Innovations in telemedicine for cardiovascular care

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\section*{ABSTRACT}
Cardiovascular disease is one of the main fields of application for telemedicine, with benefits in almost all areas in the continuum of cardiovascular disease. The greatest impact has been shown in the early diagnosis of cardiovascular disease, in second consultation, between non-cardiologist and cardiologist and between cardiologists, and in follow-up and secondary prevention of cardiovascular disease.

At present, the main area of implementation for telemedicine in cardiovascular disease is represented by pre-hospital triage, with telemedicine electrocardiogram in acute myocardial infarction. Significant results have also been achieved in the second opinion consultation of pediatric subjects with congenital cardiovascular disease, home-monitoring and the management of patients affected by chronic heart failure or with an implanted device.

However, there is significant room for further improvement in delivering telemedicine assistance even in ‘very-remote’ populations, such as detainees, patients in developing countries or in underdeveloped areas of developed countries.

\section*{Telemedicine for cardiovascular disease}

The World Health Organization defines telemedicine as ‘the delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities’ [1].

Cardiovascular disease is one of its main fields of application. All the areas in the continuum of cardiovascular disease seem to benefit from the support of telemedicine [2]. At present, a PubMed research using keywords ‘telemedicine’ and ‘heart’ may retrieve more than 1300 articles [3]. One of the oldest pioneering studies showing possible future development of joint telemedicine and cardiology dates back to 1953 [4]; in the study, Rahm et al. showed the feasibility of electrocardiogram (ECG) transmission by telephone line. Since then, the technological evolution has been going on with great strides; the real breakthrough, however, followed the telematic revolution and the spread of computers. The possibility to store, process, analyze, manage, and transmit a virtually unlimited amount of data has led to the actual implementation of methods and technologies previously confined to contexts exclusively experimental. At present, large networks aimed at the earliest treatment of acute myocardial infarction (AMI) are currently active worldwide with excellent results in terms of rates of patients reperfused within the benchmark times and lower mortality rates. In what follows, we summarize the main innovations in the field of telemedicine for the treatment of cardiovascular disease.

\section*{Early diagnosis of cardiovascular disease}

\subsection*{Remote ECG interpretation}
Telemedicine support may accelerate the diagnostic workup and allow the early diagnosis of cardiovascular disease in a broad range of conditions. In preclinical phase of arrhythmic disease, telemedicine screening may detect cases of asymptomatic atrial fibrillation (AF) [5]. In a pilot study, the trans-telephonic daily transmission of ECG facilitated the diagnosis of asymptomatic paroxysmal AF [6]. In larger cohorts of patients, a telecardiology service improved the home management of subjects with AF and detected several new AF cases [7]. Telecardiology support increased the rate of at-home diagnosis of AF from twofold (in 40 year olds) up to fourfold (60 year olds) and sevenfold (70 year olds) [8]. AF with symptoms other than palpitations is a common finding in elderly patients; telemedicine support, therefore, improves the sensitivity of diagnosis.
of AF in such patients and may be useful in at-home identification of subjects with AF and atypical presentation [8,9].

Telemedicine could be even more effective in the management of suspected AMI. General practitioners supported by remote cardiologist assistance may successfully diagnose AMI with a diagnostic accuracy of 87% [10]; on the other hand, unnecessary hospitalizations may be avoided after telemedicine consultation in more than half of cases of suspected acute cardiac event [11].

The most impressive results of the application of telemedicine in the field of cardiology are, however, those achieved in the diagnosis AMI by prehospital ECG. Given the poor performance of automated algorithms and paramedics in interpreting the ECG, even in the case of AMI [12–14], a remote confirmation by a physician is almost mandatory [15].

Prehospital ECG and consequent direct transfer for primary coronary angioplasty bypassing any emergency department delay has been shown as a very effective strategy in reducing times of reperfusion, increasing rates of timely reperfused patients and lowering cardiovascular mortality caused by AMI. Prehospital triage, possibly by telemedicine support, is, therefore, warmly recommended by international guidelines [2,16–18].

A very large body of evidence clearly supports the efficacy of telemedicine prehospital ECG for the earliest diagnosis of ST-elevation AMI (STEMI). ECG can be effectively transmitted from a moving ambulance alerting the cath-lab for primary angioplasty with a very good signal quality (98–99% concordance rates) [19–21]. Prehospital telemedicine screening is particularly useful in the case of AMI with symptoms other than chest pain or atypical clinical presentation [22].

Patients with STEMI and diagnosed prehospital had shorter treatment delay compared with those diagnosed in hospital [23]. Transmission of prehospital 12-lead ECG directly to the attending cardiologist’s mobile telephone decreased door-to-percutaneous coronary intervention (PCI) time by >1 h when patients were transported directly to PCI centers, bypassing local hospitals [24]. Prehospital electrocardiographic diagnosis and direct referral for primary PCI enables STEMI patients living far from a PCI center and in rural areas to achieve a system delay comparable with patients living in close vicinity of a PCI center [25–27].

