Framework to Assess and Address Human Capacities Needed to Leverage Open Source Software Platforms in Developing Countries. In: Choudrie, J., Islam, M., Wahid, F., Bass, J., Priyatma, J. (eds) Information and Communication Technologies for Development. ICT4D 2017. IFIP Advances in Information and Communication Technology, vol 504. Springer, Cham. https://doi.org/10.1007/978-3-319-59111-7_8. Accessed 9.01.2024.

Muinga, Naomi, Magare, Steve, Monda, Jonathan, Kamau, Onesmus, Houston, Stuart, Fraser, Hamish, Powell, John, English, Mike, & Paton, Chris 2018. Implementing an Open Source Electronic Health Record System in Kenyan Health Care Facilities: Case Study. JMIR Med Inform 2018;6(2):e22. doi: 10.2196/medinform.8403. https://medinform.jmir.org/2018/2/e22/. Accessed 9.1.2024.

Mustafa, Akif, & Shekhar, Chander 2021. Is quality and availability of facilities at Primary Health Centers (PHCs) associated with healthcare-seeking from PHCs in rural India: An exploratory cross-sectional analysis. Clinical Epidemiology and Global Health, 9, 293–298. https://doi.org/10.1016/j.cegh.2020.10.001. Accessed 8.5.2023.

National High Magnetic Field Laboratory s.a. Willem Einthoven . Internet publication. Nationalmaglab.org website. https://nationalmaglab.org/magnet-academy/history-of-electricity-magnetism/pioneers/willem-einthoven/. Accessed 14.8.2023.

Nunes, Fabiely Gomes da Silva, Santos, Adriano Maia dos, Carneiro, Ângela Oliveira, Fausto, Márcia Cristina Rodrigues, Cabral, Lucas Manoel da Silva, & de Almeida, Patty Fidelis 2022. Challenges to the provision of specialized care in remote rural municipalities in Brazil. BMC Health Services Research, 22(1). https://doi.org/10.1186/s12913-022-08805-6. Accessed 7.5.2023.

Olivari, Zoran, Giacomelli, Sara, Gubian, Lorenzo, Mancin, Silvia, Visentin, Elisa, Di Francesco, Vincenzo, Iliceto, Sabino, Penzo, Michelangelo, Zanocco, Albino, Marcon, Carlo, Anselmi, Maurizio, Marchese, Domenico, & Stafylas, Panagiotis 2018. The effectiveness of remote monitoring of elderly patients after hospitalisation for heart failure: The renewing health European project. International Journal of Cardiology 257, 137-142. https://www-sciencedirect-com.ezproxy.savonia.fi/science/article/pii/S0167527317330334?via%3Dihub. Accessed 11.9.2023.

Padvi, Pritee 2023. Electrocardiogram images from personal collection.

Pajankar, Ashwin 2020. Raspberry Pi Computer Vision Programming. Second Edition. United Kingdom: Packt Publishing Ltd.

Paton, Chris, & Karopka, 2017. The Role of Free/Libre and Open Source Software in Learning Health Systems. Yearbook of Medical Informatics, 26(01), 53–58. https://doi.org/10.15265/iy-2017-006. Accessed 4.11.2023.

Pepplinkhuizen, Shari, Hoeksema, Wiert , van der Stuijt, Willeke, van Steijn, Nicole, Winter, Michiel, Wilde, Arthur, Smeding, Lonneke, & Knops, Reinoud 2022. Accuracy and clinical relevance of the single-lead Apple Watch electrocardiogram to identify atrial fibrillation. Cardiovascular Digital Health Journal, 3(6), S17–S22. https://doi.org/10.1016/j.cvdhj.2022.10.004. Accessed 5.11.2023.

Pollock, Joshua, & Makaryus, Amgad 2022. Physiology, Cardiac Cycle. National Library of Medicine; StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK459327/. Accessed 13.8.2023.

Rafie, Nikita, Kashou, Anthony, & Noseworthy, Peter 2021. ECG Interpretation: Clinical Relevance, Challenges, and Advances. Hearts, 2(4), 505–513. https://doi.org/10.3390/hearts2040039. Accessed 9.6.2023.

Rajkumar, Eslavath, Gopi, Awathy, Joshi, Aditi, Thomas, Aleena Elizabeth, Arunima, N. M., Ramya, Gosetty Sri, Kulkarni, Prachi, Rahul, P., George, Allen Joshua, Romate, John, & Abraham, John 2023.

Applications, benefits and challenges of telehealth in India during COVID-19 pandemic and beyond: a systematic review. BMC Health Services Research, 23(1). https://doi.org/10.1186/s12913-022-08970-8. Accessed 5.11.2023.

Rakab, Amine, Swed, Sarya, Alibrahim, Hidar, Bohsas, Haidara, Abouainain, Yasmeen, Abbas, Kirellos Said, Jabban, Yazan Khair Eldein, Sawaf, Bisher, Rageh, Bushra, Alkhawaldeh, Majd, Al-Fayyadh, Israa, Rakab, Mohamad Saad, Fathey, Sherihan, Hafez, Wael, Gerbil, Amr & Hassan Hassan El-Shafei, Emad 2023. Assessment of the competence in electrocardiographic interpretation among Arabic resident doctors at the emergency medicine and internal medicine departments: A multi-center online cross-sectional study. Frontiers in Medicine, 10. https://doi.org/10.3389/fmed.2023.1140806. Accessed 10.6.2023.

Rashid, Md Mamunur, Khan, Shahriar Usman, Eusufzai, Fariha, Redwan, Md. Azharuddin, Sabuj, Saifur Rahman, & Elsharief, Mahmoud 2023. A Federated Learning-Based Approach for Improving Intrusion Detection in Industrial Internet of Things Networks. Network, 3(1), 158–179. https://doi.org/10.3390/network3010008. Accessed 7.11.2023.

Read, Emily, Gagnon, Danie, Donelle, Lorie, Ledoux, Kathleen, Warner, Grace, Hiebert, Brad, & Sharma, Ridhi 2022. Stakeholder Perspectives on In-home Passive Remote Monitoring to Support Aging in Place in the Province of New Brunswick, Canada: Rapid Qualitative Investigation. JMIR Aging 5(2), e31486. https://doi.org/10.2196/31486. Accessed 11.9.2023.

Russel, Stuart, & Norvig, Peter 2003. Artificial Intelligence: A Modern Approach. Second Edition. New Jersey, United States of America: Prentice Hall/Pearson Education, Inc.

Sattar, Yasar, & Chhabra, Lovely 2023. Electrocardiogram. In StatPearls [Internet]. StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK549803/. Accessed 5.11.2023.

Selvaraj, Sakthivel, Karan, Anup, Srivastava, Swati, Bhan, Nandita, & Mukhopadhyay, Indranil 2022. India Health System Review. PDF file. 30.3.2022. https://apo.who.int/publications/i/item/india-health-system-review. Accessed 5.5.2023.

Shereen, Kadir s.a. Anatomy of the Heart. University of Dundee School of Medicine. https://www.flickr.com/photos/dundeetilt/45733811415. Accessed 14.9.2023.

Siddique, Abu, Rahman, Tabassum, Pakrashi, Debayan, Islam, Asad, & Ahmed, Firoz 2021. Raising Health Awareness in Rural Communities: A Randomized Experiment in Bangladesh and India. PDF file. 20.10.2021. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://poverty-action.org/sites/default/files/awareness.pdf. Accessed 8.5.2023.

Silberbauer, John 2013. Wilson's Central Terminal, the keystone to electrogram recording – What, where and why? PDF file. 23.4.2013. chrome-extension://efaidnbmnnnibpcajpcglclefind-mkaj/https://www.uio.no/studier/emner/matnat/fys/FYS4250/h18/attachments-2021/wilson-central-terminal.pdf. Accessed 31.10.2023.

Software as a Medical Device Working Group 2017. Software as a Medical Device (SaMD): Clinical Evaluation. PDF file. 21.9.2017. chrome-extension://efaidnbmnnnibpcajpcglclefind-mkaj/https://www.imdrf.org/sites/default/files/docs/imdrf/final/technical/imdrf-tech-170921-samd-n41-clinical-evaluation_1.pdf. Accessed 10.9.2023.

Sriram, Shyamkumar, & Albadrani, Muayad 2022. Impoverishing effects of out-of-pocket healthcare expenditures in India. Journal of Family Medicine and Primary Care, 11(11), 7120-7128. https://doi.org/10.4103/jfmpc.jfmpc_590_22. Accessed 5.5.2023.

Statistics Division, Ministry of Health and Family Welfare, India 2023. Rural Health Statistics, 2021-22. Internet publication on ruralindiaonline.org. Ministry of Health and Family Welfare, Government of India, New Delhi. 12.1.2023. https://ruralindiaonline.org/en/library/resource/rural-health-statistics-2021-22/#:~:text=There%20were%20161%2C829%20sub%20centres. Accessed 2.5.2023.

Sung, Ruey , & Tai, Der-Yan 1986. Electrophysiologic Characteristics of Accessory Connections: An Overview. In Benditt, D.G., Benson, D.W. (Eds.). Cardiac Preexcitation Syndromes. Boston, MA : Springer, 165-199. https://doi.org/10.1007/978-1-4684-7526-5_9. Accessed 13.8.2023.

Syzdykova, Assel, Malta, André, Zolfo, Maria, & Diro, Ermias 2017. Open-Source Electronic Health Record Systems for Low-Resource Settings: Systematic Review. JMIR Medical Informatics 5(4):e44. DOI:10.2196/medinform.8131. https://medinform.jmir.org/2017/4/e44/. Accessed 9.01.2024.

Szeliski, Richard 2022. Computer Vision: Algorithms and Applications. Second Edition. Switzerland: Springer nature.

Temple, Ian, Inada, Shin, Dobrzynski, Halina, & Boyett, Mark 2012. Connexins and the atrioventricular node. Heart Rhythm, 10(2), 297–304. https://doi.org/10.1016/j.hrthm.2012.10.020. Accessed 13.8.2023.

The University of Nottingham s.a. Bipolar Leads - ECG Lead Placement - Normal Function of the Heart - Cardiology Teaching Package - Practice Learning - Division of Nursing - www.nottingham.ac.uk. https://www.nottingham.ac.uk/nursing/practice/resources/cardiology/function/bipolar_leads.php. Accessed 31.10.2023.

The World Bank s.a.a. Current health expenditure (% of GDP) – India / Data. Internet publication. The World Bank Open Data website. https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS?locations=IN. Accessed 3.5.2023.

The World Bank s.a.b. Current health expenditure (% of GDP) - United States / Data. Internet publication. The World Bank Open Data website. https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS?locations=US. Accessed 3.5.2023.

The World Bank Data s.a.c. Research and development expenditure (% of GDP) - India / Data. Internet publication. The World Bank Open Data website. Retrieved November 3, 2023, from https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?locations=IN. Accessed 3.11.2023.

The World Bank Data s.a.d. Research and development expenditure (% of GDP) - United States / Data. Internet publication. The World Bank Open Data website. https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?locations=US. Accessed 3.11.2023.

United Nations 2019. Global Issues: Ageing. Internet publication. A United Nations website. https://www.un.org/en/global-issues/ageing. Accessed 10.9.2023.

United States Food and Drug Administration (U.S. FDA) 2019. Overview of Device Regulation. Internet publication. U.S. Food and Drug Administration website. Updated 9.4.2020. https://www.fda.gov/medical-devices/device-advice-comprehensive-regulatory-assistance/overview-device-regulation. Accessed 12.9.2023.

Wanger, Jenny, Cullen, Theresa, Dunbar, Elizabeth, & Flowers, Jan 2022. Open Source Software for Public Health: Opportunities and Approaches. Sexually Transmitted Diseases, 50(8S), S31–S33. https://doi.org/10.1097/olq.0000000000001689. Accessed 4.11.2023.

Wenzel, Tobias 2023. Open hardware: From DIY trend to global transformation in access to laboratory equipment. Plos Biology, 21(1), e3001931–e3001931. https://doi.org/10.1371/journal.pbio.3001931. Accessed 4.11.2023.

World Health Organisation (WHO) 2021. WHO guideline on health workforce development, attraction, recruitment and retention in rural and remote areas. PDF file. Published 6.5.2021. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://iris.who.int/bitstream/handle/10665/341139/9789240024229-eng.pdf. Accessed 1. 6. 2023.

World Health Organisation (WHO) s.a.a. Addressing health inequities among people living in rural and remote areas. Internet publication. World Health Organisation website. https://www.who.int/activities/addressing-health-inequities-among-people-living-in-rural-and-remote-areas. Accessed 1. 6. 2023.

World Health Organisation (WHO) s.a.b. Health products policy and standards, Policies for medical devices. Internet publication. World Health Organisation website. https://www.who.int/teams/health-product-policy-and-standards/assistive-and-medical-technology/medical-devices/policies. Accessed 10.9.2023.

Zenzes, Michael, Seba, Philip, & Portocarrero Vivero-Fäh, Bettina 2023. The electrocardiogram on the wrist: a frightening experience to the untrained consumer: a case report. Journal of Medical Case Reports, 17(1). https://doi.org/10.1186/s13256-023-03806-3. Accessed 8.11.2023.

Zepeda-Echavarria, Alejandra, van de Leur, Rutger R, van Sleuwen, Meike, Hassink, Rutger J, Wildbergh, Thierry X, Doevendans, Pieter A, Jaspers, Joris, & van Es, René 2022. Electrocardiographic Devices for Home Use: A Technological and Clinical Scoping Review (Preprint). JMIR Cardio 7. https://doi.org/10.2196/44003. Accessed 7.11.2023.

Zipes, Douglas 2000. Clinical application of the electrocardiogram. Journal of the American College of Cardiology, 36(6), 1746–1748. https://doi.org/10.1016/S0735-1097(00)00971-2. Accessed 17.8.2023.

APPENDIX 1: EXAMPLES OF OPEN-SOURCE SOFTWARE AND HARDWARE

Open-source software	**Uses**	**Official Website**
OpenCV or Open Source Computer Vision Library	It processes the images using a versatile and powerful image-processing framework.	www.opencv.org
Linux operating system	It powers many computing devices, such as servers, Android smartphones, and embedded systems.	www.linux.org
Mozilla Firefox	It is an open-source web browser well-known for its speed, privacy features, and many extensions.	www.mozilla.org
LibreOffice	It is a powerful open-source office suite compatible with Microsoft Office that includes word processing, spreadsheets, presentations, and more.	www.libreoffice.org
WordPress	It is the world's most popular website and blog content management system (CMS), making creating and managing web content simple.	www.wordpress.org
GIMP	It is an open-source image editor with many features that are frequently compared to Adobe Photoshop.	www.gimp.org
Audacity	It is an open-source audio editor widely used for recording, editing, and mixing audio.	www.audacityteam.org
Apache HTTP Server	This is a popular open-source web server for hosting websites and web applications.	www.httpd.apache.org

FIGURE 1. 1. Examples of open-source software

Open-source hardware	**Uses**	**Official website**
Arduino	This is an open-source hardware and software platform used to create electronic prototypes. It is popular for home improvement projects, educational purposes, and professional applications.	www.arduino.cc
Raspberry Pi	A credit-card-sized computer with a thriving open-source hardware community. It is used in various projects, from home automation to DIY servers.	www.rasberrypi.com
3D Printing	The RepRap project and other open-source 3D printers have revolutionised additive manufacturing. The users can design, modify, and share printers.	www.reprap.org
Open Source Medical Devices	Projects such as Open Source Ventilator and OpenPCR provide open designs for medical devices, allowing for rapid innovation in times of crisis.	www.openlung.org www.opencpr.org
Open Source Farming Equipment	With projects like FarmBot, which designs robotic systems for small-scale agriculture, open-source hardware has expanded into farming.	www.farm.bot

FIGURE 1. 2. Examples of open-source hardware

APPENDIX 2: THE NORMAL PHYSIOLOGY OF THE HEART

The heart anatomy consists of four chambers: the right atrium, left atrium, right ventricle, and left ventricle (See FIGURE 2.1). These chambers work in a coordinated manner during the cardiac cycle, which comprises both contraction (systole) and relaxation (diastole) phases. Deoxygenated or venous blood from the body is transported to the heart through two main veins, the superior and inferior vena cava. This blood is directed into the right atrial chamber. As the cardiac cycle progresses, the right atrium contracts (atrial systole), which forces the blood through the tricuspid valve into the right ventricle. From the right ventricle, the blood is propelled into the pulmonary circulation through the pulmonary valve. In the lungs, at the capillary level in the alveoli, oxygenation of the blood occurs, transforming it into oxygen-rich or oxygenated blood. The oxygenated blood then returns to the heart via the pulmonary arteries, entering the left atrium. During the cardiac cycle, when the left atrium contracts (atrial systole), it pushes the oxygenated blood through the mitral valve into the left ventricle. Subsequently, during ventricular contraction (ventricular systole), this oxygen-rich blood is ejected from the ventricles into the aorta, the main systemic artery. Systemic circulation distributes oxygenated blood to various body parts through arteries like the left subclavian, common carotid, and brachiocephalic arteries. It is important to note that the atria contract simultaneously, contributing to ventricular filling, while the ventricles contract when the atria are in diastole, ensuring an efficient flow of blood throughout the circulatory system. (Hall & Hall 2021, 113-118.) A cardiac cycle (see FIGURE 2.2) is the sequence of events that take place from one heartbeat to the beginning of the next heartbeat. It consists of two main events called diastole and systole. Diastole refers to the relaxation of the heart muscle and the refilling of blood in the heart chambers, while systole involves the contraction of these muscles, causing the pumping of blood (Pollock & Makaryus 2022).

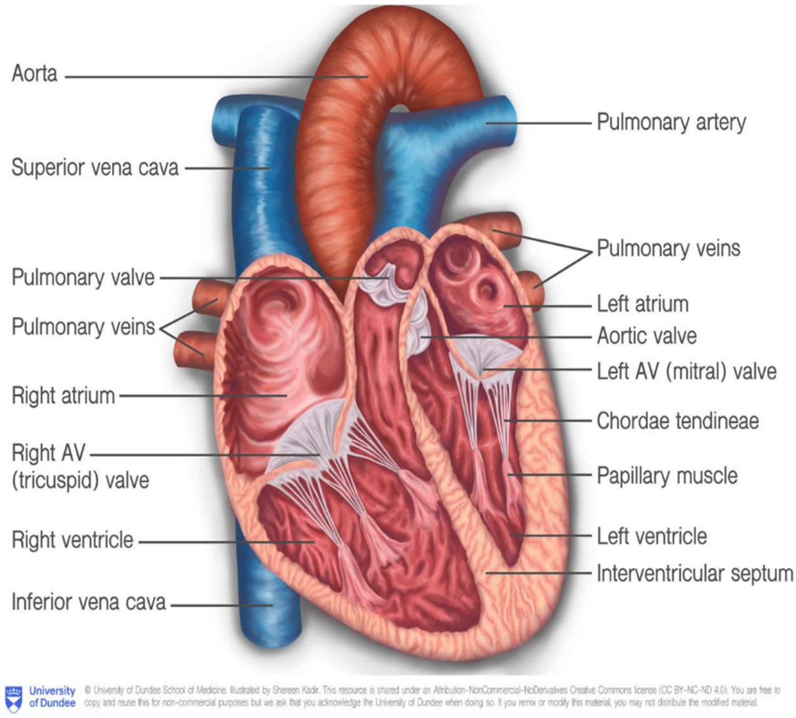


FIGURE 2. 1. Anatomy of the heart (University of Dundee s.a., CC BY -NC-ND)

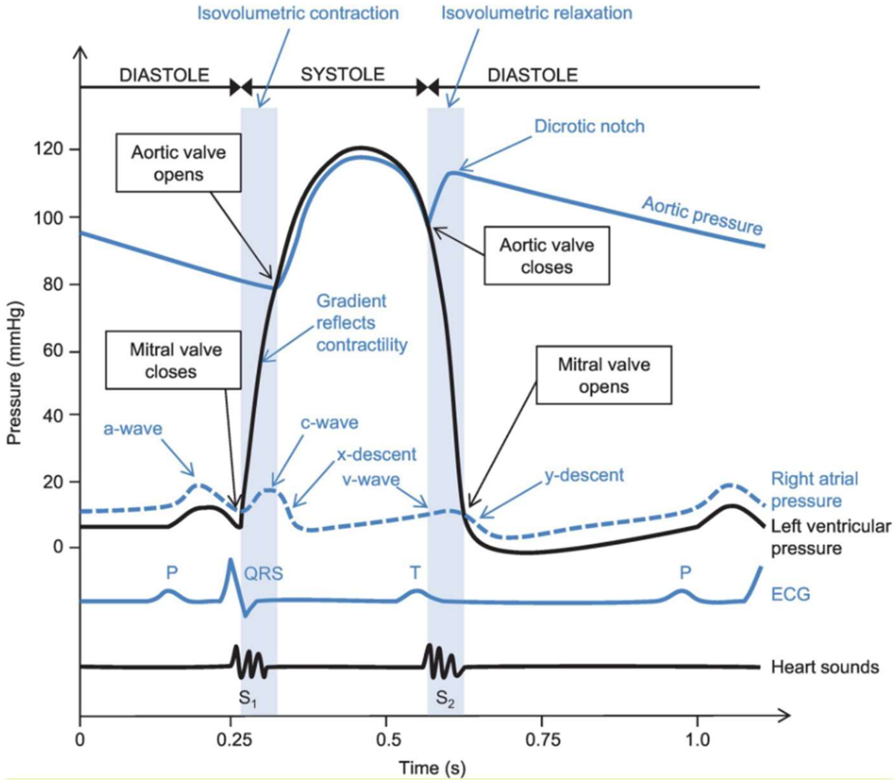


FIGURE 2. 2. Cardiac Cycle (Anesthesia Key 2020, image obtained with written permission.)

The heart comprises two types of myocardial tissues. They are specialised myocardium and contractile myocardium. The specialised myocardium does not undergo contraction but has unique features. These myocardial tissues are found in the sinoatrial (SA) node and atrioventricular (AV) node, the bundle of His and the Purkinje fibres of the heart. These structures are crucial in maintaining the heart's rhythmic and coordinated pumping, ensuring efficient blood circulation. (Hall & Hall 2021, 127.)

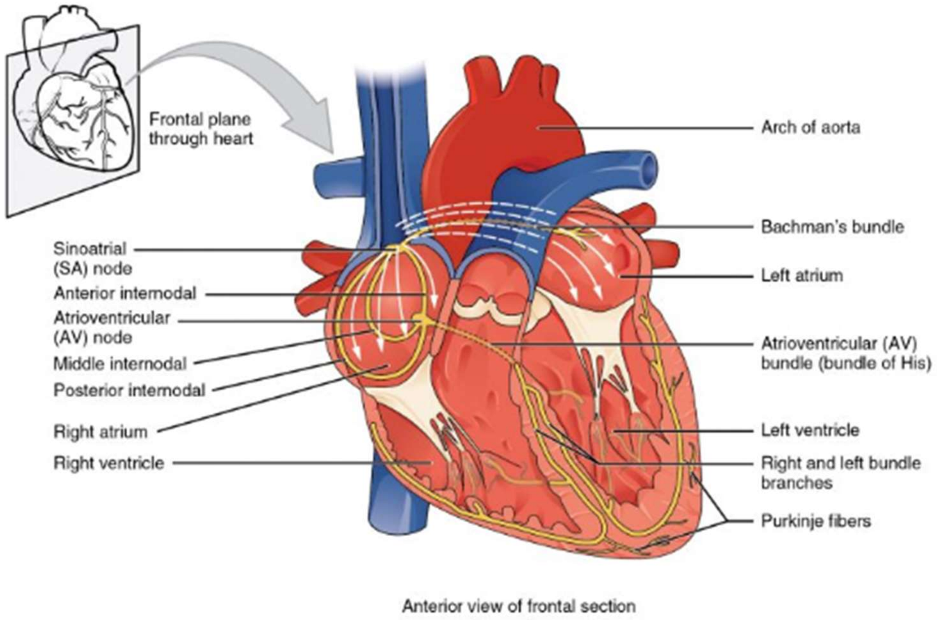


FIGURE 2. 3. The electrical conduction system of the heart (Biga 2012, CC BY -SA).

