1 INTRODUCTION

In the year 2016, approximately 9.4 million people worldwide died of ischemic heart disease (IHD). With over 16.6% of deaths attributed to it, is is the most common cause of death. All forms of cardiovascular diseases make up 31.4% or 17.9 million deaths globally. Death from IHD disproportionally affect people over 50 years of age, with 91% and 95% of deaths for men and women respectively occurring in that age range, globally. In Kyrgyzstan, 13% of all deaths in 2016 were caused by IHD. In Kazakhstan it was 47.7% of all deaths.

A 2019 report found that while IHD is the leading cause of death, the mortality trends are slowly but steadily decreasing. The authors explain the decrease with better treatment of cardiovascular risk factors and improved healthcare systems. The improvement of healthcare systems tends to be connected to economic growth in a country. ”To treat heart disease the availability of advanced diagnostic and therapeutic treatment technologies, such as cardiac catheterization laboratories for coronary angiograms and angioplasties, as well as easy access to drugs are crucial to patients' management.” Risk factor prevention is generally a thing rich countries do. ”Uncontrolled high blood pressure has been described as the leading cause of high IHD burden in former Soviet Union countries. Low adherence to antihypertensive treatments in these countries has been reported. This seems to be because of an insufficient health expenditure that forces patients to out-of-pocket payments to access medications.” globally IHD mortality rate is falling, but it remains the highest death rate and it remains especially high in middle- to low-income countries.

IHD is the condition of inadequate blood supply to an area of the heart. It is caused by a blockage in a blood vessel supplying blood to the heart. IHD is also known as coronary heart disease or coronary artery disease. A artery can be blocked by an obstruction, a blood clock, or most commonly by plaque buildup, called atherosclerosis. A complete blockage of the blood flow to the heart leads to the death of heart muscle cells and is called a heart attack or myocardial infarction. The diagnosis of IHD is possible using an exercise stress test, generally with a treadmill. During an increasingly demanding stress test, the patient is connected to an electrocardiograph which generates an electrocardiogram (ECG).

The ECG is a diagnostic tool that is an essential part of the initial evaluation of patients presenting with cardiac complaints. It provides a non-invasive, cost-effective to evaluate arrhythmias and IHD. See [2] of the first paper.

- Since the 1910s people have been using the ECG to diagnose IHD.

- Since 1954, the American Heart Association has recommended a standardized 12-lead ECG, 6 leads on the chest,

- They have a high rate of misinterpretation among non-specialized physicians and especially trainees. - Augustus D. Waller made first recording of human heartbeat in 1873 - Willem Einthoven in 1924 got the nobel prize for his discovery of the electrocardiogram - future of cardiography might be in wearable devices, meaning that ECG and applications related to it have a future and might become even more widespread

- ECG is the most common and fundamental cardiovascular diagnostic procedure - it can be used to recognize arrhythmias, electrolyte anomalies, - because of its wide use, reading and using it well is very important - most recent advance is the use of computerized methods for storage and analysis - in the US, most ECGs are recorded and interpreted digitally; their implementations might be different and thus not necessarily comparable - the ECG processing pipeline is the following: 1. signal acquisition and filtering 2. data transformation, finding the complexes, classification of the complexes 3. waveform recognition – finding the onset and offset of the waves 4. feature extractoin – measurement of amplitudes and intervals 5. diagnostic classification - the 12-lead ecg signal: records potential differences between spots on the body during each hearbeat (depolarization and repolarization and voltage of the heart cells) - the main frequency of the QRS complex on the bodies surface is about 10Hz, most information for adults in found below 100Hz; fundamental frequency of T waves is about 1-2 Hz - the signal processing can easily obscure the important information in an ECG, even though a range of 1-30 Hz yields a perfectly good-looking ECG free of artifacts - ECG sampling - until the 70s, direct writing ECGs were the norm, those were continuous in nature - initial analog to digital sampling is often performed at 10-15 kHz - oversampling is used primarily because pacemaker pulses are too short to be picked up in 500 to 1000 Hz sampling rates - low-frequency filtering - heart rate is generally above 0.5 Hz (30 bpm), below 40 bpm is uncommon - we cannot cut of here because that would distort the signal, particularly to the ST segment - digital filtering can be used as a way around this [23] - bidirectional filter that passes once with time, once against time [41] - this approach is not possible in real-time, but in post-processing it would work - a flat step response filter can used in real-time [42] - high-frequency filtering - data at 500 samples per second is recommended to reach the required 150 Hz cutoff to reduce frequency errors to about 1% - single lead complex - by using templates, variability caused by breathing or other irrelevant disturbances can be removed - ecg compression techniques - to make storage more efficient, FFT, discrete cosine transform, wavelet transforms can be used - ECG standard leads: 3 limb leads, 3 augmented limb leads, 3 exploring electrodes, 6 leads on the chest - computerized interpretation: first preprocessing (filtering, sampling, template formation, feature extraction), then diagnosis or classification - heuristic used to be the norm (decision trees, etc), but statistical methods are better because they can form better judgements (one must make sure that these methods have enough data of varying kinds to create diagnoses that are reliable) - they find that computer programs perform with 91.3% accuracy, while human readers are at 96% – they may work as supporting data and input to less experience users though