The early assessment of STEMI patients with telemedicine technologies shortens door to balloon times, reduces infarct size, limits ejection fraction reduction, shortens length of stay [28], and significantly impacts cardiovascular mortality, mostly in high-risk patients [29]. Reduction in cardiovascular mortality in STEMI patients triaged with prehospital ECG exceeds 50% [30]. Recent meta-analysis data show a 35% reduction of in-hospital mortality from STEMI [31] and 42% of 30-day mortality rates thanks to prehospital triage [32]. Therefore, direct ambulance transport to a PCI hospital should become the transfer type for STEMI patients and dedicated networks should be appositely organized in order to implement in daily practice the evidence from trials and meta-analyses. Accordingly, the combined use of prehospital ECG, telemedicine support and networks for the treatment of AMI has been already implemented in several places worldwide [33–37]; there is still a long path to pave, however.

- Telemedicine support may improve and shorten the diagnosis of silent AF.
- Telemedicine support may shorten the diagnosis and times to reperfusion in AMI.

**Second opinion**

**Remote imaging transmission and interpretation**

Telemedicine is extraordinarily effective for remote consultations, either between a cardiologist and a noncardiologist in the case of suspected cardiovascular disease, or between cardiologists and ‘other’ cardiologists (interventional cardiologist, electrophysiologist) in the case of rare or atypical overt cardiovascular disease.

A remote cardiologist may usefully support general practitioners [38]. The TELEMACO study provided home-based telemanagement services for patients with chronic cardiovascular disease, as well as second-opinion teleconsultations in cardiology for general practitioners, and the evidence that home management of patients using telemedicine may be an efficacious approach that can ensure care continuity, especially in chronic diseases [39]. Telemedicine applied to hypertensive patients at high risk of cardiovascular problems offers to general practitioners an easy-to-use tool to control blood pressure by improving connection with specialist [40].

In the field of ultrasound cardiovascular imaging, the strategy using cardiologist consultation in addition to the robot-assisted remote echocardiography at a distance was tested in a prospective, randomized open-label trial in Sweden; the time required for a complete examination was significantly reduced in the telemedicine arm [41].

Remote consultation has also been largely used for clinical management and diagnosis of pediatric cardiovascular disease [42]. In a study on nine pediatric cardiology centers with and without access to teleconsultation, telemedicine shortened the time to diagnosis and significantly
decreased the need for transport of infants with mild or no heart disease [43]. The length of hospitalization and intensive care stay and use of inotropic support were less in telemedicine patients. In 132 patients suspected of having congenital heart disease (CHD) over an 8-year period, echocardiograms were transmitted by integrated services digital network (ISDN) at 384 kbit/s; major CHD was diagnosed in 36% of infants and minor CHD in 42%. The telemedicine diagnosis was accurate in 97% of the cases (κ = 0.90); transfer to the regional unit was avoided in 72% of patients and the accuracy of diagnosis was considerably improved (the κ coefficient increased from 0.14 to 0.90). In another group of 63 patients with suspected CHD, echocardiographic images were transmitted; transmitted images were unsatisfactory in just two cases; CHD was diagnosed in 42 patients, 14 patients with major CHD were accurately diagnosed within 24 h of admission using the telemedicine link and were transferred to the regional pediatric cardiology unit [44]. A further 28 with less serious CHD continued to be managed at the district general hospital. CHD was excluded in 19. Follow-up consultation confirmed accurate diagnosis or exclusion of CHD in 57 (93%). There were four inaccurate diagnoses (6.3%; three undetected small ventricular septal defects and one pulmonary stenosis). Transmitted images were of sufficient quality to allow confirmation or exclusion of major CHD. In other 60 patients with suspected CHD or hemodynamic instability, echocardiography studies were transmitted for consultation: normal results were found just in 19 subjects and videotape review confirmed all telemedicine interpretations [45]. The echocardiogram led to immediate change in management in 25 cases (42%), and echocardiogram quality was improved in 53 studies (88%). Monetary savings from five avoided transports exceeded all expenses.

Real-time transmission of neonatal echocardiograms from community hospitals over ISDN lines was accurate and had the potential to improve patient care, enhance echocardiogram quality, aid sonographer education, and have a positive impact on referral patterns and time management, without increasing the utilization of echocardiography [46]. Telemedical echocardiography provides an accurate diagnostic data in neonates. Rapid telediagnosis facilitates appropriate care of sick neonates with possible CHD in the primary care setting. Unnecessary long-distance transfers can be avoided with this technology [47].

Digital echocardiography offers several advantages, including easy review, comparison, storage, postprocessing, and sharing of studies, quantitative analysis, and superior resolution [48]. Clinical compression has been validated in several studies. JPEG is the DICOM 3.0 standard and is ideal for short loops, serial comparisons, and quantitative analysis, while MPEG enables digitization of video streams. MPEG digitization during live neonatal telemedicine is accurate and provides an efficient method for storage [49]. Telemedicine may provide an option for data storage and transfer from limited local review to multiple offline review stations linked by a wide-area network, also for teaching purposes.

