Global Challenges and Solutions

Role of Telemedicine in ST-Elevation Myocardial Infarction Interventions

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KEYWORDS

• Telemedicine • Primary PCI • Thrombolysis • Pharmaco-invasive • Door-to-balloon time • LATIN

KEY POINTS

- Primary percutaneous coronary intervention (PCI) is the most effective technique to treat acute myocardial infarction.
- Access to primary PCI is restricted in developing countries.
- Telemedicine greatly facilitates access of primary PCI to vast populations.

INTRODUCTION

Primary percutaneous coronary intervention (PCI) has revolutionized the management of acute myocardial infarction (AMI). Although thrombolysis is still the mainstay of treatment in various parts of the world, primary PCI is vastly superior. Scientific guidelines[1,2] maintain a class I indication for treating AMI with primary PCI if performed in a timely manner by an experienced provider.[3] To mandate the urgency in performing primary PCI, parameters of door-to-balloon (D2B) times have been added.[4] Short D2B times (<90 minutes) are desirable, although this recommendation is not universal.

In developing countries, lack of infrastructure, insurance, facilities, and skilled providers greatly hamper the use of primary PCI. For example, in the entire continent of South America, less than 8% of the population has access to cardiac catheterization laboratories. In parts of Africa and some Asian countries, the situation is similarly abysmal. In these developing parts of the world, thrombolysis, often with Streptokinase, is still the predominant modality. Other developing countries predominantly use a pharmaco-invasive approach. This strategy clearly has numerous advantages: a patient with AMI receives urgent thrombolysis and is then transported for possible PCI. In sharp contrast, in various developed countries, there is a comprehensive utilization of primary PCI for an entire population.[5–8] These advanced countries use regional systems of care to optimize timeliness of reperfusion therapy.[9–11] Prehospital management is the norm and considerable reduction in morbidity and mortality has been achieved.[12–16]

The disparities of care between developed and developing countries for the management of AMI represent one of the largest global challenges in ST-elevation myocardial infarction (STEMI) interventions.

Conflicts of Interest: None.

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Telemedicine appears an effective modality for significantly increasing access for millions of patients to appropriate STEMI care.[17,18] Remotely located experts guide accurate interpretation of the electrocardiogram (ECG) and enable teleconsultation of the patient with STEMI.[19–21] A comprehensive utilization of thrombolysis, pharmaco-invasive management, and primary PCI is possible with the use of telemedicine.[17,18] Reduction of D2B times and improvement in STEMI outcomes have been demonstrated.[20,22–24] Telemedicine may also be cost-effective, in particular, when it facilitates prehospital triage.[25–27]

In this article, we discuss the various advantages of using telemedicine and our experience of using this technology to improve populated-based STEMI care in developing countries.

We tested the hypothesis that telemedicine has 4 distinct advantages in STEMI interventions.[17,18] These included (1) increased accuracy, (2) increased access, (3) guidance of comprehensive STEMI management, and (4) increased cost-effectiveness.

AMI is unique in that its diagnosis can be instantaneously made on accurate interpretation of the presenting ECG. This accuracy can be augmented by a quick clinical evaluation. In the rapid STEMI evaluation, confirmation with cardiac biomarkers is often not required. Still, there are discrepancies in the accurate interpretation of the ECG. Fig. 1 is a graphic illustration of this disparity. The accuracy of ECG in diagnosing STEMI dramatically increases between small clinics to tertiary cardiac centers. These remarkable characteristics of ECG interpretation make the use of telemedicine an exceptional modality for treating STEMI interventions. The remote cardiologist significantly augments the accuracy of ECG interpretation and STEMI diagnosis. This particular observation makes telemedicine a pragmatic and cost-effective strategy. In our experience with the Latin America Telemedicine Infarct Network (LATIN), the accuracy of ECG interpretation increased from less than 50% in small referral clinics to greater than 95% when interpreted by a remotely located, expert cardiologist. The increased accuracy is complemented by an ability to teleconsult the STEMI process as depicted in Fig. 2. With this methodology, the expert cardiologist navigates the patient with STEMI to a more scientific and pragmatic management.

There are numerous known methods to conduct the ECG analysis. These include transtelephonic, fax, and wireless transmission. Table 1 compares these modalities with telemedicine and it illustrates the relative merits of telemedicine. Numerous telemedicine protocols[17,18,21] have been used to obtain remote consultation. We have used an integrated software platform to reliably transmit ECGs and safeguard patient privacy (Fig. 3). Often, an argument is advanced that simple and inexpensive mobile phone transmission (with applications such as WhatsApp) are comparable to using a

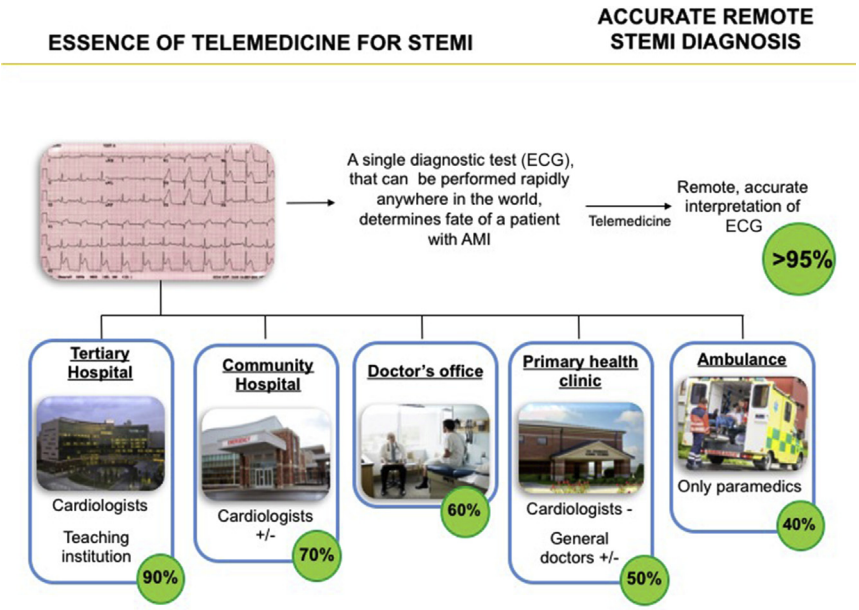

Fig. 1. Essence of telemedicine for STEMI interventions.