- since 1910 people have been suspecting that artery occlusion can be a cause of chest pain - since 1920 we know of the most common symptoms of myocardial ischemia - in the first few minutes the T wave becomes tall and upright, then the whole ST segment becomes elevated relative to the end of the PR segment - after a couple hours the T wave may invert - the development of Q waves can be an indicator of myocardial infarction - there are certain problems in ischemia detection using ECG, some types are hard to spot, depending on where in the heart the ischemic tissue is, the symptoms can look different on the ECG - apparently the exercise stress test is about 63% sensitive and 77% specific - ischemia is delineated by: ”ST elevation is based on ST/junctional ST elevation of 50.1 mV elevation in 51 inferior/lateral leads, or 50.2 mV in 51 anterior leads.

Trials performed by the GUSTO group looking at the benefit of thrombolysis have used more strict definitions such as 50.1 mV in 52 contiguous limb leads or 50.2 mV in 52 contiguous precordial leads." this had 56% sensitivity and 94% specificity - ECG is the main tool to select patients that would benefit from thrombolysis, there is a 12h window for effective treatment - a stent may be even more effective - continuous ST segment monitoring is important while T wave inversion is controversial, while it is a marker of severe coronary artery disease - thrombolysis when the ECG data is there is only really effective at up to 3h, there is little benefit after 9-12h - ischemia diagnosis can be improved by correlating heart rate and ST segment depression or elevation - while ECG is not the most accurate at first, it is real-time and thus does not cause disadvantageous delays in treatment – it is also continuously being improved with better diagnostic methods.

- ST and TP segments are normally nearly flat - changes in the ST segment and T wave are normally associated with well defined anatomic, pathological, physiological, and pharmacological events - abnormalities in the ST segment and T wave are primary repolatization abnormalities – caused by ischemia, myocarditis, drugs, toxins, electrolyte abnormalities - the changes that are direct results of changes in the ventricular depolarization show up in the QRS shape - primary and secondary repolarization abnormalities may occur concurrently - displacement of the ST segment is usually measured at the junction (J point) with the QRS complex - the 98th percentile of ST segment voltages seems to be around 0.15 to 0.20 mV - elevation of ST is of particular concern in connection to ischemia - leads V1, V2, V3 are the main leads where elevation is detected - ST segment changes are associated with ischemia are due to current flow across the boundary of healthy and ischemic tissue – injury current

- ECG is the single most important clinical test for diagnosing myocardial ischemia and infarction - ECG interpretation in emergency situations is generally the basis for immediate therapeutic intervention or further diagnostic tests - main ECG changes are: peaking T waves, ST-segment elevation or depression, changes in the QRS complex, and inverted T waves - ST segment changes are caused by injury currents - current guidelines say that if the ST segment shifts more than a predetermined amount in more than 2 leads, ischemia is present - if the ST segment is elevated, we talk of ST segment elevation myocardial infarction (STEMI) and non-STEMI (NSTEMI) - the changes to the QRS complex depend on where the lead is and where and how severe the ischemic area is - current research is moving towards identifying where and how big areas of ischemia are based on ECG readings - has section about how exactly ECG leads change during ST segment elevation