Second opinion could also rely on smartphone technology both for cardiovascular (echocardiography) imaging [50] and electrocardiography [51]. Remote expert echocardiographic interpretation can provide backup support to point-of-care diagnosis by nonexperts when read on a dedicated smartphone-based application [50]. Mobile-to-mobile consultation may improve access in previously inaccessible locations to accurate echocardiographic interpretation by experienced cardiologists.

Sending the ECG images via a multimedia message service may be a practical and inexpensive telecardiology procedure [52]. Smartphones, mobile applications (‘apps’), and the cloud are profoundly changing the practice of medicine and the way health decisions are made. On smartphone platforms, health or medical ‘apps’ may acquire and analyze a variety of vital signs through embedded sensors, interconnected devices or peripherals [53]. Smartphones may allow highly accurate interpretations on angiographic lesions and thus may serve as a supplementary teleconsultation tool in both elective and emergency situations [54]. Interpretations of the consultant cardiologist on the localization and severity of 100 lesions on both the smartphone screen and workstation monitor showed high levels of agreement with the results of the core laboratory (for all, κ > 0.80) and an excellent agreement between the consultant cardiologist and the operator regarding lesion localization.

Another challenge for future development of telemedicine is represented by the storage of rapidly increasing medical data. For example, a critical patient can generate 1 GB data or more per day and a 15 min echo study would occupy >25 GB [55]. To solve the storage problems, an outsourcing strategy of storing medical images is needed, possibly throughout a storage-as-a-service cloud computing, a strategy that not only resolves the storage problems but also facilitates big data analysis [56]. Cloud computing is a relatively new model of delivering computing resources, which consists of processing, memory, storage, and network; resources are accessible via the Internet [57]. The high availability, accessibility, and scalability are the key characteristics of cloud computing technology, which allows computing-intensive data analysis even for educational purposes. A cloud-based telecardiology platform can also promote better research and education opportunities, providing raw images,
electrocardiograms, and medical reports where experienced cardiologists denote the abnormalities of images and files and store the data, and researchers and clinicians can retrieve these files for further analysis or educational purposes [56].

- Telemedicine may allow remote second-opinion consultation.
- Cardiovascular imaging could particularly benefit from telemedicine support when second opinion is needed.
- Telemedicine may enable remote mentoring and learning.
- Smartphone and cloud technology may allow the widest implementation of telemedicine.

Follow-up and secondary prevention
Remote ECG and cardiovascular parameters monitoring
Home blood pressure telemonitoring may represent a useful tool to improve hypertension control and associated outcomes. In a recent meta-analysis on 23 randomized controlled trials and 7037 patients, compared to usual care, home blood pressure telemonitoring improved office blood pressure levels; a larger proportion of patients achieved office blood pressure normalization and home blood pressure telemonitoring led to a significantly larger prescription of antihypertensive medications [58].

Telerehabilitation
Support of telemedicine may accompany patient and cardiologist throughout rehabilitation either after an acute cardiac event, such as an AMI, or in the case of chronic conditions, such as chronic heart failure (HF). Telemedicine-based rehabilitation after cardiac surgery is feasible and safe [59]. In a nonrandomized study that compared home-based rehabilitative programs with telemedicine plus appropriate technology versus in-hospital cardiac rehabilitation after cardiac surgery, the home-based approach was found to be effective and comparable to the standard in-hospital rehabilitative approach; rehabilitation following cardiac surgery can be implemented effectively at home when coadministered with an integrated telemedicine service [60]. Telecardiology follow-up reduced hospital readmissions after AMI [61] and improved survival rates at 1 year [62]. A telemedicine approach may facilitate the delivery of cardiac rehabilitation for risk factor modification and exercise monitoring to patients who otherwise would not have access to it [63]. In a recently published review examining the effects of telerehabilitation compared with other delivery models for improving physical or functional outcomes in patients with cardiopulmonary diseases in 11 studies, telerehabilitation was no different to other delivery models for patients with cardiopulmonary diseases, in terms of exercise capacity expressed as distance on the 6-minute walk test and peak oxygen consumption and quality of life [64]. Telerehabilitation appears to have higher adherence rates compared with center-based exercise; there has been similar or no adverse events reported in telerehabilitation compared with center-based exercise. In a multicenter randomized controlled trial that comprised 140 cardiac rehabilitation patients, randomized to a 24-week telerehabilitation program in addition to conventional cardiac rehabilitation or to conventional cardiac rehabilitation alone,[65], the total average cost per patient was significantly lower in the intervention group (€2156 ± €126) than in the control group (€2720 ± €276) with an overall incremental cost of €564.40, and cost-effectiveness ratio of €21,707/quality adjusted life years (QALY). The number of days lost due to cardiovascular rehospitalizations in the intervention group was significantly lower than in the control group.