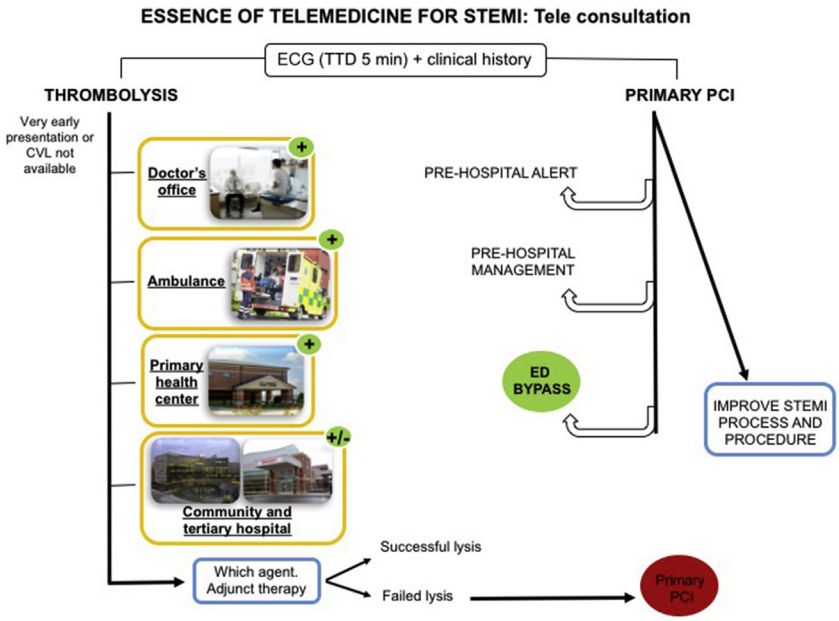

Fig. 2. Telemedicine – teleconsultation. CVL, cardiovascular laboratory.

dedicated telemedicine platform, but Table 2 demonstrates some limitations of using a mobile phone for accurate ECG interpretation.

The largest disparity in STEMI care between developed and developing countries pertains to access. Because there are tremendous structural, financial, and personnel shortages, millions of patients do not have access to contemporary STEMI treatment. Telemedicine is the novel technology that dramatically increases the access of patients to AMI care. Fig. 4 describes a telemedicine strategy that we have used in several poorer countries in South America to increase STEMI access.

METHODS

In demonstrating the effectiveness of telemedicine in STEMI interventions, we describe the creation of 2 novel, population-based STEMI programs, that used telemedicine as a foundation pillar. These 2 programs include LATIN and Rajasthan Heart Attack Treatment (RAHAT). Both programs use a hub and spoke strategy. The hub performs primary PCI and the spoke triages the patient into 1 of the 3 STEMI management pathways: thrombolysis, pharmaco-invasive strategy, and primary PCI (see Fig. 4). The main difference between the structure used for LATIN and RAHAT was the number of hubs and spokes and the respective distance between these facilities. The distance between hub and spoke determines the extent of the geographic reach of a population-based program. It takes into consideration the geographic distance, the population density, the availability of catheterization laboratories, and the traffic patterns. The other major distinction between these diverse programs included different transmission methodologies. In LATIN, we used a sophisticated and dedicated, integrated software platform, whereas in RAHAT, the more common and less expensive mobile telephone applications were used (Figs. 5 and 6).

Table 1
Comparison of 4 modes of electrocardiogram transmission

Attributes	Phone	Fax	Wireless	TM
Accuracy	+++	+++	+++	++++
Access	++++	+++	+	++++
Cost-effective	+++	++	+	+++
Timeliness	++	+++	+++	++

Abbreviation: TM, telemedicine.

Latin America Telemedicine Infarct Network

This revolutionary program has populated vast areas of Brazil and Colombia with 104 LATIN telemedicine sites. The foundation of LATIN was to provide AMI management for poor patients in less developed countries. LATIN selected Brazil and Colombia for demonstrating the utility of telemedicine to improve AMI outcomes. In Brazil, the program includes 7 cities that have networked large rural areas, up

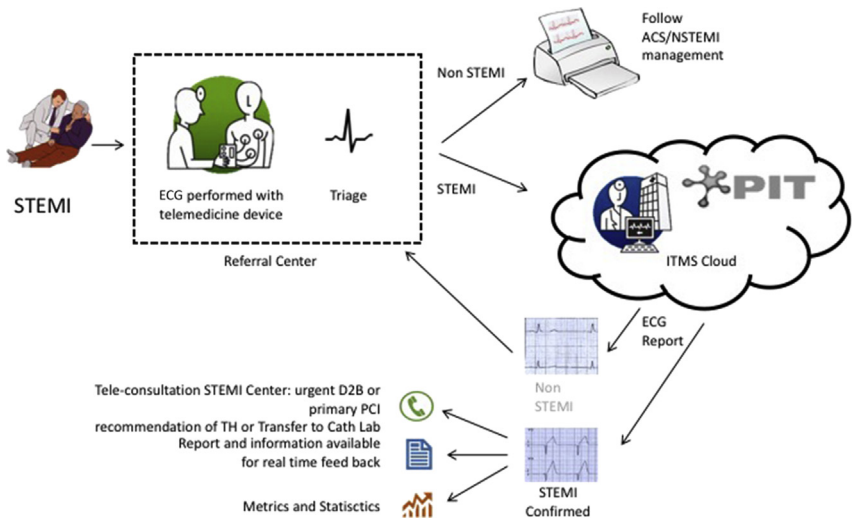

Fig. 3. Proposed LATIN structure and management. ACS, acute coronary syndrome; NSTEMI, non-ST-elevation myocardial infarction; PIT, plataforma integrada de telemedicina; TH, thrombolysis.