The sinoatrial (SA) node (see FIGURE 2.3) has a unique feature of maximum automaticity. Maximum automaticity refers to the SA node's inherent property, also known as the heart's natural pacemaker. The SA node can spontaneously and rhythmically generate electrical impulses without external stimulation. This property allows the SA node to set the pace for the heart’s contractions. The SA node has the highest intrinsic rate of spontaneous depolarisation among all cardiac cells. This unique property makes the SA node undergo depolarisation about 72 times every minute to produce a cardiac cycle. In other words, it has the fastest rate of generating cardiac impulses. This rapid depolarisation initiates the electrical signal that spreads throughout the heart, triggering the contractions of the atria and the ventricles. The SA node’s maximum automaticity ensures a regular and coordinated heartbeat, maintaining the heart’s normal rhythm and rate. (Hall & Hall 2021, 127-131.)

The atrioventricular (AV) node (see FIGURE 2.3) is considered a specialised myocardium because it possesses unique properties and functions that distinguish it from the surrounding myocardial tissue. While it is still a type of cardiac muscle, the atrioventricular node is specifically adapted to fulfil its role in the heart's electrical conduction system. The AV node demonstrates its specialisation in various ways. It is responsible for delaying the conduction of electrical impulses from the atria to the ventricles. The total delay within the AV nodal and AV bundle system, including the initial conduction delay from the SA node, is 0.16 seconds before the excitatory signal reaches the ventricular myocardium. (Hall & Hall 2021, 129.) This delay allows for proper coordination between atrial contraction and ventricular filling, ensuring efficient blood flow through the heart (Sung & Tai 1986). The AV node also exhibits a slower conduction velocity than other cardiac tissues. This occurs due to fewer gap junctions between parallel cells (Hall & Hall 2021, 127). This delay is essential to allow enough time for the atria to contract and complete ventricular filling before the ventricles are stimulated to contract (Klabunde 2023). Furthermore, the AV node acts as a protective barrier, preventing excessive electrical impulses from reaching the ventricles. This function helps maintain a controlled heart rate and protects the ventricles from being overwhelmed by rapid electrical signals (Kurian, Ambrosi, Hucker, Fedorov, & Efimov 2010; Sung & Tai 1986). In cases where the SA node, the primary pacemaker, fails to generate electrical impulses or is not functioning properly, the AV node can exhibit the subsidiary pacemaker function. It can generate electrical impulses at a slower rate to sustain a basic heartbeat until the SA node resumes its normal function or until medical intervention is provided. (Temple, Inada, Dobrzynski, & Boyett 2012.) These specialised properties of the AV node contribute to the efficient functioning of the heart's electrical conduction system, ensuring proper timing and coordination between atrial and ventricular contractions.

The Purkinje fibres and the Bundle of His (right and left bundle branches in FIGURE 2.3) are considered specialised myocardium because they have specific roles in the heart's conduction system. The Purkinje fibres have a significantly faster conduction velocity than other myocardial cells. This allows the rapid transmission of electrical signals throughout the ventricles, ensuring synchronised and coordinated ventricular contractions. These fibres distribute electrical impulses uniformly and simultaneously to the entire ventricular myocardium. This coordinated activation allows for efficient and synchronised contraction of the ventricles, optimising the heart's pumping function. The bundle of His or atrioventricular bundle is the only electrical connection between the atria and the ventricles.

It transmits electrical signals from the atrioventricular node to the ventricles, ensuring the proper sequence and timing of atrial and ventricular contractions. The bundle of His is further divided into left and right bundle branches, which distribute electrical impulses to specific regions of the ventricles. This division ensures coordinated activation and contraction of the ventricular muscle. These properties of Purkinje fibres and the bundle of His enable them to play a crucial role in the efficient conduction of electrical signals throughout the heart. (Hall & Hall 2021, 129-131.)

Atrial myocardium and ventricular myocardium constitute the major bulk of contractile myocardium. When electrically stimulated, they undergo mechanical activity, that is, contraction. All myocardial tissue is connected through electrical windows called gap junctions. They are low-resistance, fluid-filled areas that can rapidly conduct the current from one cell to another and act as electrical windows. Since an electrical network connects the myocardial cells, they are also called syncytial cells. (Hall & Hall 2021, 113-114.)

The autonomic nervous system (ANS) significantly influences cardiac activity through its two branches: the parasympathetic and sympathetic nervous systems, which have distinct effects on the heart's function. The parasympathetic nervous system, primarily via the vagus nerve, influences the heart's pacemaker and rhythm. The right vagus nerve primarily targets the sinoatrial (SA) node, while the left vagus nerve mainly influences the atrioventricular (AV) node. Vagal nerve endings release acetylcholine, which acts on muscarinic receptors. These receptors are concentrated in the SA and AV nodes. The atrial myocardium contains relatively few muscarinic receptors, while the ventricular myocardium has a minimal number of these receptors, to the point of being nearly negligible. Parasympathetic stimulation has two primary effects; firstly, it decreases the heart rate by slowing the SA node's intrinsic rhythm, and secondly, it reduces the excitability of fibres between the atrial musculature and the AV node, thereby delaying the transmission of cardiac impulses into the ventricles. Strong vagal stimulation can block the transmission of cardiac impulses from the atria to the ventricles, resulting in ventricular escape rhythms. (Hall & Hall 2021, 132.)

The sympathetic nervous system, through the release of norepinephrine, stimulates beta-1 adrenergic receptors present throughout the cardiac tissue. Sympathetic stimulation has opposing effects compared to parasympathetic stimulation. It increases the discharge rate from the SA node and enhances the conduction velocity and excitability of all heart regions. Additionally, it significantly augments the force of contraction in both the atria and ventricles. Thus, the autonomic nervous system’s parasympathetic and sympathetic branches play a critical role in regulating cardiac activity. Parasympathetic stimulation tends to slow the heart rate and reduce excitability, while sympathetic stimulation increases heart rate, enhances conduction, and boosts cardiac contractility. (Hall & Hall 2021, 132.)

For the proper physiological functioning of the heart, myocardial cells undergo a series of essential electrical events. Like neural cells, these cells exhibit a resting membrane potential, representing the baseline electrical state when not actively contracting. Depolarisation and repolarisation are critical processes within the cardiac cycle. Depolarisation corresponds to the electrical signals that stimulate the heart muscle cells to contract, while repolarisation allows the cells to reset and prepare for the subsequent contraction. These processes work harmoniously to coordinate the heart's rhythmic contractions, ensuring efficient blood pumping to meet the body's demands.

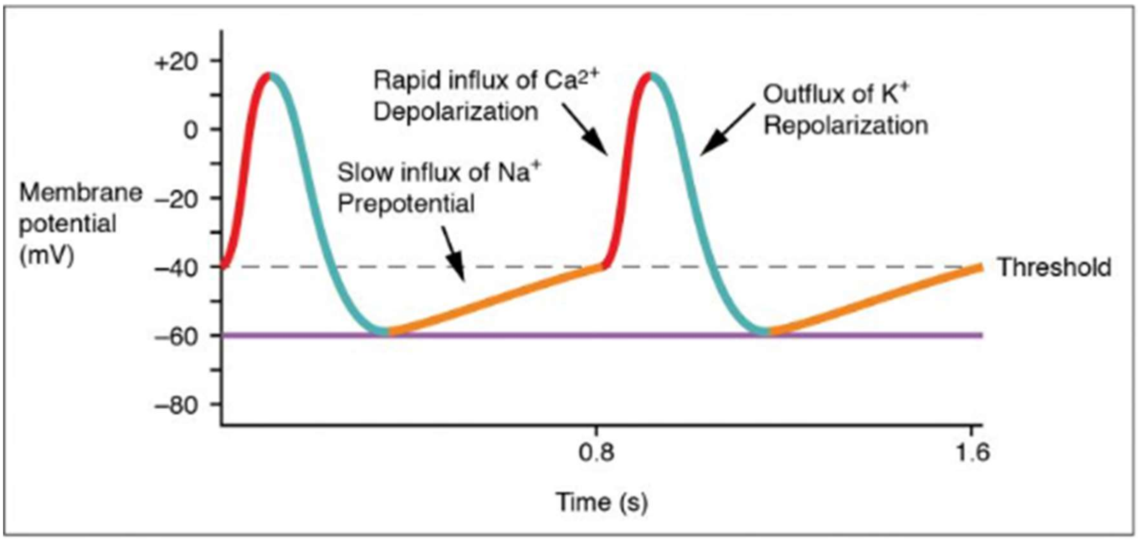


FIGURE 2. 4. Action potential in the sinoatrial (SA) node (Biga 2012, CC BY -SA)

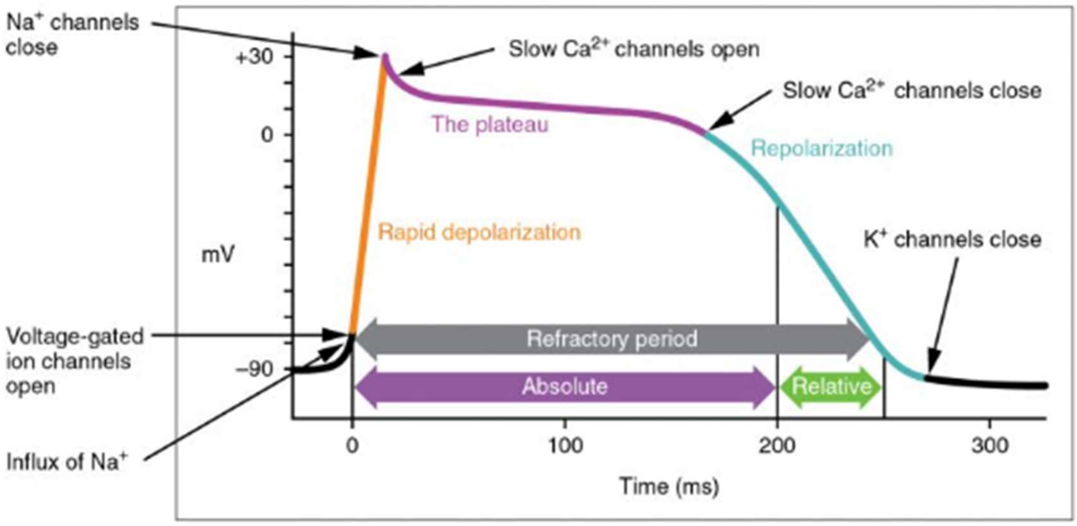


FIGURE 2. 5. Action potential in contractile myocardium (Biga 2012, CC BY -SA)

The potential difference or electric fluctuation across the cell membrane, known as the membrane potential, comes into action during an event called an action potential (see FIGURE 2.4 & FIGURE 2.5). An action potential is a transient change in the electrical potential of the cell membrane. This process is of utmost importance for the transmission of electrical signals within most cells throughout the human body. It plays a central role in neural communication, muscle contractions, and various physiological processes, allowing for the rapid and precise transfer of information and coordination of bodily functions. The generation of an action potential occurs when a stimulus, such as a change in voltage or its chemical signal, triggers a series of events that lead to the rapid depolarisation and repolarisation of the cell membrane. This depolarisation and repolarisation sequence is responsible for transmitting electrical signals along the length of the cell. The distinctive phases during an action potential are the resting state, depolarisation, repolarisation and hyperpolarisation. The action potential propagates along the length of the cell, allowing for the transmission of signals. This electrical impulse can trigger various physiological responses. FIGURE 2.4 shows action potential in a cell of the SA node, a specialised myocardium. (Hall & Hall 2021, 113-132.)

The resting membrane potential is defined as a state of electronegativity inside the cell when the cell is electrically resting. Every cell has a nucleus containing genes responsible for certain specific functionalities. Similarly, when expressed, a gene in the myocardial cell nucleus produces a messenger RNA, translated into a unique type of transmembrane protein. This transmembrane protein can utilise adenosine triphosphate (ATP). With one molecule of ATP, this protein can throw 3 Na^+ ions outside the cell and 2 K^+ ions inside the cell. This applies to every cell in the human body. These proteins are called sodium-potassium ATPases. The intracellular fluid is rich in potassium ions, and the extracellular fluid is rich in sodium ions. During this active functioning of transmembrane proteins or sodium-potassium ATPases, three sodium ions are lost while two potassium ions are gained inside. Therefore, the concentration of cations inside the cell is slightly less than in the outside or extracellular space. Consequently, the inner part of the cell becomes slightly electronegative, generating an electrical potential of -5mV. The electrical contribution of this sodium-potassium pump is minimal to the resting membrane potential of the myocardial cell. Typically, ions move across the cell membrane according to their concentration gradient. The electronegativity inside the cell and the concentration gradient and electrical gradient of sodium ions cause sodium's affinity to move inside the cell. However, in the resting cell, the sodium channels are closed. The concentration gradient of potassium causes its movement from intracellular to extracellular space. However, since the cell is slightly electronegative, it is also attracted by some electronegativity within the cell. Usually, there are a lot of potassium leaky channels, and the resting cell membrane is highly permeable to potassium. Hence, potassium starts leaking into the extracellular space during the resting phase, making the cell more electronegative. This gradually shifts electric potential from -5mV to -90mV. Because of the potassium efflux, a point comes where the inside of the cell becomes so much electronegative that the concentration gradient of potassium moves outward, and the electrical gradient inside the cell becomes equal. The net movement of potassium across the cell membrane stops; at this point, potassium achieves equilibrium potential. The electric potential of potassium is about -85mV, and the resting membrane potential is -90mV. The resting membrane potential is very near to the electric potential of potassium. In other words, the efflux of potassium ions across the cell membrane achieves the resting membrane potential. (Hall & Hall 2021, 113-132.)

When a cell is at its resting membrane potential, typically around -90 millivolts, it can be electrically stimulated by an influx of cationic charges, such as calcium ions (Ca2+). This influx causes the intracellular portion of the cell to become less electronegative. As a result, the resting membrane potential gradually increases until it reaches around -70 millivolts, known as the threshold potential. When the membrane potential reaches this threshold, voltage-gated sodium channels in the cell membrane open. These sodium channels have two gates: an activation gate and an inactivation gate. The activation gate rapidly opens while the inactivation gate slowly closes. During this phase, a brief influx of sodium ions from the extracellular space rushes into the cell, driven by their concentration gradient. This rapid influx of sodium ions causes the intracellular electronegativity to progressively decrease until it reaches zero, resulting in the loss of negative polarity within the cell. This phase is depolarisation (see FIGURE 2.4 & FIGURE 2.5). The depolarisation processes in cardiac cells vary depending on their location and function within the heart. In SA and AV nodal cells, the initiation of depolarisation is primarily dependent on calcium channels. This slow depolarisation phase sets the heart's rhythm and is often called the 'pacemaker potential'. In contrast, the ventricular myocardium, atrial myocardium, and Purkinje fibres primarily rely on sodium channels for depolarisation. This results in a rapid and coordinated depolarisation of these tissues, contributing to the efficient contraction of the heart. So, while calcium channels play a crucial role in SA and AV nodal cells, sodium channels are responsible for the fast depolarisation observed in the ventricular, atrial, and Purkinje fibre tissue. (Hall & Hall 2021, 113-132.)

As the depolarisation process is still occurring (see FIGURE 2.4 & FIGURE 2.5), specific ion channels come into play. The activation gate of sodium channels (usually voltage-gated) outside the cell is closed—meanwhile, two other voltage-gated channels open potassium and calcium channels. Due to the concentration gradient favouring their exit, potassium ions start to leak out of the cell, making the interior slightly more negatively charged. Simultaneously, voltage-gated calcium channels open. Calcium ions, abundant in the extracellular fluid, are attracted to the negatively charged interior and begin entering the cell. A critical point is reached during this phase when the loss of potassium ions (outward movement) and the influx of calcium ions (inward movement) nearly balance each other. This balanced phase is often called the 'plateau phase,' during which there is minimal change in the membrane potential and remains close to zero. As time progresses, the calcium channels eventually close, while the voltage-gated potassium channels remain open, continuing the efflux of potassium ions from the cell. As a result, the cell loses cations, causing the inner side of the cell to regain a negative charge, effectively re-establishing its negative polarity. This stage marks the repolarisation of the cell. (Hall & Hall 2021, 113-132.)

During the onset of depolarisation, when voltage-gated sodium channels open, allowing sodium ions to enter the cell, some of these sodium ions activate neighbouring inactive portions of the cell membrane. Essentially, the initially depolarising section of the membrane triggers adjacent, still-inactive areas while it undergoes repolarisation. This sequential activation continues along the membrane, where one part stimulates the next. In certain types of cells, such as cardiac muscle cells, gap junctions play a crucial role. Gap junctions are specialised protein channels that connect adjacent cells, enabling the transfer of ions and electrical signals between them. The depolarising cations from one cell can stimulate the next cell in the chain, allowing for coordinated action potential propagation through these gap junctions. This phenomenon of depolarisation followed by repolarisation or the fluctuation of electric potential across the cell membrane is referred to as an action potential. (Hall & Hall 2021, 113-132.)

APPENDIX 3: THE BASICS OF ELECTROCARDIOGRAPHY

The basic principles of electrocardiography (ECG) involve the measurement and recording of the electrical activity of the heart. Firstly, it is important to understand the generation of electrical impulses from the heart that control its contraction and relaxation. These electrical signals originate from the sinoatrial (SA) node, travel through the atria, pass through the atrioventricular (AV) node, and then propagate down the Bundle of His and Purkinje fibres to stimulate ventricular contraction (see FIGURE 2.3). (Mehta 2002, 1)

Secondly, placing electrodes and leads in an ECG involves using leads for electrical connections between specific points on the body and the ECG machine. The electrodes are placed on the patient's skin to detect electrical signals from the heart. The standard 12 lead ECG (See FIGURE 3.1) involves placing electrodes in specific locations on the limbs and chest. (Mehta 2002,4-7.) Thirdly, vectors represent the heart's electrical activity, indicating the magnitude and direction of electrical impulses. These vectors can be thought of as arrows that show the movement of electrical currents through the heart during different phases of the cardiac cycle (see FIGURE 3.2). (Hall & Hall 2021, 143-150.)

Fourthly, the heart's electrical activity is graphically represented on the ECG recording. The graph displays waves and intervals corresponding to specific electrical events in the heart. The primary waves observed are the P wave, QRS complex, and the T wave, representing atrial depolarisation, ventricular depolarisation, and ventricular repolarisation, respectively (see FIGURE 3.3). (Mehta 2002,9-19.) Subsequently, the timing and duration of various waves and intervals on the ECG provide important information about electrical conduction and heart rhythm (see Appendix 4). For example, the PR interval represents the time it takes for the electrical impulse to travel from the atria to the ventricles, and the QT interval represents the duration of ventricular depolarisation and repolarisation (Mehta 2002,16 & 18). Finally, interpreting an ECG involves analysing these waveform patterns, intervals, and overall rhythm to assess the normality or presence of any abnormalities. Various factors are considered, such as the shape and duration of waves, ST-segment elevation or depression, and the regularity or irregularity of the cardiac rhythm. It is essential to understand these basic principles for correctly interpreting the recorded electrical activity of the heart and diagnosing underlying cardiac conditions.

The ECG machine, also known as the electrocardiograph, was invented by Willem Einthoven, a Dutch physiologist, in the early 20th century. William Einthoven is considered the father of electrocardiography for his significant contribution to developing ECG machines and his pioneering work. In 1903, he introduced the string galvanometer, which allowed for the precise measurement and recording of electrical signals produced by the heart. His innovative device revolutionised the study of cardiac Physiology and paved the way for the modern ECG machine we use today. Intolerance work earned him the Nobel Prize in Physiology or Medicine in 1924. (National High Magnetic Field Laboratory, s.a.) Later, an American physician, Frank Norman Wilson, introduced the concept of Wilson's central terminal in the 1930s. The Wilson central terminal, also known as the Wilson unipolar limb leads, is a modification of the ECG electrode placement that provides additional information about the heart's electrical activity (Silberbauer 2013). The Wilson central terminal combines three limb electrodes (right arm, left arm and left leg) to create a virtual or composite electrode. The Wilson central terminal composite electrode is not physically attached to the patient but is mathematically derived from the limb leads. A six-lead ECG can be obtained using the Wilson central terminal and the standard limb leads. This expanded ECG configuration provides comprehensive information about the heart's electrical activity from different angles. The Wilson unipolar limb leads are typically labelled as aVR (right arm), aVL (left arm), and aVF (left leg). These leads, in combination with the standard bipolar limb leads, I, II, III and the precordial leads V1 to V6, allow for a more detailed assessment of the heart's electrical activity. Adding the Wilson central terminal and the corresponding unipolar limb leads enhances the ECG machine's diagnostic capabilities, particularly in identifying and localising specific cardiac abnormalities or changes in electrical conduction. The Wilson unipolar limb leads have become a standard part of modern ECG recording, providing valuable insights into the heart's electrical patterns. They are widely used in clinical practice, allowing for a more comprehensive evaluation of cardiac function and aiding in diagnosing and managing cardiac conditions. (Mehta 2002, 4-7.)

The standard 12-lead ECG comprises three limb leads, three augmented unipolar leads, and six precordial leads. The bipolar limb leads consist of three limb leads that detect variations in electric potential between two points in the frontal plane of the body. The electrodes are placed on the right arm (RA), left leg (LL), and left arm (LA), typically just above the wrist and ankles. In cases of limb amputation, the electrodes are applied to the amputated stump. **Lead I** is generated by the potential difference between the right arm (RA-) and left arm (LA+). **Lead II** is generated by the potential difference between the right arm (RA-) and left leg (LL+). **Lead III** is generated by the potential difference between the left arm (LA-) and left leg (LL+). Consequently, the current flows from the negative electrode to the positive electrode, specifically from the right arm to the left arm (Lead I), the right arm to the left leg (Lead II), and the left arm to the left leg (Lead III). Refer to FIGURE 3.1, FIGURE 3.2, and FIGURE 3.4. (Mehta 2002,5.) The unipolar augmented limb leads utilise two electrodes, where only the electrical activity of the exploring electrode is recorded. In contrast, the potentials recorded by the other electrode (the indifferent electrode) are insignificant. The indifferent electrode terminal consists of the sum of RA, LA, and LL, which equals zero. The potential difference between the RA and the indifferent electrodes is recorded when the exploring electrode is placed on the right arm. Since the potential of the indifferent electrode is negligible, it is considered zero. Consequently, the recorded potential represents the actual potential of the right arm (RA). Similarly, by placing the exploring electrode on the left arm and left leg, the actual potentials of LA and LL are recorded. These leads are labelled as VR, VL, and VF. By slightly modifying the technique, the voltage of these leads can be increased by 50%, resulting in augmented leads known as aVR, aVL, and aVF. (see FIGURE 3.1, FIGURE 3.2, and FIGURE 3.4) (Mehta 2002,4-7.).

