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Masterproef
Digital health solutions for atrial fibrillation: screening and management

Promotor:
Prof. dr. Lars GRIETEN
dr. Helene PICCARD

Valentino D’Onofrio
Scriptie ingediend tot het behalen van de graad van master in de biomedische wetenschappen
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Acknowledgements

"Adventures first! Explanations take such dreadful time"

- Lewis Caroll

Adventures are the most fun part of course. These are what makes a good story. However, explanations are, although boring, a complete must, as it was not I alone that would have been able to complete this eight months’ project. Therefore, a number of people need many thanks.

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Now, I end my education and this is where I leave my comfort zone. However, life only begins outside of your comfort zone.
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Samenvatting

Inleiding
Smartphones nemen de wereld over. Er wordt verwacht dat er tegen 2020, 6,1 miljard mensen een smartphone zullen bezitten. In de medische wereld is dit gebruik van smartphones nog niet zo geïntegreerd. Toch kunnen veel problemen in de zorg grotendeels worden opgelost met deze digitale technologie. Eén van die problemen is voorkamerfibrillatie (VKF). VKF is de meest voorkomende hartritmestoornis. Het zorgt voor een sterk verhoogd risico op beroertes. Patiënten met VKF worden behandeld met elektrische cardioversie, maar worden daarna slechts eenmalig verwacht op controle. Desalniettemin hervalt 50% van de patiënten binnen drie maanden. De digitale oplossing die we voorstellen is FibriCheck. FibriCheck is een smartphone app ontwikkeld door ons onderzoeksteam en meet het hartritme en ritmestoornissen met behulp van photoplethysmografie.

Materialen en methoden
Drie studies werden uitgevoerd om FibriCheck te evalueren voor gebruik in het zorg pad van VKF. De FLASH-studie focust op de klinische validatie van FibriCheck en de prestatie ervan in een gecontroleerde omgeving. In de SMAERT-AF studie werd FibriCheck gebruikt als hulpmiddel voor een betere opvolging voor patiënten na de behandeling. Het doel was om te evalueren of FibriCheck efficiënt kan ingezet worden om herval vroeger op te sporen en of het haalbaar is wanneer patiënten thuis, een niet-gecontroleerde omgeving, de app gebruiken. Ten laatste werd er een digitale screening opgezet in de DISTANT-AF studie. De studie evalueerde de haalbaarheid van een screening die volledig digitaal gebeurde met FibriCheck, zonder fysieke hulp van onderzoekers en artsen.

Resultaten
FibriCheck had een sensitiviteit van 99,6% en een specificiteit van 74,1%. Wanneer de kwaliteit van de metingen goed was, verhoogde de sensitiviteit en specificiteit. Tijden de opvolging van patiënten met FibriCheck werden alle patiënten die hervielen, gedetectedeerd. Patiënten met een herval die FibriCheck gebruikten, kwamen 2 dagen eerder terug naar het ziekenhuis voor een bevestigend elektrocardiogram (ECG), dan de controle groep. In deze niet-gecontroleerde omgeving waren 76% van de metingen van goede kwaliteit. Het digitaliseren van screenings was ook haalbaar. Dit wordt getoond door een hoge compliantie van 72,3% en 86,2% metingen van goede kwaliteit. Slechts 13,16% van de gecontacteerde mensen hebben daadwerkelijk geregistreerd.

Discussie en conclusie
FibriCheck is accuraat in het opsporen van VKF, zowel in een gecontroleerde omgeving als in een niet-gecontroleerde omgeving. FibriCheck detecteerde herval vroeger, wat leidde tot vroegere controleraadplegingen en bevestiging van herval. Patiënten kregen daardoor ook vroeger behandeling, wat het risico op beroertes verminderde. Dit ondersteunt zeker het idee dat een diagnostisch hulpmiddel als FibriCheck gebruikt kan worden in het zorg pad van VKF. Daarbij kan screenen ook volledig digitaal gebeuren zonder extra fysieke hulp. Dit draagt bij tot een efficiëntere manier van werken en screenen.
Abstract

Introduction
Smartphone use is increasing worldwide; 6.1 billion smartphone owners are expected by 2020. This increase is not as distinctly seen in the medical world. Although, many problems in health care can be faced with digital technology. Atrial Fibrillation (AF) is one of those problems. AF is the most prevalent heart rhythm disorder that carries an increased risk for stroke. AF patients are seen only once after treatment, although 50% relapse within three months. The digital solution we propose is FibriCheck, an app, developed by our research group. FibriCheck measures heart rhythm and rhythm disorders using photoplethysmograph (PPG) derived from the finger.

Materials and methods
Three studies were done to evaluate FibriCheck in the setting of AF care. First, the FLASH study focused on clinically validating FibriCheck and evaluate app performance in a controlled environment. Next, FibriCheck was used as a follow-up tool for better management in the SMAERT-AF study. Its purpose was to evaluate the efficacy and feasibility of FibriCheck when patients performed measurements at home, a non-controlled environment, as to allow for a better follow-up and earlier detection of relapse. Last, a digital screening was set up using FibriCheck in the DISTANT-AF study. The study evaluated the feasibility of a protocol that allows screening for AF in a completely digital way, without physical contact.

Results
FibriCheck showed an overall sensitivity of 99.6% and a specificity of 74.1%. Improving the quality of measurements led to an increase in sensitivity and specificity. During follow-up of patients with FibriCheck, all recurrences were detected. Those patients returned 2 days earlier to the hospital for ECG confirmation, compared to the control group. In a non-controlled environment, patients are well able to measure heart rhythm, as can be seen from the 76% of measurements that were of good quality and the high compliance of 88.8%. A compliance of 72.3% and 86.2% of measurements of good quality also shows that digitalizing screening is feasible. The response rate of 13.16% after initial contact should be increased.

Discussion and conclusion
FibriCheck can accurately detect AF in a controlled and non-controlled environment. Fibricheck detected relapse earlier, resulting in earlier follow-up visits and relapse confirmation. Patients received earlier treatment, reducing stroke risk. This supports the idea that such a diagnostic app provides a useful tool for monitoring and managing patients treated for AF. Furthermore, screening in a way that is completely digital, where no physical contact is needed, is feasible, and could result in a more efficient way of screening.
**List of Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>AF</td>
<td>Atrial Fibrillation</td>
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<tr>
<td>App</td>
<td>Application</td>
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<tr>
<td>CI</td>
<td>Confidence Interval</td>
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<tr>
<td>CRF</td>
<td>Case Report Form</td>
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<tr>
<td>DCC</td>
<td>Direct Current Cardioversion</td>
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<tr>
<td>ECG</td>
<td>Electrocardiogram</td>
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<tr>
<td>EU</td>
<td>European Union</td>
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<tr>
<td>FP</td>
<td>False Positive</td>
</tr>
<tr>
<td>GP</td>
<td>General Practitioner</td>
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<tr>
<td>HCP</td>
<td>Health Care Provider</td>
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<tr>
<td>HRV</td>
<td>Heart Rate Variability</td>
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<tr>
<td>IQR</td>
<td>Interquartile Range</td>
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<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
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<tr>
<td>PSVT</td>
<td>Paroxysmal Supra Ventricular Tachycardia</td>
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<tr>
<td>PPG</td>
<td>Photoplethysmogram</td>
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<tr>
<td>PAC</td>
<td>Premature Atrial Contraction</td>
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<tr>
<td>PVC</td>
<td>Premature Ventricular Contraction</td>
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<tr>
<td>ROC</td>
<td>Receiver Operating Curves</td>
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<tr>
<td>SD</td>
<td>Standard Deviation</td>
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<tr>
<td>SV-node</td>
<td>Sinoatrial Node</td>
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<tr>
<td>TEE</td>
<td>Transesophageal Echocardiogram</td>
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<tr>
<td>TM</td>
<td>Telemonitoring</td>
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<tr>
<td>ZOL</td>
<td>Ziekenhuis Oost-Limburg</td>
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1. Introduction

In 2015, 99% of the global population owned a mobile phone, 40% of which is a smartphone. Furthermore, 75% of the phones sold in 2015 were smartphones (1). In Belgium, these numbers are the same; 44% of the population uses a smartphone (2). It is expected that by 2020, 6.1 billion people all over the world will possess a smartphone (Figure 1). The reason for this is not only because prices are decreasing, allowing smartphones to become more accessible for people in developing countries, but also because the number of smartphones per individual is increasing in developed countries. In addition, by 2020, ninety percent of the global population will be covered by broadband networks, thus connecting them via the internet to everyone in the entire world (1). As the world becomes increasingly mobile, data traffic will increase. This results in more and more applications (apps) being developed and made available to the public. Already at the beginning of 2015, Apple announced to have more than 1.4 million apps in the app-store. Since the app store was launched in 2008, a true “app-revolution” is happening (3).

Figure 1. Rise of global smartphone use from 2014 to 2020. It is estimated that by 2020, 6.1 billion people own a smartphone. The biggest rise will take place in Asia Pacific. Ericsson.

1.1. Mobile health apps

The high penetration of smartphones and apps changed our perception of connectivity remarkably. Not only data exchange is important, but also the generation of data, using different types of built-in sensors such as a video camera, an accelerometer, and a gyroscope (4). This popularity makes it possible to improve society and harnesses a lot of potential for use in medicine and healthcare (5). This potential has been used extensively, as can be seen from the more than 100,000 apps related to health available in app stores (6). Mobile health apps can not only address specific needs and situations but also a wide variety of people, such as doctors, nurses, researchers, patients, and healthy people (7).
1.1.1. Apps for health professionals

Apps targeting health professionals assist them in their daily tasks. Furthermore, pharmacists, nurses, and dietitians use apps as a reference. Medical students on the other hand, use health-related apps for their education and training (4). For health researchers, smartphones are powerful tools. They can collect, store, and transfer data to remote databases. In addition, research participants can be recruited using apps (4). Research on medical apps became very popular during recent years, as can be seen from the vast amount of publications. However, there is no structure in these publications, which makes it unclear what actually is going on and where the gaps still are (6).

