Towards a Ubiquitous Healthcare System for Acute Myocardial Infarction Patients in Brazil

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Abstract

After an Acute Myocardial Infarction (AMI), the sooner the patient is approached, the greater are the chances that pharmacological therapy (using thrombolytics) be more effective than surgical intervention. Nevertheless, the thrombolytic therapy may have hazard effects on AMI patients that present any contraindication to it. As a consequence, paramedics usually hesitate about applying the thrombolytic therapy—preferring to immediately transfer patients to coronary care units (CCUs)—unless cardiologists support their decision. To cope with this scenario, we envision a ubiquitous telemedicine system for supporting cardiologists and paramedics in (i) the remote decision upon the eligibility of AMI patients to the thrombolytic therapy and (ii) the remote monitoring of patients being transferred. so-called In this paper, we present AToMS (AMI Teleconsultation & Monitoring), a system that makes extensive use of (possibly heterogeneous) wireless communication technology to allow its use by a paramedic at the location where the AMI patient is first assisted, thus reducing the delay between the onset of symptoms and the eventual application of proper treatment. All exchanged messages among paramedics and cardiologists are recorded, thus rendering a fully auditable system.

1 Introduction

Acute Myocardial Infarction (AMI) is among the leading causes of death and physical incapacity worldwide. Ischemia—a sudden reduction or interruption of the blood flow to a tissue because of an arterial constriction or obstruction—is one of the most common causes of AMI. Therefore, ischemia is a preferential target for the development of therapeutical procedures.

Currently, thrombolytic therapy is considered to be one of the most efficient therapeutical procedures to resume the blood flow in a previously obstructed artery [9, 12, 3]. This therapy consists of administering thrombolytic drugs that dissolve the arterial obstruction so that the blood flow to the patient's heart muscle can be restored, thus preventing further health damage. In the medical literature [13], the thrombolytic therapy is often compared with angioplasty—a highly-adopted procedure in ischemic AMI cases—that involves surgical intervention to unblock the obstructed artery. Crucially, the treatment with thrombolytics is far less costly than angioplasty; for instance, in Brazil less than 3% of AMI patients can afford an angioplasty intervention. Moreover, there is unequivocal benefit in terms of morbidity and mortality for prompt AMI treatment with thrombolytics in comparison with angioplasty. Nevertheless, to avoid some possible hazards of thrombolysis, caution should be taken to evaluate if an AMI patient is eligible for this treatment. Typically, a cardiologist may diagnose an AMI patient to be thrombolytic-eligible based on an electrocardiogram (ECG) and some information on the recent medical history of the patient.

The sooner an AMI patient has its blood flow restored after the onset of infarction symptoms, the better the chances of avoiding severe damage or death of its heart muscle. Recommended target delays to initiate a thrombolytic therapy go between 30 and 90 minutes of the patient calling for medical treatment [12, 3]. This scenario demands an efficient communication system that enables highly-coordinated actions among its participants.

Recent advances in wireless communication technology enable envisaging novel ubiquitous healthcare systems [14] that simplify the monitoring and treatment of patients, although much of the research effort in the area regards the use of such technology in the context of personal- and local-area networks only. Of special interest to this paper is the adoption of wireless technology in the field of telemedicine.

Wireless technology plays a key role in enabling communication capability everywhere. Despite facing some in-

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frastructure problems—as is usually the case in developing countries—Brazil is experiencing a fast deployment of several metropolitan-area networks based on wireless technology, which are basically aimed at digital inclusion.This opens up perspectives for systems based on wireless communication that can improve the quality and ubiquitousness of a large range of services in general, and healthcare/ telemedicine services in particular.

Based on the aforementioned considerations, we introduce in this paper a telemedicine system called AToMS (*AMI Teleconsultation & Monitoring System*). AToMS intends to enable the decision support and auditing when paramedics provide pre-hospital emergency services to AMI patients with the administration of thrombolytic therapy.

The design of AToMS takes into account the constraints of a developing country such as Brazil. By jointly adopting wireless appliances for ECG monitoring and PDAs with integrated communication capabilities (*e.g.* supporting GPRS, Bluetooth, WiFi, and WiMax), a paramedic may use AToMS to communicate with a cardiologist in order to decide if an AMI patient is thrombolytic-eligible or not. For instance, this communication may include the exchange of electronic health records (EHR) [5] and digitalized ECG results through a fully auditable system. Most telemedicine systems are limited to teleconsultation or to the application of wireless healthcare appliances within hospitals to ease patient management (see Section 4). In contrast, AToMS intends to bring an efficient treatment to AMI patients in a fully controlled and professionally-assisted way to the location where the first emergency assistance is delivered, thus saving precious time in providing appropriate treatment.