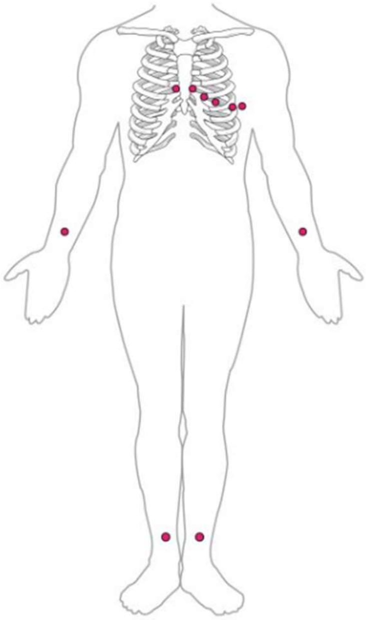


FIGURE 3. 1. Leads and electrode placement on the body (Biga 2012, CC BY -SA)

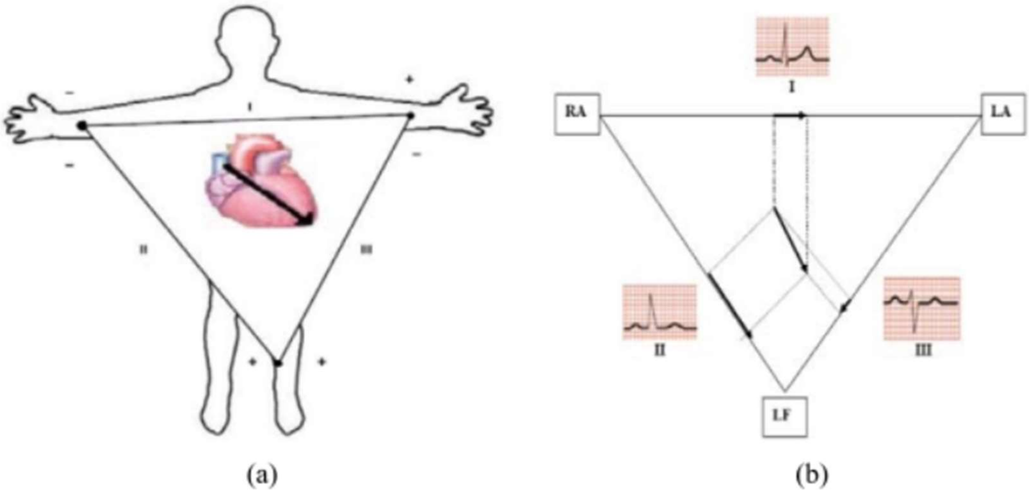


FIGURE 3. 2. (a) The direction of the cardiac vector in black arrow (b) Electrode connection between lead I, II, and III (Gohel & Tiwary 2010, CC BY -NC)

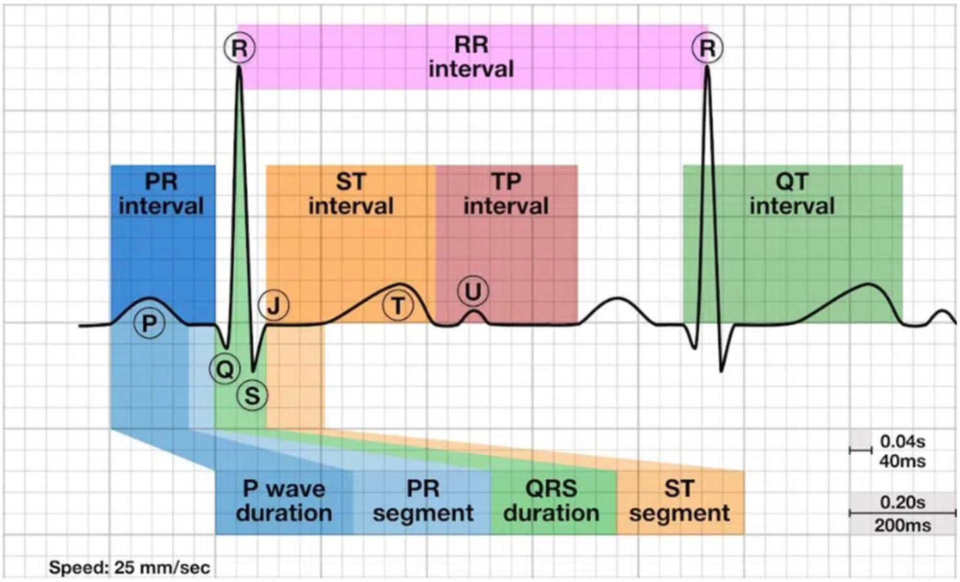


FIGURE 3. 3. Components of ECG waves (Cadogan & Buttner 2019, CC BY -NC-SA)

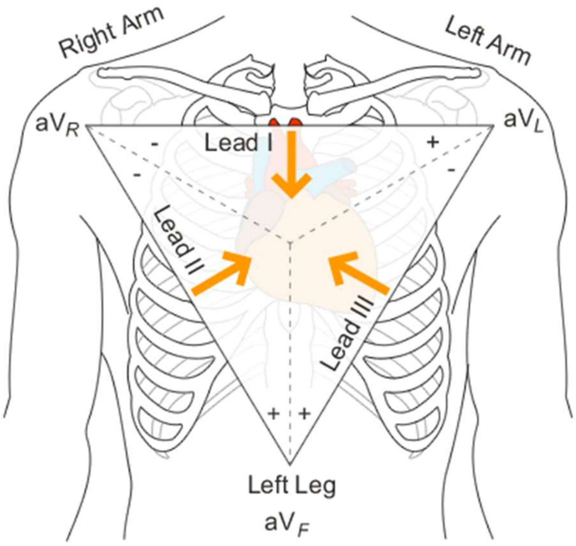


FIGURE 3. 4. Bipolar and unipolar limb leads (University of Nottingham s.a., CC BY -NC)

The six unipolar precordial leads (see FIGURE 3.1) capture the electrical potential at specific locations on the chest wall in the horizontal plane of the body. The standard positions for these precordial leads are as follows - V1: Fourth intercostal space at the right sternal border, V2: Fourth intercostal space at the left sternal border, V3: Midway between V2 and V4, V4: Fifth left intercostal space in the mid-clavicular line, V5: Fifth left intercostal space in the anterior axillary line, V6: Fifth left intercostal space in the mid-axillary line. (Mehta 2002, 6.)

The ECG machine is designed such that an electrode facing a wave of depolarisation will record a positive or upward deflection. In contrast, an electrode on the side where the wave recedes will record a negative or downward deflection.

The P wave denotes the initial positive wave representing the atrial depolarisation. It is most clearly observed in lead II. Its duration should not exceed 0.12 seconds, which is equivalent to the length of 3 small horizontal squares, and its amplitude should not surpass 0.25 millivolts, corresponding to 2.5 small squares vertically. (Mehta 2002, 9-10.)

The QRS complex is generated by the depolarisation of the ventricles, which occurs in multiple directions throughout the heart. The deflection of the QRS complex reflects the average direction of the spreading wave of depolarisation in a particular lead. The QRS complex consists of the Q, R, and S waves. The smaller amplitude waves are represented by q, r and s. There are additional R′ and S′ waves too. (Mehta 2002, 11-13.) The Q wave is a negative deflection preceding the R wave, indicating the depolarisation of the ventricular septum from left to right (Mehta 2002, 11-13). The R wave is the first positive deflection in the QRS complex, representing the depolarisation of the ventricles, starting with the anteroseptal portion followed by the major ventricular muscle mass (Mehta 2002, 11-13). The S wave is the first negative deflection following the R wave in the QRS complex. It occurs due to the depolarisation of the posterior basal part of the left ventricle, pulmonary conus, and the uppermost part of the interventricular septum. (Mehta 2002, 11.)

The T wave is produced by ventricular repolarisation. It has a smooth, dome-shaped appearance, resembling two asymmetrical limbs, with the peak closer to the end of the wave than the beginning. (Mehta 2002, 14.) The U wave represents the slow repolarisation of the Purkinje fibres, the papillary muscles, or the ventricular septum, or it can indicate slow ventricular repolarisation (Mehta 2002, 15).

There are numerous clinical applications of electrocardiography. Since ECG is a fundamental tool in cardiology, it plays a crucial role in diagnosing and monitoring various heart conditions. Some common conditions include diagnosing cardiac arrhythmias like atrial flutter, atrial fibrillation, and wide complex supraventricular tachycardia (Zipes 2000). This investigation is also necessary to detect ischaemic heart disease, which is confirmed with an ST-segment pattern on an ECG. It can either be elevated or depressed, depending on the type of myocardial infarction. ECGs are also done to check the effects of electrolyte imbalance on the heart, such as hyperkalemia or hypokalemia and metabolic disturbances (Sattar & Chhabra, 2023). Other clinical applications include monitoring the patients in the critical care unit to detect changes in their heart rhythm, assess their cardiac status, and evaluate a patient pre-operatively for any surgical intervention.

APPENDIX 4: ECG QUESTIONNAIRE FLOWCHART

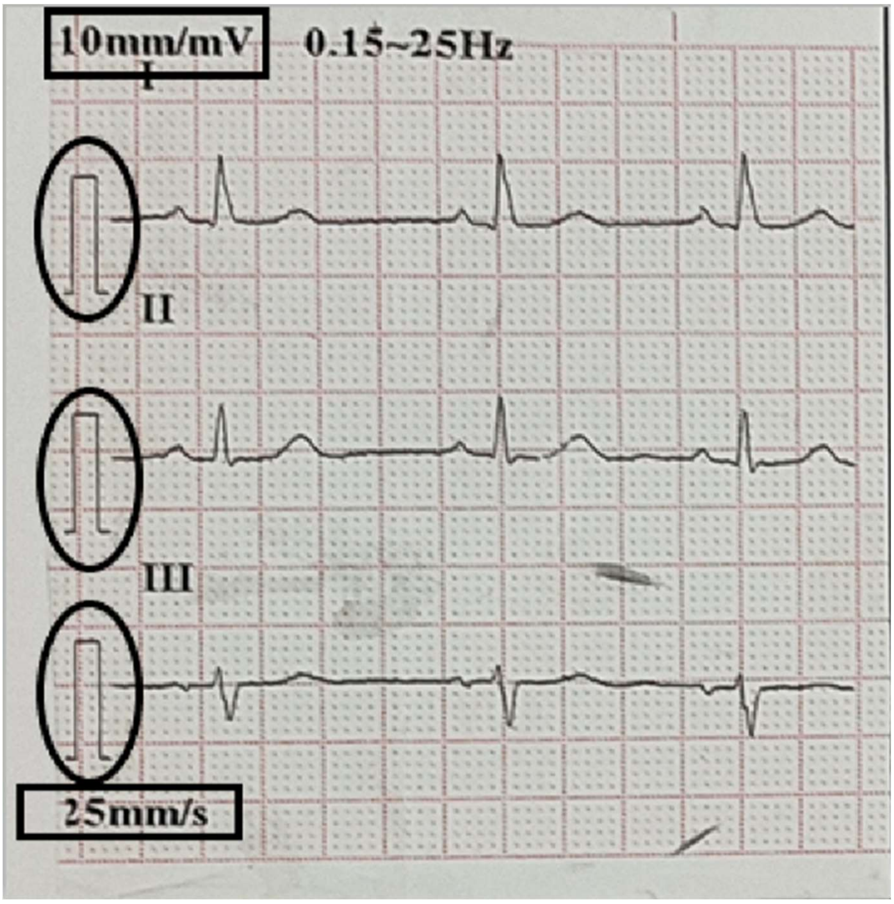
ECG INTERPRETATION QUESTIONNAIRE:

Basic concepts for ECG interpretation before beginning:

- The ECG machines or recorders are normally calibrated in such a way that 1mV of signal causes a deflection of 1 cm on the ECG paper.

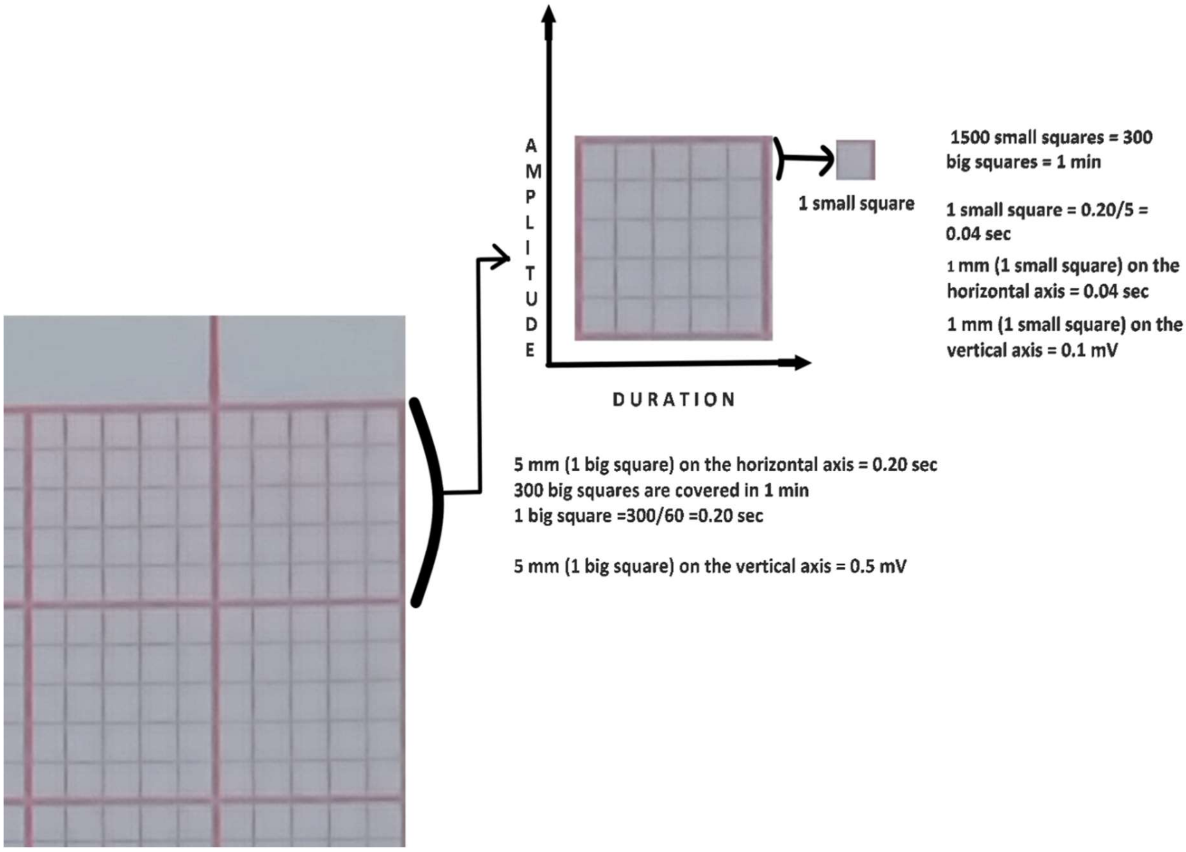
  A calibration signal usually appears at the beginning of a recording. (see FIGURE 4.1)

  FIGURE 4. 1. ECG paper calibration (Padvi 2023, CC BY -NC-SA)



- The ECG paper is set to run a paper speed of 25mm/s. However, this setting can be altered to run at slow or fast speed. Therefore, make sure to check if your ECG to be interpreted is recorded at the standard setting because this application is designed considering the fact that the standard calibration method is followed.
- The ECG paper is a graph paper that has ruled lines 1mm apart in horizontal and vertical directions. A bold, thick line is present in both directions at every fifth interval line. In 1 minute, 300 big squares are covered, which is equivalent to 1500 small squares. Hence, electrical activity recorded in 1 big square is equivalent to 0.20 seconds and in 1 small square equals 0.04 seconds on the horizontal axis. Similarly, one big square is equivalent to 0.5 mV on the vertical axis; thus, one small square is equal to 0.1 mV. (see FIGURE 4. 2.)

FIGURE 4. 2. ECG graph paper details (Padvi 2023, CC BY -NC-SA)



- COMPONENTS OF AN ECG

The picture below shows the various components of an ECG.

FIGURE 4. 3. Components of an ECG (Cadogan & Buttner 2022, CC BY -NC-SA)

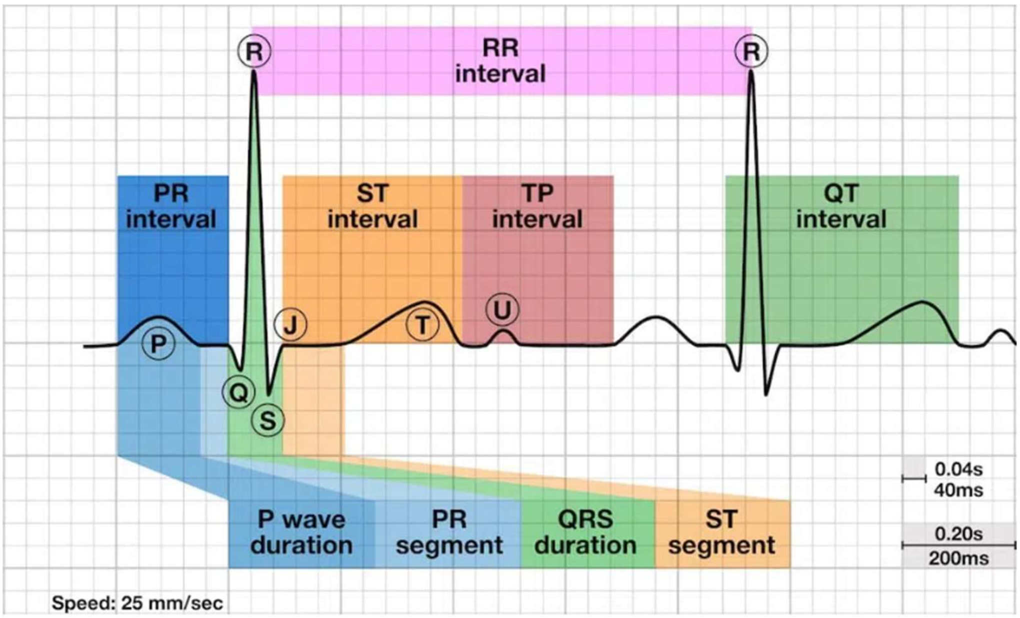


FIGURE 4. 4. Normal ECG (Burns & Buttner 2021, CC BY -NC-SA)

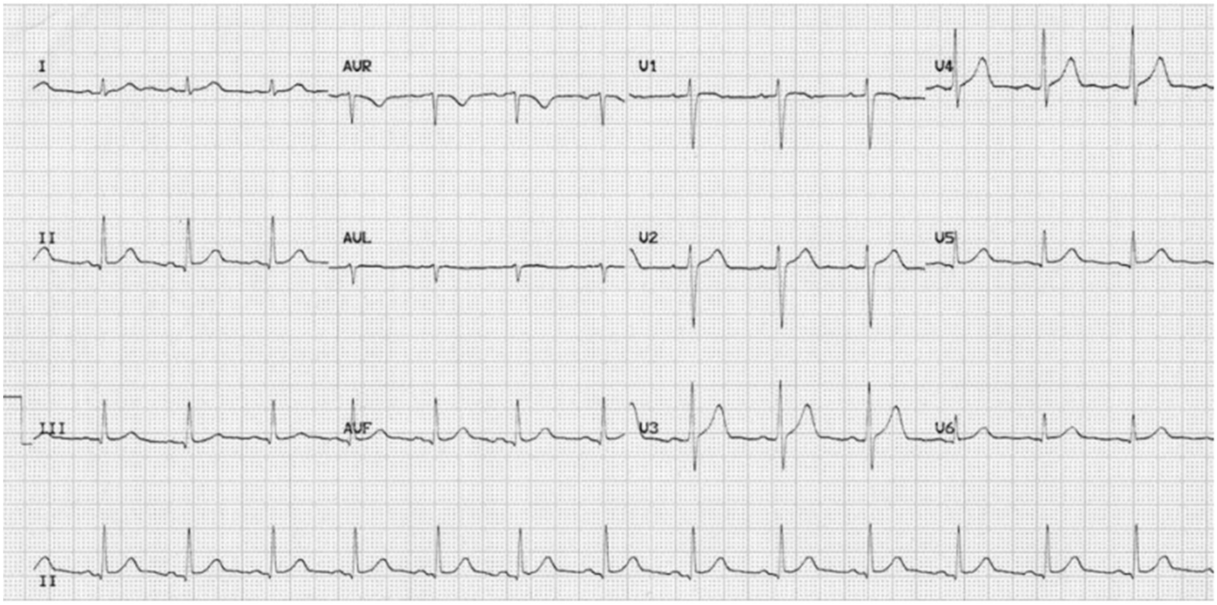
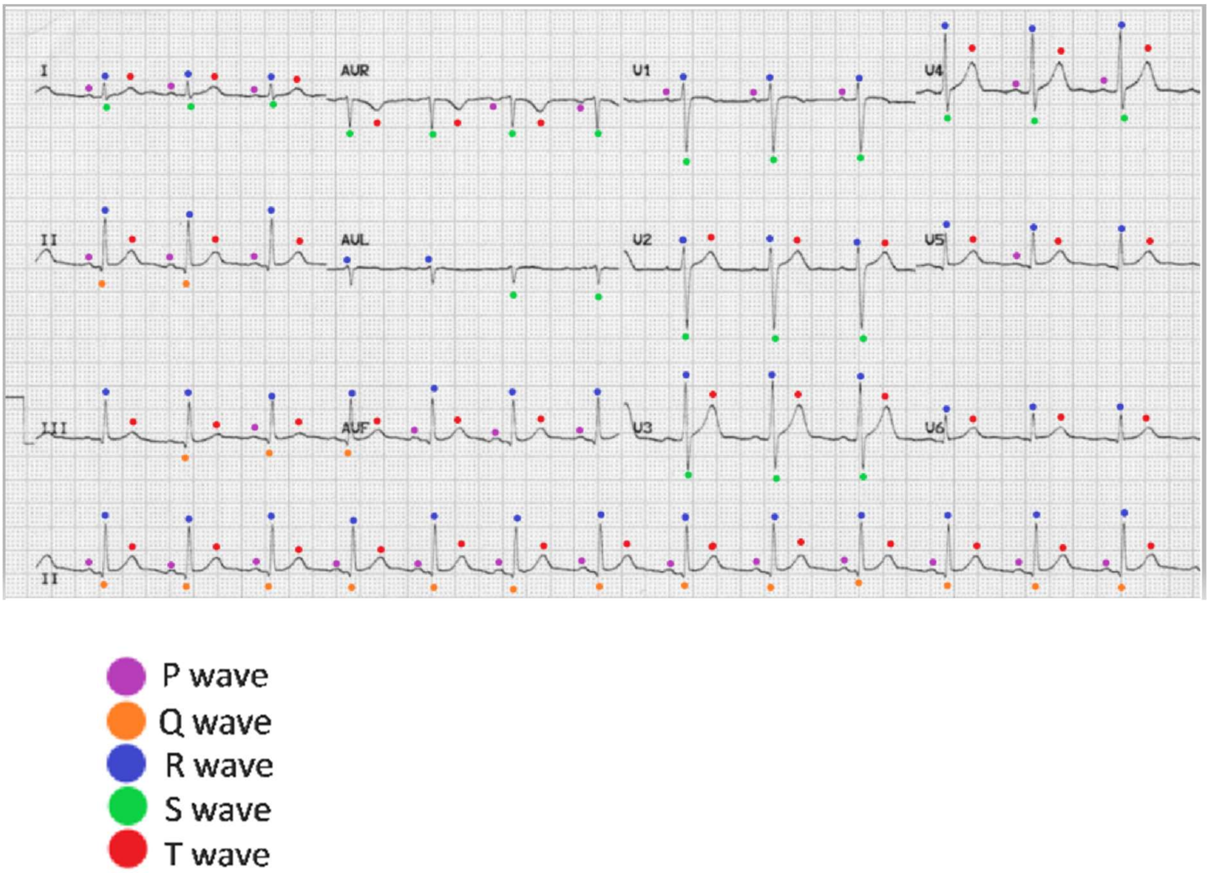


FIGURE 4. 5. PQRST complexes (Burns & Buttner 2021, CC BY -NC-SA)



NOTE:

- Positive waves are seen in lead I, II, III, and aVF.
- The P waves are upright in most leads, and they are followed by QRS complexes.
- Waves are inverted or negatively deflected in aVR.

- R wave progression is visible in precordial leads. It increases from V1 to V4.
- S wave progression is visible in precordial leads. It increases from V1 to V2, then decreases from V3 to V4 before disappearing in V5 and V6.

ECG INTERPRETATION OF FIGURE 4.4:

The ECG shows normal Sinus Rhythm because P waves follow QRS complexes at constant intervals. Therefore, the electrical activity is generated from the SA node.
Heart rate = 83 beats/minute
The heart axis is normal.
P waves are positive for most leads except aVR.
The duration of the QRS complex is one and a half small squares, which equals 0.06 seconds. It is less than 0.10 seconds.
The R wave progression is normal in the precordial leads.
The PR interval is constant.
No signs are suggestive of myocardial ischaemia or infarction.

Let us begin!

Fill in the patient information:

A. **Name:** (*input*)
B. **Age:** (*input*)
C. **Sex:** Male/Female/Binary (*maybe mark as check in the boxes)*
D. **Pre-existing medical conditions and/or on any regular medications**:

- Hypertension YES/NO
- Diabetes Mellitus YES/NO
- Stroke YES/NO
- Hyperlipidemia YES/NO
- Other (specify)

E. **Current complaints:** (*What brings the patient to a physician?*)

- Chest pain YES/NO
- Palpitations YES/NO
- Dyspnea YES/NO
- Vomiting YES/NO
- Sweating YES/NO
- Collapse/syncopal attack YES/NO

ECG INTERPRETATION:

Step 1. Glance at your ECG to get a general impression.