Even more evidence is available in the field of chronic HF. In a long-term follow-up, a 6-month home-based telemanagement program was associated with lower hospital readmission and a better quality of life of subjects with chronic HF [66]. Telerehabilitation and home-based telesurveillance may very positively impact functional class, left ventricular ejection fraction (LVEF), 6-minute walking distance, and Minnesota Living with Heart Failure Questionnaire [67].

In retrospective studies, telemedicine support was associated not only to lower hospital stays but also to reduced mortality [68]. Remote patient monitoring, carefully adherent to a strict management protocol, was found to yield similar results when compared to live nursing visits [69]. A tight cooperation between general practitioners and a telemonitoring HF clinic may lower mortality and number of days lost to hospitalization [70]. Tele-health care may positively modulate family caregiver burden after discharged from the hospital [71]. Even automated home telephone self-monitoring may reduce hospitalization in patients with severe HF [72]. In multicenter randomized trials, home-based nurse telemetry by telephone and interactive teleconsultation reduced by one-third the total and HF-related number of hospital readmissions.
Telemedicine is feasible for cardiovascular rehabi-
lishments 

Randomized studies and meta-analyses show that

Remote telemedicine monitoring of ICD is effec-

Telemedicine support may facilitate follow-up of cardio-

Remote monitoring of implantable devices
Progress in medical technologies also enabled remote monitoring of implantable devices able to report data on cardiac rhythm, device function, and worsening HF [77,78]. Implantable cardioverter defibrillators (ICDs) and cardiac resynchronization therapy (CRT) devices permit such remote telemedicine control of patients at risk and implanted with such devices [79]. Pacemaker (PM) and ICD patients are ideally suited to remote management in the form of remote follow-up as well as of remote monitoring. Large randomized trials, such as TRUST, COMPAS, CONNECT, ECOST, and EVOLVO, and the huge ALTITUDE registry provided a high level of evidence for the multiple advantages of remote management [80]. These trials demonstrated the capability of early detection of events, the ability to reduce the incidence of inappropriate shocks and also of all charged shocks and this despite fewer in-clinic visits for the patients. The studies also demonstrated the safety of remote management of ICD and PM patients and, moreover, its positive impact on the survival of patients.

Thereby, remote monitoring is probably clinically even more effective and efficient than conventional follow-up. Remote monitoring reduces emergency department/urgent in-office visits and, in general, total health-care use in patients with ICDs or defibrillators for resynchronization therapy [81]. Long-term home monitoring of ICD is safe and is able to reduce the number of appropriate and inappropriate shocks delivered [82]. Home monitoring is feasible and associated with an early detection of medical and technical events [83]. CRT-D patients followed with in-office visits had a twofold higher risk of delayed detection of clinical adverse events when compared to daily remote monitored subjects [84].

- Telemedicine support may facilitate follow-up of cardiovascular patients.
- Telemedicine is feasible for cardiovascular rehabili-
- Randomized studies and meta-analyses show that telemedicine management of HF patients may improve clinical outcome.
- Remote telemedicine monitoring of ICD is effective and efficient in reducing the risk of inappropriate shocks delivered.

Unmet needs and clinical failures
Despite enormous progress in the field of telecardiology, there are several unmet needs and several failures in the past. Key challenges are related to financial issues, acceptance, health infrastructure, and legal and privacy issues [85]. For telehealth to succeed, privacy and security risks must be identified and addressed [86]. Sensors that are located in a patient’s home or that interface with the patient’s body to detect safety issues or medical emergencies may inadvertently transmit sensitive information about household activities; similarly, routine data transmissions from an app or medical device may be shared with third-party advertisers.

Several factors, including state reimbursement and licensure policies, influence adoption of telehealth among hospitals, even in developed countries [87]. Other barriers include complex systems and lack of data standards that permit exchange of clinical data, privacy concerns, and legal barriers between different countries [88].

The lack of broadband infrastructure has proven challenging for the advancement of many forms of telemedicine, specifically high demand video and store-and-forward services, which require expansive health networks [89].

While successfully providing patients and providers with improved access to health-care resources, the telemedicine projects have faced numerous technical and social challenges in developing countries [90]. These include malfunctioning mobile devices, unreliable information, technology infrastructure, accidental damage to mobile devices, and cultural misalignment between information technology and health-care providers. To ensure sustainability, telemedicine programs must have strategic goals that are aligned with those of the national health and education system, and the initiatives must be owned and led by local stakeholders. Whenever possible, open-source technology and local information technology expertise and infrastructure should be employed.

Despite telemedicine having the potential to improve the quality of health care in developing countries, in spite of a range of programs being run, including point of care in rural and urban areas, treatment compliance, data collection and disease surveillance, and distant medical education, financial sustainability is also a concern for most programs. Government facilities are often not very effective in running telemedicine on their own, but collaborations between the government and non-profit (in particular) and for-profit organizations have led to impactful programs [91]. According to some authors, it is unlikely that telemedicine will have a widespread
and sustainable impact without government involvement, especially in rural areas; nevertheless, programs run solely by the government are unlikely to be the most effective.

