Innovations in cardiology

Towards patient centered care

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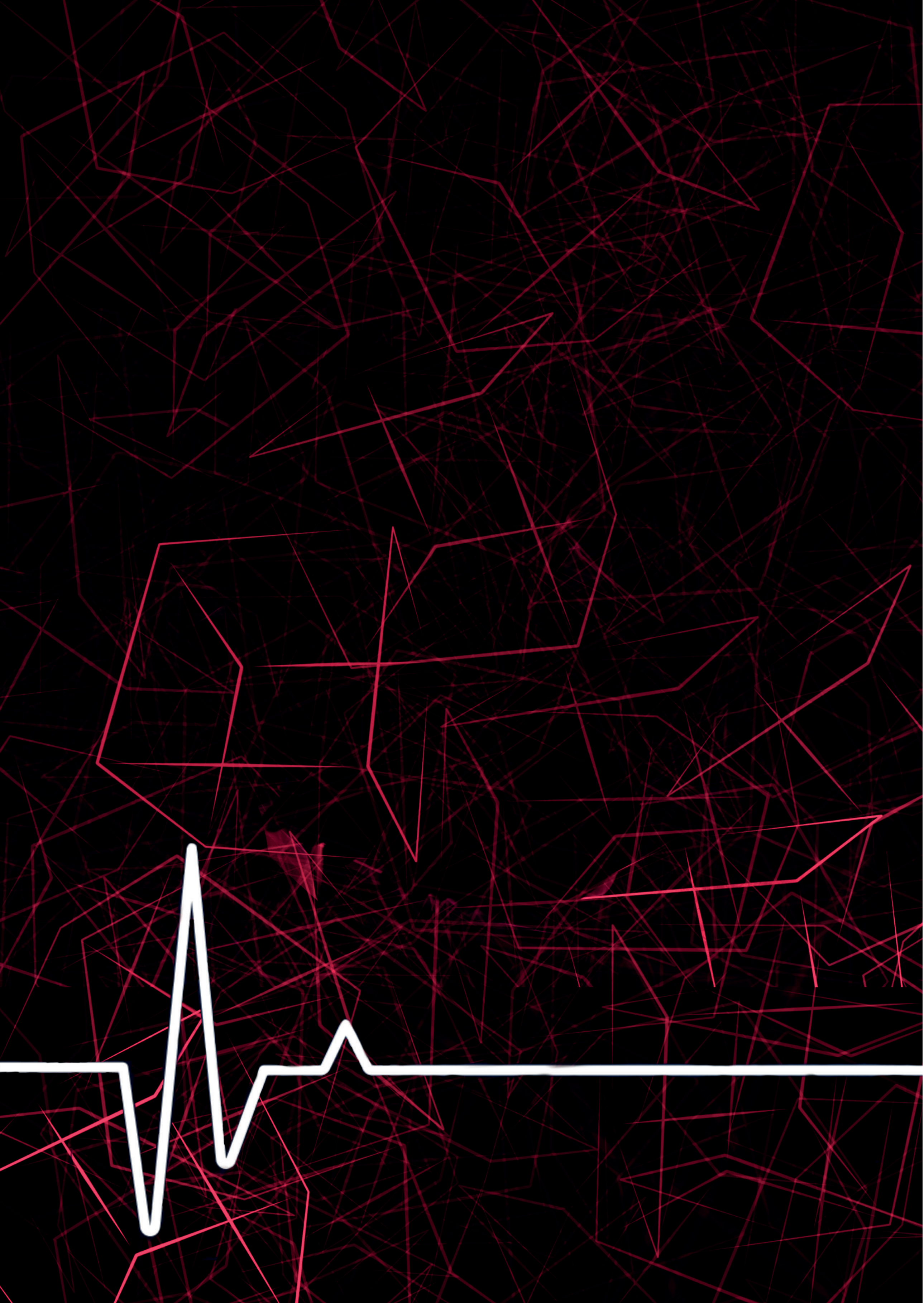

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Introduction and thesis outline

INTRODUCTION

Congenital heart anomalies are the most frequent congenital anomalies in newborns, with an incidence rate of 8 per 1000 live births[1,2]. The emergence of advanced cardiac surgical techniques for newborns and children has improved the survival rates of those affected by congenital heart disease (CHD) or genetic cardiomyopathies (GCM), with over 90% of CHD patients now reaching adulthood[3]. This enhanced overall survival has given rise to a unique patient population that necessitates lifelong monitoring at specialized healthcare facilities[4,5]. Due to potential sequelae following their initial (surgical) intervention, patients with CHD may undergo progressive alterations in their conditions as they age. Consequently, they may experience an elevated prevalence of complications, including heart failure and arrhythmias[6–9]. Patients with GCM rarely need surgical intervention. Nevertheless, they may experience complications similar to those in heart failure and arrhythmias with increasing age, necessitating life-long monitoring and follow-up[10,11].

In the context of these patients, remote monitoring would confer substantial advantages in terms of early detection of symptoms. However, despite considerable advancements in remote health monitoring technologies, the existing healthcare system primarily remains oriented towards in-person consultations in hospital settings. This focus on in-person consultations is of particular concern as health complications for these patient populations could manifest in intervals between scheduled clinical appointments[12]. Integrating medical device monitoring at home would facilitate continuous monitoring and management of patients in the periods between consultations, thus enabling the efficient detection and intervention of any developing complications. The intricate nature of CHD and GCM necessitates the implementation of an interdisciplinary treatment approach, fostering synergistic collaboration among diverse healthcare professionals to comprehensively address the multifaceted aspects inherent to the patients' conditions. Furthermore, prioritizing the promotion of interdisciplinary collaboration among experts in the fields of cardiology, genetics, and other relevant disciplines assumes critical significance in advancing our knowledge regarding the underlying mechanisms and enduring consequences associated with CHD and GCM.