to 250 miles away, with LATIN spokes. In Colombia, almost 42% of the country's 48 million people are now covered by LATIN networks. In designing this program, we confronted enormous variability in ECG interpretation and in AMI care. The LATIN spokes consist primarily of small clinics, primary health centers, and community hospitals that did not have resources to treat patients with AMI. This was done in an effort to advance AMI care to patients and facilities that lacked these assets. Several of these spokes were in a very remote, hilly regions and jungles of the 2 countries. Most of these spokes had rudimentary skills in accurately diagnosing STEMI. A strategic decision was made to transmit ECG on all patients presenting with chest pain and to back up the strategy by creating efficient and inexpensive telemedicine platforms. Figs. 7 and 8 demonstrate the enormous reach of the LATIN program with its deep penetration into remote and poor regions of Brazil and Colombia. Selection of the hubs and spokes was paramount. The selection of the hubs is relatively easy because there are only a few that are available. The hubs were mandated to provide 24/7 STEMI coverage and have reliable ambulance transportation. The spokes were chosen mainly to increase coverage and access by poor patients. A single standardized STEMI management protocol was used for all LATIN hubs and spokes. Figs. 9 and 10 depict this protocol and Fig. 11 is a further illustration based on the availability of ambulances.

Spoke efficiencies were increased by mandating excellent triage of the patient presenting with chest pain. The ECG was promptly transmitted and interpreted by an expert cardiologist located at 4 sites: Bogota, Colombia; Uberlandia and Sao Paulo, Brazil; and Santiago, Chile. Primary PCI was encouraged at all hubs and spokes, and to facilitate this, ambulance arrangements were immediately made after confirmation of ECG. We simplified a 3 T's strategy for LATIN spokes: Triage, Transmit, and

Table 2
Limitations of using mobile phone for accurate electrocardiogram interpretation

Attributes	TM	Mobile Phone
Vectorization	✓	—
ECG specific measurements	✓	—
HIPAA compliance	✓	—
Security	✓	—
Time	✓	—
Receipt of confirmation	✓	—
Codification of diagnosis	✓	—
EMR	✓	—
Accredited reviewer	✓	—
Optional teleconsultation	✓	—
Audit availability	✓	—
ICD-10 compatibility	✓	—

Abbreviations: ECG, electrocardiogram; EMR, electronic medical record; HIPPA, Health Insurance Portability and Accountability Act; ICD-10, International Classification of Diseases, 10th Revision.

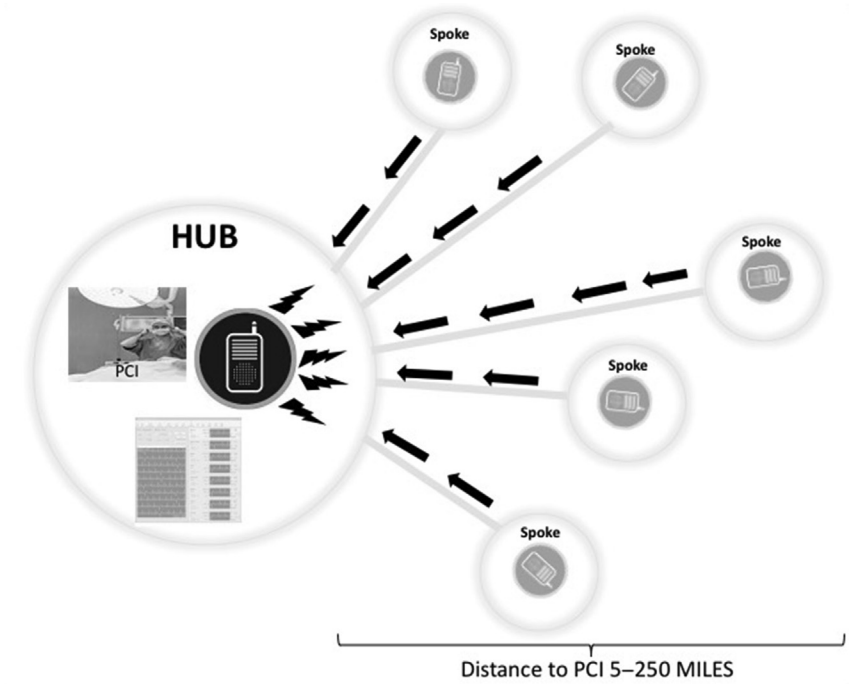

Fig. 4. Hub and spoke methodology for LATIN.

Transport. Prehospital management was routinely advocated and prehospital alert with a single phone activation was performed. In several centers, this led to emergency department (ED) bypass and reduced D2B times. The spokes provided early pharmacologic management, medical stabilization, and patient education. Training of personnel with technology was emphasized and efficient triage was supervised. Ambulance availability was the single

