Review

Advancing Telemedicine in Cardiology: A Comprehensive Review of Evolving Practices and Outcomes in a Post-Pandemic Context

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Review

Advancing Telemedicine in Cardiology: A Comprehensive Review of Evolving Practices and Outcomes in a Post-Pandemic Context

Running Title: Telemedicine Review in Cardiology

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Abstract: Telemedicine, telehealth, e-Health, and other related terms refer to the exchange of medical information or medical care from one site to another through electronic communication between a patient and healthcare provider. As telemedicine infrastructure has changed since the COVID-19 pandemic, this review provides an overview of telemedicine use and effectiveness in cardiology, with emphasis on the post-pandemic context. Pre-pandemic studies tend to report statistically insignificant or modest improvements in cardiovascular disease outcome from telemedicine use to usual care. By contrast, post-pandemic studies tend to report positive outcomes or comparable acceptance of telemedicine use to usual care. Today, telemedicine can effectively replace in person follow-ups to produce comparable (but not necessarily superior) outcomes in cardiovascular disease management. A major benefit of telemedicine is the significant reduction in follow-up time or time-to-intervention which may lead to earlier detection and prevention of adverse events. Nonetheless, there remain barriers to effective telemedicine implementation in the post-pandemic context. Providing accuracy and ease-of-use of telemedicine devices, ensuring adherence to remote rehabilitation procedures, and implementing widespread telemedicine infrastructure are such examples. Current knowledge gaps include the true economic cost of telemedicine infrastructure, feasibility of use in specific cardiology contexts, and sex/gender differences of health outcomes through telemedicine use. Future telemedicine developments will need to address these concerns to achieve widespread acceptance as the new standard of care.

Keywords: telemedicine; mHealth; e-Health; telehealth; cardiology; cardiovascular medicine; myocardial infarction

Introduction

Telemedicine, telehealth, e-Health, and other related terms refer to the exchange of medical information or medical care from one site to another through electronic communication between a patient and healthcare provider.[1] This includes consultations via video/audio (e.g. Zoom, Teams), phone calls, or chat/SMS. Major improvements to telemedicine infrastructure over the COVID-19 pandemic have now poised it as a safe, efficient, convenient, and accessible method of accessing care. Many healthcare providers and patients alike are willing to embrace it as the primary method ("the new normal") of healthcare delivery in hospitals, long-term care facilities, or outpatient settings.[2] Commonly-cited benefits of telemedicine include: lowering health system costs, increasing access to care, decreasing time for scheduled

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visits, reducing cancellation rates, fewer hospitalizations, increasing patient satisfaction, decreasing emergency department use, and improving social connectedness.[2]

Nonetheless, there remains social and logistical barriers that prevent widespread implementation of this technology, issues which are unique to each medical speciality. For example, in the context of cardiology where patients are often older in age, healthcare providers may believe telemedicine is not ideal as it is more difficult to discern medically complex issues or establish a proper relationship with the patient virtually.[2] The cognitive or physical impairments suffered by cardiology patients may also make telemedicine use unrealistic.[2] General concerns revolve around accessibility of telemedicine platforms, learning curve of using telemedicine effectively in care delivery, security or consent concerns of virtual doctor-patient communication, and literacy skills being a barrier to proper access.[3] In cardiology, the quality of critical diagnosis procedures such as physical exams or auscultations are greatly hindered (or not possible altogether) through virtual exams, which can worsen undetected health conditions.

The aim of this review is to present an overview on the evolving state of telemedicine use and effectiveness in cardiology. Emphasis is placed on telemedicine findings in a post-pandemic context from the past two years. We present peer-reviewed evidence on telemedicine for diseases such as myocardial infarction and coronary artery disease, reviews in the cardiology context, and briefly discuss ongoing clinical trials in telemedicine and cardiology.

Methods

Given that cardiology studies utilized various telemedicine technologies in different ways, a systematic review was hard to design. Instead, we conducted a comprehensive search to present the current state of the field with heterogeneous but high-quality studies and highlight emerging knowledge gaps.