An abnormal exercise ECG is defined by ST-segment displacement, generally a depression by more than 1mm, measured 0.08 seconds after the J point, that is horizontal and downsloping. These types of results are generally reported as normal or abnormal, and ischemia as positive or negative. Less severe abnormalities can include false-positive or false-negative results, but more severe abnormalities are pretty certainly bad. Other tests are pharmacologic stress tests (stress induced by pharmacologic agents), or computed tomography of the heart.

xie2020

1.1 Xie, Li, Zhou, *et al.* [1]

1.1.1 Introduction

- cvd is the leading cause of death worldwide
- 30% of deaths and 130 million cases a year [1]
- ECG is good, non-invasive and real-time: heartbeat recognition, blood pressure detection, disease detection
- discovery of ECG [4]
- electronic analysis can give suggestions
- common ECG formats are 1-lead, 3-lead, 6-lead, 12-lead
- 12-lead is the standard and more detailed
- ECG is also future proof and becoming more readily available
- a doctor's reading of an ECG is heavily dependent on their experience, training, certs
- automatic analysis is becoming more and more common
- ECG features are unique information extracted that represent the state of the heart
- source [17] is a list of common feature classifiers
- instead of feature extraction and later classification, just using one neural network to do all the work is becoming more and more common
- ECD – time-varying signal with small amplitude
- the signal needs to be significantly de-noised for approaches to work
- normally though, signals are disturbed by baseline drift, electrode contact noise, power-line interference
- severe baseline wandering can lead to misdiagnosis
- methods of denoising
  - finding the QRS complex is usually hard because PLI and EMG mask it
  - digital filtering, wavelet transform, empirical mode decomposition [25]
  - digital filters are widely used for this, wavelet too [18,16,27]
  - src [29] is a really good method apparently
  - src [30] is also great
  - src [32] is favorable
  - src [33] is a different approach
  - Butterworth filter
- feature engineering
  - Fourier transform for investigating a signal in the frequency domain
  - FFT is useful and fast for feature extraction
  - QRS is the most striking, can be used for heart rate
  - FFT does not provide any information on the time of any of the components
  - short-time FT gives time and frequency information – we can either have good time and bad frequency or vice versa
  - the wavelet transform has a time scale resolution scheme that makes this simpler

  - wavelets are good for all frequencies because they are adaptive
  - their high resolution can give them the edge
  - there are many different options of wavelets that are good for different things
  - src [71] is myocardial infarction
  - DWT is a good computational tool to assess ECG changes
  - for statistical and morphological features
  - higher-order statistics have proven to be good at ECG analysis
- dimensionality reduction is important because while more feature mean more accuracy, they also increase the computational cost
- most data has correlated variables, meaning they can be ignored
- feature selection tries to select a subset of the original features and only select the best ones – options are filters, wrappers, and embedded
- filters are the most simple version, they simply remove the redundant data and then return the relevant data
- filters use algorithms to assign scores to individual features
- filters are fast and independent of the classification, but they may not be super good or precise
- feature extraction reduces the dimension of the information but does not throw out information, which makes it more efficient and precise
- this includes primary component analysis and other types of analysis
- some features of an ECG appear randomly, also entropy, energy, and fractal dimension cannot be easily spotted with the naked eye
- kernels can be used for locally linear embedding
- some machine learning decision making algorithms are k nearest neighbors KNN, support vector machine SVM
- KNN is pretty simple and divides points into multiple group using distance; data imbalance is hard to overcome and they are expensive for high-dimensional data
- SVM has good training ability on small data sets and it is a good all-rounder
- there is no standard about the construction of a NN for ECG analysis
- a general end-to-end model seems to be the best solution, removing the need for optimization at each and every step – feature extraction is shifted to the learning body, which is a nice solution
- a list of all the databases and what they are good at
- good list of applications of the whole thing