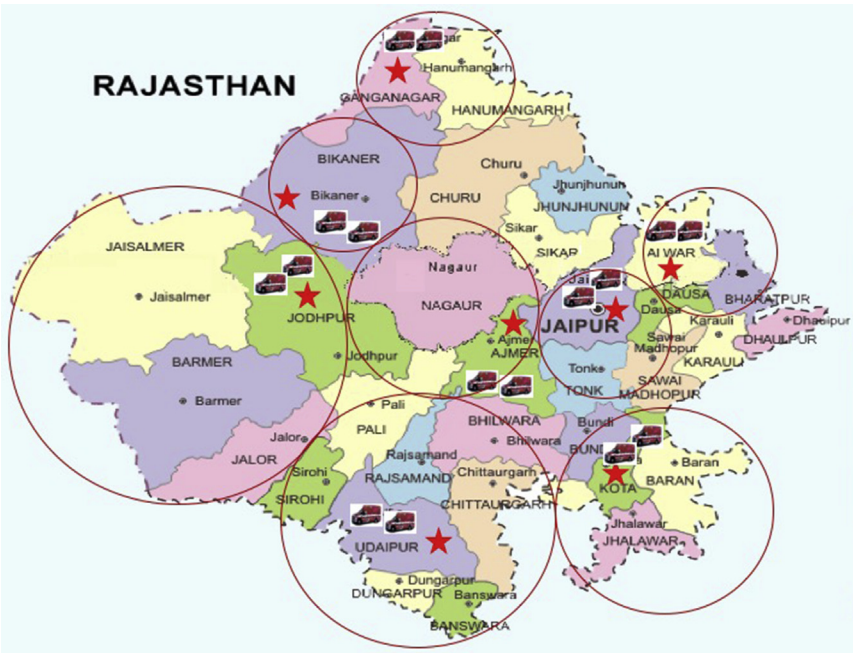

Fig. 5. Hub and spoke strategy for RAHAT.

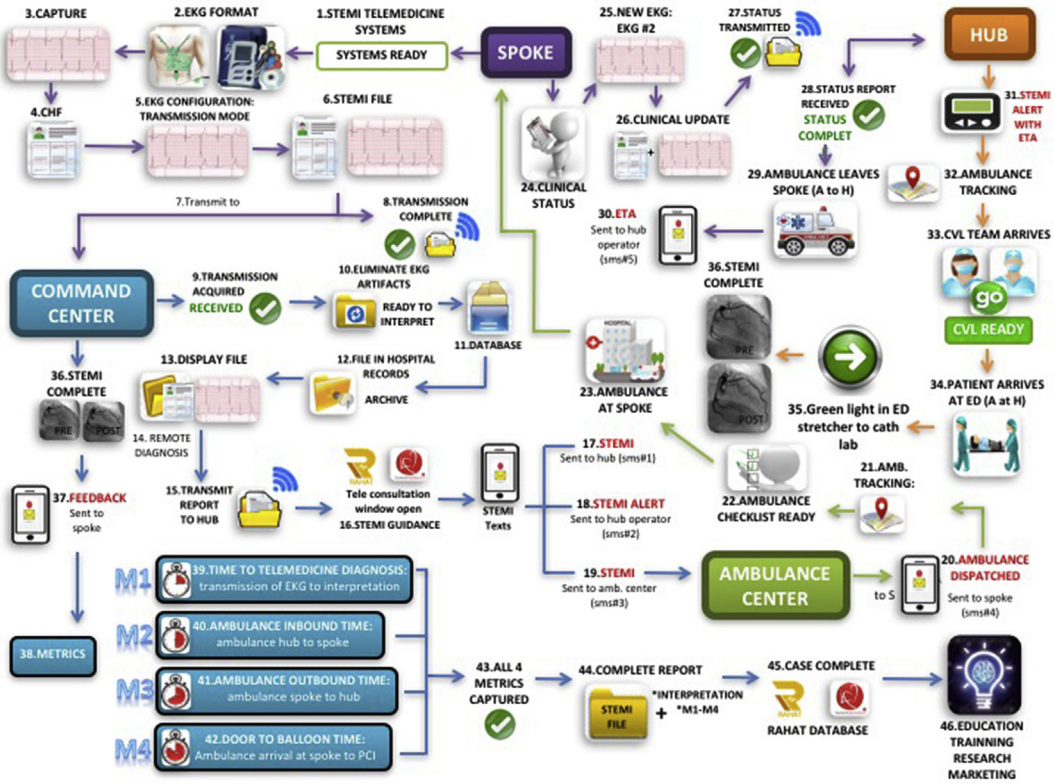

Fig. 6. Innovative telemedicine pathway for RAHAT.

biggest challenge and numerous local, community, and regional stakeholders were encouraged to provide this life-saving service for the community. Standardization and questions & answers were mandated and a comprehensive LATIN database was created.

Brazil and Colombia differ notably in the creation of LATIN structure. The spokes were

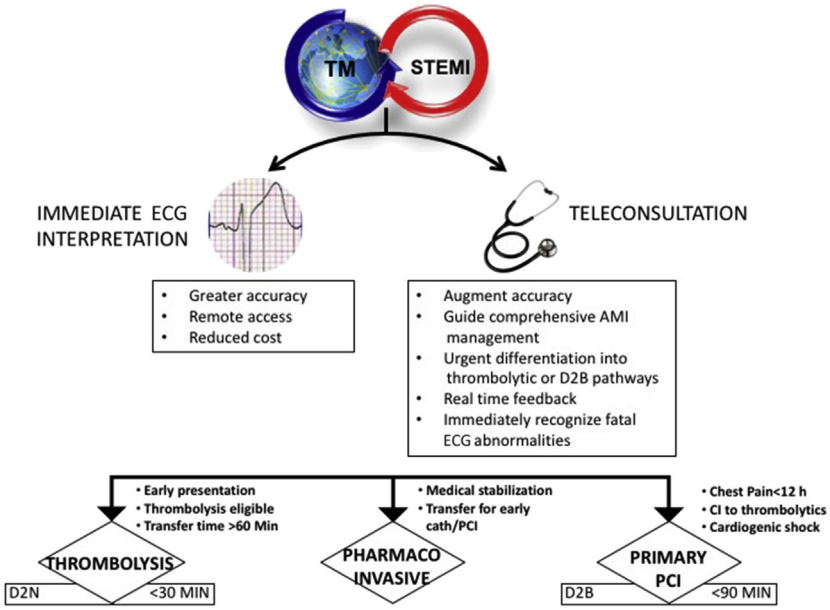

Fig. 7. Comprehensive STEMI guidance with telemedicine.