1.1.2. Apps for health consumers

Health related apps targeting health consumers have a broad range of topics; from quitting smoking, to diabetes and obesity management, to physical activity tracking. Furthermore, a large group of health related apps for patients target the management and monitoring of chronic diseases (4). Forty-four percent of people who own a smartphone have health apps, most of the time related to exercise, diet, and brain teasers. However, the largest part reported using these apps only a few times to almost never (8). Considerations for this low use of smartphone can be the fact that ill people are at home, where they have access to Wi-Fi and a laptop (5). Health apps targeting the chronically ill can enable a stronger connection between patient and provider to manage the disease. There are still challenges to be tackled to broaden the use of smartphone apps. For example, much research still has to be done to evaluate outcomes, test the efficacy, and test the safety of these apps. Furthermore, there is uncertainty on how to regulate such medical apps (9, 10).

1.1.3. Regulations and guidelines for mobile health apps

Although this field of research is currently very dynamic, research is still nascent. There is a lack of research on the safety and effectiveness of mobile medical apps (11, 12). Many mobile medical app developers are not medically trained and thus these apps still possess several risks (13). First of all, there could be privacy and security risks. Therefore, abuse and overuse should be avoided and appropriate use is crucial (14, 15). Furthermore, patient safety is not always ensured. Apps with poor accuracy could pose threats to patients and their safety, and algorithms that give erroneous scores could cause harm (13, 15). Variables that contribute to the total risk can be inherent to the app, such as false information, out of date content, or lack of feedback, or can be due to external factors, such as inadequate usage and lack of training (13). Therefore, it is necessary to have guidelines and regulations to aid medical app developers (16). However, governmental regulations could stifle technological innovation in the healthcare sector. A differentiation should be made between apps that allow clinical decision-making and those that do not (17). In 2013 the FDA laid out their regulation rules (18). Here they try to combine safety and effectiveness with innovation. It is clear when a mobile medical app is a medical device and if this is the case, it will be regulated as such. In this way, only the small subset of apps that pose risks to patients are carefully regulated (19). Despite the risks and complexities, medical apps are worthwhile as they have an enormous potential in health care, and in particular in cardiology (12).
1.1.4. **Apps for cardiovascular diseases**

Cardiovascular diseases are the leading cause of global mortality and this has led to an increasing penetration of mHealth in cardiology (20). In 2013, there were 710 apps related to cardiology and heart diseases (21). Banchs et al described that 32% of cardiology patients used health apps related to their disease. Furthermore, 60% would be willing to pay for such an app if it could prevent an emergency room visit (22). These apps are distributed over a wide range; from early diagnosis through remote electrocardiography (ECG) and status checks of implantable devices, to cardiac rehabilitation and blood pressure measurements. Most of these mobile medical apps in cardiology, however, are used for the detection of arrhythmias (21, 23).

1.2. **Arrhythmias**

Arrhythmias are irregularities in the hearth rhythm. These irregularities are caused by problems in the electrical system of the heart. Electrical impulses that stimulate contraction happen too slow, too fast or erratically. Three main types can be distinguished; premature beats, ventricular arrhythmias, and supraventricular arrhythmias (24). Most common are the premature beats. However, most of the time they are harmless. If symptoms occur, patients feel a flutter or a skipped beat. Premature beats can occur in the atria; premature atrial contraction (PAC), or in the ventricles; premature ventricular contraction (PVC). Secondly, arrhythmias can arise in the ventricles, and are known as ventricular arrhythmias. These are more dangerous and always require medical care. A fast but regular beat is a ventricular tachycardia. If this is prolonged, ventricular tachycardia can turn into ventricular fibrillation, which is a more serious condition, where the hearth does not pump regularly because of disorganized electrical signals. An immediate electroshock is necessary. The last type of arrhythmia are the supraventricular arrhythmias. These irregularities are tachycardia’s that arise in the atria. Again, three types can be distinguished; atrial fibrillation (AF), atrial flutter and paroxysmal supra ventricular tachycardia (PSVT). In atrial flutter, electrical signals spread fast and regular in re-entrant circuits. PSVT occurs when the connection between the atria and ventricles is disturbed. This leads to the electrical signal in the atria to return back to the atria and thus causing extra heartbeats (24).

1.3. **Atrial Fibrillation**

AF is the most common type of serious arrhythmia. In AF, ectopic firing occurs, which means that the electrical signal does not start in the sinoatrial node (SA-node), but all over the atria (Figure 2). Furthermore, these electrical signals re-enter other electrical circuits that started in other parts of the atria, resulting in the sustaining of these ectopic beats (25). These signals travel throughout the atria in a fast and irregular way, sometimes at a rate of more than 300 beats per minute, which causes the atria to quiver or fibrillate. The abnormal signals travel to the ventricles. The ventricles will thus also beat too fast and irregular. AF results in higher risk for stroke and heart failure, since blood can pool in the atria leading to clots and because the ventricles do not fill properly, rendering them inadequate to pump the right amount of blood to the body and lungs (24). The chief hazard is a 4 - 5 fold increased risk for stroke, chronic heart failure, acute coronary syndrome, and a doubling of mortality (26).
1.3.1. Epidemiology

AF is one of the most important public health problems in the western world. Two percent of the population is the current prevalence, and this has doubled compared to numbers reported last decade. This increase in prevalence is partly due to the greater ability to diagnose AF chronic (non)cardiac diseases (27). In the European Union (EU) in 2010, 8.8 million people were affected by AF (28). In the Netherlands alone, 250,000 people are diagnosed with AF, which is 5.5% of its population (29). Both the Framingham Study and the Rotterdam Study determined a lifetime risk of developing AF of 25%. This is alarmingly high and the need for continuing research, more effective therapies, and preventive strategies is immense (30, 31). This high prevalence is set to increase in the following years. By 2060 the numbers would be doubled compared to 2010 in the EU. Where in 2010, 1.8% of the total European population was affected, 3.5% would be diagnosed with AF by 2060 (28). The prevalence increases markedly with age. The mean age of patients with AF is 69.3 years (29). AF is present in 0.16% of people younger than 49 years, while it is present in 17% of people aged 80 years and older (27). Furthermore, older patients have higher associated morbidity and mortality than younger patients (32). This is due to the fact that aging reflects longer exposure to predisposing conditions for AF and may involve age related cardiac abnormalities (30). In addition, there is a male preponderance for reasons that are not known, with a male to female ratio of 1.2:1 (27, 30). The incidence for AF is also considerably less for African Americans than that of whites (30).

1.3.2. Management of Atrial Fibrillation

Acute management of AF starts with a decision on which treatment strategy is most optimal. This decision is based on hemodynamic factors, symptoms, and symptom duration (33, 34). Initially, physicians should focus on hemodynamic instability, that occurs most in patients with AF with rapid ventricular response. These patients should immediately receive treatment to restore sinus rhythm. If patients are hemodynamically stable, symptom duration should be considered. Treatment of patients that are hemodynamically stable can consist of either rate control or rhythm control, or a combination (35). When symptoms are present for less than 48h, and the ventricular rate is fast, rate control can be necessary (33, 35). The goal of rate control is to restore a normal ventricular heart rate. In this way, it protects the patient from ventricular tachycardia consequences. Rate control can be obtained using drugs that slow nodal conduction, such as β-blockers or calcium channel
blockers (33, 36). An initial rate control strategy can be beneficial for many patients, although rhythm control, directed at restoring the heart rhythm to normal sinus rhythm, should be considered (37). The standard procedure for rhythm control is by Direct Current Cardioversion (DCC) in which the patient receives an electrical shock, but pharmacological cardioversion, the use of medication to restore sinus rhythm, can also be considered (36). Using DCC, two approaches to restore sinus rhythm exist. The first one is to treat patients with rate-controlling and anticoagulation drugs to prevent formation of thromboembolisms and perform DCC three weeks later (33, 37). Another approach is to perform transesophageal echocardiography (TEE), as a guidance for thrombus formation, followed by DCC if no thrombi can be seen (33, 36, 37). After DCC, all patients require full anticoagulation for four to six weeks (33). Long term management of AF focuses on reducing stroke risk by managing symptoms using rate and rhythm control, mostly pharmacological. Catheter ablation can also be an option. Ablation consists of creating lesions in the right and left atria to disrupt the re-entrant circuits in AF (38). However, ablation is chosen as a second-line therapy because of higher invasiveness (35).

1.3.3. Economic burden

Due to high prevalence and incidence, AF is an immense economic and public health burden (33). It is estimated that the cost for AF is more than 1% of all health care costs (31). In the Netherlands, total costs amount €583 million (29). Many factors contribute to these high costs. The major contributor are hospitalizations, which make up 52%, and even 70% in The Netherlands, of total costs for AF (26, 29, 30). Other expensive factors are drugs, consultations, further investigations and paramedical procedures (26, 30). Health care costs for patients who are managed with DCC can rise to $5,000 per year, with hospital care taking up the greatest amount. However, patients with permanent AF have the lowest cost (34, 35). Factors as increasing prevalence, hospitalizations, and the aging population all drive the increase of health care expenditures for AF further (33).

1.3.4. Screening for Atrial Fibrillation

AF is often asymptomatic. It is then only detected by chance or when a stroke occurs (36). It is estimated that undiagnosed AF is present in 1% of a screened population, if a screening would have been performed. This estimate rises to 1.4% for people aged 65 or older. This only adds to the economic and health burden of AF. Screening for AF is feasible and should help reduce this burden (37, 38). Currently, there exist three different screening strategies. First, screening can be done in routine practice, where the patient with clinical signs presents at a general practitioner (GP), who then makes an initial diagnosis i.e. normal case finding. The second is opportunistic screening. The GP will detect the pulse by palpation of patients who consult him for any reason, even if this is not related to AF. This can be followed by an ECG at the hospital if the pulse was irregular. Lastly, there is systematic screening, where people are invited to the hospital for an ECG. This implies that everyone has to present themselves at the hospital and the physician will take an ECG (39, 40). Studies showed that there are more cases detected when actively screened compared to routine practice. However, there is no significant difference between systematic and opportunistic screening (40). This suggests that targeted screening is more effective but that screening for AF thus could improve in terms of efficiency and cost-effectiveness (37, 40).
1.3.5. Atrial Fibrillation detection

Screening for AF is only possible with a 12-lead ECG, which, at the moment, is still the golden standard test, although this test is time consuming and simpler methods, like pulse taking and remote ECG devices, that are accurate exist (39). On a normal ECG from a patient in sinus rhythm, a regular rhythm can be seen from the regular distance between R peaks (RR interval) (Figure 3). Moreover, a P wave can be distinguished and clearly seen. In contrast, on an ECG from a patient with AF, RR intervals are irregular, meaning that beats are irregular. Also, there is no P wave visible (41).