Note that, as being location-independent as long as some wireless technology is available for communication, AToMS may be used by paramedics in ambulance services or by non-specialized physicians in remote regions, for instance. Furthermore, the communication system may be used for continually monitoring the AMI patient while it is transferred to a coronary (cardiac) care unit (CCU), enabling a specialized team to be appropriately prepared to promptly take care of the patient at its arrival.

The remainder of this paper is organized as follows. Section 2 presents current telemedicine solutions to address the issue of thrombolytic administration in Brazil. In Section 3, we introduce AToMS characteristics and components. Section 4 discusses the related work in the use of wireless devices in healthcare and telemedicine. Finally, in Section 5, we summarize the ideas behind the proposition of AToMS and derive perspectives on its further applicability in other contexts.

2 Tackling AMI in Brazil

Many developing countries, such as Brazil, have large socioeconomic contrasts characterized by a deep social inequality and an unequal distribution of the produced wealth. The welfare may be highly non-uniform depending on the socioeconomic classes and distances to more urbanized areas. Therefore, despite the presence of technological advancements, the benefits of such advancements may be significantly restricted because of either socioeconomic or geographic constraints. Concerning healthcare, telemedicine diffusion may significantly help shrinking these gaps in developing countries [11]. Moreover, the advent of wireless networking plays a key role in enabling telemedicine initiatives with longer reach and easier deployment.

In Brazil, there are some recent telemedicine initiatives that propose ‘thoracic pain protocols’ combining the use of both thrombolysis and angioplasty in AMI cases. The main goal of such protocols is to reduce the reaction time in AMI cases by increasing the adoption of thrombolytic therapy among emergency teams in pre-hospital care facilities, where most AMI patients are initially treated. At the regional level, health authorities in Rio de Janeiro have recently established a project called TIET [4] (standing for “Thrombolytic treatment of AMI on emergency with teleconsultation.”). Essentially, the TIET project aims at:

- displacing the thrombolytic treatment from CCUs in large hospitals to pre-hospital care facilities, which receive patients rescued by emergency teams;
- training the emergency rescue teams to early diagnose an AMI and to initiate as soon as possible the thrombolytic treatment;
- providing a teleconsultation infrastructure that offers means for cardiologists to assist emergency teams in deciding upon the eligibility of a given AMI patient for thrombolytic treatment.

In March 2005, a resolution from the public health authorities in the State of Rio de Janeiro establishes the deployment of the TIET project in all its public health emergency units. One of the requirements defined in this project is that these emergency units should have electrocardiographs and fax machines connected to conventional phonelines. The main goal of this requirement is to provide a sort of rudimentary teleconsultation infrastructure by allowing a paramedic to confirm with a cardiologist the AMI diagnosis and the eligibility of the patient for a thrombolytics administration when ECGs are not enough clear or the paramedic is not enough experienced. Furthermore, if the AMI case so demands, this infrastructure allows a CCU to early prepare for the imminent arrival of the AMI patient using an ambulance service.

The TIET project, as initially conceived, presents two main limitations on its efficiency and performance from the technological standpoint:

- the TIET teleconsultation system is hard to audit. The full control of the teleconsultation session is with the cardiologist being consulted. In spite of the aforementioned advantages of thrombolytic therapy, there are still several cardiologists who are in favor of an angioplasty without a previous thrombolytic administration. Furthermore, paramedics avoid taking the responsibility of applying thrombolytics as a consequence of the general contraindications associated to them, although recent researches demonstrate advantages of their use even in some contraindicated cases [10]. As there is no centralized record in the original TIET teleconsultation system, direct auditing actions become particularly difficult to be successfully implemented, thus limiting the enforcement of thrombolytics administration in the indicated cases;

- the TIET teleconsultation system relies on a fixed communication infrastructure, forcing the AMI patient to be displaced to an emergency unit before being properly treated with thrombolytics. Depending on how difficult is the access to the closest emergency unit, the thrombolytic administration may be made unfeasible to this patient due to the accumulated delay after the onset of symptoms.

The increasing availability of wireless technology has motivated the proposition of alternative solutions to the TIET system. At a first glance, the availability of such recent and advanced wireless technologies in developing countries such as Brazil may seem somewhat unlikely. Nevertheless, wireless technology is rapidly expanding in developing countries, particularly in those with large territories like Brazil, mainly motivated by digital inclusion initiatives.In these cases, wireless technology is outpacing wired alternatives as a means of telecommunication access because there are lots of locations without any previous high-quality communication infrastructure, be it wired or wireless. The decreasing costs and relatively easy deployment of wireless networks turn them into very attractive alternatives as compared to wired solutions for a first deployment or major upgrade in the telecommunication infrastructure. As a consequence, the increasing availability of wireless technology in developing countries may enable a diverse set of wireless telemedicine applications. The discussion about a ubiquitous telemedicine system to support the pre-hospital AMI treatment with thrombolytics gave rise to AToMS, a telemedicine system that builds upon TIET shortcomings.