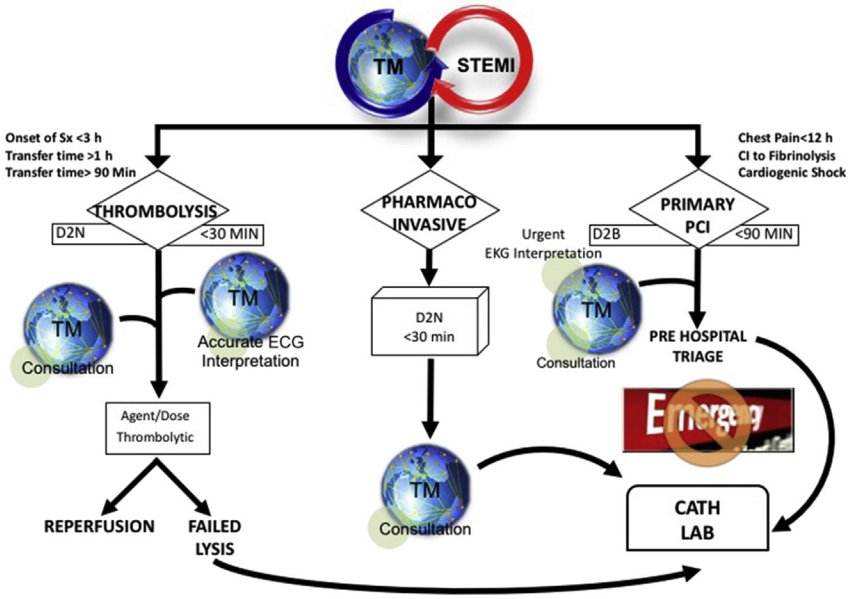

Fig. 8. LATIN protocol. Sx, syndrome.

located farther apart in Brazil but there was geographically more difficult terrain in Colombia. Both countries had infrastructure deficiencies and both had financial constraints. Brazil possessed sophisticated telemedicine knowledge, as the technology has been prevalent for decades.[22,28] Insurance approval for STEMI interventions was challenging in both countries. Lack of intensive care unit beds was another hurdle, although this deficit improved as the program advanced. It was obvious to LATIN sites that with our rapid STEMI intervention, the need for intensive beds decreases. Public awareness was advanced in both countries.

Rajasthan Heart Attack Treatment

This telemedicine-centered, population-based STEMI program covers approximately 65 million patients of India's most populous state. It covers the size of Finland and the population of France.

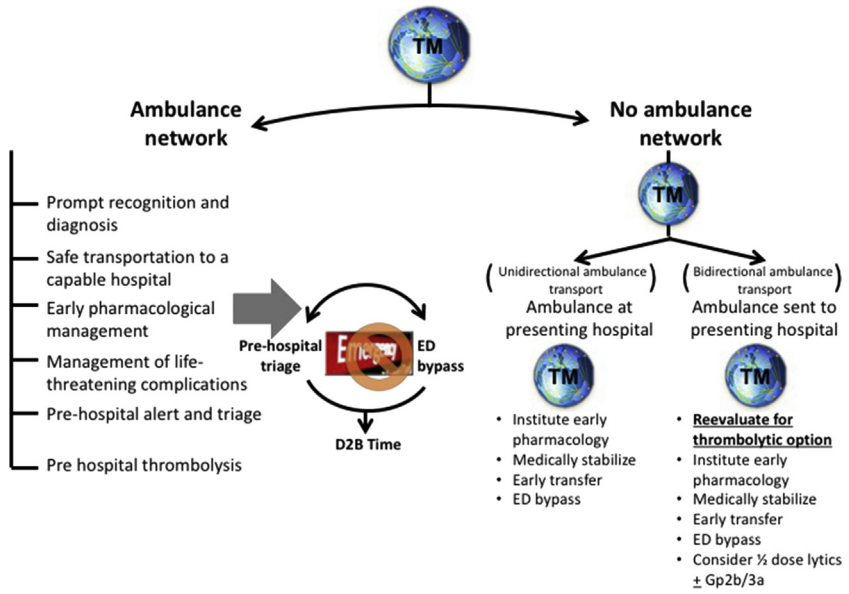

Fig. 9. Telemedicine ambulance management.