As with many other health improvement projects, a key challenge is moving telemedicine approaches from pilot projects to national scalable programs while properly engaging health workers and communities in the process [92]. By harnessing the increasing presence of mobile phones among diverse populations, there is promising evidence to suggest that telemedicine can be used to deliver increased and enhanced health-care services to individuals and communities.

Connectivity issues between systems and interchangeability of data often compromise the full development of the whole potential of telemedicine. Interoperability is categorized as three levels, including data interoperability, system interoperability, and device interoperability [56]. Data interoperability refers to the ability of data sharing between hospitals; DICOM medical images with unified and open standard data format facilitate the first level of interoperability, while cloud computing can realize device interoperability.

Different legal systems, diversity of certification, and homologation too many times reduce the effectiveness of strategies based on telemedicine. Many initiatives, albeit deserving and clinically effective, last the short period of funding.

Nevertheless, despite the tremendous progress in the field of telemedicine for the treatment of cardiovascular disease, there is a significant room for further formidable improvement. Telemedicine is still far from being a commonly accessible modality of health care. Data from 4727 US hospitals in the 2013 Healthcare Information and Management Systems Society Analytics database yielded these findings: two-thirds of rural hospitals defined as nonmetropolitan had no telehealth services or were only in the process of implementing a telehealth application, and data do not change when considering hospitals in urban areas; among hospitals with ‘live and operational’ telehealth services, two-third indicated only a single department/program with an operational telehealth service [93]. The challenge for the future is delivering telemedicine cardiovascular assistance also to ‘very remote’ populations.

‘Very remote’ populations are those not easily accessing telemedicine technologies because of ‘nonmedical’ restrictions, such as detainees. Preliminary studies show that telemedicine ECG assistance may (partially) overcome technical limitations of patients with suspected acute cardiovascular disease and sentenced to prison [94,95].

‘Very remote’ populations are those in rural peripheral areas where cardiologist consultation is very far to achieve. Extremely ‘remote’ populations are those in developing countries or in underdeveloped areas of developed countries. With the inadequate health infrastructures, understaffed and underfunded health systems, developing countries are ill-prepared to cope with the increasing demand for cardiovascular care, particularly for populations in remote and underserved rural areas, where 60% of the population currently reside. Telehealth has been suggested as a strategy to overcome the current health workforce shortage in such areas and to increase access to prevention and curative services for emerging cardiovascular disease [96,97]. However, some initiatives have been undertaken in order to deliver the best remote cardiovascular assistance in rural underdeveloped areas [98]. Main areas of intervention include tele-echocardiography and tele-ECGs, home monitoring, and text messaging for medication adherence monitoring [99]. Telemedicine may allow also programs of international cooperation [100] between spoke offices in developing countries [101].

M(obile)-health is emerging as a promising tool to address access, coverage, and equity gaps in developing countries and low-resource settings. The results for m-health interventions showed a positive impact on chronic diseases in in low- and middle-income countries, improving attendance rates, clinical outcomes, and quality of life, and were cost-effective [102]. In a study from India on mobile technology counseling in congestive HF subjects, significantly more study subjects were categorized as New York Heart Association Class I and II, had a higher mean 6-minute walk test distance, showed greater improvements in walking distance, and had fewer symptoms; the study also demonstrated a significant increase in quality of life [103]. Possible portable diagnostic devices that can communicate to smartphones and tablets by making tele-health care possible in developing countries have been designed by some authors, and possible models and components have been proposed [104]. Mobile real-time telemonitoring and diagnostic facility to command and control remote medical devices through mobile phones have been tested in the Philippines, phone-based, effectively freeing offsite medical specialists from stationary monitoring consoles and endowing the system with the potential to increase the number participating consultants [105]. The ECG readings are analyzed using a detrended fluctuation technique and classified into pathological cases using an algorithm. The method successfully categorized the subjects enrolled in the study. The synergy of mobile monitoring and
fluctuation analysis may, therefore, represent a powerful platform to reach remote, underserved communities with poor or nonexistent wired communication structures. In studies from six Asian and African countries including the Philippines, China, Kenya, South Korea, Taiwan and India, mobile phone technology has shown to improve health outcomes for chronic disease conditions such as diabetes, heart disease, and hypertension [106].

Also, tele-cardiology tools have been recently evaluated in African countries; touch screen medical devices enable cardiac tests such as electrocardiograms to be performed in remote underserved areas, while the test results are transferred wirelessly via mobile phone connection to specialist physicians who can interpret them and provide assistance with case management [97]. An international, multicenter program of remote consultations in telemedicine-assisted pediatric cardiac critical care has been tested in four hospitals in Latin America [107]; telemedicine was considered useful by participants in the cardiac intensive care unit, for patient outcomes, and for education. In another study held in Colombia, the implementation of an international pediatric cardiac critical care telemedicine program was associated with lower cardiac intensive care unit and hospital length of stay [108].