![Figure 3. ECG recording. Top panel: normal ECG. Bottom panel: ECG of a heart in Atrial Fibrillation.](image)

Another, recent technique is photoplethysmography (PPG). It is an optical measurement technique that sends infrared light into the tissue, mostly the fingertip. The probe needs a light source and a detector to detect the vascular pulse wave that propagates through the body. The light is backscattered and the amount of backscattered light correlates with blood volume. Blood moves from the heart to the fingertips in a wave-like motion and PPG thus reflects blood movement in the vessels. Blood movement and PPG are affected by the heartbeat, hemodynamics, and physiological conditions. A typical PPG wave consists of two waves: a systolic and diastolic wave (Figure 4)(42, 43).

![Figure 4. PPG Waveform characteristics.](image)
PPG is already used in the clinic to measure oxygen saturation, but it can also measure blood pressure, cardiac output, heart rate, and heart rate variability (HRV) (42). HRV is related to several cardiovascular diseases and using PPG to measure HRV is beneficial since it is a non-invasive method. Heart rate and HRV are traditionally detected by RR intervals on an ECG. PPG peaks are comparable to R peaks, and thus, heart rate and HRV can be extracted from a PPG using peak intervals (Figure 5)(44).

![Figure 5. ECG versus PPG. Top panel: ECG with RR intervals. Bottom panel: PPG with PP intervals.](image)

### 1.4. Smartphone applications for Atrial Fibrillation detection

PPG is easy to use, simple, and cost efficient. This offers many benefits for future healthcare (44). For example, PPG can be acquired from smartphones using the camera and white light emitting diode (LED) that are standard on smartphones. The subtle color changes are seen as pulsatile intensity changes (45). Intensity changes of video frames are correlated with variations of light absorption of blood and backscattering of light. This makes it easy to detect heart rate, without the need of extra tools (44). It is not only shown that smartphones have the potential to implement PPG to calculate the heart rate (45, 46) but they can also accurately distinguish AF from sinus rhythm (47, 48). Currently, several apps exist to detect AF. Most AF patients have access to mobile technology, although app use for health related activities is limited but present (49). Acceptability of apps for detection of AF needs to be increased (48). However, these apps are becoming prevalent, making community screening for AF relatively easy and cheap (47). They are even likely to bypass current technologies (50).

#### 1.4.1. FibriCheck

One such app is FibriCheck. FibriCheck is an easy to use app for iPhone. It not only measures heart rate using PPG, but it also distinguishes AF from normal sinus rhythm (Figure 6). This makes screening and management for (silent) AF very easy. Furthermore, FibriCheck is connected to an online platform that stores all measured data. Physicians are than able to review measurements. This allows for a close and fast remote follow-up of patients, making it unnecessary for patients to visit the physician often. Consultations are then only necessary if AF is detected. This has benefits not only for the public health, but also for the economic burden of AF.
Screening has become a very important part of AF. It is shown that early detection is effective not only in terms of health but also in terms of costs, i.e. it is very cost-efficient (51). Furthermore, screening for AF needs to be time-efficient. Studies show that screening by pharmacists with mobile technology is time-effective, but also accepted by pharmacists as well as patients (52, 53). However, no real screening program using such an app currently exists. On the other hand, management of AF needs to be more efficient, especially in terms of follow-up of patients. Patients who receive DCC are only seen once after treatment for a check-up with the cardiologist, although risk of relapse is high. Smartphone apps, like FibriCheck, that detect AF can play a crucial role in early detection of silent and recurring AF. These apps are easy to use, cheap, and readily accessible for thousands of people all over the world. Furthermore, linking patients to physicians via their own smartphone in an at-home setting has many benefits.

1.5. FibriCheck as a digital health solution

Three studies are conducted in order to study the use of FibriCheck for screening and management of AF. First of all, FibriCheck is clinically validated. Performance of the app is tested and evaluated in a controlled environment. In the second study we will develop a screening program using FibriCheck. The screening will be completely digital, and the feasibility of screening digitally will be evaluated. Digital screening allows thousands of people to be easily screened for AF. People can self-screen for AF. Physicians review all data, and if AF is detected, the patient can be contacted for further investigations or treatment. This allows for a fast detection, leading to earlier start of treatment and in this way not only reducing the risk of stroke, but ultimately also the public health and economic burden of AF. The third study evaluates the use of FibriCheck as a management tool for follow-up. Patients will receive FibriCheck after DCC and measure their heart rhythm at home. In this way, patients can be remotely followed, and if relapse of AF should occur, patients can be contacted earlier. This, again leads to faster detection and thus earlier start of treatment.

2. Materials and Methods

2.1. Digital Health Solution

The FibriCheck application, developed by Qompium, is the app proposed as a digital health solution for AF and used in these studies. It not only detects AF, but also distinguishes between sinus rhythm and irregular rhythms. FibriCheck currently runs on iOS devices (iOS 7 or higher). The heart rhythm is measured via PPG. The smartphone is steadily held in the right hand, while the left index finger is placed on the rear camera and LED light source (Figure 7). The LED light is activated at the start of the measurement. Light absorption is measured during 60 seconds. After 60 seconds, a question list for context collection is shown, and the measurement can be seen in the history section off the app.

![Figure 7](image)

**Figure 7.** Top: The smartphone is held steadily in the right hand, while placing the left index finger on the camera and LED light source. The heart rhythm is then measured with PPG. Bottom left: The change in light absorption is measured for 60 seconds. Bottom right: After 60 seconds the measurement is completed, a context can be added and the measurement is sent to the online dashboard.
The measurement is then automatically sent to the online dashboard via the internet. On the online platform, each recorded signal is visualized (Figure 8). This allows for a review of the complete 60 seconds. Measurements are labeled green (normal), orange (warning) or red (urgent). Furthermore, an RR-interval plot and a point carré plot are generated. Dispersion in both of these graphs indicates the presence of an arrhythmia. Additional review of measurements, to control for signal quality and provide more information on motion signals, was done using MATLAB (Mathworks, Natick Massachusetts, USA).

Three studies were done using FibriCheck, in order to study the performance of the app in hospital settings, at home as a management tool for follow-up of patients, and as a screening tool.

![Online dashboard](image.png)

**Figure 8. Online dashboard.** Per patient, measurement history is displayed and measurements are classified as urgent, warning, or normal. For each measurement the signal is visualized and 2 additional plots are made. A regular heart rhythm is displayed.

### 2.2. Clinical Validation

The FLASH-study focused on validation of the iOS version of the app in correlation to a normal ECG, in order to achieve a trustworthy app that makes accurate diagnoses. A prospective interventional study was set up in the hospital Ziekenhuis Oost-Limburg (ZOL) between November 2014 and June 2016.
2.2.1. Patients

Patients that were scheduled for DCC at the hospital, were asked to participate and were included after signing the informed consent. Patients were older than 18 years and were confirmed to have AF by an experienced cardiologist. Patients that were physically unable to perform measurements, had a pacemaker activity, had perniosis, or did not have a successful restoration of sinus rhythm were excluded. 1700 app measurements were expected.

Patients were classified in different groups after measurements and ECG taking based on their heart rhythm. First, patients were divided as having a regular heart rhythm or having an irregular heart rhythm. Next, since FibriCheck is able to distinguish irregular heart rhythms, irregular rhythms were further classified in AF, Atrial Flutter, Extrasystoles or Others.

2.2.2. Procedures

In total, patients were asked to perform six measurements with the smartphone app by placing the left index finger on the camera. Three measurements of one minute each were performed before DCC, where patients still had an irregular heart rhythm. Three measurements were performed after restoring a normal sinus rhythm. At the same time of the measurements an ECG was taken, along with baseline characteristics, such as blood pressure, and oxygen saturation, which were continuously monitored for all patients using the Intellivue MX800 bedside monitor (Philips Healthcare, Best, The Netherlands). Furthermore, demographics and medical history were obtained via medical record review using MEDAR and MEDIWEB (AGFA, Healthcare, Mortsel, Belgium). All data from measurements were automatically uploaded to the online dashboard, where they could be reviewed further.

2.2.3. FibriCheck version

The app version used for clinical validation of the app algorithm was a previous version that required patients to press start two times. First, the app was started and started seeking a signal. When a signal of good quality was found, the start button was pressed for the second time to start the actual measurement. At the end of each measurement of 60 seconds, the data needed to be uploaded manually to the dashboard, where all data was then accessible. The app only showed heart rate to patients.

2.3. Atrial Fibrillation Management

The SMAERT-AF-study focused on the validation of Fibricheck in a remote setting at home, to study whether the app is capable of detecting possible recurrence of AF before the scheduled appointment with the cardiologist. Furthermore, the use of Fibricheck as a management tool for better follow-up of patients was tested. A prospective, block randomized interventional study was set up in the hospitals ZOL (Genk, Belgium) and Jessa (Hasselt, Belgium) between January 2016 and June 2016.
2.3.1. Patients

Patients, older than 18 years, that had AF confirmed by an experienced cardiologist, and were successfully treated with DCC were asked to participate maximal 24 hours after treatment. Patients that were physically not able to perform measurements, had a pacemaker activity, perniosis, or did not have a successful conversion to sinus rhythm were not included. A study size of 42 patients was needed for a power of 80%.