1.2 Plan

- databases:
  - MIT-BIH Normal Sinus Rhythm Database for normal ECGs
  - European ST-T Database for ST and T wave changes – patients with ischemia
  - INCART database for ischemia, arrhythmias, coronary artery disease
  - Lobachevsky University Electrocardiography Database for 12-lead stuff for different

cardiological diseases
  - long therm ST database – for st segment detection
  - suggestions why only 5 minutes are used/necessary to detect stuff
- use the Butterworth filter in the Julia DSP.jl package to filter the noise out
- use FFT, SFFT, Wavelet for feature extraction, also in julia if possible
- find some simple type of filter to do feature selection –
- classification could be done using the NearestNeighbors.jl package

1.3 Outline

1.3.1 Problem Statement

- ischemia and similar diseases are some of the most deadly and common diseases
- IHD – what is it? how can it be diagnosed (ECG)? how can it be treated(Stents)?
- what is the research problem that people are facing?
- the QRST–wave complex changes when ischemia is present, enabling its detection
- heat disease is a significant and deadly medical issue
- poorer countries like Kyrgyzstan are disproportionately affected because many of the newer and better methods cannot be afforded / implemented
- health expenditure in KG is low, the lower it is the worse these conditions are
-

1.3.2 Rationale – Justification – Why

- when it comes to ischemic heart disease (IHD), rapid decision making is important – why
- ECG is one of the most widely used diagnostic tools – why
- reading an ECG is very difficult, which leads to different results among different physicians – relevance
- this could reduce the time it takes to diagnose IHD, which is crucial –
- detect changes during myocardial ischemia, some of those remain invisible to physicians
- promising method because other people are doing this
- what are the applications in practice?
- freely available ECGs on the internet – MIT-BIH, European ST-T database and the others

1.3.3 Goals and Objectives

- to develop software that analyzes 12–lead ECG to detect IHD – how will we do that?
- create a 12–lead ECG analysis tool to diagnose IHD
- mathematically model the changes in the ECG compared to at-rest and normal ECGs
- mathematical model and implementation that can speed up diagnosis (which is critical)
- get 100 digitized ECGs from healthy volunteers
- use FFT for analysis
- Fourier Transform, Fast Fourier Transform, Discrete Fourier Transform

- compare the different transforms for this specific problem

2 LITERATURE REVIEW

2.1 Outline

2.1.1 Current State of the Problem

- advances in IHD treatment (see research proposal)
- current methods for ECG modeling
- what is the progress in using FFT and DFT to model ECGs
-

2.2 Important Points

2.2.1 background and purpose

- ischemia and similar diseases are some of the most deadly and common diseases
- when it comes to ischemic heart disease (IHD), rapid decision making is important
- ECG is one of the most widely used diagnostic tools
- reading an ECG is very difficult, which leads to different results among different physicians
- to develop software that analyzes 12–lead ECG to detect IHD
- this could reduce the time it takes to diagnose IHD, which is crucial
- detect changes during myocardial ischemia, some of those remain invisible to physicians

2.2.2 goals

- create a 12–lead ECG analysis tool to diagnose IHD
- we will mathematically model the changes of the ECG compared to at–rest, nominal ECGs

2.2.3 questions, problematic, rationale

- the ECG is the most widely used method to assess heart conditions
- the QRST–wave complex changes when ischemia is present, enabling its detection
- a mathematical model could make the analysis of ECGs easier for doctors and speed up their diagnosis
- the model needs to work well for this to be possible
- such a tool would remove some of the problems that normally exist (mentioned above)

2.2.4 background, literature review

- heart disease is a significant medical issue
- one of the most deadly ones
- middle income countries like KG are hit harder
- health expenditure in KG is also one of the lowest
- IHD is the main killing disease
- for most treatment methods, the longer the treatment is delayed, the lower the chances of survival become
- if the necessary infrastructure is nonexistent, treatment times cannot be reduced to acceptable levels
- basically, in Kyrgyzstan most modern and good methods do not work because of the missing infrastructure and economic limits
- computers can help to analyze an ECG, which makes diagnosis easier

2.2.5 methods

- get 100 digitized ECGs from healthy volunteers

- from this a good model of healthy and stressed ECGs should be created
- maybe use FFT for the analysis
- use a Maplesoft Signal Processing Tool for wave analysis