The aim of this thesis was to explore the collaboration between cardiology and biomedical engineering fields to enhance data analysis. Through improved data analysis, the objective was to contribute to enhancing patient care, minimizing complications, and ameliorating the overall quality of life for this distinct group of patients. The thesis further aimed to examine the potential benefits of three areas of innovation within the cardiology practice. Specifically, the research assessed the impact of eHealth technologies on CHD and GCM patient outcomes, evaluated the efficacy of Virtual Reality (VR) technology in alleviating preprocedural anxiety and enhancing patient education for both congenital and acquired heart diseases, and investigated the capability of an Artificial Intelligence (AI) model for automatic arrhythmia detection through electrocardiogram (ECG) analysis.

eHealth

eHealth technology leverages electronic resources for delivering healthcare services, information, and education, incorporating a wide range of technologies, such as telemedicine, mobile health, health information technology, and wearable devices[13]. Despite the growing popularity of eHealth, its adoption among patients with CHD and GCM has been limited[4]. However, the benefits of eHealth technology underscore its potential to improve patient care, particularly for those who require lifelong follow-up at specialized hospitals, i.e. patients with CHD and GCM[14]. The use of eHealth technologies, such as wearable devices, can simplify the monitoring of vital parameters, allowing patients to track their health from their own homes, and whenever deemed necessary[15]. Additionally, eHealth technology can increase convenience for CHD and GCM patients by enabling remote consultations, thereby increasing accessibility of healthcare[14,16]. This shift towards on-demand consultations based on recorded vital signs may also contribute to lowering healthcare costs. Lastly, eHealth technology has the potential to promote personalized treatment for CHD and GCM patients, using AI models to analyze patient data collected using eHealth technology[15].

Virtual reality

Preprocedural anxiety affects up to 80% of patients undergoing medical interventions, and may lead to complications and prolonged hospitalization[17,18]. To address this issue, 360-degree virtual reality (VR) technology has emerged as a promising approach for generating a more immersive and interactive patient experience. By presenting a video within a 360-degree field around the patient, VR provides an enhanced sense of presence, and potentially reduces anxiety[19,20]. While traditional methods rely on oral or paper communication, VR offers an alternative approach. It utilizes computer-generated simulations to create an immersive three-dimensional environment, allowing users to interact with it using specialized equipment, such as a VR headset and controllers[21]. In medical contexts, virtual reality (VR) has the potential to alleviate preprocedural anxiety by either distracting patients from their concerns about the upcoming procedure or providing exposure therapy in a controlled, safe virtual environment[22–24].

Artificial intelligence

As previously highlighted, artificial intelligence (AI), provides a solution to analyze the growing amounts of data collected from digital health technologies. This term, AI, encompasses a variety of subfields such as machine learning (ML) and deep learning (DL). These techniques allow for the training of computer models to identify patterns in data sets for diagnosis or prognosis of a disease[25–28]. The increasing use of eHealth devices has led to an exponential increase in the volume of acquired data, which poses a challenge for processing and analysis of this data. Patients with CHD and GCM often undergo ECGs, as these patients are prone to develop cardiac arrhythmias[29]. To address this challenge of handling massive data, AI can be used to classify ECGs automatically, based on previous examples. This classification entails analyzing an ECG by a neural network model that then detects the presence of an arrhythmia. The advantage of DL is that, the model identifies features from the input data, without the need for experts to engineer features important for the task at hand[30]. The success of the network to correctly perform a prediction heavily depends on the quantity of the training data and the accuracy of their associated labels[31]. AI and specifically DL techniques offer large potential for processing extensive amounts of data and automating intricate tasks involved in ECG analysis, thereby alleviating manual expert analysis.

THESIS OUTLINE

This thesis contains three distinct parts, each part focuses on different technologies to improve patient care using eHealth technology, improve patient education using VR technology, or provide physician assistance using AI technology. The first part evaluates the effectiveness of telemonitoring and eHealth of patients with CHD or GCM. **Chapter 2** presents a randomized controlled trial that investigates the impact of telemonitoring on unplanned consultations and quality of life for 72 patients. Of the 72 patients, 38 performed telemonitoring at home, while the remaining 34 received regular care.

The second part assesses the use of VR in the context of patients undergoing cardiac surgery, encompassing a review of digital patient education in **Chapter 3**. The review compares various digital modalities to evaluate which one is best suited to alleviate preprocedural anxiety in patients. The efficacy of VR in reducing preprocedural anxiety is explored in **Chapters 4** and **5**, with **Chapter 4** focusing on patients undergoing a patent foramen ovale or atrial septal defect procedure, and **Chapter 5** focusing on patients receiving an ablation, pacemaker- or ICD-implantation. Due to the COVID-19 pandemic, some consultations were conducted via telephone, and in-person versus in-person and telephone consultations were compared.

The focus of the third part is on the application of AI in on diagnosis or prognosis of patients with CHD. This part begins with a review of AI techniques for the diagnosis and treatment of CHD in **Chapter 6**. **Chapter 7** delves into the data-point precise detection of R-peaks in single-lead ECGs, which may be a crucial step towards the accurate automatic detection of arrhythmia.

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