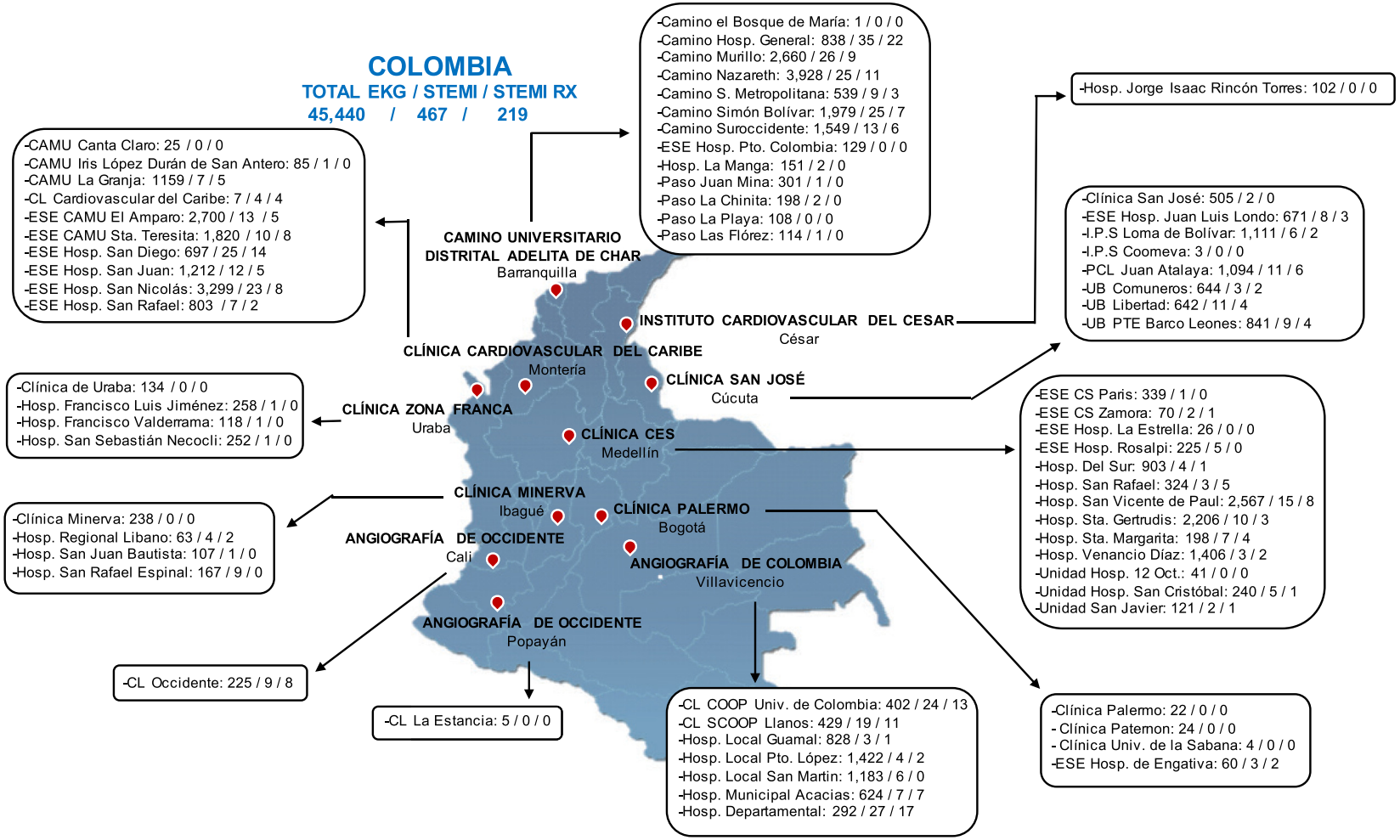

Fig. 10. LATIN: Colombia telemedicine structure.

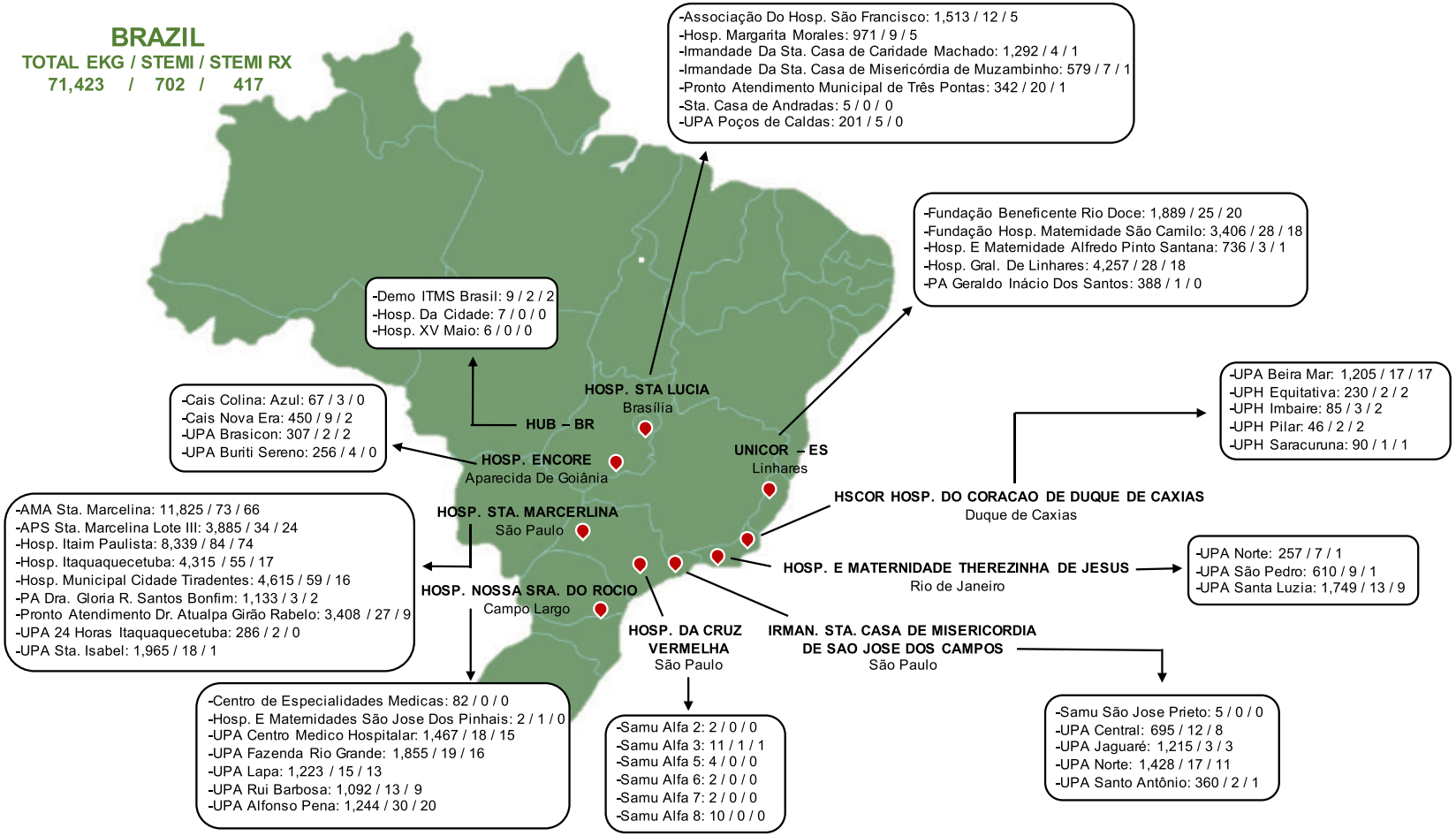

Fig. 11. LATIN: Brazil telemedicine structure.