Search Strategy and Selection Criteria

A set of detailed searches was conducted in February 2023 in two peer-reviewed databases (PubMed, Ovid MEDLINE(R) ALL) and clinicaltrials.gov, using MeSH terms where appropriate (see Appendix for detailed search strategy). Keywords in the peer-reviewed database search include: telemedicine, virtual clinic, ehealth; meeting on the phone/by video; cardiology; patient satisfaction; patient outcomes; hospitalization; risk factors; blood pressure; cholesterol; heart attack; not pediatrics. Keywords used for clinicaltrials.gov include: Telemedicine/Telehealth/e-Health; clinic; effectiveness; feasibility - with conditions for coronary disease and heart attack. A total of 724 relevant hits were collected from the peer-reviewed databases and 883 hits were collected from clinicaltrials.gov. The title, abstract and study description of all studies were screened for our eligibility criteria of research on the feasibility of telemedicine in cardiology. Studies were excluded if they had small sample sizes ($n < 50$) or were not sufficiently controlled (if an interventional study). Studies on pediatric cardiology research were also excluded. Only English articles were included. A total of 8 primary research publications, 4 clinical trials, and 3 reviews representative of the highest quality research in the field were ultimately chosen. The studies start from 2011 although most studies were published 2020 or onwards. Pilot studies were conducted in January 2023 to refine the search parameters.

Role of the Funding Source

There is no funding to declare.

Results

The sample consists of peer-reviewed & published clinical research, ongoing clinical trials, and reviews on the effectiveness of telemedicine in cardiology. Results are stratified into research conducted

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before the pandemic (before 2019) and research conducted during or after the pandemic (2020 and after). A summary of the major findings from each included study is presented in Tables 1–3.

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Table 1. Summary of Published Clinical Studies.

Author (Year)	Aim	Disease	Study Design	Interventional Population (n)	Control Population (n)	Outcomes	Main Findings
				PRE-PANDEMIC			
Shah et al. (2011)	To evaluate the effect of 2 tele-interventions compared with usual care on risk factor modification, process of care, and cost of disease management.	Myocardial Infarction	Randomized Controlled Trial	131 tele-nurse, 138 web only	137	(1) reduction in systolic BP, LDL cholesterol, body weight, and glycosylated hemoglobin (2) adherence to evidence-based therapies (3) improvement in health behaviors	The main outcomes were not statistically significant. There were sight improvements in the nurse-administered intervention relative to the education-only group as compared with the web-only intervention relative to education-only. There were improvements in SBP between the nurse-administered intervention arm and education-only arm. There were no statistically significant differences in changes over time by treatment groups for A1c, SBP, DBP, or LDL.
Korzeniowska-Kubacka et al. (2015)	To compare the influence of CR on physical capacity, safety, adherence and return to work in post-MI male and female patients with preserved left ventricular systolic function, and to assess who benefited more from this model of training.	Myocardial Infarction	Non-Randomized Study	57 men, 30 women	-	(1) ECG results (2) HR and BP at baseline, at the end of each interval, and at recovery	Hybrid rehabilitation resulted in a comparable improvement in physical capacity in post-MI low-risk male and female patients. Although hybrid rehabilitation facilitated patients' adherence to the training program, their return to work was significantly greater only in men.

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POST-PANDEMIC							
Treskes et al. (2020)	To investigate whether smart technology in clinical practice can improve BP regulation and to evaluate the feasibility of such an intervention.	Myocardial Infarction	Single-Center, Non-Blinded, Randomized Feasibility Controlled Trial	100	100	(1) BP control (2) feasibility: via patient satisfaction, measurement adherence, all-cause mortality, and hospitalizations for nonfatal adverse cardiac events	Smart technology yields similar percentages of patients with regulated BP compared with the standard of care. Such an intervention is feasible in clinical practice and is accepted by patients.
Osterech et al. (2021)	To evaluate the effects of a 12-months intensive prevention program (IPP), based on repetitive contacts between non-physician "prevention assistants" and patients.	Myocardial Infarction	Randomized Controlled Trial	134	136	(1) global cardiovascular risk factor control (2) single risk factors, medical treatment, serious clinical events, costs and quality of life	IPP was associated with a significantly better risk factor control compared to UC after 24 months and a trend towards less serious clinical events with minimal cost.
Shah et al. (2021)	To evaluate whether sociodemographic characteristics influence use of a digital health intervention (DHIs) targeting 30-day readmission reduction after acute myocardial infarction (AMI).	Myocardial Infarction	Multicenter Prospective Study	133	-	(1) use of the vital sign monitoring and medication tracking features (2) disease severity as marked by treatment with CABG	Age, sex, and race were not significantly associated with DHI use. Being married was associated with high DHI use. The presence of a spouse, perhaps a proxy for enhanced caregiver support, may encourage DHI use.