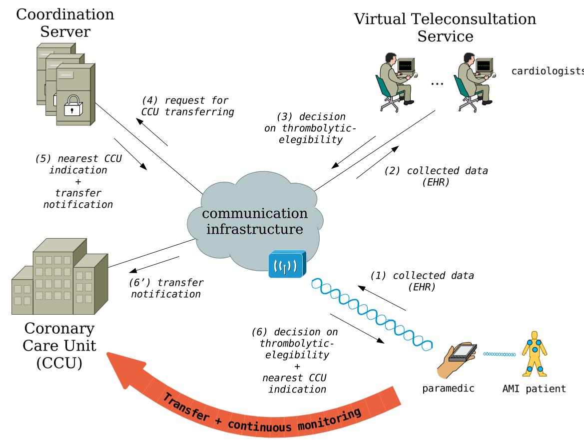

Figure 1. Typical scenario in AToMS.

3 AToMS Overview

We envision the design and implementation of a highly-automated *AMI Teleconsultation & Monitoring System* (AToMS) that relies on mobile communications to assist emergency teams and cardiologists to:

- exchange information about an AMI patient and decide on its eligibility for receiving thrombolytics in a timely fashion, and

- track the patient's evolution while it is being displaced to the nearest available CCU.

The AToMS system aims at covering not only conventional emergency units, but virtually *any* place where the AMI patient can be first approached by an (possibly mobile) emergency team or ambulance service. To achieve this goal, the system considers many different networking technologies to enhance its possible ubiquitousness.

Human intervention in the AToMS system is usually restricted to requests for consultation from paramedics and replies to such a consultation from cardiologists. A request for consultation is made through an *electronic health record* (EHR) of the AMI patient [5], which comprises data such as digitalized ECG and the patient's recent medical history. Such a history can be either retrieved from a coordination server (see below), or promptly filled in by the paramedic, or both. The system conveys the patient's EHR to a cardiologist, which can then take proper decisions on whether the patient is thrombolytic-eligible or not.

Figure 1 presents the AToMS's main actors and components, which are explained along this section. In the typical scenario illustrated in this figure, paramedics handle mobile devices (*e.g.* PDAs, mobile phones, or laptops) that communicate with wireless ECGs through a wireless personal-area

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network (WPAN), *e.g.* a Bluetooth network. Data gathered from the wireless ECG is collected by the paramedic's mobile device to be sent as part of the EHR to an available cardiologist through a wireless wide-area network (WWAN), *e.g.* GPRS (step 1 in Figure 1). The AToMS system directs the collected data from the AMI patient to a *virtual teleconsultation server* (step 2), which is responsible for putting the paramedics promptly in contact with an available cardiologist in case of an AMI incident. Such a virtual server thus allows the system to have its cardiologists scattered around (*e.g.* in their own offices or in different hospitals) instead of physically available in a typical call center.

Our proposed system enables a decision support tool that allows a cardiologist to decide on the applicability of thrombolytic therapy in an AMI patient by a paramedic *at the local* where the emergency team reached this patient (step 3). This may significantly reduce the delay between the onset of symptoms and the effective application of the thrombolytics. It should be remembered that there is usually a reasonable delay between the onset of symptoms and the request for professional aid. Hence, mitigating the delay between the arrival of the emergency team at the location of the AMI patient and the thrombolysis administration may be decisive for a successful intervention. Similarly, if we consider remote regions without easy and fast access to a CCU, the remote support by a cardiologist on the applicability of the thrombolytic therapy on a given AMI patient may be crucial to comply this eventual application of thrombolytics within the recommended target delays between the call for aid and effective intervention. Further, decisions taken by a cardiologist on the thrombolytic eligibility can trigger a request for transferring the AMI patient to a CCU (step 4).

The coordination server then indicates the nearest CCU that is able to properly proceed with the treatment and also generates a transfer notification to this CCU. The emergency team then receives orientation on the thrombolytic eligibility of the AMI patient and on the nearest CCU able to receive this patient (step 6). Meanwhile, the nearest CCU receives the transfer notification about the imminent arrival of an AMI patient (step 6'). Furthermore, while the AMI patient is being displaced to the nearest available CCU, the patient can be continuously monitored. Based on the monitoring information and the patient's EHR, a cardiologist at the CCU keeping track of the AMI patient can be promptly notified about any alteration on the patient's state and prepare in advance the CCU team for the imminent arrival of this particular patient.