This program was begun almost 3 years after initiation of LATIN and benefited from the lessons learned at LATIN. Creation of the hubs and spokes was less challenging, and ECG transmission was simpler and used more common social-networking platforms. Advanced communication pathways incorporated greater technological innovations, including GPS navigation of ambulances and real-time tracking of patients. Data collection was more robust and teleconsultation performed by more experienced cardiologists.

Beyond our experience with these large, population-based STEMI programs, numerous researchers have created telemedicine-centered STEMI programs. We know of robust programs in India, Indonesia, China, and Russia. It is intriguing to know that physicians have used telemedicine for AMI applications without always attributing the success to telemedicine.

RESULTS

LATIN has recently completed its pilot phase during which 104 LATIN sites (21 hubs and 83 spokes) were created in 2 large countries. All LATIN sites used similar technology platforms and the same standardized protocol despite enormous regional differences. The following is a summary of the results with the pilot phase of this program.

The LATIN protocol instituted a 4-part strategy: (1) all patients presenting to the spoke with chest pain had an urgent 12-lead ECG that was wirelessly transmitted using telemedicine platforms; (2) urgent, cost-effective, and accurate diagnosis was performed remotely, constantly seeking to reduce time to telemedicine diagnosis (TTD) times; (3) based on the duration of chest pain and clinical presentation, the remote cardiologist directed urgent teletriage into thrombolysis, pharmaco-invasive, or primary PCI pathways; (4) telemedicine facilitated accurate ECG diagnosis and teleconsultation for the entire door-to-treatment process. Using dedicated LATIN network methodology, 104 telemedicine centers were created, 62,000 ECGs were remotely interpreted, 642 STEMIs were diagnosed (1.04%), and 297 patients with STEMI were urgently reperfused (46%), mainly by primary PCI. Overall, mortality was 8%. TTD of 5.58 minutes was achieved. ECG accuracy was 98%, and a mean cost of diagnosing and managing the STEMI process via telemedicine was USD $287.

For the Colombia subset, individual results were also tabulated. A total of 77 LATIN telemedicine centers (11 hubs, 66 spokes) were created that use standardized, guidelines-based protocols for treating AMI. LATIN expanded its network via its spokes that were located between 5 to 250 miles from the hubs and whose function was to urgently triage, stabilize, and transfer patients to the hub. LATIN spokes included primary health centers and small clinics that lacked facilities to diagnose and treat patients with AMI. Installed technology at each LATIN site included an ECG device with multiport transmission capabilities and patented telemedicine-integrated platforms. Each ECG was vectorized into a standard format for real-time interpretation by remote cardiologists who guided the patient along the entire management pathway. In its pilot phase, LATIN incorporated a strategy to transmit ECG for all patients who presented with chest pain. Ambulance availability and training of paramedics was the most difficult challenge and this task was reliably accomplished for all LATIN sites. Primary PCI coverage 24/7 was available at all hubs, a robust database existed, and ED bypass was successfully accomplished with prehospital alert. TTD of 5.7 minutes was achieved for interpreting 47,000 transmitted ECGs with 99% accuracy. The diagnosis of STEMI was made by remote ECG interpretation in 467 patients, and 219 patients were successfully treated (215 PCI/pharmaco-invasive, 4 thrombolysis). Mortality data are being collected.

Barranquilla, the large Colombia costal town, had a regional LATIN-based initiative: Barranquilla Operational Telemedicine Enterprise for Revascularization of Occluded Arteries (BOTERO). It collected data for 11 spokes strategically located in areas of dense population that were meticulously selected and intelligently networked with a hub that had expert capability to perform 24/7 primary PCI. Telemedicine platforms were installed at all BOTERO sites using broadband technology. Continuous quality improvements were implemented to reduce TTD. Broad education initiatives were created in cooperation with Antioquia University and local educational societies. Single call activation was initiated and feedback mechanisms between the hub and spokes were developed. ED bypass at the hub was routinely achieved. Since January 2014, BOTERO treated a total of 100 patients with STEMI, including 64% men with a mean age of 63 years; 59% had hypertension; 20% had diabetes mellitus; Killip class was I in 35%, II in 31%, III 22%, and IV 7%; 19% were smokers and 3% had previous PCI. Major improvement was observed in the process and mortality

parameters between 2014 and 2015. Time to first medical contact (FMC) was reduced from 247 to 207 minutes ($P<.4$) and symptom to balloon times (S2B) from 384 to 167 minutes ($P<.0001$). TTD was 5.9 minutes for the entire cohort and 98% accuracy of diagnosis was achieved. Thirty-day mortality was reduced from 11.1% to 3.2%.

Extremely encouraging results were also noted in Hospital Santa Marcelina in Sao Paulo, Brazil, which caters to the poorest population of Brazil and it demonstrated a 50% reduction in mortality after completion of the pilot phase of LATIN.