- There is room for a further increase in telemedicine use in clinical practice.
- ‘Remote’ populations (rural areas, detainees, developing countries) are those who can potentially most benefit from further implementation of telemedicine in the next future.

Expert commentary

Telemedicine and its implementation in the field of cardiovascular disease have been shown as significantly impacting clinical practice in the whole continuum of cardiovascular disease (Table 1). Greatest effects were found in early diagnosis of cardiovascular disease, second opinion on cardiovascular imaging, and secondary prevention of cardiovascular disease.

Prehospital ECG triaging significantly lowered the time to treatment in AMI, while home monitoring and rehabilitation in patients with chronic HF or with an implanted device effectively improved the quality of the cardiovascular care. Despite gaps in evidence and clinical failures, the use of telemedicine in cardiovascular disease may contribute to reduce mortality, lower readmission for recurrence, improve quality of life and limit costs. Lack in funding, short living government support, unmatchable software and devices, incompatible between national legal systems, however, still hinder the spread of telemedicine. Position papers and clinical practice guidelines issued by Scientific Societies may be useful in highlighting possible benefits achievable thanks to telemedicine and overcoming such constraints.

However, further delivering of telemedicine in ‘very remote’ (in developing countries or in under-developed areas of developed countries) populations with cardiovascular disease is expected for the next future.

Five-year view

In the next five years, a large implementation of telemedicine support is expected both in developed countries and in developing areas of the world. The generalized use of smartphones and tablets will allow the capillary accessibility to programs of rehabilitation or telemonitoring through dedicated apps for patients affected by cardiovascular disease.

Lack of funding and short-living government support will be probably counterbalanced by reduced managing costs allowed by new technologies and expected increasing possible revenues for investors and private companies ready to bet in the field of telemedicine. The continuously reducing resources available for health care, the aging population in developed countries, and the increasing number of subjects affected by chronic cardiovascular disease will make the use of organizational models based on telemedicine increasingly necessary and convenient.

Cloud technology and broadband connecting systems will allow the storage and processing of large amounts of data even in the absence of complex technologies ‘on field’.

Financial and competing interests disclosure

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.
Table 1. Main studies showing a clinical impact of telemedicine on the cardiovascular continuum.