2.3.2. Procedures

After signing the informed consent randomization occurred. Drawing numbers; even numbers represented the telemonitoring group, while uneven numbers represented the control group. Baseline characteristics, such as demographics, medical history, blood pressure, and BMI of all patients were taken, available on the Intellivue MX800 bedside monitor (Philips Healthcare, Best, The Netherlands) or via medical record review using MEDAR and MEDIWEB (AGFA, Healthcare, Mortsel, Belgium). All patients planned a follow-up appointment with their cardiologist 4 to 6 weeks after treatment as part of their standard care path.

Patients in the control group were only asked to take an ECG at this follow-up appointment. Patients in the telemonitoring group were given an iPhone 5S with FibriCheck installed. They were given education about performing proper measurements. They were then asked to perform two measurements each day, one in the morning and one in the evening, and, additionally, if symptoms occurred.

All measurements were uploaded automatically to the online dashboard for daily follow-up and review. Each measurement was reviewed for the recurrence of AF and for signal quality. Normal (green) measurements were reviewed as regular heart rhythm, and the patient continued performing measurements. If a measurement was urgent (red), and of good signal quality, an event report was made and the cardiologist was contacted to confirm the diagnosis. If AF was confirmed the usual care path was followed and the study was ended for these patients. The same procedure was followed after two consecutive warning (orange) measurements of good quality. At the end of the study a confirmative ECG was taken for all patients. Patients who did not measure at all or performed measurements of bad quality were contacted for re-education. After 5 consecutive days of no measurements or 5 recordings of bad quality the patient was excluded from the study.

2.3.3. FibriCheck version

The version used for this study was the same as described earlier. It was the final version of the app, that was later added to the app store in this form. Measurements were automatically started after pressing start once. The app sought signals of good quality automatically before starting a 60 second measurement. Data was transferred automatically to the online dashboard. The app showed heart rate, heart rhythm, and gave an indicating label (green, orange, or red) to the measurement.
2.4. Atrial Fibrillation Screening

The purpose of the DISTANT-AF study was to develop a screening program to detect (silent) AF in the general population in a completely digital way. Using smartphone technology and telemonitoring, there is no more need for physical contact and screening for AF becomes very easy and time-efficient. A prospective, decentralized cohort study was set up in May 2016.

2.4.1. Participants

Participants were 18 years or older, physically able to perform measurements, and in the possession of a personal iOS device (iPhone 5 or higher). They were not included if they had a pacemaker dependent activity or had perniosis. Since the screening program is directed to the general population, no confirmation by an experienced cardiologist of AF was necessary at the start of the study. 25 participants were needed for an evaluation of the digital process.

2.4.2. Procedures

Personnel of the cardiology department at the hospital ZOL and people who showed prior interests were invited by e-mail to participate. The e-mail contained basic information about the study and people were directed to the study website with a link. The study website contained general information about AF and FibriCheck. It also contained information about the study. Participants that were interested needed to self-certify based on the provided inclusion criteria. If they were not eligible, they could not register. If they were eligible, they were invited to register. Registering was done by first reading and accepting a digital informed consent. Only if the informed consent was accepted, participants could fill out their own case report form (CRF). Participants needed to fill in a form containing demographics, contact information, and calculate a CHADS\_VASc score to determine their risk profile for AF. All data were automatically uploaded and could be consulted by researchers.

After a complete registration, participants were provided with a link to the apple app store, where they could download and install the app. Furthermore, they received an e-mail containing a QR code, that allowed them to link their app account with the online dashboard. Participants were also asked to read the instructions, provided on the study website, carefully in order learn about app use and to perform proper measurements. Participants needed to measure their heart rhythm using FibriCheck twice daily, one in the morning and one in the evening, and, additionally, if symptoms occurred, during 5 consecutive days. All measurements were automatically uploaded to the online dashboard, where they were reviewed after 5 days.

Each measurement was reviewed for signal quality and for the occurrence of AF. Measurements were labeled green (normal), orange (warning), or red (urgent). Normal measurements were reviewed as a regular heart rhythm. A report regarding their condition was sent and no further actions needed to be taken. If 2 warning measurements or 1 urgent measurement that were of good signal quality occurred, the heart rhythm was irregular. Participants were contacted for a confirmative ECG. If AF, or other irregularities, were confirmed, the usual care was started. On the other hand, warning and urgent measurements could also be of bad signal quality, due to bad finger placement or high pressure. These measurements are false positives. If fifty percent of measurements were false positive, participants were re-invited to join the study.
At the end of the study, participants were contacted via e-mail informing them about their heart rhythm with a report and about the study end. Participants with only normal measurements were deleted from the online dashboard, which made them unable to use the app further. Participants with detected irregularities were encouraged to join the follow-up path with the app. Attached to the e-mail was a questionnaire about user experience. After filling in this survey, the study was completely closed.

2.4.3. FibriCheck version

The version used for this study was the same definite version as the SMAERT-AF study. This version is available in the apple app store under “FibriCheck”, so that it was easily accessible for all participants.

2.5. Statistical Analysis

All statistical analyses were done using Statistical Package for Social Sciences (SPSS® Statistics), release 22.0 (IBM® Inc, Chicago, Illinois, USA). All data was tested for normality using the Shapiro-Wilk test. Continuous variables are represented as mean ± standard deviation (SD) or as median (interquartile range) (IQR). Categorical variables are shown as number (%). Two continues variables were compared using independent samples t-test. Three or more groups of continues data were analyzed using one-way ANOVA. Categorical data was assessed using Chi-square goodness-of-fit. Statistical significance was considered at 2-tailed p-value <0.05. Calculations of sensitivity, specificity and accuracy were done with receiver operating curves. Missing data were left out for all analyses. Characterization of signal quality was done using MATLAB® (Mathworks®, Natick Massachusetts, USA).
3. Results

3.1. Clinical Validation - FLASH

3.1.1. Study Population

In total, 1467 measurements were performed during 2 years at the hospital ZOL. Most of the measurements were done as part of the FLASH study. However, in June 2015 a screening event took place, where approximately 500 people measured their heart rhythm with FibriCheck. This leads to a higher amount of measurements that could be used for the validation of FibriCheck. However, no demographics were taken during this event, which resulted in a high amount of missing values when analyzing demographics. Furthermore, clinical characteristics were not analyzed due to the high amount of missing values.

Baseline characteristics are represented per measurement, not per patient. 1020 measurements were analyzed and classified in four groups based on their cardiac rhythm (Table 1). The majority of measurements (69.7%) were taken by males. Gender does not significantly differ between groups. Measurements were done with patients that have an average of 68. Age is significantly different between groups (p=0.009). In the higher age group more irregular measurements were taken. Again, the majority of measurements were taken by patients who underwent DCC (90%). Treatment does differ statistically significant, with more patients receiving ablation for regular measurements.

3.1.2. Sensitivity and Specificity

Sensitivity and Specificity was analyzed for 1467 measurements, including those without demographic information. Overall, FibriCheck showed an accuracy of 91.3% (95% Confidence Interval (CI): 0.898-0.927). Sensitivity and specificity was determined to be 99.6% and 74.1% respectively (Table 2).

Four Receiver Operating Curves (ROC) were established. Each measurements received a score, based on which the algorithm will label the rhythm as normal or irregular. Theses scores were used to constitute the ROC curves. Since the algorithm of FibriCheck uses a score of 1.2 as cut-off value, this was also used here. Performance of FibriCheck was evaluated for all measurements (Figure 9A), for measurements of good quality (Figure 9B), for all measurements of AF (Figure 9C), thus filtering for other irregularities, and for good quality measurements of AF (Figure 9D). All graphs had an accuracy higher than 90%. Sensitivity increased with 0.2% if only good quality measurements were taken into account, both if all rhythms (99.8%) or if only AF (99.7%) were taken into account. Good quality of measurements of AF resulted in an accuracy of 98.7%. Specificity increased drastically if only AF rhythms were reviewed, regardless of quality, 87.5% for all AF measurements and 91.3% for AF measurements of good quality.
Table 1. Baseline characteristics of the study population

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total Population n=1020</th>
<th>Atrial Fibrillation n=446</th>
<th>Atrial Flutter n=73</th>
<th>Extrasystoles n=94</th>
<th>Sinus rhythm n=487</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>68 ± 11</td>
<td>69 ± 11</td>
<td>70 ± 10</td>
<td>71 ± 11</td>
<td>67 ± 11</td>
<td>0.009*</td>
</tr>
<tr>
<td>Gender (Male)</td>
<td>709 (69.7)</td>
<td>309 (69.3)</td>
<td>49 (67.1)</td>
<td>60 (63.8)</td>
<td>340 (69.8)</td>
<td>0.981</td>
</tr>
<tr>
<td>DCC</td>
<td>665 (90.0)</td>
<td>326 (99.4)</td>
<td>45 (88.2)</td>
<td>54 (93.1)</td>
<td>294 (81.7)</td>
<td>0.000*</td>
</tr>
<tr>
<td>Ablation</td>
<td>74 (10.0)</td>
<td>2 (0.6)</td>
<td>6 (11.8)</td>
<td>4 (6.9)</td>
<td>66 (18.3)</td>
<td></td>
</tr>
</tbody>
</table>

Data are shown as mean ± SD for continuous variables or as number (%) for categorical variables. *p-value <0.05: Continuous variables were tested with one-way ANOVA; categorical variables with Chi-square goodness-of-fit.