2.3 Advice from Imanaliev

1. Search for the recent advancements in published papers
2. Search for the advancements in software of the related problems
3. Study the Fourier Transform and Fast Fourier Transforms, and their representation on chosen software
4. Comparison of the different transforms for the related problem
5. Scan of the paper based verified cardiograms and digitalising
6. Comparison of the scanned graphs with the verified graphs
7. Adjustment of the software parameters
8. Error estimate
9. Analysis of the results with doctors
10. Real time method probation
11. Adjustment of the parameters
12. Thesis preparation and submission
13. Scientific Paper preparation and submission
14. Distribution of the results in media and analysis of references
15. Adjustment of the parameters

2.4 Content requirements

2.4.1 Introduction

- short, verbal problem statement
- rational relevance of the selected topic
- formulates goals and objectives of the project
- refer to some information
- maybe a brief description of the main results

2.4.2 Literature Review

- overview of the current state of the problem
- based on analysis of literary sources
- don't summarize sources, just give the important information they contain
- don't just call it ”Literature Review”, call it something like ”Mathematical models and methods of magnetotelluric monitoring”

REFERENCES

xie2020 [1] L. Xie, Z. Li, Y. Zhou, *et al.*, "Computational Diagnostic Techniques for Electrocardiogram Signal Analysis," *Sensors (Basel)*, vol. 20, no. 21, Nov. 2020. DOI: `10.3390/s20216318`.

prasad2018 [2] B. V. P. Prasad and V. Parthasarathy, "Detection and classification of cardiovascular abnormalities using fft based multi-objective genetic algorithm," *Biotechnology & Biotechnological Equipment*, vol. 32, no. 1, pp. 183–193, 2018. DOI: `10.1080/13102818.2017.1389303`. [Online]. Available: `https://doi.org/10.1080/13102818.2017.1389303`.

bera2005 [3] S. Bera, B. Chakraborty, and D. J. Roy, "A mathematical model for analysis of ecg waves in a normal subject," *Measurement*, vol. 38, pp. 53–60, Jul. 2005. DOI: `10.1016/j.measurement.2005.01.003`.

liu2014 [4] Y. Liu, Z. Syed, B. M. Scirica, *et al.*, "ECG morphological variability in beat space for risk stratification after acute coronary syndrome," *J Am Heart Assoc*, vol. 3, no. 3, e000981, Jun. 2014.

ieva2013 [5] F. Ieva, A. M. Paganoni, D. Pigoli, and V. Vitelli, "Multivariate functional clustering for the morphological analysis of electrocardiograph curves," *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, vol. 62, no. 3, pp. 401–418, 2013, `https://www.jstor.org/stable/24771812`.

armstrong1979 [6] P. W. Armstrong, D. G. Watts, D. C. Hamilton, *et al.*, "Quantification of myocardial infarction: template model for serial creatine kinase analysis," *Circulation*, vol. 60, no. 4, pp. 856–865, Oct. 1979.

imponeriu2001 [7] A. Cimponeriu, C. F. Starmer, and A. Bezerianos, "A theoretical analysis of acute ischemia and infarction using ECG reconstruction on a 2-D model of myocardium," *IEEE Trans Biomed Eng*, vol. 48, no. 1, pp. 41–54, Jan. 2001.

timmis2019 [8] A. Timmis, N. Townsend, C. P. Gale, *et al.*, "European Society of Cardiology: Cardiovascular Disease Statistics 2019," *European Heart Journal*, vol. 41, no. 1, pp. 12–85, Dec. 2019. DOI: `10.1093/eurheartj/ehz859`. [Online]. Available: `https://doi.org/10.1093/eurheartj/ehz859`.

murphy1978 [9] E. Murphy, S. Rahimtoola, and A. Grüntzig, "Transluminal dilatation for coronary-artery stenosis," *The Lancet*, vol. 311, no. 8073, p. 1093, 1978, Originally published as Volume 1, Issue 8073. DOI: `https://doi.org/10.1016/S0140-6736(78)90931-5`. [Online]. Available: `http://www.sciencedirect.com/science/article/pii/S0140673678909315`.

sigwart1987 [10] U. Sigwart, J. Puel, V. Mirkovitch, *et al.*, "Intravascular stents to prevent occlusion and restenosis after transluminal angioplasty," *N Engl J Med*, vol. 316, no. 12, pp. 701–706, Mar. 1987.