<table>
<thead>
<tr>
<th>First author</th>
<th>Year</th>
<th>Country</th>
<th>Study population</th>
<th>Device/technical solution</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalvini [5]</td>
<td>2005</td>
<td>Italy</td>
<td>310</td>
<td>Trans-telephonic event monitors</td>
<td>Early diagnosis of acute myocardial infarction</td>
</tr>
<tr>
<td>Wu [6]</td>
<td>2012</td>
<td>Taiwan</td>
<td>70</td>
<td>Trans-telephonic electrocardiograph monitoring</td>
<td>More clear diagnosis, and more quickly vs. Holter monitoring</td>
</tr>
<tr>
<td>Scalvini [7]</td>
<td>2005</td>
<td>Italy</td>
<td>7516</td>
<td>Portable electrocardiographer for GP</td>
<td>Most paroxysmal atrial fibrillation episodes asymptomatic, and the trans-telephonic electrocardiograph monitoring easily detected these episodes</td>
</tr>
<tr>
<td>Brunetti [8]</td>
<td>2012</td>
<td>Italy</td>
<td>27,841</td>
<td>Mobile ECG recorder and mobile telephone transmission</td>
<td>Telecardiology service useful tool in the home management of chronic atrial fibrillation and in the first detection of new cases of atrial fibrillation</td>
</tr>
<tr>
<td>Scalvini [10]</td>
<td>2002</td>
<td>Italy</td>
<td>952</td>
<td>Portable electrocardiographer for GP</td>
<td>Improved sensitivity of diagnosis of AF in elderly EMS patients and useful in at-home identification of subjects with AF and atypical presentation</td>
</tr>
<tr>
<td>Molinari [11]</td>
<td>2002</td>
<td>Italy</td>
<td>456</td>
<td>Teleconsultation</td>
<td>Diagnostic accuracy of 87% for chest pain</td>
</tr>
<tr>
<td>Terkelsen [19]</td>
<td>2002</td>
<td>Denmark</td>
<td>250</td>
<td>Early diagnosis of acute myocardial infarction</td>
<td>Door-to-needle times shorter amongst patients with prehospital diagnosing ECG transmission from a moving ambulance feasible, reduces in-hospital delays and allows faster triage</td>
</tr>
<tr>
<td>Giovas [20]</td>
<td>1998</td>
<td>Greece</td>
<td>N/A</td>
<td>Ambulance ECG recorder, connected to a notebook computer and coupled to a cellular telephone for transmission to a hospital-based station</td>
<td>Early diagnosis of cardiovascular disease</td>
</tr>
<tr>
<td>Brunetti [22]</td>
<td>2010</td>
<td>Italy</td>
<td>27,841</td>
<td>Mobile ECG recorder and mobile telephone transmission</td>
<td>Lower errors and delay in STEMI diagnosis in elderly patients with atypical presentation</td>
</tr>
<tr>
<td>Terkelsen [23]</td>
<td>2005</td>
<td>Denmark</td>
<td>161</td>
<td>Prehospital diagnosis with of telemedicine and direct referral to an interventional center</td>
<td>Median time to balloon 41 min shorter vs. diagnosed prehospital and admitted to a local hospital group and 81 shorter vs. in-hospital diagnosis group</td>
</tr>
<tr>
<td>Sejersten [24]</td>
<td>2008</td>
<td>Denmark</td>
<td>565</td>
<td>Transmitting a prehospital ECG directly to the attending cardiologist’s mobile telephone</td>
<td>Median time from 911 call to PCI shorter (74 vs. 127 min), door-to-PCI time 63 min shorter (34 vs. 97 min)</td>
</tr>
<tr>
<td>Sørensen [25]</td>
<td>2011</td>
<td>Denmark</td>
<td>759</td>
<td>Prehospital diagnosis with telemedicine and direct referral to a primary PCI center</td>
<td>Lower errors in STEMI diagnosis in elderly patients with atypical presentation</td>
</tr>
<tr>
<td>Brunetti [27]</td>
<td>2014</td>
<td>Italy</td>
<td>297</td>
<td>Prehospital diagnosis with telemedicine and direct referral to a primary PCI center</td>
<td>Median time from 911 call to PCI shorter (74 vs. 127 min), door-to-PCI time 63 min shorter (34 vs. 97 min)</td>
</tr>
<tr>
<td>Sanchez-Ross [28]</td>
<td>2011</td>
<td>USA</td>
<td>142</td>
<td>Fully automated wireless network to enable automatic ECG transmission and direct communication between EMS personnel and offsite cardiologists for direct triage of patients to the cardiac catheterization laboratory</td>
<td>System delay 92 vs. 153 min in patients without prehospital diagnosis</td>
</tr>
<tr>
<td>Brunetti [29]</td>
<td>2014</td>
<td>Italy</td>
<td>240</td>
<td>Prehospital diagnosis with telemedicine and direct referral to a primary PCI center</td>
<td>Shorter time-to-balloon (0:41 vs. 1:34, −0:53 h, −56%); higher rates of patients timely treated (85% vs. 35%, +141%)</td>
</tr>
<tr>
<td>Chan [30]</td>
<td>2012</td>
<td>Canada</td>
<td>594</td>
<td>Prehospital diagnosis with telemedicine and direct referral to a primary PCI center</td>
<td>Shorter door-to-balloon times (63 vs. 119 min), higher LVEFs (50% vs. 35%), and shorter length of stay (3 vs. 5.5 days)</td>
</tr>
<tr>
<td>Boman [41]</td>
<td>2014</td>
<td>Sweden</td>
<td>38</td>
<td>Cardiological consultation in addition to the robot-assisted remote echocardiography</td>
<td>Relative mortality risk reduction 15% in the intermediate risk STEMI tertile, 27% in the highest tertile</td>
</tr>
<tr>
<td>Webb [43]</td>
<td>2013</td>
<td>USA</td>
<td>674</td>
<td>Telemedicine for pediatric second opinion</td>
<td>Higher proportion of 90 min door-to-balloon time benchmark (80% vs. 9%), lower 30-day (5% vs. 13%), and 1-year (7% vs. 18%) mortality</td>
</tr>
<tr>
<td>Randolph [47]</td>
<td>1999</td>
<td>USA</td>
<td>133</td>
<td>Telemedicine for pediatric second opinion</td>
<td>Reduced time to specialist consultation (median 12 vs. 86 days)</td>
</tr>
<tr>
<td>Scalvini [60]</td>
<td>2013</td>
<td>Italy</td>
<td>200</td>
<td>Trans-telephonic electrocardiograph monitoring</td>
<td>Reduced transport to a tertiary care center (4% vs. 10%), time to diagnosis (100 vs. 147 min), length of stay (1 vs. 26 days), and length of intensive care unit stay (1 vs. 2.5 days)</td>
</tr>
<tr>
<td>Dalleck [63]</td>
<td>2011</td>
<td>New Zealand</td>
<td>226</td>
<td>Home-based cardiac rehabilitation program with telemedicine</td>
<td>No significant differences in the change from baseline to post-program values between the conventional and the telemedicine groups</td>
</tr>
<tr>
<td>Frederix [65]</td>
<td>2015</td>
<td>Belgium</td>
<td>140</td>
<td>Telerehabilitation program</td>
<td>Incremental cost-effectiveness ratio of €21,707/QALY</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>First author</th>
<th>Year</th>
<th>Country</th>
<th>Study population</th>
<th>Device/technical solution</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giordano [67]</td>
<td>2013</td>
<td>Italy</td>
<td>602</td>
<td>Home-based telesurveillance program including multidisciplinary management and remote telemonitoring for patients with chronic heart failure</td>
<td>Improvement in NYHA class, LVEF, 6-minute walking distance, and quality of life</td>
</tr>
<tr>
<td>Sohn [68]</td>
<td>2012</td>
<td>Germany</td>
<td>1124</td>
<td>Nurse calls and calls to treating physicians for therapy adjustments</td>
<td>35% lower mortality in chronic heart failure</td>
</tr>
<tr>
<td>Dendale [70]</td>
<td>2012</td>
<td>Belgium</td>
<td>160</td>
<td>Intense follow-up facilitated by telemonitoring</td>
<td>Lower all-cause mortality (5% vs. 17.5%), total number of follow-up days lost to hospitalization (13 vs. 30 days), and number of hospitalizations for heart failure per patient (0.24 vs. 0.42)</td>
</tr>
<tr>
<td>Kurtz [72]</td>
<td>2011</td>
<td>France</td>
<td>138</td>
<td>Automated home telephone self-monitoring</td>
<td>Time to readmission for heart failure increased from 95 days to 198 in patients with advanced heart failure</td>
</tr>
<tr>
<td>Giordano [73]</td>
<td>2009</td>
<td>Italy</td>
<td>460</td>
<td>Home-based telemanagement for chronic heart failure. The patients received a portable device, transferring, by telephone, a one-lead trace to a receiving station where a nurse was available for interactive teleconsultation. Remote monitoring of implantable devices</td>
<td>Lower risk of readmission (HR = 0.50), lower cost for hospital readmission (€ 843 vs. 1298)</td>
</tr>
<tr>
<td>Landolina [81]</td>
<td>2012</td>
<td>Italy</td>
<td>200</td>
<td>Remote ICD monitoring</td>
<td>Rate of urgent visits for heart failure, arrhythmias, or ICD-related events 35% less frequent, reduced time from an ICD alert condition to review of the data (1.4 vs. 24.8 days)</td>
</tr>
<tr>
<td>Guédon-Moreau [82]</td>
<td>2013</td>
<td>France</td>
<td>433</td>
<td>Home monitoring of ICD</td>
<td>38% major adverse events vs. 41%, 193 vs. 657 shocks delivered, 52% inappropriate shocks lower</td>
</tr>
<tr>
<td>De Ruvo [84]</td>
<td>2011</td>
<td>Italy</td>
<td>132</td>
<td>Remote ICD monitoring</td>
<td>86% higher risk of delayed detection of clinical adverse events in the control group</td>
</tr>
</tbody>
</table>