Table 2. ROC curve characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>All rhythms n=1460</th>
<th>All Rhythms Good Quality n=1359</th>
<th>Atrial Fibrillation n=1246</th>
<th>Atrial Fibrillation Good Quality n=1168</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of positive measurements</td>
<td>450</td>
<td>403</td>
<td>430</td>
<td>389</td>
</tr>
<tr>
<td>AUC</td>
<td>91.3%</td>
<td>93.9%</td>
<td>96.3%</td>
<td>98.7%</td>
</tr>
<tr>
<td>95% CI</td>
<td>0.898-0.927</td>
<td>0.927-0.952</td>
<td>0.952-0.974</td>
<td>0.982-0.992</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>99.6%</td>
<td>99.8%</td>
<td>99.5%</td>
<td>99.7%</td>
</tr>
<tr>
<td>Specificity</td>
<td>74.1%</td>
<td>77.8%</td>
<td>87.5%</td>
<td>91.3%</td>
</tr>
<tr>
<td>Cut-off value</td>
<td>1.19</td>
<td>1.19</td>
<td>1.19</td>
<td>1.19</td>
</tr>
</tbody>
</table>
3.1.3. Quality Assessment

Signal quality was visually assessed and labeled as good, medium or bad quality. Measurements were labeled good quality if peak detection was good, i.e. all peaks were detected by the algorithm, and if peaks met certain conditions regarding their form and height. The underlying rhythm was clear to be determined. Bad quality measurements were the opposite, and the underlying rhythm was not possible to be determined. Measurements of medium quality were those measurements that were sufficiently good to label heart rhythm accurately, but had some segments during one minute that were of poorer quality.

In total, 1466 measurements were evaluated for signal quality (Table 3). The greatest part of measurements were of good quality (83.7%). Only 7.2% and 9.1% of measurements were of bad or medium quality, respectively.

Table 3. Quality assessment of measurements

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total n=1466</th>
<th>Sinus rhythm n=929</th>
<th>Atrial Fibrillation n=450</th>
<th>Other rhythms N=83</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Quality</td>
<td>1228 (83.7%)</td>
<td>784 (84.4)</td>
<td>370 (82.2)</td>
<td>73 (88.0)</td>
</tr>
<tr>
<td>Medium Quality</td>
<td>133 (9.1%)</td>
<td>98 (10.5)</td>
<td>33 (7.3)</td>
<td>2 (2.4)</td>
</tr>
<tr>
<td>Bad Quality</td>
<td>105 (7.2%)</td>
<td>46 (5.0)</td>
<td>47 (10.4)</td>
<td>8 (9.6)</td>
</tr>
</tbody>
</table>

Data are shown as number (%).

Figure 9. ROC curves for evaluating FibriCheck performance. A. Measurements from all rhythms; B. Measurements of good quality; C. Measurements of AF; D. Measurements of AF of good quality. AF: Atrial Fibrillation.
Overall, in different groups, most measurements were of good quality. The Chi-square goodness-of-fit test determined a statistically significant difference in quality between groups (Table 4). More measurements of bad quality were observed for irregular rhythms, both AF and others. On the other hand, more measurements were done of medium quality for sinus rhythm compared to irregular rhythms.

**Table 4. Chi-Square Goodness-of-fit test.** Measurements between groups differ significantly for quality. p<0.05

<table>
<thead>
<tr>
<th></th>
<th>Asymptotic Significance (2-sided)</th>
<th>Value</th>
<th>df</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td></td>
<td>22,875</td>
<td>6</td>
<td>.001*</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td></td>
<td>24,272</td>
<td>6</td>
<td>.000*</td>
</tr>
<tr>
<td>Linear-by-Linear</td>
<td></td>
<td>1,474</td>
<td>1</td>
<td>.491</td>
</tr>
<tr>
<td>Association</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td></td>
<td>1462</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Since assessment of medium quality was very subjective, measurement quality was also evaluated by differentiating quality in only two groups; good or bad. Here, 1361 (93.4%) of measurements were of good quality, and the remaining of bad quality (Table 5).

**Table 5. Quality assessment of measurements, based on two groups.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total n=1466</th>
<th>Sinus rhythm n=929</th>
<th>Atrial Fibrillation n=450</th>
<th>Other rhythms N=83</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Quality</td>
<td>1361 (93.4%)</td>
<td>882 (95.2)</td>
<td>403 (90.0)</td>
<td>75 (91.5)</td>
</tr>
<tr>
<td>Bad Quality</td>
<td>96 (6.6)</td>
<td>44 (4.8)</td>
<td>45 (10.0)</td>
<td>7 (8.5)</td>
</tr>
</tbody>
</table>

Data are shown as number (%).

Chi-square goodness-of-fit again showed a statistically significant difference between groups for signal quality. More measurements were of bad signal quality for irregular rhythms (Table 6)

**Table 6. Chi-square goodness-of-fit test.** Based on two groups of signal quality, measurements were differed statistically significant.

<table>
<thead>
<tr>
<th></th>
<th>Asymptotic Significance (2-sided)</th>
<th>Value</th>
<th>df</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td></td>
<td>14,268</td>
<td>2</td>
<td>.001*</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td></td>
<td>13,622</td>
<td>2</td>
<td>.001*</td>
</tr>
<tr>
<td>Linear-by-Linear</td>
<td></td>
<td>10,878</td>
<td>1</td>
<td>.001*</td>
</tr>
<tr>
<td>Association</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td></td>
<td>1456</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2. Digital Monitoring and Management of AF – SMAERT-AF

3.2.1. Study Population

In total, 30 patients were included in the hospitals Jessa (Hasselt, Belgium) and ZOL (Genk, Belgium) from January 2016 until May 2016 (Table 7). Twenty (66.7%) patients were male, ten (33.3%) female, with a mean age of 66. Both the telemonitoring (TM) group and the control group contained 15 patients. Averagely, patients had 35 days between DCC and their follow-up appointment. Eight patients had a relapse of AF, six in the TM group and two in the control group. There were no statistically significant differences between groups.

Table 7. Baseline characteristics of the study population.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total Population n=30</th>
<th>Telemonitoring n=15</th>
<th>Standard Care n=15</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>66 ± 8</td>
<td>64 ± 7</td>
<td>67 ± 8</td>
<td>0.525</td>
</tr>
<tr>
<td>Gender (Male)</td>
<td>20 (66.7)</td>
<td>8 (53.3)</td>
<td>12 (80.0)</td>
<td>0.123</td>
</tr>
<tr>
<td>Follow-up (Days)</td>
<td>35 ± 16</td>
<td>35 ± 15</td>
<td>34 ± 18</td>
<td>0.602</td>
</tr>
<tr>
<td>Recurrence (Yes)</td>
<td>8 (26.7)</td>
<td>6 (40.0)</td>
<td>2 (13.3)</td>
<td>0.107</td>
</tr>
</tbody>
</table>

Data are shown as mean ± SD for continuous data or as number (%) for categorical data. p-value <0.05: differences were tested with independent-samples t-test for continuous data or with Chi-square goodness-of-fit for categorical data.

3.2.2. Telemonitoring

15 patients were remotely monitored by daily measurement taking of their heart rhythm with FibriCheck. Initially, a follow-up appointment was planned 35 days after DCC (Table 8). However, actual follow-up visits occurred after 32 days, 3 days earlier than planned. This period varied from 13 to 69 days. In total, 901 measurements were received, with an average of 60 measurements per patient.

On average, patients measured between one or two times per day (1.89). This is slightly less than the asked frequency of two measurements per day (Table 8). In total, 117 measurements were missed. However, this still led to a high compliance of 88.8%.

Table 8. Telemonitoring characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Telemonitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initially Planned Follow-up period (days)</td>
<td>35 ± 15</td>
</tr>
<tr>
<td>Actual Follow-up period (days)</td>
<td>32 ± 15</td>
</tr>
<tr>
<td>Total Measurements</td>
<td>901</td>
</tr>
<tr>
<td>Measurements per patient</td>
<td>60 ± 30</td>
</tr>
<tr>
<td>Measurements per patient per day</td>
<td>1.89 ± 0.43</td>
</tr>
<tr>
<td>Urgent Measurements</td>
<td>243 (26.9)</td>
</tr>
<tr>
<td>Missed Measurements</td>
<td>117</td>
</tr>
</tbody>
</table>
During 32 days of follow-up, 243 urgent measurements were collected (Table 8). 185 (76%) of those measurements were events, both AF or other irregularities. Only 58 (24%) of measurements were false positives (FP), all due to bad signal quality (Figure 10).

**Figure 10. Urgent Measurements.** In total, 243 urgent measurements were received, of which 185 (76%) were real events of AF and 58 (24%) were false positive (FP).

### 3.2.3. Detecting irregularities

In the TM group six patients had a recurrence of AF (Table 7). On average, relapse took place 6 days after DCC (Figure 11). The earliest recurrence occurred after two days, while the latest on day 9. All recurrences were detected with FibriCheck. Detection with FibriCheck led to contacting the cardiologist. Most of the time, this resulted in an earlier follow-up appointment than initially planned. Averagely, the actual follow-up took place after 32 days, which was 3 days earlier than initially planned and 2 days earlier than the average follow-up period of the control group. All recurrences detected by FibriCheck were confirmed with an ECG on the follow-up appointment.

**Figure 11. Recurrence of AF in TM group.** Recurrence took place averagely on day 6. This led to contacting the cardiologist, and resulting to an earlier follow-up than planned, and than the control group.
3.2.4. Types of irregularities detected

Six patients had a recurrence of AF. However, not all were true AF. Four patients had recurrent AF (Figure 12; 3-5 and 7). These patients had sinus rhythm immediately after DCC treatment. Later, a relapse occurred and they constantly had an irregular rhythm. One patient had multiple recurrences of AF episodes (Figure 12; 2). The heart rhythm was alternately irregular or regular. During the follow-up appointment the ECG showed possible irregularities. Therefore, it was decided to start Holter monitoring to confirm these episodes. One patient had a recurrence of an irregular rhythm (Figure 12, 6). However, the irregularity detected were frequent PAC’s. Last, one patient did not have a confirmed recurrence of AF (Figure 12, 8). Although this patient had most of the time sinus rhythm, some measurements were irregular. These were frequent ectopic beats. This only results in an irregular rhythm if these occur at high frequency. Therefore, this was not seen as a true recurrence.