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Chan et al. (2021)	To compare the safety and efficacy of allied health care practitioner-led remote intensive management (RIM) with cardiologist-led standard care (SC).	Myocardial Infarction	Randomized Controlled Trial	301	152	(1) hypotension, bradycardia, hyperkalemia, or acute kidney injury requiring hospitalization (2) 6-month indexed left ventricular end-systolic volume (LVESV) adjusted for baseline LVESV	Among low-risk patients with revascularization after myocardial infarction, RIM by allied health care professionals was feasible and safe. There were no differences in achieved medication doses or indices of left ventricular remodeling.
Liu et al. (2021)	To evaluate the success of using 24-hour tele-ECG services via the WeChat group application, to reduce the time taken for diagnosis and treatment of ST-elevation myocardial infarction.	Myocardial Infarction	Controlled Before and After Study	70	70	(1) reperfusion time comparison between two groups (2) critical time points of symptom onset, FMC, first ECG, ECG diagnosis, time of arrival and discharge from the non-PCI hospital, time of arrival at the PCI hospital, catheterization laboratory activation and wire-crossing	The median symptom onset to first medical contact time was similar between WeChat to control groups, but the median first medical contact to wire, door to wire and first medical contact to catheterization laboratory activity were significantly shorter in the WeChat group. Pre-hospital ECG transfer via WeChat resulted in earlier reperfusion of transferred myocardial infarction patients.
Kołtowski et al. (2021	To assess how teleconsultations are received by physicians and patient, whether all medical issues can be addressed during a teleconsultation, and the type of consultation patients would be willing to have in the future.	Non-Specific	Observational Study	100	-	acceptance of teleconsultation	Teleconsultation acceptance rate was rated 8 among patients, and 10 for physicians. Over half of the patients (57%) would prefer to have teleconsultation over traditional visit next time. The vast majority of patients (85%) stated all medical issues were addressed. The time from visit to visit was identical with the pre-pandemic period, as teleconsultations took place instead of regular visits.

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Table 2. Summary of Unpublished Clinical Studies.

Study Name	Date Started	Date Completed	Aim	Condition	Phase	Study Design	Participants (n)	Randomization	Interventions	Status	Trial #
PRE-PANDEMIC											
Telemedicine in Cardiac Surgery: A Pilot Study	Jul 2010	Jan 2015	To compare the accuracy of surgeons' decisions during follow-up visits via video-teleconference (V-Visit) to surgeons' decisions during traditional face-to-face follow-up visits (FTF-Visits).	Coronary Artery Disease	Early Phase 1	Interventional (Clinical Trial)	40	Non-Randomized	Evaluate video clinic visit prior to Face-to-Face usual care visit	Completed with results	NCT01163474
Mobile Health in Structural Heart Disease (ASEF-VALUES)	Aug 2014	Jan 2016	To assess the impact of new mobile health devices on health outcomes among patients with rheumatic and structural heart disease in a resource limited area, to see if mobile health assessments accelerate medical-decision-making and shortens the time to definitive therapy.	Rheumatic Heart Disease	Phase 2 Phase 3	Interventional (Clinical Trial)	253	Randomized	mHealth standard of care	Completed	NCT02881398
POST-PANDEMIC											
Mobile App and Digital System for Patients After Myocardial Infarction (afterAMI)	Dec 2020	-	To study the impact of application-supported model of care with comparison to standard care, via cardiovascular risk factors control, rehospitalizations, patient's knowledge regarding risk factors, return to work and quality of life.	Myocardial Infarction	N/A	Interventional (Clinical Trial)	100	Randomized	Behavioral: Mobile application (afterAMI)	Recruiting	NCT04793425
Telehealth-enhanced	Mar 2022	-	To investigate the feasibility of conducting a randomized controlled	Acute Corona	N/A	Interventional	40	Randomized	Behavioral: Telehealth-	Recruiting	NCT05328353

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Hybrid Cardiac Rehabilitation Among Acute Coronary Syndrome Survivors	trial of telehealth-enhanced hybrid cardiac rehabilitation (THCR) compared with traditional cardiac rehabilitation (CR) among acute coronary syndrome (ACS) survivors.	ry Syndrome, Myocardial Infarction	(Clinical Trial)	enhanced Hybrid CR Behavioral: Traditional CR		75

Table 3. Summary of Review Findings.