Step 2. Take a clear picture of the ECG you want to interpret.

Step 3. Follow the guided step-by-step instructions as you proceed.

1. **CALIBRATION:**

Check for the 'n' shaped signal at the beginning of the recording, as shown in the example in FIGURE 1.

Note that two large squares are equivalent to 1 mV.

The image input will be displayed here where it is possible to manoeuvre

a. Does the ECG have a standard calibration mark? YES/NO

If YES: ECG follows standard calibration. Proceed

If NO: SORRY, ECG CANNOT BE INTERPRETED (*Because the application prototype is designed using standard calibrations*)

b. Do the waves in aVR show negative deflection (see FIGURE 5.)? YES/NO

If YES: Proceed

If NO: Suspect either TECHNICAL ERROR or DEXTROCARDIA.

ERROR MESSAGE DISPLAY

For TECHNICAL ERROR → Repeat ECG and correlate the findings.

For DEXTROCARDIA → If the P wave is inverted in Lead I, too, it is probably dextrocardia.

SORRY, ECG CANNOT BE INTERPRETED (*Because the application prototype is not designed for dextrocardia yet*)

c. Do waves in Lead I and Lead II show positive deflection (see FIGURE 5. for reference)? YES/NO

If YES: ECG is taken properly. Proceed.

If NO: Suspect TECHNICAL ERROR.

ERROR MESSAGE DISPLAY

For TECHNICAL ERROR → Repeat ECG and correlate the findings.

If YES for 1. a, 1. b, and 1. c, then **SUB-CONCLUSION UNDER CALIBRATION: ECG HAS STANDARD CALIBRATION. Go to Section 2.**

2. RHYTHM AND RATE DETERMINATION:

Check the rhythm strip, a prolonged recording of a single lead II with about 12 consecutive complexes. If the rhythm strip is not recorded, one can look at leads I, II, aVF, and V1. Look at the bottom of FIGURE 4. and FIGURE 5. and notice the recorded rhythm strip of lead II. Look at FIGURE 3. for reference.

2.1. Are the P waves present? YES/NO

If YES: Proceed to 2.2

If NO: GO to 2.6.1.

2.2. Are the QRS complexes present? YES/NO

If YES: Proceed to 2.3

If NO: **CONSULT SENIOR PHYSICIAN**

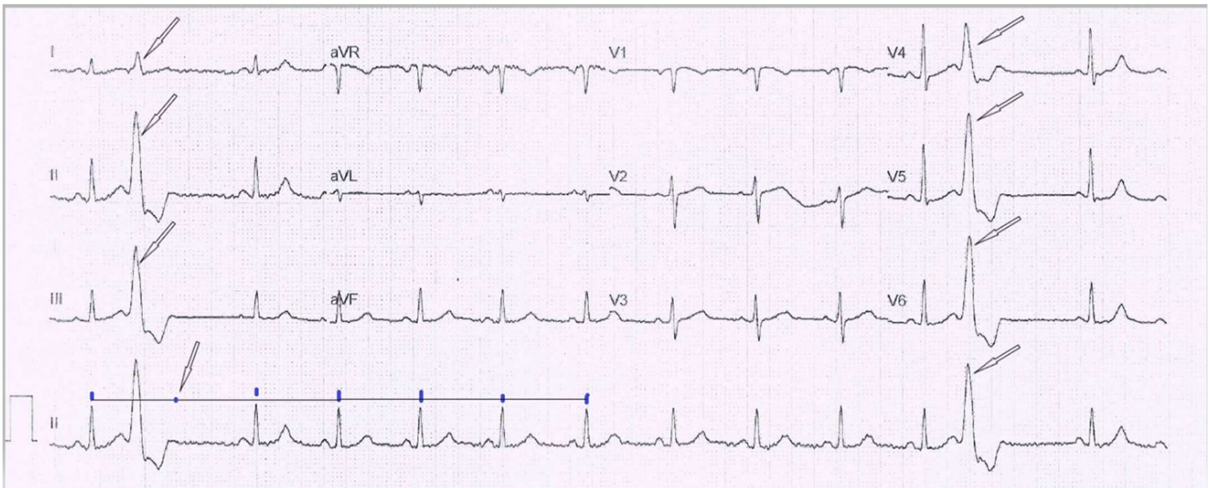
2.3. Do the P waves follow the QRS complexes at regular intervals? YES/NO

If YES: **SUB-CONCLUSION: REGULAR RHYTHM**. Go to 2.6.

If NO: **SUB-CONCLUSION: IRREGULAR RHYTHM.** Proceed to 2.4.

2.4. Does your ECG show one or more odd, wide and tall QRS complexes , as shown in the figure below? YES/NO

FIGURE 4. 6. Premature ventricular complex (PVC) (Padvi 2023, CC BY -NC-SA)



Description: In the above ECG, arrows show the premature ventricular complex (PVC). Note the pause after these complexes. In the rhythm strip (bottom lead II), the blue dots indicate the RR interval. Look at the second blue dot pointed by the arrow. The expected normal beat should have been there. However, after the first PQRS complex, there is a PVC which is followed by a compensatory pause. The next PQRST complex is at a regular and constant period until there is another PVC. Also, notice the T wave inversions and prominent R waves in the PVC.

Ventricular Premature beats (VPB)/ Premature Ventricular Complexes(PVC):

- *Ventricular premature beats result from premature discharge from an ectopic focus in the ventricles.*
- *It is characterised by the prominent beats that arise prematurely.*
- *Since they arise from ventricles, P waves are absent.*
- *The QRS complex is wide, bizarre, and tall.*
- *The deflection of T waves disagrees with the deflection of the QRS complex, which means if the R wave is prominent, then the T wave is inverted, and if the S wave is prominent, then the T wave is upright.*
- *PVCs occur earlier in the cardiac cycle than the expected next normal beat. They often have a compensatory pause following them, which is longer than the usual pause in the normal rhythm before the next expected beat. The PVC's early timing is called a premature ventricular beat.*

If YES: Calculate heart rate using regular rhythm if only one premature beat is present. (2.6). Sub-Conclusion: The rhythm is regular with a heart rate of …. until the presence of Premature Ventricular Complex. GO TO SECTION 3.

If more than one PVC are noted in your ECG, calculate the heart rate using an irregular rhythm 2.7.

FINAL CONCLUSION: THE ECG SHOWS IRREGULAR RHYTHM WITH MULTIPLE PREMATURE ECTOPIC BEATS WITH VENTRICULAR RATE =(….)BPM.

Correlate with the symptoms to rule out the other causes.

If NO: Proceed to 2.5

2.5. Does the distance between two P waves and R waves vary with respiration with PQRS complexes belonging to normal morphology and with consistent distance between them? YES/NO

If YES**: SUB-CONCLUSION: "IRREGULAR CARDIAC RHYTHM DUE TO RESPIRATION".**
Calculate the heart rate using the smallest R-R interval or P-P interval and the largest R-R interval or P-P interval, thus giving a range for heart rate. For instance, 60-70 bpm. (see 2.6.)

If NO: Calculate heart rate in an irregular rhythm (2.7). Then go to 2.7.1. IRREGULAR RHYTHM DISTURBANCES

2.6. Heart rate in regular rhythm:

METHOD 1. Calculate heart rate by counting the number of big squares between the RR interval:

Formula: Heart rate = 300/ Number of big squares

NUM-BER OF BIG BOXES	1	2	3	4	5	6	7	8	9
HEART RATE	300	150	100	75	60	50	43	38	33

METHOD 2. Calculate heart rate by counting the number of small squares between the RR interval:

Formula: Heart rate = 1500/ Number of small squares

FIGURE 4. 7. Heart rate calculation (Padvi 2023, CC BY -NC-SA)

Calculating heart rate using Method 2.:

Number of small squares = 23

Heart rate = 1500/23 = 65 bpm

Calculate heart rate on your ECG: (BOX TO FILL IN)beats per minute (bpm)

SUB-CONCLUSION: HEART RATE = ...BPM

2.6.1. Ventricular Tachycardia (VT):

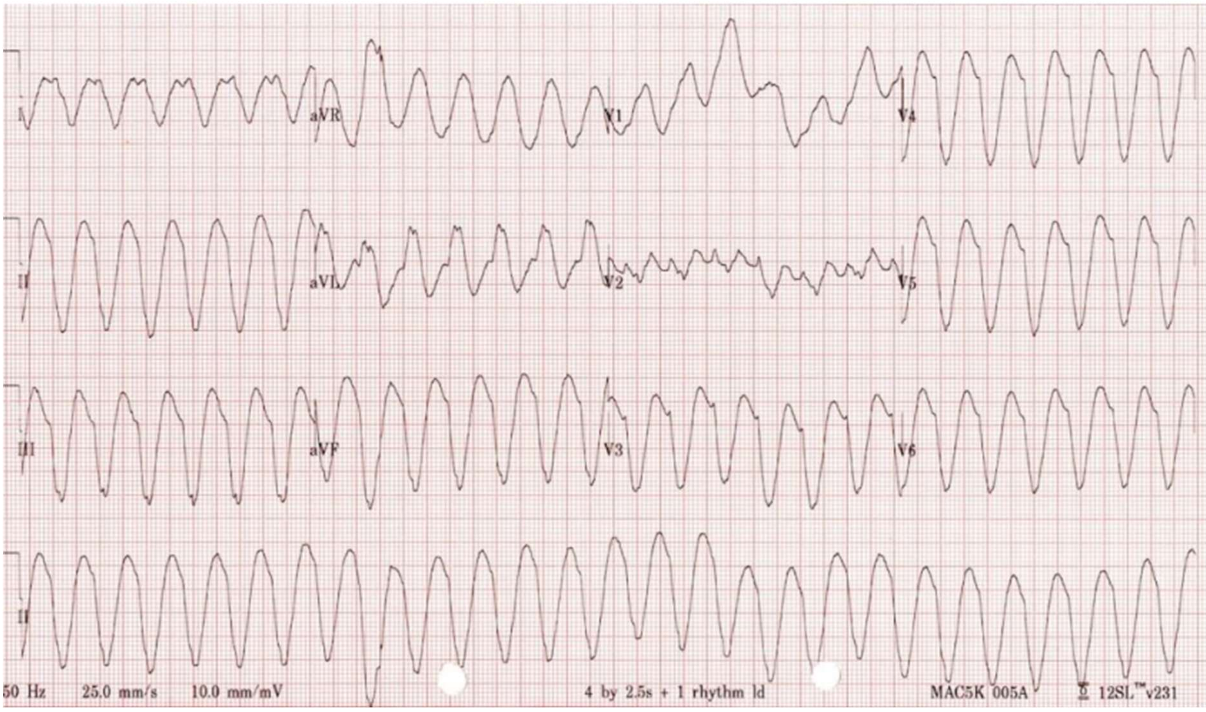
In VT, the heart rate is rapid, usually more than 100 beats per minute.

The rhythm is regular; that is, the intervals between consecutive QRS complexes are relatively consistent. However, the ventricular rate is faster.

QRS complex is wide and bizarre. Ventricular tachycardia originates in the ventricles, causing abnormal and wide electrical activation patterns; therefore, QRS complex duration in ventricular tachycardia is typically greater than 0.12 seconds.

P waves are either absent or are dissociated from QRS complexes, indicating that the atria and ventricles are beating independently which is a characteristic of ventricular tachycardia.

FIGURE 4. 8. Ventricular tachycardia (VT) (Burns & Buttner 2023, CC BY -NC-SA)



Description: The above ECG shows monomorphic sustained ventricular tachycardia (one focus in the ventricles is dominant and hence shows the same pattern).
It has a regular rhythm.
The ventricular rate by the six-second method is 160 beats per minute.
P waves are absent. Hence, an atrial rate cannot be obtained.
QRS complexes are wide, with a duration of more than three small squares—about 0.32 seconds.
PR interval cannot be determined.

Does your ECG comply with the picture and description of VT? YES/NO

Calculate ventricular rate using the six-second method as described above. (box to fill in)

If YES:

FINAL CONCLUSION: THE ECG SHOWS VENTRICULAR TACHYCARDIA WITH VENTRICULAR RATE.....BPM.

If NO: Go to 4.5.

2.7. Heart rate in irregular rhythm:

When an ECG shows irregular rhythm, and one cannot determine the heart rate using either method 1 or 2, then use the six-second method. It can be used to calculate atrial and ventricular rates in rhythm disturbances.

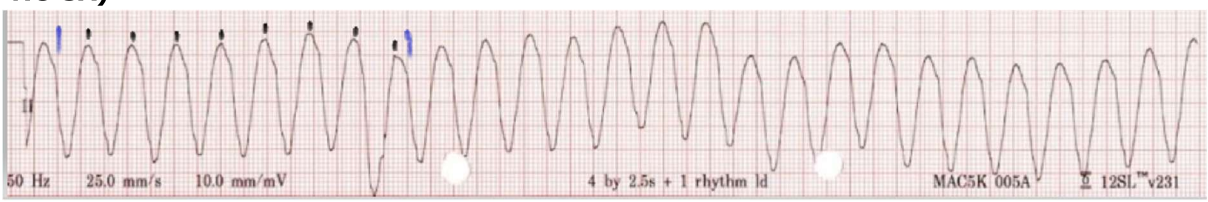
In the case of irregular RR intervals, calculate heart rate using the smallest and largest RR interval and give a range. For example, 60- 100 beats per minute.

SIX SECOND METHOD:

Follow the steps below:

i) Mark 15 big squares on the ECG
ii) Count the QRS complexes within those big squares to get the ventricular rate
iii) Count the P waves within those big squares to get the atrial rate

FIGURE 4. 9. Pictorial demonstration for ventricular rate calculation (Burns & Buttner 2023, CC BY -NC-SA)



In this ECG strip, 15 big squares are counted and marked in blue. Then, the QRS complexes within those 15 big squares are counted. This example shows that there are 8 QRS complexes.

Fifteen big squares equal 3 seconds (1 big square = 0.20 seconds).

Hence, 30 big squares are equivalent to 6 seconds (15+15 = 30, therefore, 3*2 = 6).

8 QRS in 15 big squares will become 8 * 2 = 16 QRS complexes in 30 big squares.

To get the heart rate in 1 minute, which equals 60 seconds, 6 * 10 = 60; hence, 16* 10 = 160 beats/minute.

a. Ventricular rate: (Box to fill in)bpm

Check 2.7.1. **Irregular Rhythm Disturbances** if you suspect abnormal ventricular activity.

b. Atrial rate: (Box to fill in)bpm

2.7.1. Irregular Rhythm Disturbances:

2.7.1.A. Ventricular Fibrillation (V-Fib):

Ventricular fibrillation is characterised by rapid, irregular, and chaotic electrical activity in the ventricles of the heart, leading to ineffective pumping of blood.

On an ECG, no distinct P waves, QRS complexes or T waves could be appreciated.

This is a medical emergency and requires rapid response. Check if the patient is responsive and if they are breathing. If the patient is in a non-responsive and gasping state, it is a sign of cardiac arrest. Follow CPR and defibrillator protocol.

Example picture:

FIGURE 4. 10. Ventricular fibrillation (Burns & Buttner 2022, CC BY -NC-SA)

FIGURE 4. 11. Ventricular fibrillation (Burns & Buttner 2022, CC BY -NC-SA)

NOTE: *V-Fib is a highly unstable rhythm that can rapidly deteriorate into cardiac arrest. In this condition, the heart is not effectively pumping blood, leading to loss of consciousness and loss of pulse. This makes it challenging to capture V-Fib on a standard 12 lead ECG because the patient's condition can deteriorate too quickly to obtain an ECG recording. Such cases need continuous monitoring on an ECG, and there are no discernible patterns of QRS complexes, P waves, or T waves. The ECG shows a chaotic and irregular waveform, as shown in FIGURE 10. and as highlighted in FIGURE 11. The diagnosis of V-Fib is often based on clinical presentation, such as sudden loss of consciousness, absence of a pulse, and unresponsiveness, rather than solely on ECG findings. This condition calls for rapid and immediate intervention.*

Does your ECG match the description in this section? YES/NO

If YES: **FINAL CONCLUSION: THE ECG SHOWS VENTRICULAR FIBRILLATION.**

If NO: Proceed to 2.7.1.**B**

2.7.1.B. Polymorphic Ventricular Tachycardia (PVT)/(Torsade de Pointes) (TdP):

TdP is a distinctive form of PVT characterised by its unique appearance on an ECG. It is often associated with ***prolonged QT interval****, which can be congenital or acquired.*

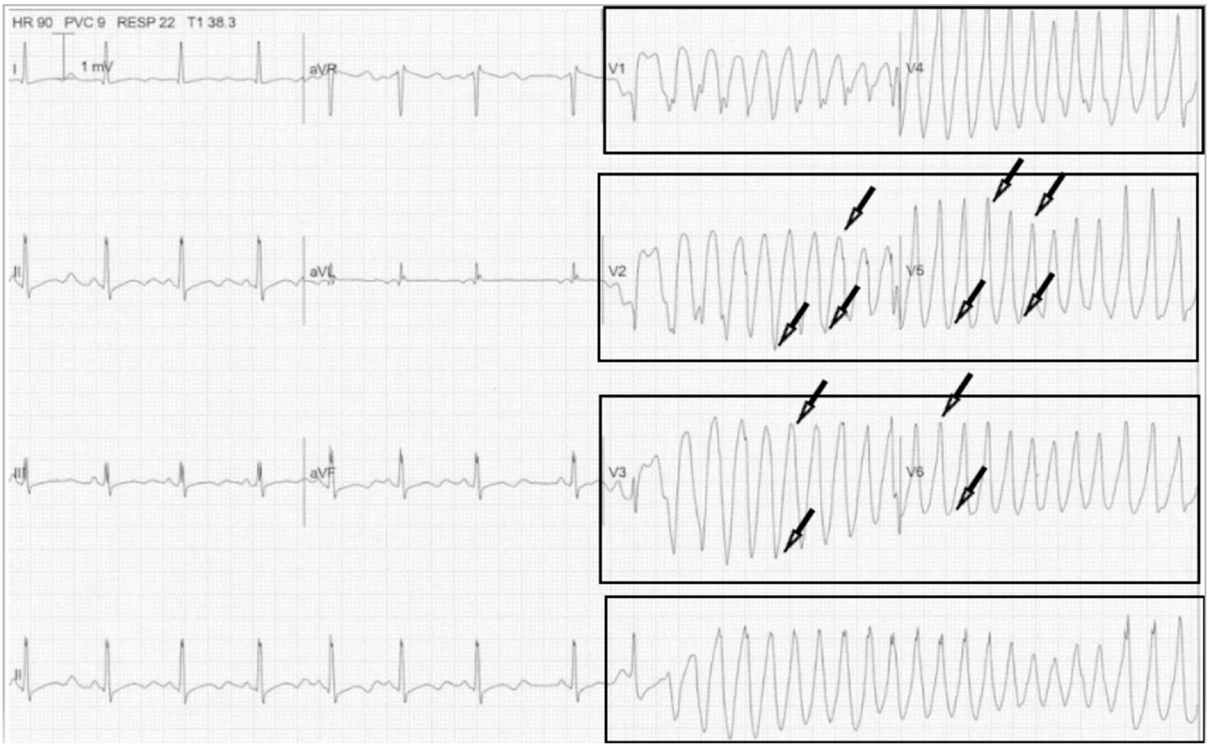
Heart rate is usually between 150 to 250 beats per minute.

Polymorphic appearance means that the QRS complexes in PVT vary in morphology, that is, in their shape and direction. They appear to twist around the baseline, creating a characteristic twisting pattern.

Certain medications can trigger TdP, examples being certain antiarrhythmics, antipsychotics, or certain antibiotics. Electrolyte imbalances such as low potassium or magnesium levels can also cause TdP.

This is a critical condition and requires immediate attention because it can deteriorate into ventricular fibrillation, which can lead to cardiac arrest.

FIGURE 4. 12. Torsades de Pointes (Burns & Buttner 2023, CC BY -NC-SA)



Description: *This ECG depicts PVT with "Torsades de Pointes, " which literally means twisting two points. In the rhythm strip, one can notice irregularity, varying R-R intervals followed by the twisting pattern of QRS complexes. In V2, the arrow above points to a blunt end, whereas the arrows below point to sharp ends of QRS complexes. Similarly, in V5, the arrows above point towards the pointed R waves and the arrows below show blunt S waves. This is due to the fact that the QRS complexes have a constantly changing amplitude, direction and duration. This is because multiple ectopic foci in the ventricles produce electric signals and hence cause the variation in its (QRS complex's) morphology. It is, therefore, called Polymorphic Ventricular Tachycardia.*

Does your ECG match the description in this section? YES/NO

If YES: **FINAL CONCLUSION: THE ECG SHOWS POLYMORPHIC VENTRICULAR TACHYCARDIA.**

If NO: **CONSULT SENIOR PHYSICIAN**

SUB-CONCLUSIONS:

If YES in questions 2.1, 2.2, 2.3, and 2.6 (input from the heart rate) is between 60 - 100 bpm. **ECG IS NORMAL WITH SINUS RHYTHM**. Proceed to section 3.

If YES in questions 2.1, 2.2, 2.3, and 2.6 (input from the heart rate) is less than 60 bpm. **ECG IS NORMAL WITH SINUS BRADYCARDIA.** Proceed to section 3.

If YES in questions 2.1, 2.2, 2.3, and 2.6 (input from the heart rate) is more than 100 bpm. **ECG IS NORMAL WITH SINUS TACHYCARDIA.** Proceed to section 3.

If YES in questions 2.1, 2.2, 2.3, 2.5, and 2.6 (input from the heart rate) is provided in range, then the **ECG IS NORMAL WITH SINUS ARRHYTHMIA.** Proceed to section 3.

FINAL CONCLUSIONS:

THE ECG SHOWS IRREGULAR RHYTHM WITH MULTIPLE PREMATURE ECTOPIC BEATS WITH VENTRICULAR RATE =(….)BPM

THE ECG SHOWS VENTRICULAR TACHYCARDIA WITH VENTRICULAR RATE…..BPM.

THE ECG SHOWS VENTRICULAR FIBRILLATION.

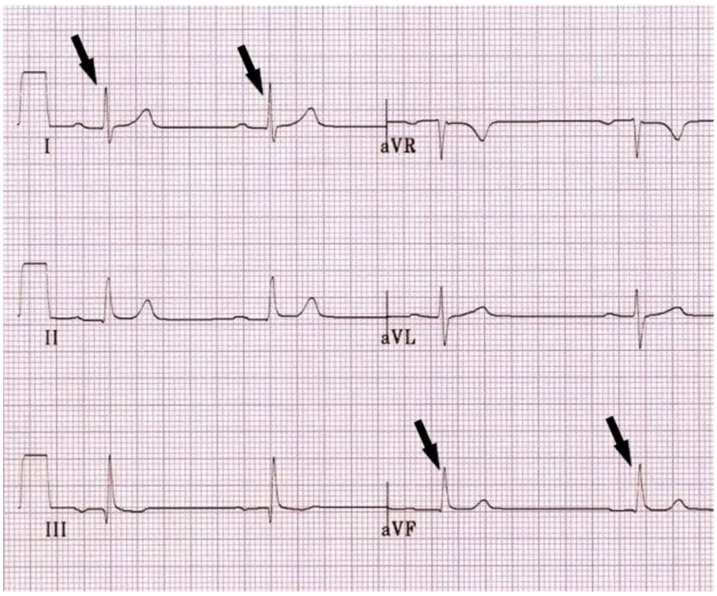
THE ECG SHOWS POLYMORPHIC VENTRICULAR TACHYCARDIA

3. AXIS DETERMINATION:

Check Lead I and aVF to determine the QRS axis in the frontal plane of the heart. In normal circumstances, the QRS complexes are predominantly positive in these leads.