**Figure 12.** Different patterns of irregular measurements. Each patient had different types of AF recurrence. 1. Constant sinus rhythm, no recurrence; 2. Intermittent AF, alternate irregular and regular measurements; 3-5. Recurrent AF, constant irregularity after a period of sinus rhythm. 6. Premature atrial contractions, these do not always result in irregularities; 6. Recurrent AF; 7. Frequent ectopic beats, these do not always result in irregularities.
3.3. Digital Screening for AF – DISTANT-AF

In this section, the results from a completely digital screening are displayed. It was evaluated if this type of screening, without physical contact, was feasible. The need for this digital way of working is great. It allows for a more efficient screening compared to the systematic screening that is done every year in Belgium and in ZOL (Genk, Belgium). During this systematic screening of one week in June 2016, 1300 people visited the hospital for a screening by professionals. In order to screen every person, at least four professionals per hour were needed, during the whole workday. Therefore, digital screening could be interesting because it will not only diminish the need for hospital visits, but also the intensive work that is needed from professionals.

3.3.1. The digital connection

In total, 190 people were contacted in May 2016 (Figure 13). All people were informed about the study via e-mail. 113 (59.5%) people opened and read the e-mail. Of those that opened the e-mail, 52 (46.0%) people clicked the provided link and were directed to the study website for more information and possible registration. This already resulted in the loss of 72.63% of contacted people before registration.

*Number of people from Mail to Website*

![Diagram showing the flow of people from mail to website](image)

**Figure 13. Flow of the number of people contacted until the opening of the study website.** 190 people were contacted via e-mail. 113 people (59.5%) opened and read this e-mail. Of these, 52 clicked on the link and were directed to the study website. Losing 72.63% of people contacted.
3.3.2. Study website

The purpose of the study website was to provide basic information on AF, FibriCheck and DISTANT. Furthermore, registration could be done via this website and instructions on measuring could be consulted (See appendix 1). During the study period, the website was visited in total 274 times by 69 unique visitors. The daily visits were tracked (Figure 14). Website visits peaked immediately after sending e-mails with the link, but also during weekends, and mostly on Sundays.

Figure 14. website views and unique visitors. Website visitors peaked after sending e-mails and during weekends.
3.3.3. Registration

Following the website visit, people were allowed to register if all criteria were met. In total, 25 people registered (Figure 15). Four people were disqualified because they did not meet inclusion criteria after all. Three people had an incomplete registration. However, in two cases demographic information was available, so they could still be included. A registration of 25 people from 190 people that were contacted, led to a response rate of 13.16%.

Figure 15. Registrations. 25 people registered, 18 were complete and 4 disqualified. Three registrations were incomplete, but two of them could still be included.

3.3.4. Screening population

After registration, 20 participants were provided with an instructive e-mail to install FibriCheck and link the app to the dashboard. Three people never installed FibriCheck after multiple reminders. They did not screen and thus were excluded. In total, 17 participants measured their heart rhythm for 5 days (Table 9). They had a mean age of 35, and the minority was male (35.3%). Most participants were of Belgian nationality (88.2%), one was Dutch and one was Italian. CHADSVASC score was calculated to determine stroke risk. However, the highest score was one, for all females, resulting in only a 1.3% risk for stroke.

Table 9. Baseline characteristics of screening population

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total n=17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>35 ± 14</td>
</tr>
<tr>
<td>Gender (Male)</td>
<td>6 (35.3)</td>
</tr>
<tr>
<td>Nationality</td>
<td></td>
</tr>
<tr>
<td>Belgian</td>
<td>15 (88.2)</td>
</tr>
<tr>
<td>Dutch</td>
<td>1 (5.9)</td>
</tr>
<tr>
<td>Italian</td>
<td>1 (5.9)</td>
</tr>
<tr>
<td>CHADSVASC Score</td>
<td></td>
</tr>
<tr>
<td>No Risk</td>
<td>4 (26.7)</td>
</tr>
<tr>
<td>1.3% Risk</td>
<td>11 (73.3)</td>
</tr>
</tbody>
</table>

Data are shown as mean ± SD for continuous variables or as number (%) for categorical variables.
### 3.3.5. Remote screening

The time needed for participants to install FibriCheck after registration was 1 day (IQR 0 - 3.5 days) (Table 10). Overall, no extra interactions were needed (IQR 0 – 1 extra interactions). Averagely, 7 measurements per patient were done during 5 days. One to two (1.45) measurements per day were done per patient, despite the desired two measurements per day. However, this still led to a high compliance of 72.3%.

**Table 10. Characteristics of remote screening**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total n=17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to first measurement (days)</td>
<td>1 (IQR 0-3.5)</td>
</tr>
<tr>
<td>Extra Interactions</td>
<td>0 (IQR 0-1)</td>
</tr>
<tr>
<td>Measurements per patient</td>
<td>7 ± 3</td>
</tr>
<tr>
<td>Measurements per patient per day</td>
<td>1.45 ± 0.31</td>
</tr>
<tr>
<td>Total Measurements</td>
<td>123</td>
</tr>
<tr>
<td>Regular Measurements</td>
<td>106 (86.2)</td>
</tr>
<tr>
<td>Urgent measurements</td>
<td>17 (13.8)</td>
</tr>
<tr>
<td>False Positives</td>
<td>16 (94.1)</td>
</tr>
<tr>
<td>Events</td>
<td>1 (5.9)</td>
</tr>
</tbody>
</table>

Data are shown as mean ± SD or median (IQR) for continuous variables or as number (%) for categorical variables.

A total of 123 measurements were received. The majority (86.2%) of those were regular (Figure 16). Only 17 (13.8%) urgent measurements were received. The most part of urgent measurements (94.1%) were FP due to bad signal quality or bad peak detection. Only 1 event was detected. This event was not real AF, but were extrasystoles. However, the amount of extrasystoles did not exceed 10 in one minute. Therefore, the measurement was labeled orange (intermediate), and no actions needed to be taken. No one exceeded the maximum of 50% of bad quality measurements during five days.

![Figure 16. Measurements received.](image)

In total 123 measurements received, 106 were regular. Of 17 urgent measurements, 16 were FP and 1 was an event.
3.3.6. Participant experience

Participants were asked to fill in a questionnaire related to their experience using the app during five days of screening. Eight questionnaires were collected (appendix 7.2). Six (75%) participants indicated they would use telemonitoring completely voluntary. 87.5% gave a score of one, on a scale of one to five, when asked about the influence this screening had on their daily life. Furthermore, 50% scored four points, indicating that telemonitoring was enjoyable during the screening.

All participants scored a four or five when asked how content they were about FibriCheck, and how easy it was using the app. 87.5% indicated that two measurements per day was enough, although opinions were divided on how well they were able to keep performing two measurements daily. Overall, 87.5% indicated having no difficulties during the study, nor having problems with sending medical information online. All participants were content about the communication with researchers during the study.
4. Discussion

The digital future is now. Nowadays, there are more mobile telephone subscriptions than there are people in the entire world. Only 8 years ago using smartphone devices was just imagination, now there is no living without. People spend around three hours daily on their smartphone, of which 90% is dedicated to the use of apps. 91% of people indicate their smartphone as "very important", and for 93% of millennials it is even more important than their toothbrush (60).

The use of smartphones and apps is also getting more attention every day in the health care sector. Health care providers (HCP’s) excessively use smartphones, not only as a replacement for pagers for better communication, but also for information management, health record maintenance, education, data acquisition, and most importantly for clinical decision making and patient monitoring. Smartphones provide many benefits for HCP’s, such as faster decision making with lower error rates, higher accessibility, and improving efficiency, leading to a better patient care. Medical applications are being developed for remotely monitoring health conditions of patients. They can be used to accurately track health, heart rate, and HRV by ECG of PPG (61). In this way, it is possible to monitor patients with heart rhythm disorders, like AF.

4.1. FibriCheck

The app used here, that measures heart rate and heart rhythm, is FibriCheck. FibriCheck is a medical application that is easy-to-use. Its primary objective is to allow for a better and easier follow-up of patients by physicians. Its main advantage is that it not only detects irregular heart rhythms, but the app is also linked to the online dashboard. This allows for a close interaction between patient and physician, without the need of hospital visits. Furthermore, FibriCheck makes use of the intrinsic sensors that are present in every smartphone; the camera and LED-light. Using these two sensors, the app is able to deduct the heart rhythm based on the PPG principle. Other intrinsic sensors the app uses are the accelerometer and gyroscope. In this way, movements of the smartphone, which leads to bad signal quality, can be visualized in order to filter FP measurements. The use of these intrinsic sensors eliminates the need for additional hardware, like other more traditional sensors need (e.g. Holtermonitor).

4.2. Clinical Validation

In total, 1467 measurements were used for validating FibriCheck. Demographics were only analyzed for 1020 measurements, due to measurements taken during the screening event in 2015. However, a statistically significant difference could be seen for age between groups. Age was higher for irregular measurements. This can be due to the fact that measurements were taken before and after DCC. If DCC failed, only measurements before were inserted, which resulted in an increase in irregular rhythms without an increase in regular rhythms. The higher age for irregular rhythms could have been the result of DCC failing in elder patients.

In a controlled environment, FibriCheck is shown to detect AF and irregularities with high accuracy. Specific detection of AF resulted in an accuracy of 98.7%, with a sensitivity of 99.5%. Of course, AF is not the only rhythm disorder. Atrial Flutter or extrasystoles were also detected with
FibriCheck. If all rhythms were taken in account, accuracy and sensitivity still remain high (91.3% and 99.6%, respectively). Specificity is lowest when all rhythms were included (74.1%) and highest if only AF rhythms are reviewed (91.3%). Of course, specificity rose if only AF rhythms were present, due to the fact that the algorithm is made for AF detection and therefore, increasing the number of true negatives by filtering other irregularities that were classified as negative. Furthermore, sensitivity increases with 0.2% if only measurements of good quality were included. Of course, FibriCheck will classify measurements better if the signal quality is good.