stefanini2013 [11] G. G. Stefanini and D. R. Holmes, "Drug-eluting coronary-artery stents," *N Engl J Med*, vol. 368, no. 3, pp. 254–265, Jan. 2013.

pinto2011 [12] D. S. Pinto, P. D. Frederick, A. K. Chakrabarti, *et al.*, “Benefit of transferring st-segment–elevation myocardial infarction patients for percutaneous coronary intervention compared with administration of onsite fibrinolytic declines as delays increase,” *Circulation*, vol. 124, no. 23, pp. 2512–2521, 2011. DOI: 10.1161/circulationaha.111.018549.

armstrong2013 [13] P. W. Armstrong, A. H. Gershlick, P. Goldstein, *et al.*, “Fibrinolysis or primary PCI in ST-segment elevation myocardial infarction,” *N Engl J Med*, vol. 368, no. 15, pp. 1379–1387, Apr. 2013.

ibanez2017 [14] B. Ibanez, S. James, S. Agewall, *et al.*, “2017 ESC Guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation: The Task Force for the management of acute myocardial infarction in patients presenting with ST-segment elevation of the European Society of Cardiology (ESC),” *European Heart Journal*, vol. 39, no. 2, pp. 119–177, Aug. 2017. DOI: 10.1093/eurheartj/ehx393. [Online]. Available: https://doi.org/10.1093/eurheartj/ehx393.

roffi2016 [15] M. Roffi, C. Patrono, J.-P. Collet, *et al.*, “2015 ESC Guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation: Task Force for the Management of Acute Coronary Syndromes in Patients Presenting without Persistent ST-Segment Elevation of the European Society of Cardiology (ESC),” *European Heart Journal*, vol. 37, no. 3, pp. 267–315, Jan. 2016. DOI: 10.1093/eurheartj/ehv320. [Online]. Available: https://doi.org/10.1093/eurheartj/ehv320.

navarese2013 [16] E. P. Navarese, P. A. Gurbel, F. Andreotti, *et al.*, “Optimal timing of coronary invasive strategy in non-ST-segment elevation acute coronary syndromes: a systematic review and meta-analysis,” *Ann Intern Med*, vol. 158, no. 4, pp. 261–270, Feb. 2013.

lasinovic2015 [17] D. Milasinovic, A. Milosevic, J. Marinkovic, *et al.*, “Timing of invasive strategy in NSTE-ACS patients and effect on clinical outcomes: A systematic review and meta-analysis of randomized controlled trials,” *Atherosclerosis*, vol. 241, no. 1, pp. 48–54, Jul. 2015.

neumann2019 [18] F. J. Neumann, M. Sousa-Uva, A. Ahlsson, *et al.*, “2018 ESC/EACTS Guidelines on myocardial revascularization,” *Eur Heart J*, vol. 40, no. 2, pp. 87–165, Jan. 2019.

eagle2004 [19] K. A. Eagle, M. J. Lim, O. H. Dabbous, *et al.*, “A validated prediction model for all forms of acute coronary syndrome: estimating the risk of 6-month postdischarge death in an international registry,” *JAMA*, vol. 291, no. 22, pp. 2727–2733, Jun. 2004.

morrow2000 [20] D. A. Morrow, E. M. Antman, A. Charlesworth, *et al.*, “TIMI risk score for ST-elevation myocardial infarction: A convenient, bedside, clinical score for risk assessment at presentation: An intravenous nPA for treatment of infarcting myocardium early II trial substudy,” *Circulation*, vol. 102, no. 17, pp. 2031–2037, Oct. 2000.

knuuti2019 [21] J. Knuuti, W. Wijns, A. Saraste, *et al.*, “2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes: The Task Force for the diagnosis and management of chronic coronary syndromes of the European Society of Cardiology (ESC),” *European*

Heart Journal, vol. 41, no. 3, pp. 407–477, Aug. 2019. DOI: 10.1093/eurheartj/ehz425. [Online]. Available: https://doi.org/10.1093/eurheartj/ehz425.