3.1. Are the QRS complexes in lead I and lead aVF positively deflected as in the picture below? YES/NO

FIGURE 4. 13. Normal cardiac axis (Cadogan & Buttner 2022, CC BY -NC-SA)

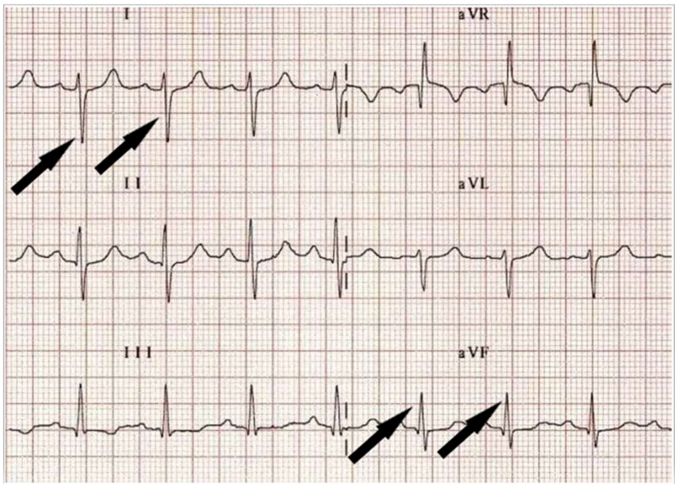


If YES: **SUB-CONCLUSION: NORMAL CARDIAC AXIS.** Proceed to section 4.

If NO: Proceed to 3.2

3.2. As in the picture below, are the QRS complexes in lead I negatively deflected and lead aVF positively deflected as in the picture below? YES/NO

FIGURE 4. 14. Right axis deviation (Cadogan & Buttner 2022, CC BY -NC-SA)

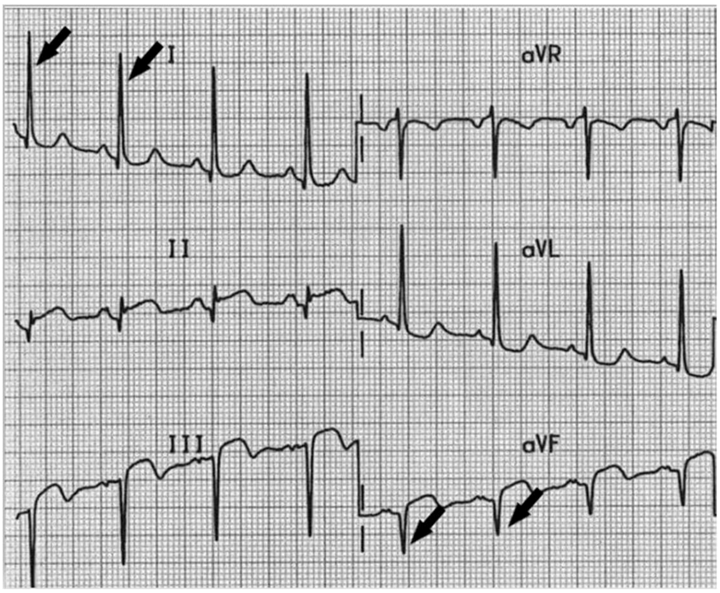


Note that in lead I, the height of the S wave is more than the R wave; therefore, one can say that the QRS complex is negatively deflected. Similarly, in lead aVF, the height of the R wave is more than the S wave; the QRS complex is mostly positively deflected.

If YES**: SUB-CONCLUSION: RIGHT AXIS DEVIATION**. Proceed to section 4.
If NO: Proceed to 3.3

3.3. As in the picture below, are the QRS complexes in lead I positively deflected and lead aVF negatively deflected? YES/NO

FIGURE 4. 15. Left axis deviation (Cadogan & Buttner 2022, CC BY -NC-SA)



If YES: **SUB-CONCLUSION: LEFT AXIS DEVIATION.** Proceed to section 4.

If NO: **ERROR. CONSULT SENIOR PHYSICIAN**

SUB-CONCLUSIONS:

If YES in 3.1. ECG SHOWS NORMAL CARDIAC AXIS. Proceed to Section 4.

If YES in 3.2. ECG SHOWS RIGHT AXIS DEVIATION. Proceed to Section 4.

If YES in 3.3. ECG SHOWS LEFT AXIS DEVIATION. Proceed to Section 4.

If NO in 3.3. ERROR. CONSULT SENIOR PHYSICIAN

4. P Wave :

P waves represent the atrial depolarisation on an ECG.

The criteria for normal P waves are:

- *The duration should not exceed 0.12 seconds or three small horizontal squares.*
- *The amplitude should not exceed 0.25 mV or 2.5 small vertical squares.*
- *P waves are upright in all leads except in aVR.*
- *They should have smooth and rounded contours.*
- *P waves may be upright or biphasic in chest leads V1 and V2. If biphasic, the terminal negative deflection should not exceed 1 mm in depth and 0.03-sec duration (1 mm horizontal square).*
- *In a normal ECG, P waves should always be followed by QRS complexes.*

HINT: The P waves are best viewed in lead II.

4.1. Are P waves present in the ECG? YES/NO

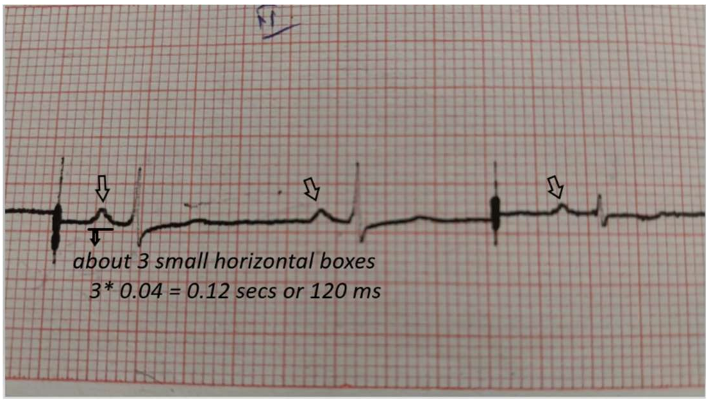
If YES: Proceed with 4.2

If NO: Go to 4.5. ABSENT P WAVEs

4.2. What is the duration of the P wave? (Box to fill in the duration in seconds or milliseconds)

How many small horizontal squares are
covered from the beginning to the end of the P wave?

FIGURE 4. 16. Normal duration of the P wave (Padvi 2023, CC BY -NC-SA)



The normal duration of the P wave should not be greater than 0.12 seconds/120 milliseconds.

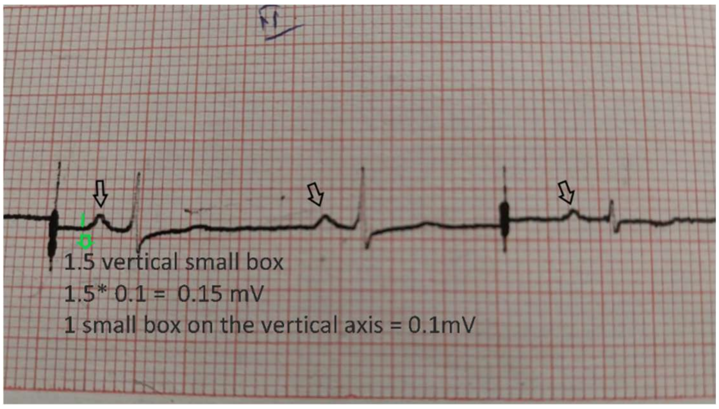
If the duration is equal to or less than 0.12 seconds/120 milliseconds, then the P wave is normal. Proceed with 4.3.

If the duration is more than 0.12 seconds/120 milliseconds, then the P waves are wide. Proceed with 4.3.

4.3. What is the amplitude of the P waves? (Box to fill in the amplitude in the mV)

How many small vertical boxes are covered by the P wave?

FIGURE 4. 17. Normal amplitude of the P wave (Padvi 2023, CC BY -NC-SA)



The normal amplitude of the P wave should not be greater than 0.25 mV.

The P wave is normal if the amplitude is not more than 0.25 mV. Go to the question 4.4. a

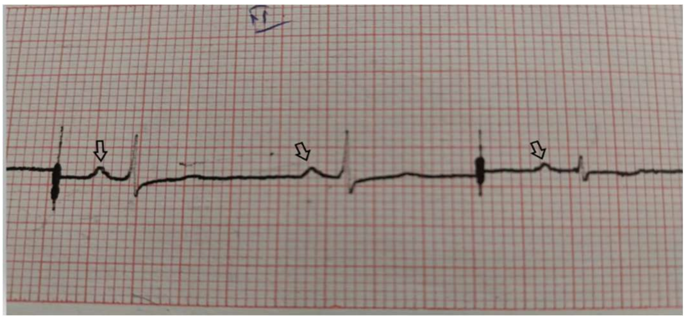
If the amplitude is not more than 0.25 mV, but the duration is more than 0.12 seconds, then go to 4.4. b

If the amplitude is more than 0.25 mV, then go to question 4.4. c

4.4. What is the morphology of the P wave?

4.4.a. Smooth, rounded and upright in Lead II? YES/NO

FIGURE 4. 18. Smooth, rounded and upright P wave in Lead II (Padvi 2023, CC BY -NC-SA)

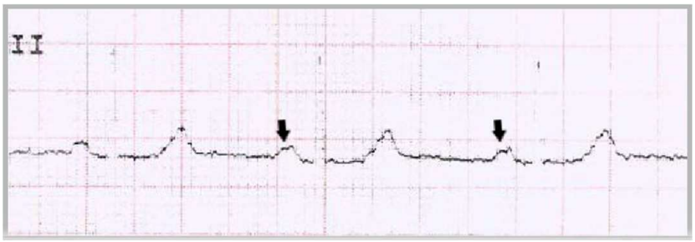


If YES: then the P wave is normal. Go to the question 4.4.d.

If NO: then go to question 4.4.b

4.4.b. Wide and notched in Lead II? YES/NO

FIGURE 4. 19. Wide and notched P wave in Lead II (Padvi 2023, CC BY -NC-SA)

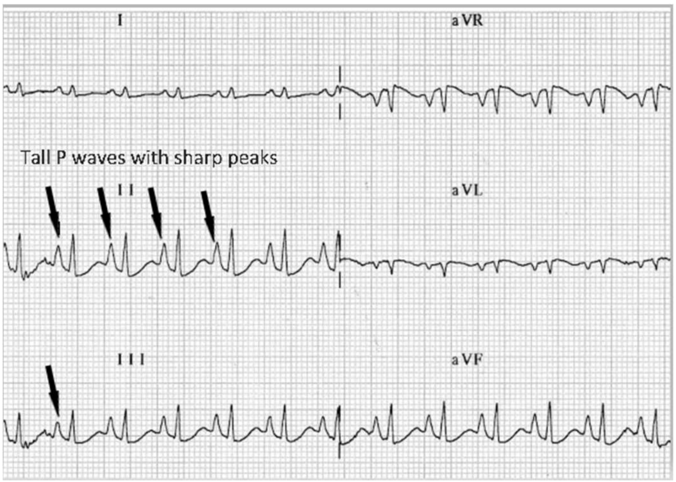


If YES: Go to question 4.4.e. ii

If NO: **CONSULT SENIOR PHYSICIAN**

4.4.c. Tall and pointed in Lead II? YES/NO

FIGURE 4. 20. Tall and pointed P wave in Lead II (Burns & Buttner 2021, CC BY -NC-SA)



If YES: then go to question 4.4.f.

If NO: **CONSULT SENIOR PHYSICIAN**

4.4.d. Is the P wave the same as lead II in lead V1 and V2? YES/NO

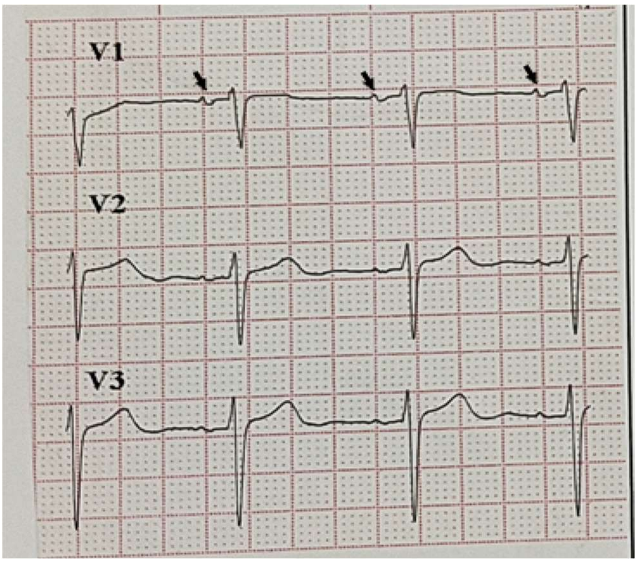
If YES: **SUB-CONCLUSION: NORMAL P WAVE. Go to Section 5.**

If NO: Go to 4.4.e. i

4.4.e. Biphasic P wave in V1 and V2: (Mark YES or NO for the appropriate choice)

i) Terminal negative deflection is not greater than 1 mm deep and has a duration of 0.03 seconds. YES/NO

FIGURE 4. 21. Normal P wave (Padvi 2023, CC BY -NC-SA)

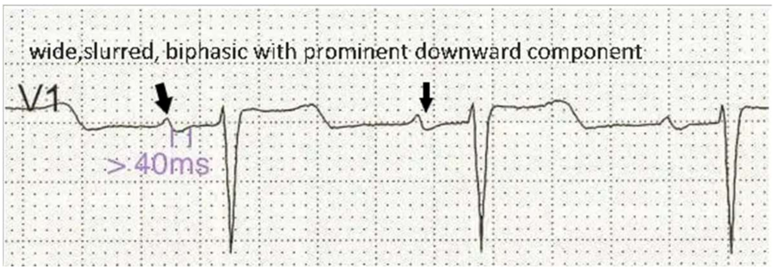


If YES: **SUB-CONCLUSION: NORMAL P WAVE. Go to Section 5.**

If NO: **CONSULT SENIOR PHYSICIAN**

ii) Wide, slurred, biphasic, and downward components are prominent. YES/NO

FIGURE 4. 22. Left atrial enlargement (Burns & Buttner 2021, CC BY -NC-SA)

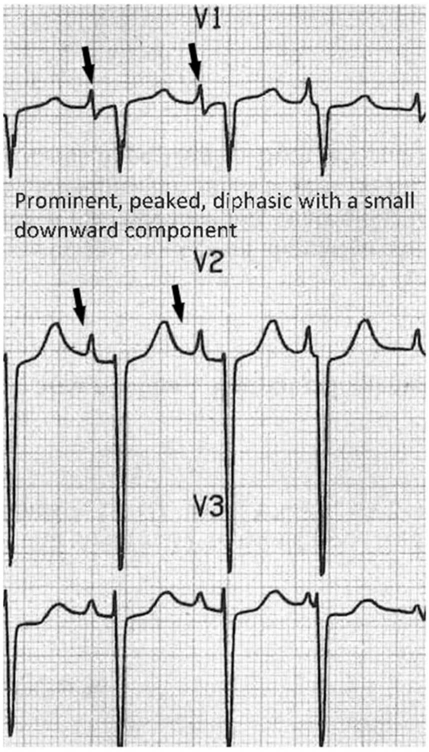


If Yes: **SUB-CONCLUSION: LEFT ATRIAL ENLARGEMENT. Go to Section 5.**

If NO: **CONSULT SENIOR PHYSICIAN**

4.4.f. Peaked, prominent and diphasic with a small downward component. YES/NO

FIGURE 4. 23. Right atrial enlargement (Burns & Buttner 2021, CC BY -NC-SA)



If YES: **SUB-CONCLUSION: RIGHT ATRIAL ENLARGEMENT. Go to Section 5.**

If NO**: CONSULT SENIOR PHYSICIAN**

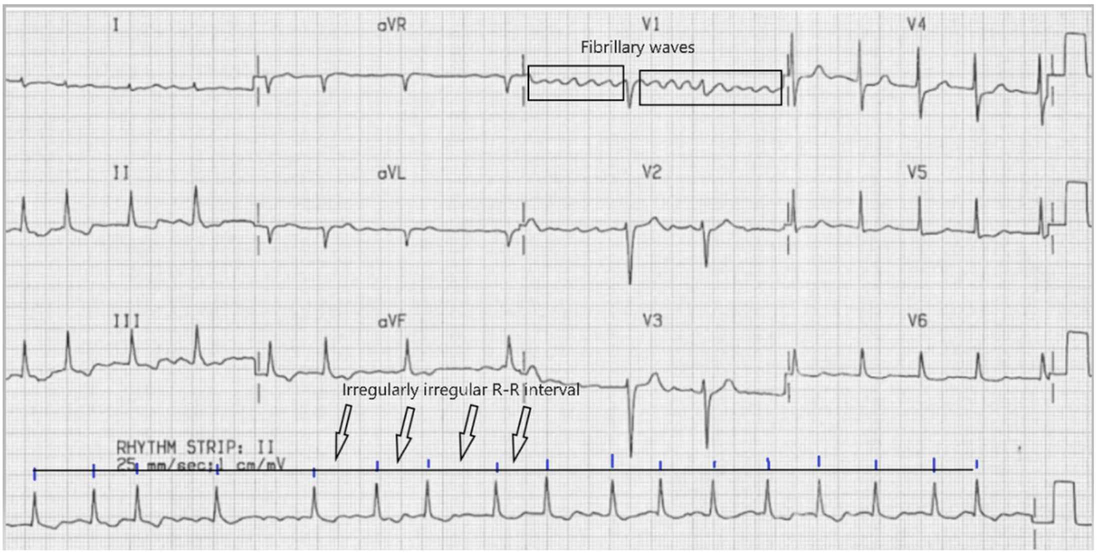
4.5. ABSENT P WAVES:

P waves can be absent or not clearly visible in various conditions. Some of them are listed below. Compare the findings with your ECGs.

4.5.1. Atrial Fibrillation (A-Fib):

a. Are the R -R intervals irregular? Or Does the interval between two consecutive R waves vary in an irregular and unpredictable manner?
b. Are the QRS complex narrow or normal in width?
c. Is the ventricular rate less than the atrial rate?
d. Does it comply with the example picture below?

FIGURE 4. 24. Atrial fibrillation (A-Fib) (Burns & Buttner 2023, CC BY -NC-SA)



Description: *The ECG prominently shows that P waves are absent and R-R intervals are irregularly irregular. The QRS complexes are narrow and about 1.5 small squares in duration, which is 0.06 sec (less than 0.10 sec).*

By the 6-second method, the ventricular rate is 100 bpm.

Please note that the atrial rate cannot be counted here because there are no P waves present. However, in such cases, look for clinical signs such as the presence of pulse deficit. The peripheral pulse count (wrist pulse) would be less and irregularly irregular, whereas the apical pulse count via auscultation would be much more. This difference is called pulse deficit.

In A-Fib, the atrial rate is between 300-600 bpm, and the electrical activity is so fast, chaotic, and irregular that the P waves are absent.

If YES: for 4.5.1. a, b, c, and d, then check ventricular rate (2.7. a)

FINAL CONCLUSION: THE ECG SHOWS ATRIAL FIBRILLATION WITH AN ATRIAL RATE OF ABOVE 300 BPM AND VENTRICULAR RATE (2.7- A) BPM.

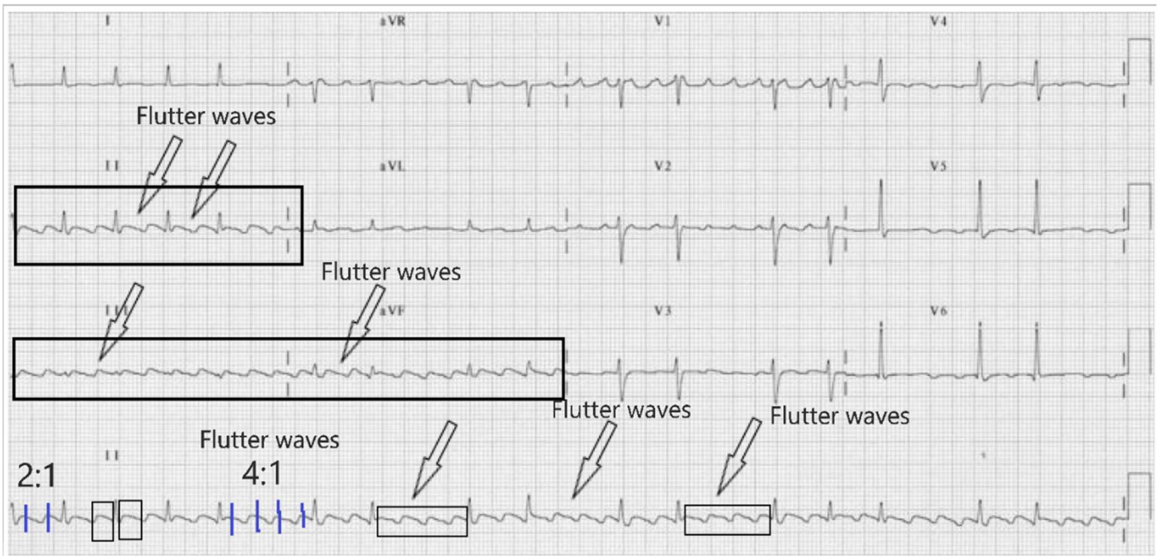
If NO: Proceed to 4.5.2

4.5.2. Atrial Flutter:

a. Does your ECG show a 'saw-tooth appearance' or flutter waves? YES/NO

b. Does it resemble the example provided? YES/NO

FIGURE 4. 25. Atrial flutter waves (Burns & Buttner 2022, CC BY -NC-SA)



Tip: If you don't see upright flutter waves, turn your ECG to see the pattern resembling the flutter waves as shown in the above ECG.

Description: *The ECG shows flutter waves or 'F' waves, which can be seen clearly in lead II, III, aVF, and rhythm strip.*

The atrial rate is about 300 bpm (the F wave covers one big square).

The ventricular rate is 68-136 bpm (smallest R-R interval =11 small squares and largest R-R interval = 22 small squares).

The ventricular rate is irregular.

P waves are absent. Flutter waves are seen in varying ratios, i.e., 2:1 to 4:1.

QRS complexes are 0.04 seconds, which is less than 0.10 seconds.

This ECG shows Atrial Flutter with variable conduction.

If YES: for 4.5.2.a. and 4.5.2.b. then CHECK ATRIAL RATE if between 250-300 bpm and regular/ir-regular RR interval, then **FINAL CONCLUSION: ATRIAL FLUTTER.**

If NO: Rule out other causes like Sinoatrial block and supraventricular tachycardia, among others. CONSULT SENIOR PHYSICIAN

SUB-CONCLUSIONS:

If YES in 4.1, 4.4.a, 4.4.d, 4.4.e.i), and if the value in question 4.2. is less than or equal to 0.12 sec, and if the value in question 4.3. less than 0.25 mV, then P WAVE IS NORMAL ON THE ECG. Proceed to Section 5.

If YES in 4.1, with a value in 4.2 more than 0.12 sec and a value in 4.3 not more than 0.25 mV, and YES in 4.4.b, 4.4.e.ii), then ECG SHOWS LEFT ATRIAL ENLARGEMENT. Go to Section 5.

If YES in 4.1, with a value in 4.3 more than 0.25mV, with YES in 4.4.c and 4.4.f, then ECG SHOWS RIGHT ATRIAL ENLARGEMENT. Go to Section 5.

If NO in any of 4.4.b, 4.4.c, 4.4.e. i), 4.4.e.ii), 4.4.f, and 4.5.2, then, CONSULT SENIOR PHYSICIAN

If NO in 4.1, then, go to 4.5. ABSENT P WAVES.

FINAL CONCLUSIONS:

If NO in any of 4.4.b, 4.4.c, 4.4.e. i), 4.4.e.ii), 4.4.f, and 4.5.2, then, CONSULT SENIOR PHYSICIAN.

If YES: for 4.5.1. a, b, c, and d, then, THE ECG SHOWS ATRIAL FIBRILLATION WITH AN ATRIAL RATE OF ABOVE 300 BPM AND VENTRICULAR RATE (2.7- A) BPM.

If YES: for 4.5.2.a. and 4.5.2.b. then; THE ECG SHOWS ATRIAL FLUTTER

5. QRS COMPLEX/QRS INTERVAL:

On the ECG, checking the QRS complexes in frontal and precordial leads is important. QRS complex morphology examines ventricular depolarisation.