DISCUSSION

The gains of primary PCI must be provided to patients in developing countries. The disparities in STEMI care are overwhelming and inversely correlated with GDP, particularly in poorer countries of Africa, Asia, and South America. These suffocating limitations will require considerable time to resolve. Capital infusion, human resources development, and structural improvements will be necessary before primary PCI can be made available to the millions vulnerable to AMI. During this phase, thrombolytic therapy will remain the dominant modality. However, often the administration of this therapy is constrained by the same financial infrastructure limitations that prevent primary PCI. The narrow therapeutic window for thrombolysis is another challenge. A lack of patient awareness remains a major deterrent for both thrombolysis and primary PCI. With uneducated patients and a shortage of trained experts and facilities, it is unrealistic to expect patients in poorer countries to provide thrombolytic therapy in the very short 3-hour treatment opportunity. Poor countries, therefore, face a double dilemma: primary PCI is simply lacking and thrombolytic therapy is often delayed. Therefore, as noted previously, many patients with STEMI do not receive reperfusion therapy at all.

In the presence of these pervasive challenges, telemedicine provides a desirable modality. It increases access for millions of patients to STEMI management, as demonstrated in LATIN.[17,18] The advantages of telemedicine also have been observed by numerous other telemedicine networks[19,20,23–25,28] that report the feasibility of treating large populations with telemedicine. A report by Matsuda and colleagues[28] shows that the LATIN protocol can be applied for developing countries to improve access to PCI. A single hub with multiple spokes between 7.6 miles of distance (±1.5 miles) in the east side of Sao Paulo reported that in 34 patients with STEMI, 91.1% received primary PCI and 2.8% received pharmaco-invasive treatment, with a mean spoke-to-hub time of 188 minutes and a mean D2B time of 40 minutes (±18.7 minutes). Applications of telemedicine were also demonstrated in Quebec, Canada. Between 2006 and 2012, in Chaudière-Appalaches, Tanguay and colleagues,[23] implemented a telemedicine platform to improve patient care in the prehospital setting. The 208 patients in the study were divided into 3 groups: patients on the way toward a PCI center when STEMI was diagnosed, patients initially directed to the nearest hospital and subsequently rerouted to a PCI center after STEMI diagnosis, and patients directed to a local hospital without transfer for PCI. Measure of different time intervals was done, showing a reduced time from positive ECG to hospital arrival among patients of the first group (18 minutes), compared with those of the second group (29 minutes), $P<.001$. Another prehospital ECG network in Apula, Italy, created by Brunetti and his group of investigators,[25] reported the data from the 594,140 ECGs interpreted over 9 years. Fifteen percent of patients with chest pain were abnormal, 6178 had ST elevation, and 40,106 patients had other ECG abnormalities, allowing direct access to catheterization laboratory or hospitalization for these patients.

A further demonstration of access of patients to AMI care was revealed in work done by Rasmussen and his researchers,[24] which reported 81% of the study population was able to be treated in less than 120 minutes, even to longest distance of greater than 95 km; 89% of the patients were treated before that time frame.

Another study to assess the importance of prehospital diagnosis of STEMI was conducted by Sørensen and colleagues[20] in Denmark. This group took into consideration whether the patient was from a rural or urban community. In 759 patients, the proportion of patients able to achieve less than 120 minutes D2B time was 86% with prehospital diagnosis, compared with 32% in patients without it ($P<.001$). In a median of 4.3 years' follow-up, all-cause mortality was 18% in patients with prehospital diagnosis compared with 31% in patients without it ($P = .003$).

The use of telemedicine for prehospital ECG diagnosis may reduce treatment time regardless of whether thrombolysis or primary PCI is required. Rapid ECG availability can shorten D2B time from 20 to 81 minutes.[29] Sanchez-Ross and colleagues[26] compared 92 patients

with prehospital ST elevation using a wireless network versus 50 who used alternative methods and reported shorter D2B time (63 minutes in the wireless network vs 119 minutes in control, $P<.00004$), lower peak troponin (39.5 ng/mL vs 87.6 ng/mL, $P = .005$), higher left ventricular ejection fractions (50% vs 35%, $P = .004$) and shorter length of hospitalization (3.0 days vs 5.5 days, $P<.001$).

Dallan and colleagues[21] conducted a study between 2013 and 2014 comparing the number of patients treated before and after the implementation of the LATIN protocol, using telemedicine to transmit the ECG directly from remote hospital to referral centers with cardiologists available 24/7 so as to make the correct diagnosis, and allowing patients with STEMI to go straight to the catheterization laboratory, bypassing the ED. The authors reported the D2B time using the LATIN protocol was 32 minutes compared with 85 minutes using the previous protocol ($P<.05$). Furthermore, the volume of patients increased from 25 patients in 9 months to 25 patients in only 3 months with the application of LATIN protocol.

Cost-effectiveness has also been extensively researched. Yoculan and colleagues[22] determined that in a possible scenario in which the rate of performed PCI increases from 19% to 60%, the savings could be $13 million, related to the decrease in indirect cost of mortality, disabilities, and pharmacologic treatment. In Italy, Brunetti and colleagues[27] demonstrated the savings per ECG was from €8.10 to €38.41, and 69 lives per year were saved with a cost per quality-adjusted life year gained of €1927.

In our assessment, telemedicine is a promising modality that can increase access, augment accuracy, and provide a comprehensive management strategy while being cost-effective. Several of these programs are pilot studies and have incorporated first-generation telemedicine technology. These innovations will clearly improve and the economies of scale will lower the cost of telemedicine applications. Simplification of the protocols will also occur. Our LATIN protocol, although innovative in acquiring ECGs at small, remotely located clinics, is not cost-effective for routine ECGs. The newer protocols mandate presence of ECG and at least 2 risk factors before transmitting ECGs. Ambulance availability and trained paramedics remain the Achilles heel in resource-constrained, poorer countries. Improving ambulance availability and structure is critical, and barriers such as insurance denials will fall as the benefits of primary PCI become evident.

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