AF: atrial fibrillation; ICD: implantable cardioverter defibrillators; NYHA: New York Heart Association; STEMI: ST-elevation acute myocardial infarction; GP: general practitioner; EMS: emergency medical service; GSM: global system for mobile communications.

Figure 1. Main fields of innovation for telemedicine in cardiology.
Key issues

- Cardiovascular disease is one of the main fields of application of telemedicine.
- Almost all the areas in the continuum of cardiovascular disease apparently benefit from telemedicine support (arrhythmias, heart failure, cardiovascular risk factors, acute coronary syndrome).
- Telemedicine support has been shown to positively impact the management of cardiovascular disease mainly in three broad areas: early diagnosis of cardiovascular disease, second consultation, follow-up, and secondary prevention (Figure 1).
- At present, the main area of implementation of telemedicine for the management of cardiovascular disease is prehospital triage with prehospital electrocardiogram of ST-elevation acute myocardial infarction for consequent direct transfer for primary coronary angioplasty.
- Significant results have been achieved also in second-opinion consultation of pediatric subjects with congenital cardiovascular disease, home monitoring, and management of patients affected by chronic heart failure or implanted with a device (pacemaker, implantable cardioverter defibrillator, cardiac resynchronization therapy device).
- There is large room for further improvement in delivering telemedicine assistance even in ‘very remote’ populations (detainees, patients in developing countries).

References

Papers of special note have been highlighted as:

• of interest
• of considerable interest


• This is the most used definition of telemedicine.


• These are the few guidelines on the use of telemedicine in the management of cardiovascular disease.


• This is the first paper in the field of telecardiology for cardiovascular disease.


• This is the most important study in the field of telecardiology for general practitioners.


17. Ting HH, Krumholz HM, Bradley EH, et al. American Heart Association Interdisciplinary Council on Quality of Care and Outcomes Research, Emergency Cardiovascular Care
This study shows the efficacy of telemedicine in the management of acute myocardial infarction.  
• This study shows a lower cardiovascular mortality in acute myocardial infarction thanks to telemedicine.


• This study shows a lower cardiovascular mortality in subjects with chronic heart failure with telemedicine follow-up.


• This study shows one-third lower rehospitalization in subjects with chronic heart failure with a home-based nurse telemanagement.


86. Hall JL, McGraw D. For telehealth to succeed, privacy and security risks must be identified and addressed. Health Aff. 2014;33:216–221.


91. Jaroslavski S, Saberwal G. In eHealth in India today, the nature of work, the challenges and the finances: an interview-based study. BMC Med Inform Decis Mak. 2014;14:1.