The criteria for a normal QRS complex morphology are:

a. Duration should not be more than 0.12 sec or not more than 2.5 small squares (0.10 sec).
b. Ideally, no Q waves should be seen on the normal ECG. If at all Q waves are visible, they should be less than 0.04 sec or one small square and less than 2 mm in amplitude, in lead I, II, aVL, aVF.
c. R wave should progress (increase) from V1 to V5, and S wave should progress (increase) from V1 to V3 and disappear in V6. (See Figure 5)
d. In lead aVR, QRS has negative deflection.

5.1. Are QRS complexes in the ECG normal as per a, b, c, and d? YES/NO

If YES: **SUB-CONCLUSION: QRS COMPLEXES ARE NORMAL. Go to Section 6**.

If NO: Follow **5.2. ABNORMAL QRS COMPLEX**

5.2. ABNORMAL QRS COMPLEX

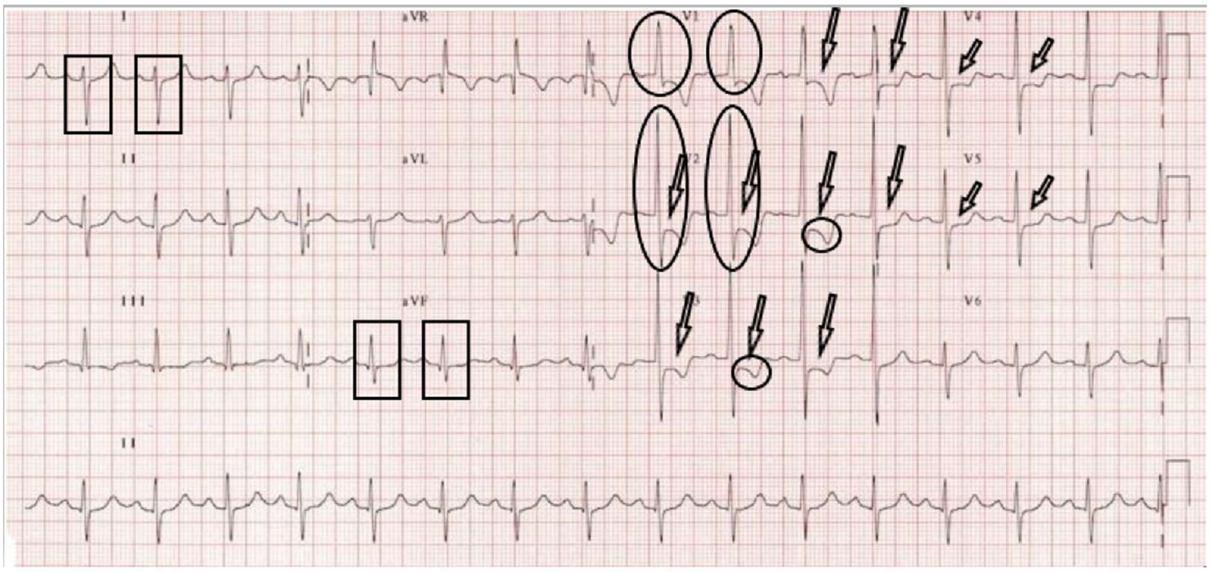
5.2.1. Are large R waves present in V1 and V2?

5.2.2. Is the R:S ratio more than or equal to 1mm?

5.2.3. Are strain patterns present?

5.2.4. Does it resemble as shown in the picture below? YES/NO

FIGURE 4. 26. Right ventricular hypertrophy (Burns & Buttner 2021, CC BY -NC-SA)



Description: The ECG shows normal sinus rhythm, with a heart rate of 94 bpm (R-R and P-P interval is equal to 16 small squares).
There is prominent negative deflection of QRS complexes in lead I, and aVF has a positive deflection of QRS. Hence, there is a right-axis deviation.
P waves are round and smooth with 0.12 sec in duration.
QRS complexes cover two small horizontal squares; hence, the duration is 0.08 sec (< 0.12 sec).
There are tall dominant R waves in V1, V2, V3, and V4. The amplitude of R waves is more than 7 mm, and hence, the R:S ratio is more than 1.
There is the presence of dominant S waves in V6. The amplitude of S waves is 7mm and R waves is 6 mm, hence R:S ratio is less than 1.
ST segment is depressed in V1, V2, V3, V4, and V5, and strain patterns are visible.
T waves show inversion in V1, V2, V3, V4, and V5.
This ECG shows Right Ventricular Hypertrophy.

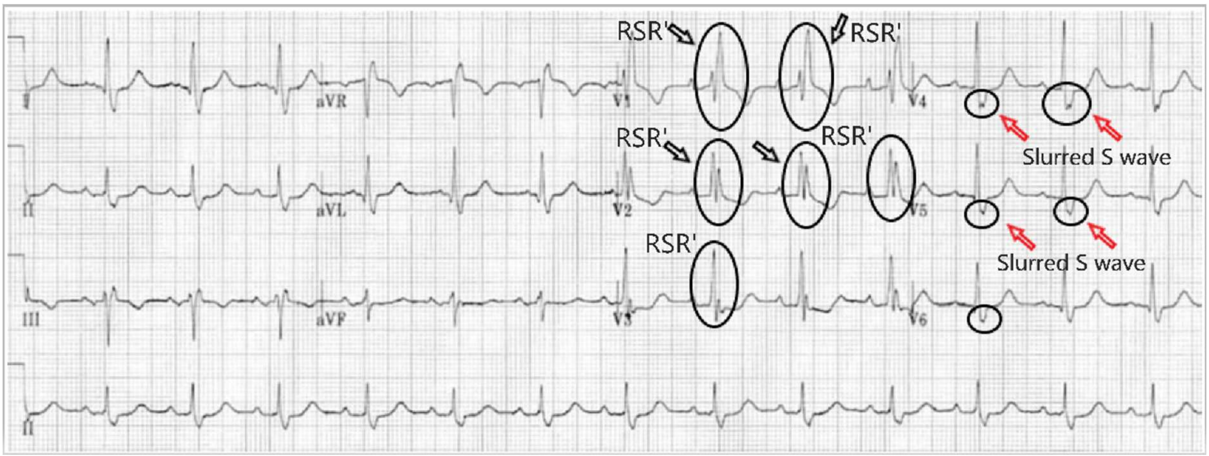
If YES to 5.2.1, 5.2.2, 5.2.3, and 5.2.4:
Then, **SUB-CONCLUSION: RIGHT VENTRICULAR HYPERTROPHY. Go to Section 6.**
If NO: Proceed to 5.2.5.

5.2.5. Are 'M' waves or RSR' patterns seen in V1 and V2?

5.2.6. Can you appreciate slurred S waves in lateral leads, especially V6?

5.2.7. Does it resemble as shown in the picture below? YES/NO

FIGURE 4. 27. Right bundle branch block pattern (Burns & Buttner 2022, CC BY -NC-SA)



Description: Notice the presence of 'M' waves or RSR' patterns in V1, V2, and V3.
Slurred wide S waves are seen in V4, V5 and V6.
ST depression with T wave inversion is appreciated in leads V1 and V2 but not so much in V3. The reason for ST depression and T wave inversion is that abnormal depolarisation of the ventricles is represented by abnormal QRS complex, i.e., RSR' in leads V1 and V2 is followed by abnormal re-polarisation, which is represented by T waves. This is called appropriate discordance.

The above findings comply with the Right Bundle Branch Block.

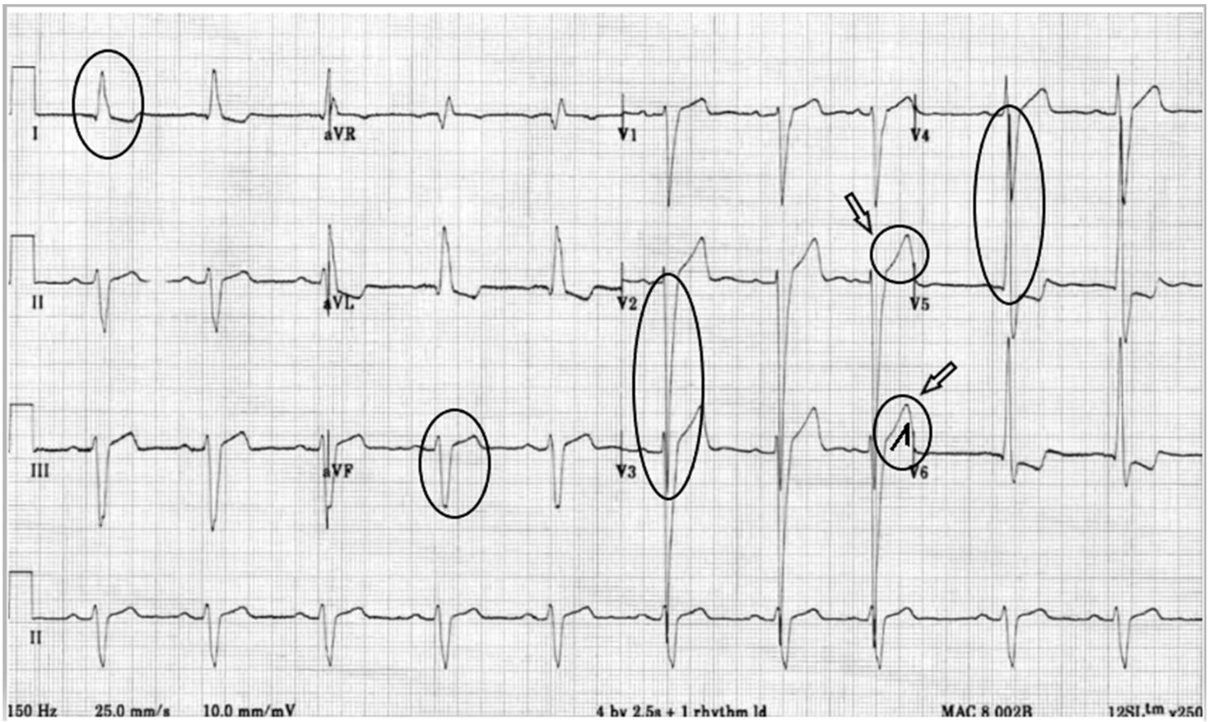
If YES to 5.2.5., 5.2.6., and 5.2.7.:
Then**, CONCLUSION: RIGHT BUNDLE BRANCH BLOCK**. Go to Section 6.

NOTE: IF THERE IS A RIGHT BUNDLE BRANCH BLOCK OR POSTERIOR WALL MYOCARDIAL IN-FARCTION, THEN RIGHT VENTRICULAR HYPERTROPHY CANNOT EXIST.

If NO to 5.2.5., 5.2.6., and 5.2.7.: Proceed to 5.2.8.

5.2.8. Are deep S waves present in V1 and V2?
5.2.9. Are tall R waves present in V5 and V6?
5.2.10. Are tall R waves (more than 11 mm in amplitude) present in aVL?
5.2.11. Are strain patterns present?
5.2.12. Does it resemble as shown in the picture below? YES/NO

FIGURE 4. 28. Left ventricular hypertrophy (Burns & Buttner 2021, CC BY -NC-SA)



Description: This ECG shows normal sinus rhythm at the rate of 62 bpm.
The QRS complexes in lead I are positively deflected and in lead aVF are negatively deflected, indicating a left-axis deviation.
Wide QRS complexes are present, and their duration is 0.12 sec.
There are deep S waves in V1, V2, V3, and V4. The amplitude of the S wave in V2 is 45 mm (deepest), and the amplitude of the R wave in V5 is 36 mm (tallest). The sum of the deepest S wave and the tallest R wave is more than 35.
Also, notice that the amplitude of the R wave in aVL is > 11 mm
ST segment is elevated in V1, V2, V3, and V4. The strain pattern is visible in V2, V3 and V4.
Inverted T waves are seen in V5 and V6.
The above findings on the ECG suggest Left Ventricular Hypertrophy.

NOTE: ST-segment elevation should not be confused with myocardial infarction or myocardial ischaemia. It is advisable to correlate the findings based on the patient's symptoms.

If YES to 5.2.8, 5.2.9, 5.2.10, 5.2.11, and 5.2.12.:

a. Measure the height of the deepest S wave. (box to fill in)

b. Measure the height of the tallest R wave. (box to fill in)

If a + b is more than 35, then according to Skolow Lyon’s criteria,

SUB-CONCLUSION: LEFT VENTRICULAR HYPERTROPHY. Go to Section 6.

If NO to 5.2.8, 5.2.9, 5.2.10, 5.2.11, and 5.2.12.: Proceed to 5.2.13.

5.2.13. Are ‘M’ waves or RsR’ present in V5 and V6?

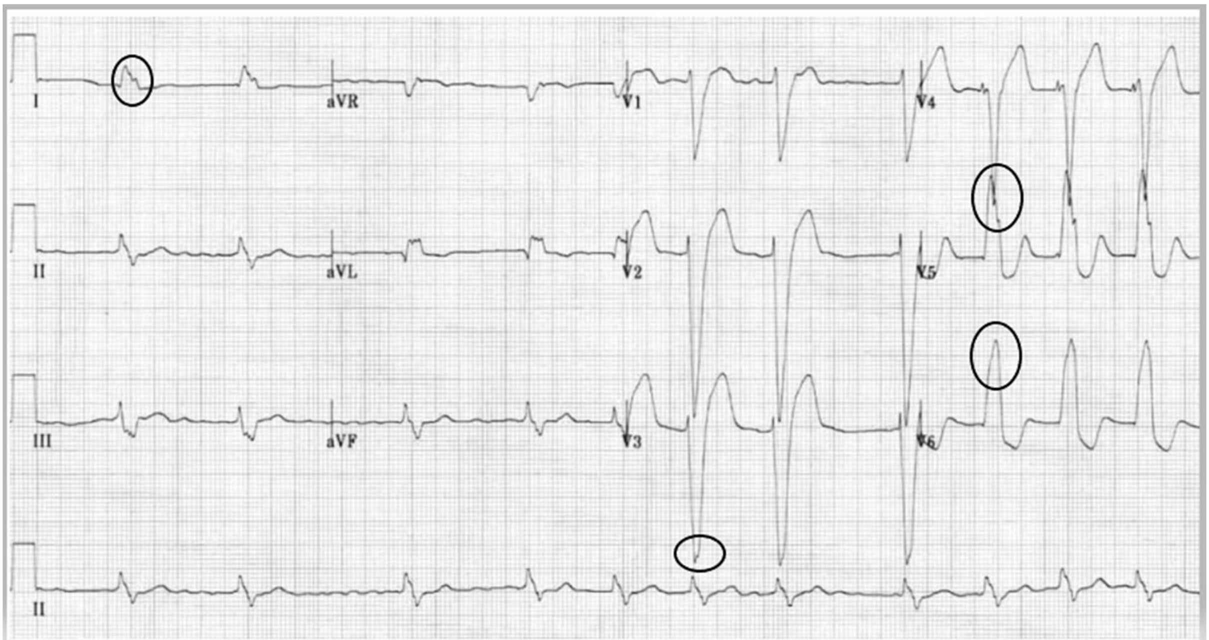
5.2.14. Are deep and wide rS waves/patterns present in V1?

5.2.15. Do lateral leads show RsR’ pattern?

5.2.16. Are Q waves absent?

5.2.17. Does it resemble as shown in the picture below? YES/NO

FIGURE 4. 29. Left bundle branch block (Burns & Buttner 2023, CC BY -NC-SA)



Description: The P waves are absent in this ECG.

In leads V1, V2, and V3, deep S waves are seen, with slurring noticeable in lead V3.

The RsR' pattern is seen in lead I, V5 and V6 (if observed very closely).

The rS pattern is seen in V1, V2, and V3.

Broad and tall R waves are seen in V5 and V6.

The Q waves are absent in precordial leads.

The ST-segment elevation is seen in V1, V2, V3 and V4. V5 and V6 show ST depression.

Note the flutter waves in the rhythm strip.

This ECG is suggestive of the Left bundle Branch block with Atrial Flutter.

If YES to 5.2.13, 5.2.14, 5.2.15, 5.2.16, and 5.2.17: Then,

SUB-CONCLUSION: LEFT BUNDLE BRANCH BLOCK. Go to Section 6.

If NO: **CONSULT SENIOR PHYSICIAN**

SUB-CONCLUSIONS:

If YES in 5.1, then, ECG SHOWS NORMAL QRS MORPHOLOGY.

If YES in 5.2.1, 5.2.2, 5.2.3, and 5.2.4, then ECG SHOWS RIGHT VENTRICULAR HYPERTROPHY. Go to Section 6.

If YES in 5.2.8, 5.2.9, 5.2.10, 5.2.11, and 5.2.12, then, ECG SHOWS LEFT VENTRICULAR HYPERTROPHY. Go to Section 6.

If YES in 5.2.13, 5.2.14, 5.2.15, 5.2.16, and 5.2.17, then, ECG SHOWS LEFT BUNDLE BRANCH BLOCK. Go to section 6.

If YES in 5.2.5, 5.2.6, and 5.2.7, then, ECG SHOWS RIGHT BUNDLE BRANCH BLOCK. Go to Section 6.

FINAL CONCLUSION:

If NO in 5.2.13, 5.2.14, 5.2.15, 5.2.16, and 5.2.17, then, CONSULT SENIOR PHYSICIAN

6. PR INTERVAL:

The PR interval is measured from the beginning of the P wave to the beginning of the QRS complex.
The significance of the PR interval is that it represents the time taken for electrical activity or the excitation to spread from the SA node via the atrial muscles and the AV node and the bundle of His into the ventricular muscles. In other words, the PR interval includes the sum duration of atrial depolarisation, atrial repolarisation and the slight delay that occurs at the AV node.

6.1. The duration of the normal PR interval is 0.12 – 0.20 sec (3 - 5 small squares). (See Figure 3)

a. What is the PR interval in your ECG? (*Box to fill in*) sec

b. Is the PR interval within normal limits? YES/NO

If YES: PR interval is normal with 'a' sec. Go to section 7

If NO: Follow **6.2. ABNORMAL PR INTERVAL**

6.2. ABNORMAL PR INTERVAL:

6.2.1. Is the rhythm regular, but the PR interval is > 0.20 sec? YES/NO

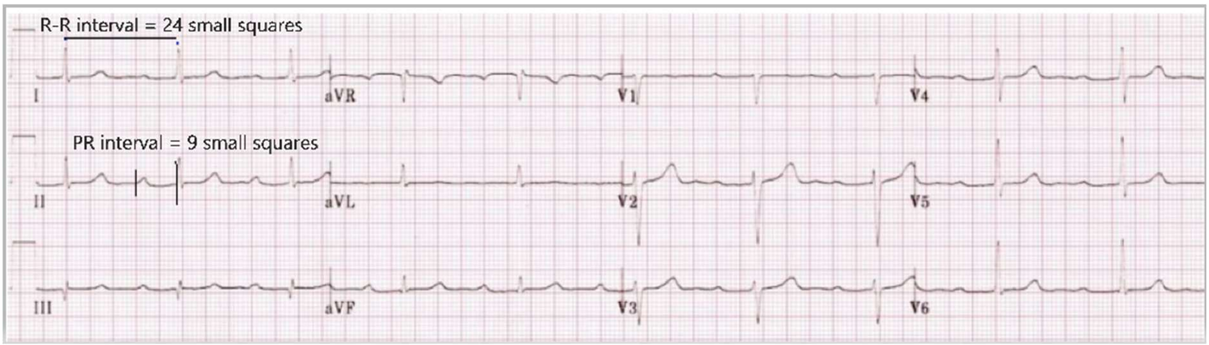
If YES: Proceed to 6.2.2

If NO: Go to 6.2.4

6.2.2. Does heart rate suggest bradycardia? YES/NO

6.2.3. Does it resemble the picture below? YES/NO

FIGURE 4. 30. First-degree heart block (Buttner & Larkin 2021, CC BY -NC-SA)



Description:

The above ECG shows sinus bradycardia with a regular rate of 62 bpm.

The PR interval is 0.36 seconds. Other than this, there are no other significant findings.

This ECG shows a First-Degree Heart Block.

If YES to 6.2.2, and 6.2.3, then **SUB-CONCLUSION: FIRST-DEGREE HEART BLOCK**. Go to Section 7.

If NO: **CONSULT SENIOR PHYSICIAN**

6.2.4. Does the PR interval INCREASE gradually with subsequent DROP of a beat (QRS waves)? YES/NO

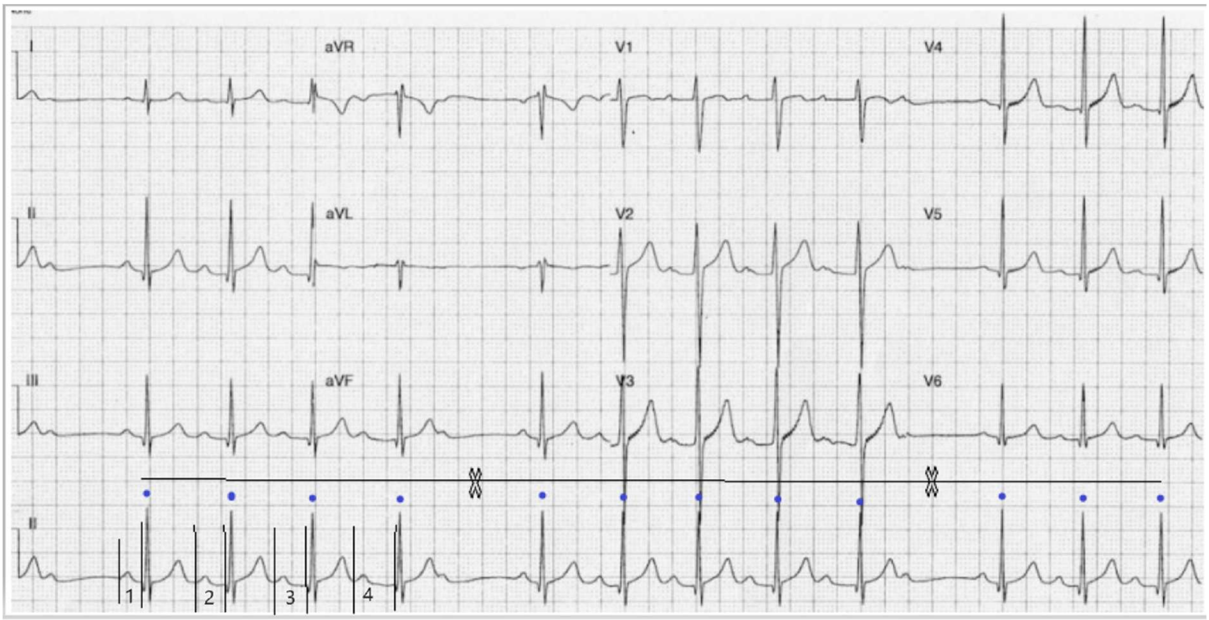
If YES: Proceed to 6.2.5

If NO: Go to 6.2.7.

6.2.5. In the dropped beat, do you notice the absence of the QRS complex after the P wave? YES/NO

6.2.6. Does it resemble as shown in the picture below? YES/NO

FIGURE 4. 31. Second-degree AV block or Mobitz Type 1 heart block (Burns & Buttner 2021, CC BY -NC-SA)



Description:

Note that the PR interval duration on the rhythm strip, which is denoted by numbers 1 to 4, is seen increasing gradually.

There is no QRS complex after the fifth P wave. Then, there is no QRS complex after the sixth P wave.

These ECG findings are suggestive of Second-Degree AV Block, also known as Mobitz Type 1 Heart Block.

If YES IN 6.2.5 AND 6.2.6: Then, **CONCLUSION: SECOND DEGREE AV BLOCK/MOBITZ TYPE 1/WENCKEBACH TYPE HEART BLOCK.** Go to Section 7.