The high accuracy of FibriCheck to label AF or irregularities is strongly dependent on the quality of measurements. 60 second heart rhythm measurements can be labeled incorrectly as irregular if the measurement performed was of bad quality, thus giving rise to FP. Several factors, that are mostly extrinsic and related to app use, play a significant role in signal quality. Therefore, it is of utmost importance to teach or explain patients how to perform heart rhythm measurements properly.

The detection method used is PPG, and this is influenced by a number of factors, such as the sympathetic nervous system, skin structure, oxygen saturation, blood flow rate, temperature of the finger, and measurement environment. These factors explain the difference between individual patients, leading to more time needed for a good quality signal to be found. However, it is noted that patients with perniosis or extreme cold fingers were not included and thus were not part of the patient population.

The two most important factors generating bad signal quality are pressure and motion. The placement of the left index finger on the camera was determined to be the easiest position. However, using iPhone 5S’s, cameras and LED-lights are completely built-in. Therefore, many patients pressed their finger too hard. Applying too much pressure resulted in a longer duration before a signal of good quality was found.

Movement was the principle factor leading to bad signal quality and FPs. Patients performing measurements were asked to move as little as possible. However, in the controlled environment in the hospital, patients lying in a bed, had no support for their arms at all. This made it difficult for patients to hold still for an entire minute. Furthermore, patients were interested and started asking questions, which again leaded to movement. The best method for performing measurements while remaining still for one minute was determined to be while sitting straight at a table, to support the arms.

Assessment of signal quality was done using MATLAB® (Mathworks®, Natick Massachusetts, USA). Quality was visualized with MATLAB, and several criteria were checked to label measurements as good, bad or medium quality. Measurements were labeled of good quality if peak detection was good, and if peaks met certain conditions regarding their form. Furthermore, motion signals derived from the accelerometer and gyroscope were visualized to determine segments where patients had moved and thus possibly had bad signal segments. If none of the criteria were met, the measurement was labeled as bad quality. Measurements of medium quality were those measurements that were sufficiently good to label heart rhythm accurately, but had some segments during one minute that were of poorer quality. It is important to note that this assessment was done visually, based on the experience of the researcher. Therefore, it was a subjective method, especially for those labeled as...
medium quality. However, classifying quality in two or three groups draws the same conclusion. The problem of subjective quality assessment is addressed in the latest FibriCheck version, where an extra label is added. The algorithm will classify measurements as green, orange, red or blue, where blue stands for “bad quality measurement”. This automatic labeling makes usability of the dashboard and diagnosing AF via the dashboard even more easier for physicians.

In total, during the in hospital validation, 101 measurements of bad signal quality were performed. There were significantly more bad quality measurements in the “AF” and “other irregularities” groups. This is explained by the fact that noise is designated as peaks, resulting in a high score and a label as irregular. However, this not always results in a FP as patients with AF performing bad measurements were still correctly classified as irregular. This can also be seen if quality is divided in only bad or good. There are significantly more measurements of medium quality for regular measurements. This is explained by the fact that medium quality measurements are those measurements that were sufficiently good to label heart rhythm accurately, but had some segments during one minute that were of poorer quality. Motion during some parts of the measurements are seen more clearly by the researcher between other regular parts, leading to more medium quality labels.

4.3. Digital monitoring of AF

Since FibriCheck shows high accuracy, its use as a management tool for better follow-up of patients is the next step that needs to be evaluated. The management of AF starts with the decision between rate or rhythm control. Mostly, the first option is rate control but, if this does not lead to better patient outcomes, rhythm control is needed. Rhythm control can be done using various techniques, but DCC is the most used. Patients receive an electroshock that restores normal sinus rhythm. Afterwards, patients receive anticoagulation for four to six weeks. At this time, a follow-up is planned with the cardiologist. During this follow-up, an ECG is taken to control for recurrence of AF. This is the only follow-up that is planned, after which patients are not regularly checked for recurrence. Although DCC has a success rate of up to 95%, 40-60% of patients relapse within three months, and this only increases to 60-80% within one year (62). AF recurrence is not unusual especially during the first two weeks. Furthermore, recurrence of AF can be intermittent, and only episodes of AF occur. In this way, recurrence is not always detected during the follow-up appointment. Therefore, a better follow-up of patients is needed and FibriCheck can be a valuable asset. The close link between patients and physicians allows for a better follow-up where possible recurrence could be picked up earlier, without the need of extra hospital visits.

In total, 30 patients were included. The mean age was 66. Most patients did not have a smartphone, but all had access to Wi-Fi. This is consistent with what can be seen in society. Most people of that age have access to Wi-Fi. However, older people do not always have a smartphone. This is one of the difficulties faced. Many patients showed interest in learning how to use FibriCheck. However, the oldest patients, aged 80 or higher, were most of the time excluded as they did not have Wi-Fi, or would not have been able to use FibriCheck or a smartphone correctly.

15 patients performed daily measurements during their one-month follow-up period. Measurements were automatically send to the dashboard available for researchers. Daily review
allowed for a close follow-up. As can be seen from the average number of measurements per day (1.89), compliance was relatively high (88.8%). However, there were still 117 missing measurements. These missing values can be explained partly by patients who were on holiday during their follow-up. They were not willing to perform measurements during their vacation. This can be described by the fact that people want to spend their holiday relaxing and not worrying, making these measurements a greater burden. Another possible explanation is the fact that patients used smartphones they received from the hospital, and were worried losing them.

At the end of follow-up, patients were asked about their experience with FibriCheck. Most people indicated that it was not as great a burden as initially thought. When asked how patients felt in having someone seeing personal medical information online every day, they responded better than expected. It was expected that people felt their privacy was somewhat invaded by such close follow-up. However, most patients responded with a secure feeling. The fact that someone experienced is looking over them, made them feel safe.

FibriCheck is easy to use and this can be seen from the number of FP. By all patients, 243 measurements were urgent, of which only 24% was FP due to bad signal quality. This shows that, even in a remote setting, where no experienced researcher is available for adjustment, people are able to perform measurements properly. Furthermore, if patients had several following measurements of bad signal quality, they were contacted for re-education. The daily reviews allow for fast interventions if needed, leading to better measurements afterwards. This, together with the high compliance, shows that a follow-up using FibriCheck is feasible for patients, even with an average age of 66, which is the older part of the population that is not used to working with smartphones.

In 6 patients AF recurred. FibriCheck succeeded to detect all recurrences. Detection and recurrence took place in the first two weeks after treatment, with average recurrence 6 days after treatment. If irregularities were detected, the cardiologist was contacted for further actions. This resulted in most cases in an earlier follow-up consultation than initially planned. Averagely, patients that were remotely monitored visited the hospital on day 32, two days earlier than patients in the control group. Not only recurrent AF was detected, one patient had intermittent AF. This means that some episodes of AF occurred during follow-up. These do not happen all the time, and could have been lost if only one follow-up took place. Furthermore, frequent ectopic beats, that do not always lead to irregularities were also detected. This shows that FibriCheck is able to detect different types of relapse, that could have been lost when only one follow-up took place, and thus leaving patients unknowing and at high risk for stroke.

Two days earlier seems not much. However, it truly is clinically relevant. It is already shown that an AF burden of more than one hour per day has important negative prognostic implications and significantly increases the risk for stroke (63). A confirmation of recurrence two days earlier thus results in better patient outcomes. Although, anticoagulation therapy also reduces this burden.

Recurrence averagely took place in week one, while actual follow-up consultations occurred on day 32. This period of three weeks in between is very long and should be further reduced to reduce stroke risk. The long period in between can be addressed to the fact that this type of follow-up is not
yet incorporated in the standard care path. FibriCheck is not yet a certified medical tool. Therefore, if the cardiologist was contacted, the action performed most was wait and see. The cardiologists suggested to wait for other urgent measurements and more evidence of recurrence. Furthermore, cardiologists were not contacted for only one single event, since natural restoration of sinus rhythm can, and has, occurred. This contributes to a delay for recurrence confirmation by ECG at the hospital. The ultimate goal is to implement FibriCheck in the standard care path of patients with AF. If this is the case, it will be the cardiologist who prescribes the app to their patients. This allows for a bigger investment of the cardiologist in the follow-up, and thus reducing the time between detection and confirmation.

4.4. Digital screening for AF

In terms of stroke prevention, FibriCheck can be used in the care path for a better follow-up to detect AF recurrence earlier. Additionally, FibriCheck can also be used as a screening tool to detect AF in earlier stages, again decreasing the risk for stroke. Screening for AF has been done in various ways and has been shown to be beneficiary compared to routine care. However, these screening programs have not been carried out efficiently. Digitalization of screening with FibriCheck for AF could have many benefits. Since it only requires placing a finger for 60 seconds on the camera, it is fast, cheap, and very easy to use. Furthermore, a complete digital screening reduces the amount of personnel needed and the need for hospital visits, resulting to a decreased cost. A complete digital screening was set up and tested with personnel at the cardiology department at ZOL and people that showed prior interest to evaluate if complete digitalization was feasible.

The screening process started with an initial e-mail to inform and invite people to start screening. The overall response rate was 13.16%, which means that 13.16% of contacted people did register. This is slightly lower than expected. Averagely, sending surveys or invites via e-mail reaches a response rate of 24%. However, the average email view reported was 59.5%, which is more than the reported overall views of 31% for e-mail surveys. Although e-mail remains the best way to reach people, response rates remain low (64). There are many factors influencing whether people will register after reading the first e-mail. Response rate is dependent on demographics. Some people will have a higher tendency to enter the study than others. However, the population used here was personnel from the cardiology department. It was expected they would be most eager to participate because of their high background knowledge of AF. On the other hand, not everyone had a personal iPhone available. If the amount of iPhone owners from Belgium is extrapolated to the hospital, only 30% has an iPhone and thus were eligible to register. Additionally, the design of the e-mail is very important. Everyone receives e-mails on a daily basis. It is very important to stand out compared to others. Here, MailChimp was used to send e-mails. In this way, it was easy to design a simple but original e-mail to attract people’s attention. The e-mail and registering website were also designed to be able to open on smartphone devices. Since it was a study to evaluate FibriCheck as a screening tool, smartphone compatibility of e-mails and websites was necessary. Many people would be reading and registering on their smartphones, allowing for a smooth follow-up of steps to be taken on one device only. On the other hand, e-mail is not the only way of reaching out. There are many more digital ways to inform people. Social media are currently very popular and could possibly also be used. However, social media are much more public, which is not beneficial for
gathering medical information like heart rhythm disorders.