hakeem2019 [22] A. Hakeem, B. Ghosh, K. Shah, *et al.*, "Incremental prognostic value of post-intervention pd/pa in patients undergoing ischemia-driven percutaneous coronary intervention," *JACC: Cardiovascular Interventions*, vol. 12, no. 20, pp. 2002–2014, 2019. DOI: https://doi.org/10.1016/j.jcin.2019.07.026. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1936879819315419.

jeremias2019 [23] A. Jeremias, J. Davies, A. Maehara, *et al.*, "Blinded physiological assessment of residual ischemia after successful angiographic percutaneous coronary intervention: The define pci study," English, *JACC Cardiovascular Interventions*, vol. 12, no. 20, pp. 1991–2001, Oct. 2019. DOI: 10.1016/j.jcin.2019.05.054.

myers2017 [24] P. Myers, B. Scirica, and C. Stultz, "Machine learning improves risk stratification after acute coronary syndrome," *Scientific Reports*, vol. 7, Oct. 2017. DOI: 10.1038/s41598-017-12951-x.

goto2019 [25] S. Goto, M. Kimura, Y. Katsumata, *et al.*, "Artificial intelligence to predict needs for urgent revascularization from 12-leads electrocardiography in emergency patients," *PLOS ONE*, vol. 14, e0210103, Jan. 2019. DOI: 10.1371/journal.pone.0210103.

udenchuck1998 [26] P. J. Kudenchuk, C. Maynard, L. A. Cobb, *et al.*, "Utility of the prehospital electrocardiogram in diagnosing acute coronary syndromes: the Myocardial Infarction Triage and Intervention (MITI) Project," *J Am Coll Cardiol*, vol. 32, no. 1, pp. 17–27, Jul. 1998.

hemsey2012 [27] J. K. Zègre Hemsey, K. Dracup, K. Fleischmann, *et al.*, "Prehospital 12-lead ST-segment monitoring improves the early diagnosis of acute coronary syndrome," *J Electrocardiol*, vol. 45, no. 3, pp. 266–271, 2012.

kumar2019 [28] A. Kumar, R. Ranganatham, R. Komaragiri, and M. Kumar, "Efficient QRS complex detection algorithm based on Fast Fourier Transform," *Biomed Eng Lett*, vol. 9, no. 1, pp. 145–151, Feb. 2019.

alupadasu2012 [29] R. Valupadasu and B. R. R. Chunduri, "Identification of cardiac ischemia using spectral domain analysis of electrocardiogram," in *2012 UKSim 14th International Conference on Computer Modelling and Simulation*, 2012, pp. 92–96. DOI: 10.1109/UKSim.2012.22.

bradley2011 [30] C. P. Bradley, R. H. Clayton, M. P. Nash, *et al.*, "Human ventricular fibrillation during global ischemia and reperfusion: paradoxical changes in activation rate and wavefront complexity," *Circ Arrhythm Electrophysiol*, vol. 4, no. 5, pp. 684–691, Oct. 2011.

arsanova2017 [31] L. Maršánová, M. Ronzhina, R. Smíšek, *et al.*, "Ecg features and methods for automatic classification of ventricular premature and ischemic heartbeats: A comprehensive experimental study," *Scientific Reports*, vol. 7, no. 1, p. 11 239, Sep. 2017, ISSN: 2045-2322. DOI: 10.1038/s41598-017-10942-6. [Online]. Available: https://doi.org/10.1038/s41598-017-10942-6.

sahambi1997 [32] J. S. Sahambi, S. N. Tandon, and R. K. P. Bhatt, "Using wavelet transforms for ecg characterization. an on-line digital signal processing system," *IEEE Engineering in Medicine and Biology Magazine*, vol. 16, no. 1, pp. 77–83, 1997. DOI: 10.1109/51.566158.

HA.106.180200 [33] P. Kligfield, L. S. Gettes, J. J. Bailey, *et al.*, "Recommendations for the standardization and interpretation of the electrocardiogram," *Circulation*, vol. 115, no. 10, pp. 1306–1324, 2007. DOI: 10.1161/CIRCULATIONAHA.106.180200. eprint: https://www.ahajournals.org/doi/pdf/10.1161/CIRCULATIONAHA.106.180200. [Online]. Available: https://www.ahajournals.org/doi/abs/10.1161/CIRCULATIONAHA.106.180200.