Note that the AToMS system is fully auditable. The *coordination server* records all data flows in the system (EHRs, replies to consultations, and so on), building up a database that can be later used for statistical data analysis and independent supervision of decisions taken by both paramedics and cardiologists, for instance.

4 Related Work

In recent years, advancements in mobile computing have opened new perspectives in the area of telemedicine [7]. In a hospital environment, patient monitoring is eased by the development of new wireless devices to monitor physiological signals [6]. The management of health records, the sharing of medical information, and the displacement of patients are also favored by the increasing adoption of wireless devices. The adoption of wireless devices in telemedicine in order to extend the reach of a given medical treatment and to efficiently monitor a patient beyond the restricted environments in hospitals is receiving an increasing attention in recent years. In the particular area of cardiology, there are investigations on the applicability of mobile computing to situations such as remote continuous monitoring of arrhythmias in moderate-risk patients and early classification of AMI patients during their transportation to a hospital with CCU [8].

The above-mentioned related work applies wireless technology on the medical area to mainly address two issues: (i) to ease the monitoring and healthcare of patients within the hospital environment; and (ii) to provide a continuous monitoring of patients that have been previously identified as being subject to some health risk. In contrast, our project focuses on the adoption of mobile computing to allow interventions in reaction to AMI cases in an efficient and economically advantageous way, at the local where the AMI patient receives its first treatment by an emergency team. In the context of this project, a key feature is the possibility of a paramedic to interact through a fully auditable system with a cardiologist, allowing the latter to evaluate and support the application of a given intervention.

5 Summary and Outlook

In this paper, we have introduced AToMS (*AMI Teleconsultation & Monitoring System*), a first step towards a ubiquitous healthcare system for dealing with pre-hospital emergency care of AMI patients. AToMS proposes the adoption of recently-released wireless appliances for healthcare, in particular wireless ECG devices combined with a general-purpose PDA for long-distance wireless communication. The key feature of the proposed system is to allow a paramedic at the location where the AMI patient is first approached to remotely consult a cardiologist. This feature reduces the delay between the onset of symptoms and the moment a thrombolytic-eligible AMI patient receives proper thrombolytic therapy. This is important because the sooner the thrombolytic is administrated, the better are its benefits in terms of reducing mortality and morbidity rates. Moreover, the continuous monitoring, transmission, and recording of an ECG prior to admission into a CCU can greatly speed up in-hospital management, thus leading to benefits for both the AMI patient and the healthcare staff at the CCU awaiting for the patient's arrival. Therefore, we expect that AToMS has a significant socioeconomic impact. Furthermore, AToMS intends to be fully auditable, thus allowing the composition or consultation of an electronic health record (EHR) for each patient, statistical data analyses, and independent supervision of decisions taken by both paramedics and cardiologists.

The increasing availability of wireless technology (even in developing countries) is the key enabler for more ambitious and ubiquitous telemedicine systems for pre-hospital healthcare such as AToMS. We believe many typical settings we envisage for AToMS are to be found in other developing countries with similar characteristics in comparison with Brazil. For example, in such countries, it is unlikely to expect doctor-manned ambulances to provide first emergency care to an AMI patient, thus enabling a teleconsultation system for an ambulance paramedic is a feasible, low-cost alternative solution. Therefore, AToMS can be seen as a core proposition that is flexible enough to allow its replication and eventual adaptation to different scenarios in distinct developing countries. Further, some features such as the support of wireless healthcare appliances may be incorporated in other general-purpose ubiquitous healthcare systems. AToMS can be thus thought of as a first step towards a ubiquitous healthcare system that uses telemedicine to provide pre-hospital assistance for AMI patients. To improve the system's availability and ubiquitousness, we envisage that AToMS should deal with highly heterogeneous networks—thereof addressing issues such as wireless technology redundancy, smart hand-offs (both vertical and horizontal), and so on.

Wireless technology keeps advancing in different directions and we expect them to have significant impact on the development of truly ubiquitous healthcare systems. Within this context, we point out recent research advancements in wireless sensor networks (WSNs) [1] and wireless mesh networks (WMNs) [2]. WSNs investigate the development of low-cost sensor networks that impact data gathering in ubiquitous healthcare systems. WMNs diversify the capabilities of previous ad hoc networking with the goal to provide an "always-on, anywhere, anytime" infrastructure, which clearly may improve ubiquitousness of telemedicine systems in the future.

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