If NO: **CONSULT SENIOR PHYSICIAN**

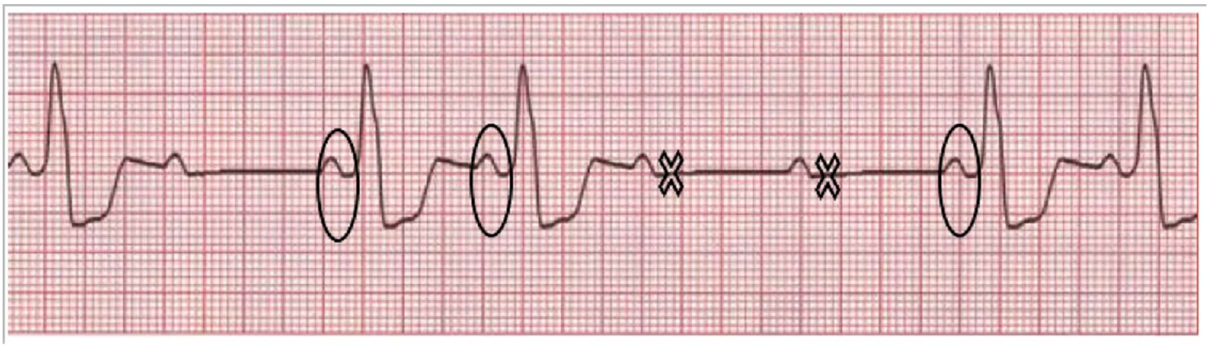
6.2.7. Does the PR interval remain CONSTANT with subsequent DROP of a beat (QRS waves)? YES/NO

If YES: Proceed to 6.2.8

If NO: Go to 6.2.9

6.2.8. Does it resemble as shown in the picture below? YES/NO

FIGURE 4. 32. Second-degree AV block or Mobitz Type 2 heart block (Burns & Buttner 2022, CC BY -NC-SA)



Description:

Note that the marked PR intervals are constant in duration. There is no QRS complex after the P wave on two occasions (cross-marked).

These ECG findings are suggestive of Second-Degree AV Block or Mobitz Type 2 Heart Block.

If YES IN 6.2.8: Then,

CONCLUSION: SECOND-DEGREE HEART BLOCK – MOBITZ TYPE 2. Go to Section 7.

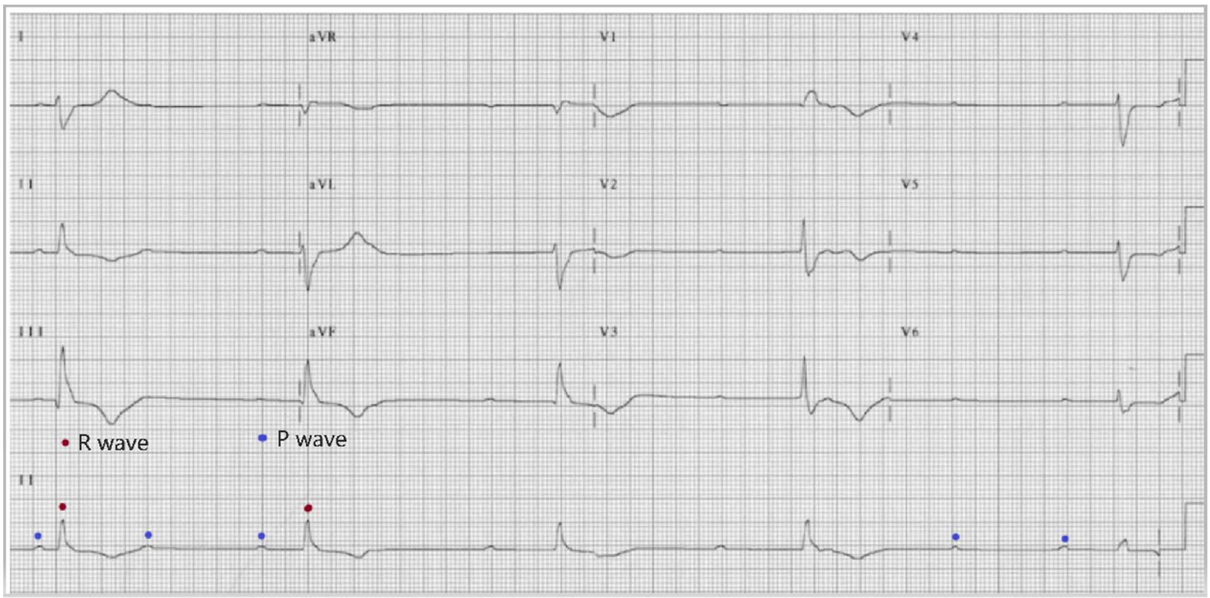
If NO: **CONSULT SENIOR PHYSICIAN**

6.2.9. Is the synchrony between atrial rhythm and ventricular rhythm absent? OR

Are there constant P-P and R-R intervals with broad QRS complex patterns? YES/NO

6.2.10. Does it resemble as shown in the picture below? YES/NO

FIGURE 4. 33. Complete heart block (Buttner & Larkin 2023, CC BY -NC-SA)



Description:

There is asynchrony in the electrical conduction between the atria and the ventricles. The P waves are not followed by QRS complexes, which means the electrical impulse from atrial tissues is not being conducted to the ventricular tissues.
The atrial rate calculated from the PP interval is about 62 bpm (24 small squares).
The ventricular rate calculated from the RR interval is about 28 bpm (54 small squares).
This ECG shows a Complete Heart Block.

If YES in 6.2.9 and 6.2.10: **FINAL CONCLUSION: THIRD DEGREE HEART BLOCK/ COMPLETE HEART BLOCK**.

If NO: **CONSULT SENIOR PHYSICIAN**

SUB-CONCLUSIONS:

If YES in 6.1, then, THE ECG SHOWS NORMAL PR INTERVAL WITH 'a' seconds. Go to Section 7.

If YES in 6.1.1, 6.2.2 and 6.2.3, then THE ECG SHOWS FIRST DEGREE HEART BLOCK. Go to section 7.

If YES in 6.2.4, 6.2.5 and 6.2.6, then, THE ECG SHOWS SECOND DEGREE HEART BLOCK/ MOBITZ TYPE 1/ WENCKEBACH TYPE HEART BLOCK. Go to Section 7.

If YES in 6.2.7 and 6.2.8, then, THE ECG SHOWS SECOND DEGREE HEART BLOCK/ MOBITZ TYPE 2. Go to Section 7.

If NO in any of these questions 6.2.2, 6.2.3, 6.2.5, 6.2.6, 6.2.8, 6.2.9, and 6.2.10, then, CONSULT SENIOR PHYSICIAN.

FINAL CONCLUSION:

If YES in 6.2.9 and 6.2.10, then, THE ECG SHOWS THIRD DEGREE HEART BLOCK/COMPLETE HEART BLOCK.

7. ST SEGMENT:

- *The ST segment is measured from the ST junction to the beginning of the T wave.*
- *In normal circumstances, the ST segment is present at the isoelectric line, however, sometimes a variation of 1 mm (one small square) is acceptable.*
- *ST segment deviation of more than 1 mm above or below the isoelectric line in any lead is abnormal.*
- *The normal duration for the ST segment is less than 0.20 sec.*

7.1. Is the ST segment on your ECG within the normal parameters mentioned above? YES/NO

If YES: **ST SEGMENT IS NORMAL**. Go to section 8.

If NO: Proceed to 7.2

There are various patterns of the ST segment elevation (not discussed here) depending upon the phases of myocardial infarction that the patient undergoes at the time of ECG recording. Make sure you take a close look at all 12 leads of the ECG.

7.2. Are the T waves tall, peaked and symmetrical? Or

Is the ST segment elevated more than 1 mm above the isoelectric line in two or more adjacent leads? Or

Are the T waves inverted? Or

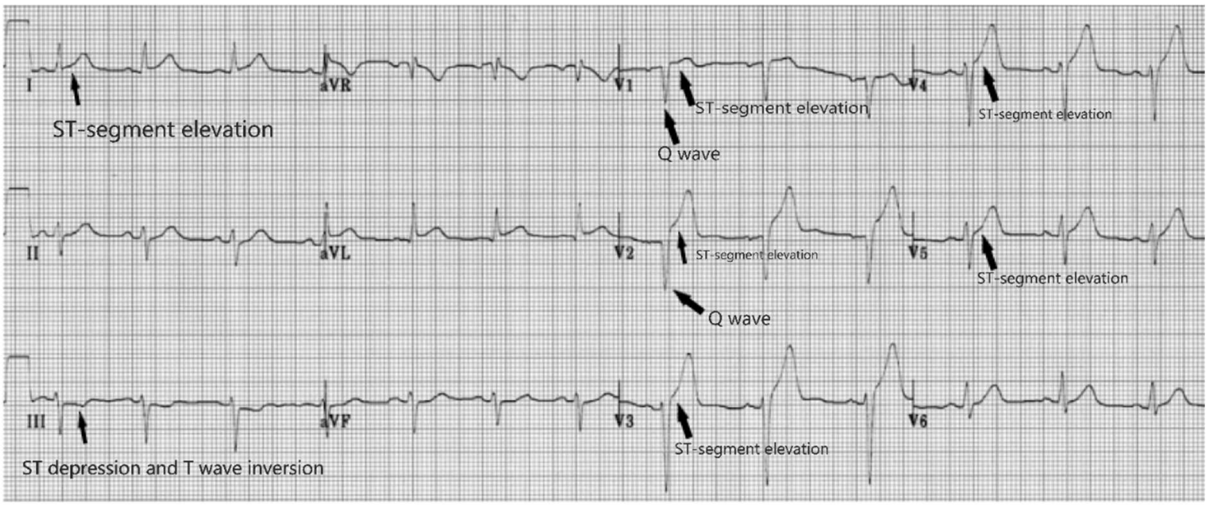
Is there a presence of pathological Q waves:

How to identify pathological Q waves?

If the Q wave is more than 0.04 sec (1 small square)

and more than a third of the R wave, with no ST-segment elevation, is indicative of an old myocardial infarction. YES/NO

FIGURE 4. 34. Myocardial infarction (Burns & Buttner 2023, CC BY -NC-SA)



Description:

In this ECG, the ST segment is elevated above the isoelectric line in lead I, aVL, V1, V2, V3, V4, and V5.

Tall, symmetrical T waves are seen in V2, V3, and V4

The reciprocal changes are seen in lead III, where the ST segment is depressed with T wave inversion.

The pathological Q waves are seen in lead V1 and V2 with ST elevation, indicating the fully evolved myocardial infarction in the septum area of the heart.

These findings on the ECG are suggestive of Hyperacute Anteroseptal Myocardial Infarction with some lateral wall involvement.

If YES: FINAL CONCLUSION: ACUTE MYOCARDIAL INFARCTION IS PRESENT.

HOW TO KNOW WHICH AREA OF THE HEART IS AFFECTED BY MYOCARDIAL INFARCTION?

- Look for, in which leads you see the above-mentioned ST segment changes.

If changes are seen in lead II, III, and aVF, then it is INFERIOR WALL MYOCARDIAL INFARCTION.
If changes are seen in lead I, aVL, V5, and V6, then it is LATERAL WALL MYOCARDIAL INFARCTION.
If changes are seen in V1 and V2, then it is SEPTAL MYOCARDIAL INFARCTION.
If changes are seen in V3 and V4, it is ANTERIOR WALL MYOCARDIAL INFARCTION.

Please NOTE that MI can occur in varying combinations, and therefore, changes might be seen in multiple leads at once, as shown in the example. Kindly correlate the findings on your ECG with the description provided to draw a conclusion as to which wall of the heart is involved.

If NO:

7.2.1. Are the ST segments depressed or negatively deflected in any of the leads?

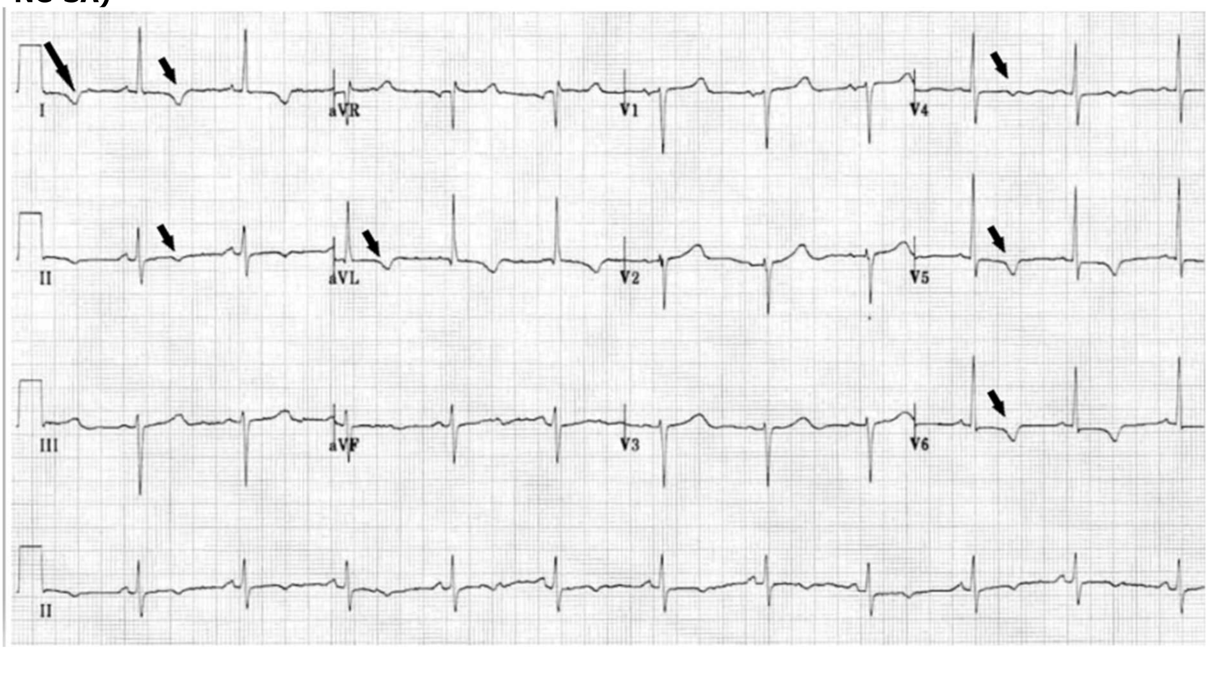
and

Can the T-wave changes be seen in the leads?

and

Does it roughly resemble the diagram below? YES/NO

FIGURE 4. 35. Inverted T wave in myocardial ischaemia. (Burns & Cadogan 2022, CC BY -NC-SA)

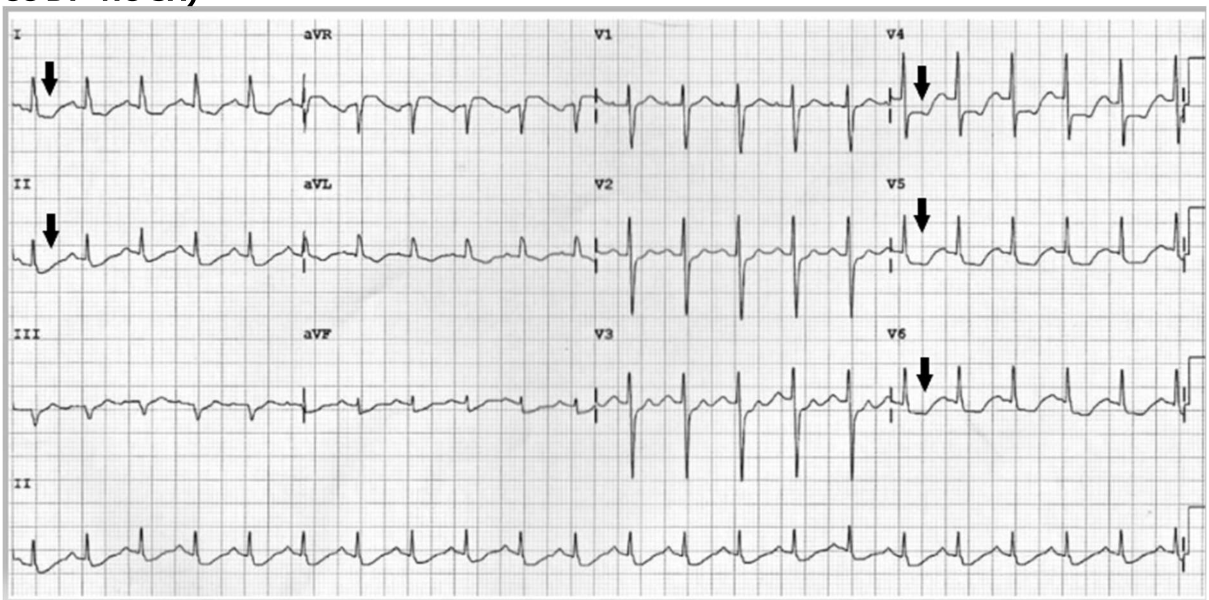


Description:

Note the inverted T waves in lead I, II, aVL, V4, V5, and V6. These inverted T-wave findings are significant in this ECG because QRS complexes in lead I, II, aVL, V4, V5, and V6 have dominant R waves or are positively deflected.

This finding is suggestive of Myocardial Ischaemia.

FIGURE 4. 36. Depressed ST segment in myocardial ischaemia. (Burns & Cadogan 2022, CC BY -NC-SA)



Description:

Note that the ST segment is depressed in lead I, II, aVF, V4, V5, and V6. This is suggestive of Sub-endocardial Myocardial Ischaemia.

If YES: **FINAL CONCLUSION: SUBENDOCARDIAL MYOCARDIAL ISCHAEMIA PRESENT.**

If NO: CONSULT SENIOR PHYSICIAN

SUB-CONCLUSION:

If YES in 7.1, then THE ECG SHOWS NORMAL ST SEGMENT. Go to Section 8.

FINAL CONCLUSION:

If YES in 7.2, then THE ECG SHOWS ACUTE MYOCARDIAL INFARCTION. CORRELATE WITH THE PATIENT'S MEDICAL HISTORY AND SIGNS/SYMPTOMS.

If YES in 7.3, then THE ECG SHOWS MYOCARDIAL ISCHAEMIC CHANGES. CORRELATE WITH THE PATIENT'S MEDICAL HISTORY AND SIGNS/SYMPTOMS.

8. T WAVES:

The T waves represent the ventricular repolarisation process of the heart.

Criteria for normal T wave:

- *Normally, T waves are asymmetrical. It rises slowly and towards the end has a fast fall.*
- *In limb leads, the T wave should be upright if the QRS complex is positive and inverted if the QRS complex is negative.*
- *They should be upright in normal circumstances in leads V3 to V6.*
- *The amplitude of the T wave should not be greater than 2/3 and not less than 1/8 of the height of the R wave before the T wave.*
- *In leads III, aVR, and V1, T wave inversion findings is normal variation.*

Symmetrical/ tall/ inverted T wave findings should not be ignored as they are indicative of myocardial infarction. T wave changes are significant in leads which show upright QRS complexes.

MI-related abnormalities related to T waves are covered in Section 7.

8.1. Do the T waves comply with the above-mentioned criteria? YES/NO

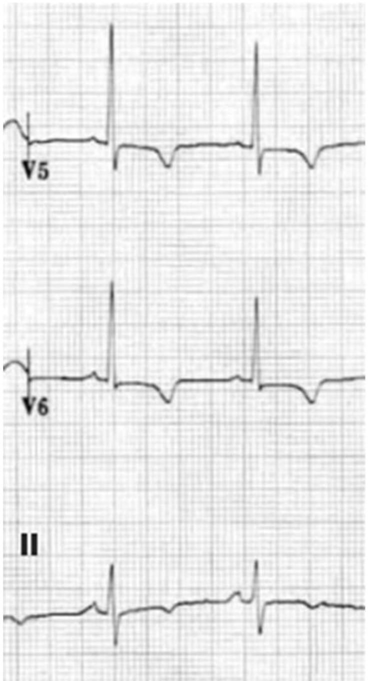
If YES: Sub-Conclusion: Normal T waves

If No: Proceed to 8.2 and **CONSULT SENIOR PHYSICIAN.**

8.2. Abnormal T waves:

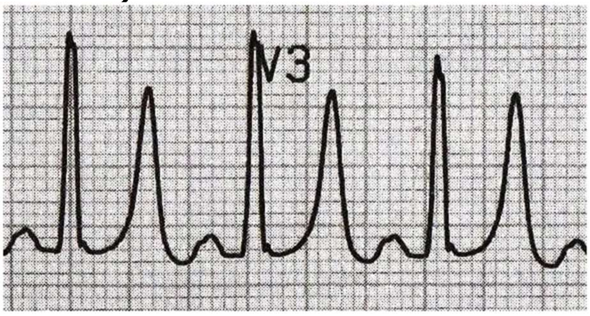
- Inverted T waves are indicative of myocardial ischaemia and digoxin toxicity.

FIGURE 4. 37. T wave inversion in myocardial ischaemia. (Burns & Cadogan 2022, CC BY -NC-SA)



- Tall T waves are seen in hyperkalaemia, posterior wall myocardial infarction in leads V1 and V2, and acute subendocardial ischaemia or infarction.

FIGURE 4. 38. Tall, symmetrical and peaked T waves in hyperkalaemia. (Burns & Buttner 2021, CC BY -NC-SA)



- Flat T waves are seen in people with thick chest walls, emphysema, and pericardial effusion, among other causes.

SUB-CONCLUSION:

If YES in 8.1, then THE ECG SHOWS NORMAL T WAVES.

If NO in 8.1, then CONSULT SENIOR PHYSICIAN.

9. CONCLUSION:
ECG shows the following findings:

All Sub-Conclusions or Final Conclusions from Sections 1 to 8.

APPENDIX 5: TRANSCRIPTION OF AN INTERVIEW WITH MR MAARTEN BLIETZ

Transcription of the video interview with Mr Maarten Blietz on 25 February 2023. Mr Blietz, from the Netherlands, has experienced the usage of the remote monitoring system for two members of his family. First for his son, Mr Robert Jan, who had Down's syndrome and second for his wife, Mrs Iet Blietz, who suffered from chronic respiratory conditions and frequent falls. In both cases, no cameras were installed in the monitoring systems.