Year	Title	Author	Aim	Review Type	Main Findings

2016	eHealth in cardiovascular medicine: A clinical update	Hugo Saner, Enno van der Velde	To describe opportunities and challenges of eHealth and telemedicine in the framework of our health systems and, in particular, in the context of today's cardiology services.	Narrative Review	**PRE-PANDEMIC**
					• The most promising applications of eHealth and telemedicine include:
					  ○ prevention and lifestyle interventions
					  ○ chronic disease management (e.g., hypertension, diabetes and heart failure)
					  ○ arrhythmia detection (e.g., early detection of atrial fibrillation and telemonitoring via devices such as pacemaker, internal cardioverter defibrillators and implantable rhythm monitoring devices)
					  ○ telerehabilitation
					• Major obstacles to telemedicine integration into daily clinical practice are:
					  ○ limited large-scale evidence of cost-effectiveness
					  ○ lack of interoperability
					  ○ inadequate or fragmented legal frameworks
					  ○ lack of reimbursement
					POST-PANDEMIC

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2021	Mobile health in preventive cardiology: current status and future perspective	Kozik et al.	To highlight and summarize the latest available literature on mHealth applications and provide perspective on future directions and barriers to implementation.	Narrative Review	• Evidence supports mHealth efficacy in CVD prevention and management • Food and Drug Administration approval of wearable sensors is a milestone for the mHealth field, solidifying the validation of commercial wearables in healthcare applications • Future mHealth applications include multimedia app-based programs and wearable data-collecting devices integrated with Electronic Health Record interfaces • Socioeconomic status and age remain significant barriers to patient mHealth uptake, while lack of reimbursement structures and application heterogeneity are barriers to clinician utilization • Policies to promote access to technology will be critical to reach diverse populations and advance health equity
2022	Improving medication adherence in patients with hypertension through pharmacist-led telehealth services	Fuentes et al.	To provide an overview of the current evidence of pharmacist-led telehealth to improve medication adherence in hypertensive patients.	Scoping Review	• Most telemedicine-mediated pharmacist interventions were in the outpatient setting for remote monitoring • Pharmacists-led patient interviews were more effective through use of telemedicine • Collaborations between other medical professionals and pharmacists have been found to improve medication adherence • This shift in practice has demonstrated an improvement in patients' health as a result • Limitations of telepharmacy for hypertensive patients include monitoring blood pressure and identifying symptoms of hypertensive crises from home

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(i) Published Clinical Research

Of the 8 published research taken from peer-reviewed databases, 7 studies were on myocardial infarction (MI), and 1 study was about cardiovascular disease in general. Two studies were published before the pandemic (2019) and 6 studies were published afterwards.

Pre-Pandemic Studies

Of the 2 studies published before 2019, the oldest study by Shah et al. (2011) evaluated the effect of virtual telemedicine interventions compared to usual care and nurse-administered care on risk factor modification and outcomes of long term cardiovascular disease management.[4] A total of 450 patients in the U.S. with recent myocardial infarction and hypertension were enrolled into a 3-arm randomized controlled trial, called the Secondary Prevention Risk Interventions via Telemedicine and tailored patient Education (SPRITE) trial. The telemedicine intervention itself was HealthVault, a web-based data tracking system of home BP measurements. A total of 150 participants were randomized to one of each arm: (1) standard care (control group); (2) a nurse-administered behavioral and education self-management intervention plus the use of HealthVault; or (3) a Web-based behavioral and education self-management intervention plus the use of HealthVault. Both interventional groups received ambulatory blood pressure (BP) monitors and HealthVault. The primary outcome was reduction in systolic BP at 12 months when compared to control, and secondary outcomes were reductions in LDL cholesterol, body weight, glycosylated hemoglobin, with adherence to preventative care and improvement in health behaviours. Measurements were taken at baseline and 12 months. Results indicated that a significant proportion of participants (43%) did not adhere to cardiovascular disease medication after 12 months. Only 75% of participants completed follow-ups within 14-months of enrollment. The main outcomes were not statistically significant for changes over time by treatment groups for hemoglobin A1C, SBP, DBP, or LDL. Behavioural improvements were slightly better in the nurse-administered arm compared to the web-administered arm when both were compared to control, with a differential improvement of 4.0 mmHg (p-value = 0.11) in SBP in the nurse-administered arm.