In total, 25 people registered. 20 people were provided with a QR code and invited to start screening, of which 17 actually screened. The average age of our population was 35. This is not a population expected to be at risk for AF. This can also be seen from the calculated CHA2DSVASC scores. All participants had the lowest risk score. This is even further illustrated by the fact that only one event took place. The event was one of intermediate risk, so there was no need for further actions. However, this is not important as it was not the detection of AF that needed to be tested in this study. The primary endpoint was the development of a digital protocol and evaluating its feasibility. Therefore, healthy participants that were willing to screen were our main target.

On average it took participants one day after registration to install FibriCheck and start screening. This delay can be partly explained because the process was not automated. After registration, the researcher needed to manually generate QR codes and send instruction mails.

Overall, a high compliance (72.3%) was observed. Although lower than for patients in the SMAERT-AF study, this was not expected since the population consisted of healthy participants. Compliance was expected to be lower because a healthy person is not as invested as patients with known heart disease. The high compliance can be partly addressed to the fact that registered people were those with the most interest in screening. On the other hand, the high compliance shows that FibriCheck is easy and fun to use, and that participants like the idea of knowing their heart condition. Additionally, when asked after screening, 75% of participants indicated that they would start telemonitoring completely voluntary. All participants indicated that two measurements per day was sufficient, but most scored a 3 or 4 on a scale of 5 when asked how difficult compliance was to them.

In total, 123 measurements were received, of which only 13% were FP. This, again, shows that FibriCheck is easy to use, even with only a digital manual and no explanation of an experienced person. This also illustrates that people are able to properly perform measurements and that FibriCheck as a digital screening tool can be feasible. The simplicity of FibriCheck is once more demonstrated when asked after screening, where 71% scored the app 5 points on a scale of 1 to 5. Furthermore, the feasibility of the digital work flow is shown, participants rated communication 5 points, and most participants had no difficulties during the study.

4.5. Limitations

FibriCheck shows great potential, both as a management and screening tool. The biggest difficulty it shows is the age of its target population. Since risk for AF increases remarkably with age, FibriCheck will need to be used by the older part of the population. In this part of the population, smartphone penetration is lowest. In the SMAERT-AF study, this was partly assessed, although the oldest patients were not included. The use of FibriCheck by older participants was completely not evaluated in the DISTANT-AF study. Solutions need to be found to overcome this, such as the help of children and grandchildren. Furthermore, FibriCheck currently only runs on iOS devices. However, once FibriCheck is registered as a medical tool, expansion to android is very easy. Nonetheless, FibriCheck shows great potential as a diagnostic tool for monitoring and management of patients that were treated for AF and for screening for AF.
5. Conclusion

Smartphones have penetrated society remarkably. Smartphones essentially are small computers. They have an enormous capacity and connect people all over the world. Apps exist in abundance and are used excessively. Smartphones and apps have changed the world and made it easier for all levels of society. Even in healthcare, smartphones are used to provide easier communication and an easier work environment for HCP’s. Apps are developed to face many problems, to create a better health care, and provide better patient outcomes. AF is one of those problems where digital technology can help.

FibriCheck, a smartphone application to detect heart rhythm irregularities can function as a digital solution for AF in different settings. FibriCheck can accurately identify irregularities and AF both in the controlled environment of the hospital, and in a remote setting at home. FibriCheck is easy and simple to use, even for patients of older age. Furthermore, it is cheap since no additional hardware is needed. Providing patients with a direct link to their physician allows for close follow-up and generates safety. Complete digitalization for screening is feasible and more efficient. Although, digital screening can be made more attractive.

All this supports the idea that FibriCheck as a diagnostic tool can be used for monitoring and management of patients treated for AF and for screening to early detect AF. This in a patient-centered way, leading to a drastic reduction in the risk for stroke. FibriCheck allows for a more efficient care, not only in terms of stroke, but also in terms of cost. FibriCheck has enormous capabilities and will be defining AF care in the near future.
6. References


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7. Appendix

7.1. Study website with information on AF, FibriCheck and the DISTANT-AF study

![DISTANT website](image)

Voorkamertachycardie is een harrtrimtoornis. Het hart klopt niet meer regelmatig en dit verhoogt de kans op beroertes en hartfalen. Vroege diagnose is belangrijk om de behandeling snel te starten. Dit is niet altijd mogelijk omdat symptomen niet altijd aanwezig zijn.

Fibricheck kan hier hulp bieden. Fibricheck is een smartphone applicatie waarmee het harrtrimme gemeten kan worden met behulp van de camera en het lopen. Op deze manier wordt de poles nemen snel en gemakkelijk. Dit harrtrimme wordt dan doorgezonden naar een online dashboard waar de dokter of cardioloog het ritme kan controleren op ritmestoornissen.

Registreer Nu!

Registreer nu om aan onze studie deel te nemen.

Je kan enkel registreren als je voldoet aan volgende criteria:
- 18 jaar of ouder
- Geen pacemaker
- Fysiek kapabel om meelopen te doen
- In het bezit van iPhone 5 of hoger

Het is niet belangrijk of je een genezen patient bent met voorkamertachycardie of niet.
Gemakkelijk

Een meting gebeurt door de vinger op de camera en het lampje te leggen gedurende 1 minuut.

Veilig

De metingen worden naar een online dashboard gestuurd waar de arts deze kan controleren. U staat dus in constant verbinding met uw arts.

Betrouwbare

Vergeet studies totdat u aanziet dat de app werkt met een betrouwbaarheid van 95%.

Leer meer over de DISTANT-studie

Over de studie

De distant studie heeft tot doel een nieuwe screening op poten te zetten die vroegtijdig detecteert. Hoe belangrijk voor de arts het is dat de screening legt het oog op het bloedsuiker en het effectieve van de studie. De studie wordt beoordeeld op basis van de resultaten die worden geleverd de onderzoeker. Als de screening effectief en voorspellend wordt, kan in snel tempo worden onderzocht of de studie behandeling begeeft.

Hoe werkt het?

Wanneer je de app installeert, kies je van ons een balje, waarmee je de app kan installeren. Na het installeren van de app, kun je aan de slag. Je moet twee maal per dag een keer de vinger met een keer de andere, of als je dat veel en dit gedurende 5 dagen. Elke meting wordt gecontroleerd door de onderzoeker. Wanneer er iets aan de hand is, dan is het gewoon verder tot het eind. Je wordt elk gecontroleerd door de onderzoeker die de resultaten beoordeelt en beoordelen door de onderzoeker. Je wordt dan ontheffd dat je beïnvloedt door bepaalde en in de normale behandeling vandaar.

Voor wie?

Je kan enkel registreren als je volgt aan de volgende criteria:
- 18 jaar of ouder
- Stemmen in een
- Een specifiek lid van de familie die
- In het bezit van iPhone 5 of hoger

Het is niet belangrijk of je een gewijzigd patiënt bent met voorgemelde klinische of niet.
### 7.2. Questionnaire on participant experience during five days of screening

<table>
<thead>
<tr>
<th>Question</th>
<th>Total (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you heard about telemonitoring before?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>5 (62.5)</td>
</tr>
<tr>
<td>Yes, via newspapers</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>Yes, via friends or family</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>No</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>When would you use telemonitoring? (Multiple responses possible)</td>
<td></td>
</tr>
<tr>
<td>Completely voluntarily</td>
<td>6 (75)</td>
</tr>
<tr>
<td>Only when necessary</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>When recommended by physicians</td>
<td>4 (50)</td>
</tr>
<tr>
<td>With a history of heart disease</td>
<td>2 (25)</td>
</tr>
<tr>
<td>When recommended by family or friends</td>
<td>2 (25)</td>
</tr>
<tr>
<td>Would you participate other screenings?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>4 (50)</td>
</tr>
<tr>
<td>Yes, completely voluntarily</td>
<td>2 (25)</td>
</tr>
<tr>
<td>Yes, when recommended by physician</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>No</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>How enjoyable was telemonitoring?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1 (12.5)</td>
</tr>
<tr>
<td></td>
<td>4 (50)</td>
</tr>
<tr>
<td></td>
<td>3 (37.5)</td>
</tr>
<tr>
<td>What influence had telemonitoring?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 (87.5)</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1 (12.5)</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>How content are you about FibriCheck?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
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<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4 (50)</td>
</tr>
<tr>
<td></td>
<td>4 (50)</td>
</tr>
<tr>
<td>How easy was FibriCheck?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
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<td></td>
<td>0</td>
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<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2 (25)</td>
</tr>
<tr>
<td></td>
<td>6 (75)</td>
</tr>
<tr>
<td>How easy were two measurements per day?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 (12.5)</td>
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<tr>
<td></td>
<td>1 (12.5)</td>
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<tr>
<td></td>
<td>2 (25)</td>
</tr>
<tr>
<td></td>
<td>3 (37.5)</td>
</tr>
<tr>
<td></td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>How did you feel about online medical information?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1 (12.5)</td>
</tr>
<tr>
<td></td>
<td>3 (25)</td>
</tr>
<tr>
<td></td>
<td>5 (62.5)</td>
</tr>
<tr>
<td>How content were you about the communication?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3 (37.5)</td>
</tr>
<tr>
<td></td>
<td>5 (63.5)</td>
</tr>
<tr>
<td>How did you feel about the amount of measurements? (enough)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 (87.5)</td>
</tr>
<tr>
<td>Did you experience any difficulties? (No)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 (87.5)</td>
</tr>
</tbody>
</table>
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Richting: *master in de biomedische wetenschappen-klinische moleculaire wetenschappen*
Jaar: *2016*

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*D’Onofrio, Valentino*

Datum: *8/06/2016*