Interviewer: *Okay, so today we are going to interview Mr Blietz. These questions are for the purpose of my thesis, and this input, whatever Mr Blietz is going to give us, is going to prove a valuable asset, so do I have permission to interview and record?*
Mr Blietz*: Sure*

Interviewer*: So this is all on camera. All right! The first question is what are your views on the constantly changing and evolving technology?*
Mr Blietz: *Yes, interesting question, we have experienced these phenomena only as a very positive certainly regarding their increasing knowledge of health and healing issues. For example, doctors know these days much more about children and all the persons with the syndrome of Down. When our child with syndrome of Down was born, doctors were telling us that most likely we would survive him but in due time science, also in this field has so much improved that those children with syndrome of Down are getting now much older than before and might probably survive their parents.*

Interviewer*: Are you comfortable with this evolving technology or are you finding it difficult to get used to it?*
Mr Blietz: *No, during the time we are getting used to it because we read about it, We heard about it, we have also lost information from our doctors and show that is very positive way. Yes!*

Interviewer*: So as an elderly person, would you like to be monitored by your family members or healthcare provider for your safety and well-being?*
Mr Blietz*: Yes, I wouldn't mind at all to be monitored but then preferably by the healthcare authorities for safety and well-being of myself and my own family members. And then I yes, for sure I would grant permission to monitor my loved ones in this way, if it is in our and their interest and if it helps to science to develop further.*

Interviewer: *And could you please share your experience or experiences?*
Mr Blietz: *Of course, unfortunately, we only have to have the experience of not being asked for cooperation in these respects, at that time. Some 50 years ago, it was not yet relevant enough to get more knowledge about this matter. I think it was not common to ask for some cooperation from families with the child with syndrome of Down. We have never heard of people being asked in that way. Of course, in our family, we have two examples of beloved persons who were monitored for their own safety. When my wife was still living at home, we had a so-called emergency button connected to a central operator, who was then asking through a loudspeaker what was happening and if you wished a doctor, an ambulance, police, or call or want someone else in the family, that was without the camera. With Robert Jan, the son, it was about the same system in his bedroom. It was working well, though still without a camera, to which we would not have any objection. No problems with the privacy at all. Our slogan is Safety First!*

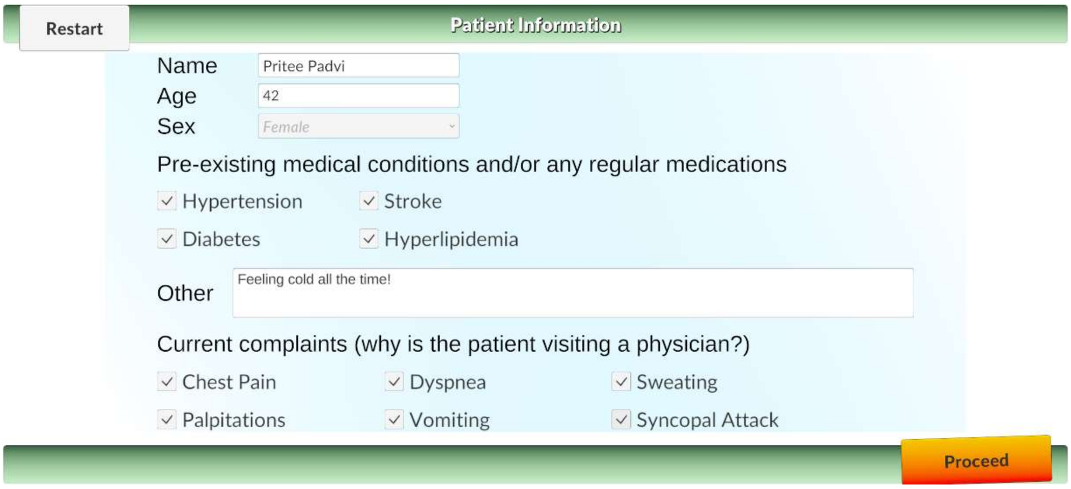
Interviewer: *So, you don't mind giving permission to monitor?*
Mr Blietz: *Certainly not! No problem no! I would love that.*

Interviewer: *Then what do you think? What are the limitations for the privacy issues? I mean, what do you think, like, okay, this is now the limit?*
Mr Blietz: *Yeah, the words privacy is a little bit heavy. In my view, the word privacy is often used and misused. As far as security and health are concerned, I think that privacy is not that important enough to be an obstacle for the progress in healthcare and health science and security of our loved ones.*
Interviewer: *Thank you so much for your answers and your feedback!*
Mr Blietz: *You are welcome! Thank you!*

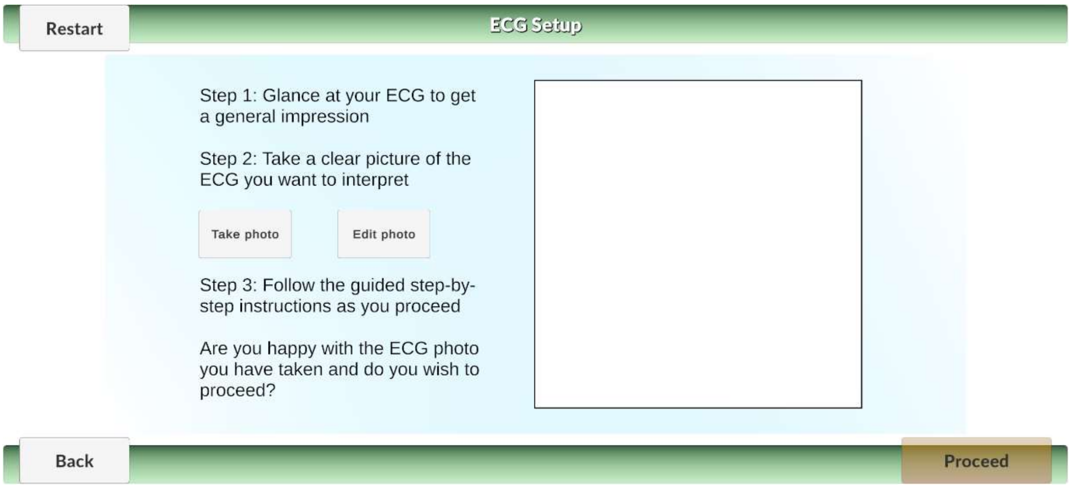
APPENDIX 6: A SAMPLE FLOW OF THE IMPLEMENTED ECG INTERPRETATION APPLICATION

Below is the sample flow from start to finish through the implemented ECG interpretation application.

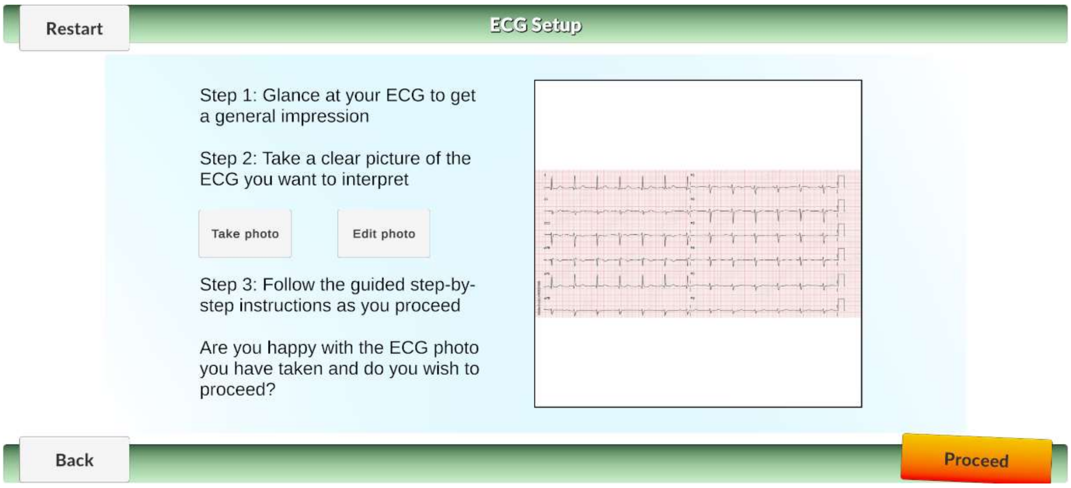
The app starts with the title screen. There is also a disclaimer here since this app is a SaMD proto-type and should not be used for medical diagnosis.



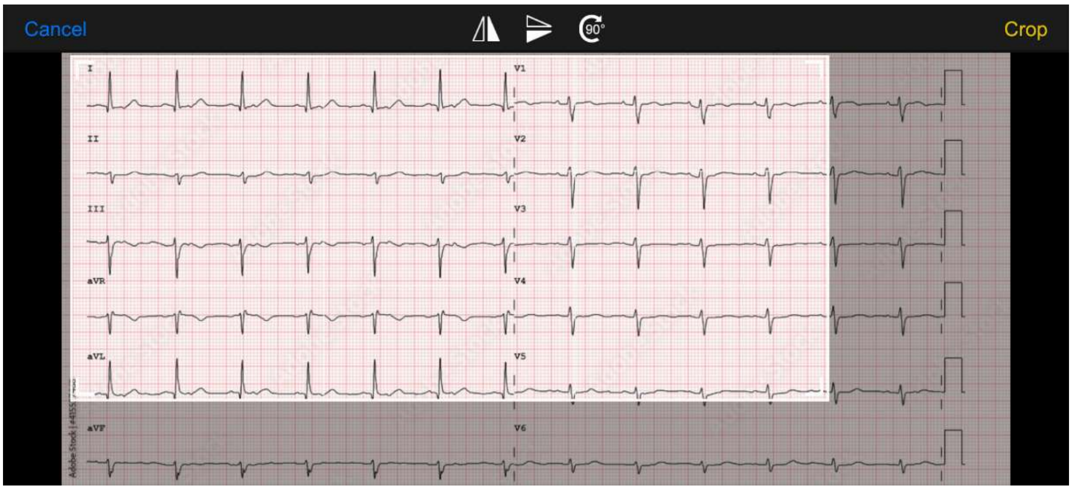
After this, some information about the patient can be filled in.



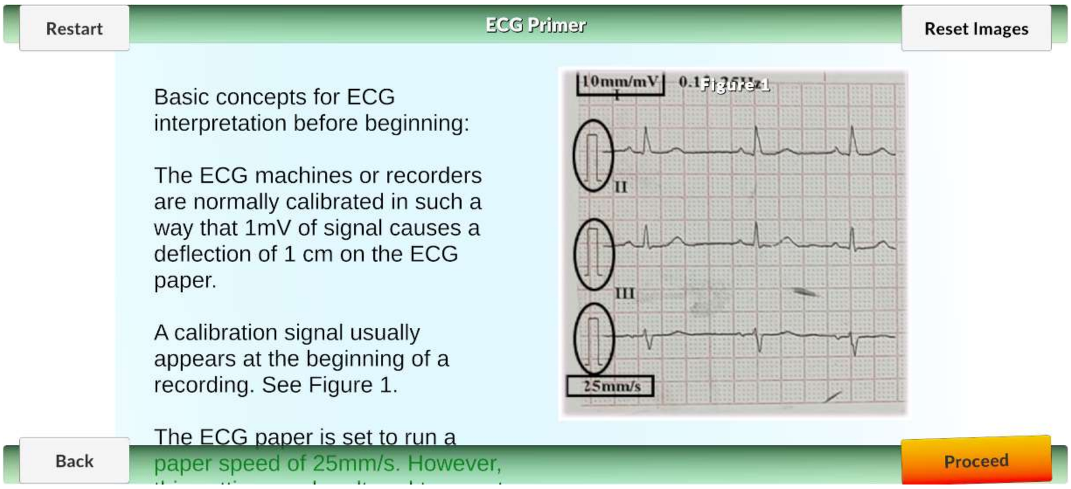
The next step is to take a photograph of the ECG to be analysed using the phone's camera.



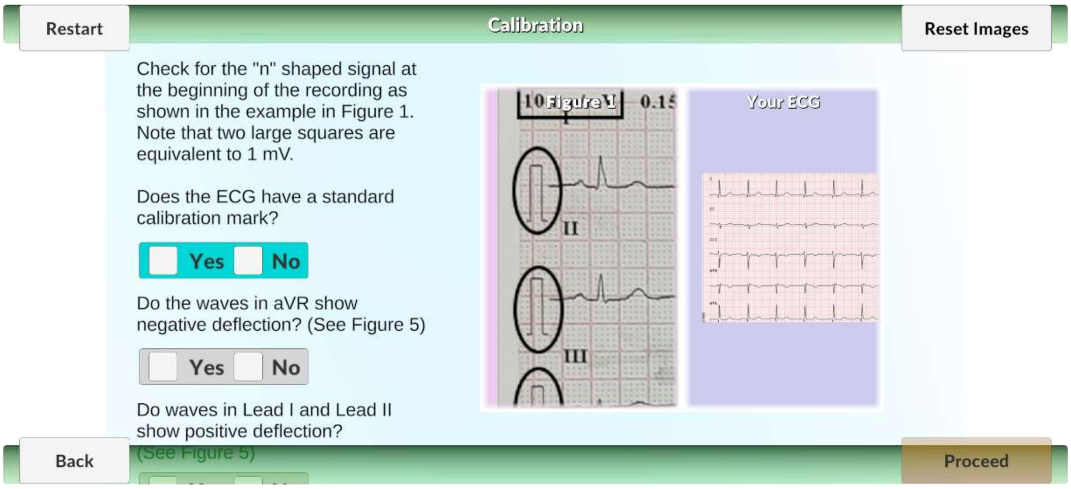
Once the photo is taken, the ECG appears in the app.



There is also some editing functionality at this stage, and the user can crop and rotate the image as desired.



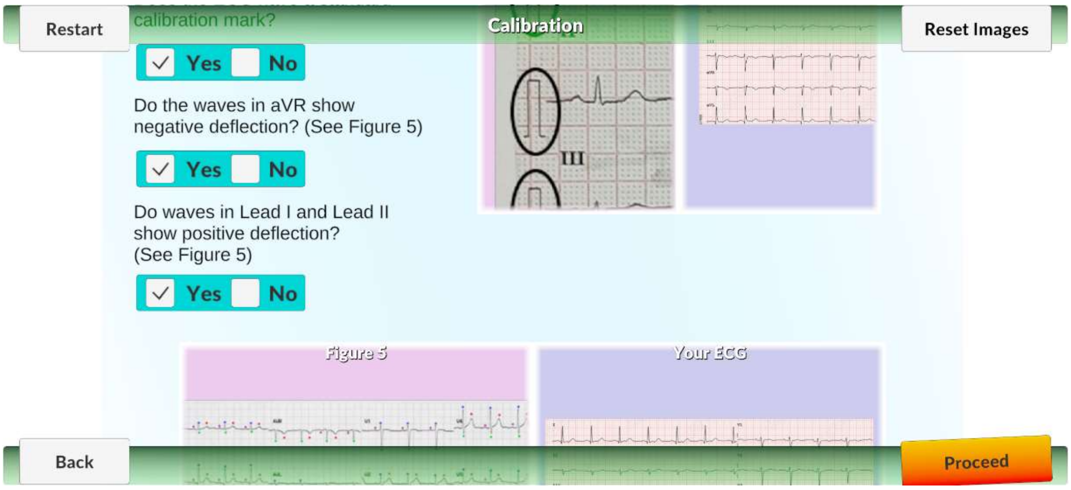
Upon proceeding, the user is given a basic primer on ECGs as a refresher. When done, the user can proceed to the next stage.



At this stage, the expert system begins its work. There are numerous questions to answer on every screen. The app will follow a specific flow based on the answers given on each screen.

The user can zoom in on the entire screen and move and zoom in precisely on every image. A Reset Images button also resets all images to their original size and positioning.

At any step, the user can opt to go back and answer questions differently if desired. The expert system will take this all into account accordingly.



Restart | **Rhythm and Rate Determination 1** | Reset Images

Check the rhythm strip which is a prolonged recording of a single lead II which has about 12 consecutive complexes.

If the rhythm strip is not recorded, one can look at leads I, II, aVF, and V1.

Look at the bottom of Figure 4 and Figure 5, and notice the recorded rhythm strip of lead II.

Look at Figure 3 for reference.

Figure 4

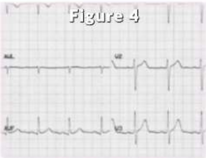
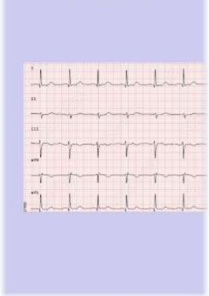


Figure 5

Your ECG



Back | Proceed

Restart | **Rhythm and Rate Determination 1** | Reset Images

Look at the bottom of Figure 4 and Figure 5, and notice the recorded rhythm strip of lead II.

Look at Figure 3 for reference.

Are the P waves present? — Yes / No

Are the QRS complexes present? — Yes / No

Do the P waves follow the QRS complexes at regular intervals? — Yes / No

Back | Figure 3 | Proceed

prominent then the T wave is upright.

Restart | **Rhythm and Rate Determination 1** | Reset Images

• PVCs occur earlier in the cardiac cycle than the expected next normal beat. They often have a compensatory pause following them which is a longer than the usual pause in the normal rhythm before the next expected beat. The PVC's early timing is why it is called a premature ventricular beat.

Does your ECG show one or more odd, wide and tall QRS complexes as shown in Figure 6? — ☑ Yes / No

Does your ECG show more than one premature beats? — Yes / No

Does the distance between two P waves and R waves vary with respiration with PQRS complexes belonging to normal morphology and with consistent distance between them? — Yes / No

Back | Proceed

Restart | **Rhythm and Rate Determination 2** | Reset Images

Heart Rate in Regular Rhythm

METHOD 1
Calculate heart rate by counting the number of big squares between the RR interval:

Formula: Heart rate = 300/ Number of big squares

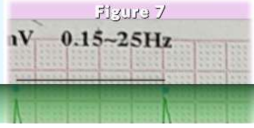
METHOD 2
Calculate heart rate by counting the number of small squares between the RR interval:

Formula: Heart rate = 1500/ Number of small squares

Heart Rate Table

NUMBER OF BIG BOXES	1	2	3	4	5	6	7	8	9
HEART RATE	300	150	100	75	60	50	43	38	33

Figure 7



Back | Proceed

Restart | **Rhythm and Rate Determination 2** | Reset Images

Calculate heart rate on your ECG: 66 beats per minute (bpm)

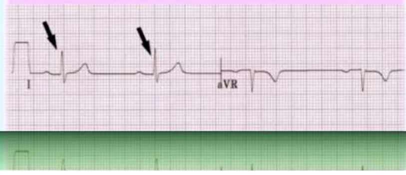
Back | Heart Rate = 66 | Proceed

Restart | **Axis Determination** | Reset Images

Check Lead I and aVF to determine the QRS axis in the frontal plane of the heart. In normal circumstances, the QRS complexes are predominantly positive in these leads.

Are the QRS complexes in lead I and lead aVF positively deflected as in the picture below? ☑ Yes ☐ No

Figure 13



Back | Heart Rate = 66 | Proceed

Restart | **P Waves 1** | Reset Images

P waves represent the atrial depolarisation on an ECG. The criteria for normal P waves are:

• The duration should not be more than 0.12 seconds or three small horizontal squares.

• The amplitude should not be more than 0.25 mV or 2.5 small vertical squares.

• P waves are upright in all leads except in aVR.

• They should have smooth and rounded contours.

• It is possible that P waves are upright or biphasic in chest leads V1 and V2. If biphasic, then the terminal negative deflection should not be greater than 1 mm in depth and 0.03-sec duration (1 mm horizontal square).

• In a normal ECG, P waves should always be followed by QRS complexes

Back | Heart Rate = 66 | Proceed

Restart | **P Waves 1** | Reset Images

HINT: The P waves are best viewed in lead II.

Are P waves present in the ECG? ☑ Yes ☐ No

Your ECG

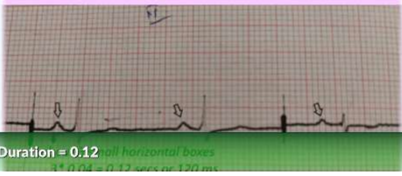
Back | Heart Rate = 66 | Proceed

Restart | **P Waves 1** | Reset Images

What is the duration of the P wave?

How many small horizontal squares are covered from the beginning to the end of the P wave? **0.12**

Figure 16



Back | Heart Rate = 66, P Wave Duration = 0.12 | Proceed

Restart | **P Waves 1** | Reset Images

What is the amplitude of the P waves? How many small vertical boxes are covered by the P wave? **2**

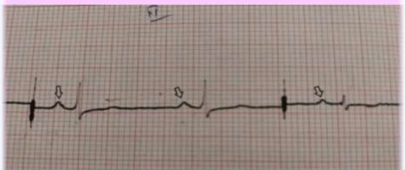
Figure 17

Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2 | Proceed

Restart | **P Waves 2** | Reset Images

Smooth, rounded and upright in lead II? ☑ Yes ☐ No

Figure 18



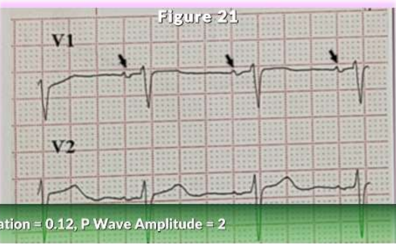
Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2 | Proceed

Restart | **P Waves 5** | Reset Images

Is the P wave the same as lead II in lead V1 and V2? ☑ Yes ☐ No

Terminal negative deflection not greater than 1 mm deep and 0.03 seconds duration? ☐ Yes ☐ No

Figure 21



Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2 | Proceed

Restart | **QRS Complex 1** | Reset Images

On the ECG, it is important to check the QRS complexes in frontal leads and precordial leads. QRS complex morphology examines ventricular depolarisation.The criteria for a normal QRS complex morphology are:

1. Duration should not be more than 0.12 sec or not more than 2.5 small squares (0.10 sec).

2. Ideally, no Q waves should be seen on the normal ECG. If at all Q waves are visible, they should be less than 0.04 sec or 1 small square and less than 2 mm in amplitude, in lead I, II, aVL, aVF.

3. R wave should progress (increase) from V1 to V5, and S wave should progress (increase) from V1 to V3 and disappear in V6. (See Figure 5)

4. In lead aVR, QRS has negative deflection.

Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2 | Proceed

Restart | **QRS Complex 1** | Reset Images

wave should progress (increase) from V1 to V3 and disappear in V6. (See Figure 5)

4. In lead aVR, QRS has negative deflection.

Are QRS complexes in the ECG normal as per points 1, 2, 3 and 4? Yes / No ✓

Are large R waves present in V1 and V2? Yes ✓ / No

Is the R:S ratio more than or equal to 1mm? Yes ✓ / No

Are strain patterns present?

Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2 | Proceed

Restart | **QRS Complex 1** | Reset Images

Are large R waves present in V1 and V2? Yes ✓ / No

Is the R:S ratio more than or equal to 1mm? Yes ✓ / No

Are strain patterns present? Yes / No ✓

Does it resemble the picture below? Yes / No

Your ECG

Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2 | Proceed

Restart | **QRS Complex 2** | Reset Images

Are 'M' waves or RsR' pattern seen in V1 and V2? Yes / No

Can you appreciate slurred S waves in lateral leads, especially V6? Yes / No

Does it resemble the picture below? Yes / No

Your ECG

Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2 | Proceed

Restart | QRS Complex 2 | Reset Images

Are 'M' waves or RsR' pattern seen in V1 and V2? ☑ Yes ☐ No

Can you appreciate slurred S waves in lateral leads, especially V6? ☑ Yes ☐ No

Does it resemble the picture below? ☑ Yes ☐ No

Your ECG

Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2 | Proceed

Restart | PR Interval 1 | Reset Images

the SA node via the atrial muscles, and the AV node and the bundle of His into the ventr...

In other words, the PR interval includes the sum duration of atrialdepolarisation, atrial repolarisation and the slight delay that occurs at the AV node.

The duration of a normal PR interval is 0.12 - 0.20 sec.

0.12 sec

What is the PR interval in your ECG?

Is the PR interval within normal limits? ☑ Yes ☐ No

Is the rhythm regular but the PR interval > 0.20 sec? ☐ Yes ☐ No

Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2s, PR Interval = 0.12 | Proceed

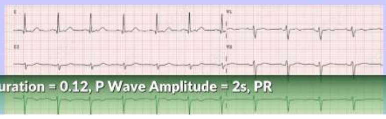
Restart | ST Segment | Reset Images

ST segment deviation of more than 1 mm above or below the isoelectric line in any lead is abnormal.

The normal duration for the ST segment is less than 0.20 sec.

Is the ST segment on your ECG within the normal parameters mentioned above? ☑ Yes ☐ No

Your ECG



Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2s, PR Interval = 0.12 | Proceed

Restart | T Waves | Reset Images

• In leads III, aVR, and V1, T wave inversion findings is normal variation.

Symmetrical/ tall/ inverted T wave findings should not be ignored as they are indicative of myocardial infarction.

T wave changes are significant in leads which show upright QRS complexes.

Do the T waves comply with the above-mentioned criteria? ☑ Yes ☐ No

Your ECG

Back | Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2s, PR Interval = 0.12 | Final Report

Restart

Final Report

Name: Pritee Padvi
Age: 42
Sex: Female

PRE-EXISTING MEDICAL CONDITIONS AND/OR ANY REGULAR MEDICATIONS

Hypertension
Diabetes
Stroke
Hyperlipidemia
Feeling cold all the time!

CURRENT COMPLAINTS (WHY IS THE PATIENT VISITING THE DOCTOR?)

Chest Pain
Palpitations
Dyspnea
Vomiting
Sweating
Syncopal Attack

Back

Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2s, PR Interval = 0.12

CURRENT COMPLAINTS (WHY IS THE PATIENT VISITING THE DOCTOR?)

Restart

Final Report

Chest Pain
Palpitations
Dyspnea
Vomiting
Sweating
Syncopal Attack

CONCLUSIONS

The ECG has standard calibration.

Irregular rhythm.

The rhythm is regular until the presence of Premature Ventricular Complex.

Heart rate = 66 beats per minute.

Normal cardiac axis

Back

Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2s, PR Interval = 0.12

Syncopal Attack

Restart

Final Report

CONCLUSIONS

The ECG has standard calibration.

Irregular rhythm.

The rhythm is regular until the presence of Premature Ventricular Complex.

Heart rate = 66 beats per minute.

Normal cardiac axis

The P waves are wide.

Normal P Wave.

Right bundle branch block

PR interval = 0.12 sec.

Back

Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2s, PR Interval = 0.12

PR interval is normal with 0.12 sec.

Restart

Final Report

The rhythm is regular until the presence of Premature Ventricular Complex.

Heart rate = 66 beats per minute.

Normal cardiac axis

The P waves are wide.

Normal P Wave.

Right bundle branch block

PR interval = 0.12 sec.

PR interval is normal with 0.12 sec.

ST segment is normal.

Normal T waves.

Back

Heart Rate = 66, P Wave Duration = 0.12, P Wave Amplitude = 2s, PR Interval = 0.12