A 2015 study in Poland by Korzeniowska-Kubacka et al. evaluated a hybrid model of cardiac rehabilitation in men and women after myocardial infarction.[5] The study compared the effect of usual out-patient care versus teleECG monitoring on physical capacity, safety, adherence and return to work in patients with preserved left ventricular systolic function post-MI. All patients (57 male and 30 female) underwent an 8-week 24-session training program. The first 10 sessions were conducted in an out-patient clinic, with the remaining training completed at home via teleECG monitoring. Patients underwent a symptom-limited exercise stress test while the ECG was monitored, and HR and BP were measured at baseline, at the end of each interval, and at recovery. Results indicate that hybrid rehabilitation facilitated patients' adherence to the 8-week training program and led to a significant improvement in physical capacity in all patients. A comparative analysis of adherence and returning to work between female and male patients revealed that returning to work was significantly greater only in men post MI.

Post-Pandemic Studies

Of the studies occurring during or post-pandemic, 1 study was published in 2020, and 5 studies were published in 2021. The 2020 Netherlands study by Treskes at al. evaluated the feasibility of whether smart technology in clinical practice can improve BP regulation through a single-center, non-blinded, randomized clinical trial.[6] A total of 200 patients were randomized equally to regular follow-up or smart technology intervention (virtual follow-up with smart technology use on smartphone-compatible devices consisting of a BP monitor, step counter, weight scale, and single-lead ECG device). Regular follow-up was defined as 4 visits to the outpatient hospital clinic at 1, 3, 6, and 12 months after acute MI. A 10-second ECG, BP measurements and 15-minute patient interview were conducted by a nurse practitioner at every visit. Laboratory testing was performed at 1-month, 6-month, and 12-month follow-up. A stress ECG was performed at 3 months. A 24-hour Holter

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monitoring procedure was performed at 3 and 6 months. A transthoracic ECG was performed at 6 and 12 months.

The primary outcome was BP control. Secondary outcomes measured proxies for feasibility, such as patient satisfaction (via general questionnaire and smart technology-specific questionnaire), measurement adherence, all-cause mortality, and hospitalizations for non-fatal adverse cardiac events. After 1 year, 79% of telemedicine patients had controlled BP versus 76% of control patients ($P = 0.64$). Overall satisfaction with standard of care was the same between groups (mean SD scores, 82.6 [14.1] vs 82.0 [15.1]; $P = 0.88$). The all-cause mortality rate was 2% in both groups ($P > 0.99$). A total of 20 hospitalizations for non-fatal adverse cardiac events occurred (8 in the intervention group and 12 in the control group). For the telemedicine arm, 90.3% of patients were satisfied with the smart technology intervention. The investigators concluded that smart technology yields similar patient outcomes of regulated BP compared with the standard of care, making telemedicine feasible in clinical practice, and accepted by patients.

The remaining studies published in 2021 present a similar narrative on the effectiveness of telemedicine internationally. A Chinese study by Liu et al. evaluated the effectiveness of providing 24-hour teleECG services via WeChat (a popular mobile app messaging platform), for patients who were transferred from a non-PCI to PCI hospital.[7] The goal was reducing the reperfusion time and improving preventative treatment for ST-elevation myocardial infarction. Through a controlled pre-post study, 70 ST-elevation myocardial infarction (STEMI) post-primary PCI patients had ECGs taken from the non-PCI hospital and pre-transmitted to the PCI hospital via WeChat. The control group had 70 patients who did not pre-transmit ECG, who were subsequently equipped with normal 12-channel ECG machines at the PCI hospital. Primary outcome was reperfusion time. Secondary outcomes included critical time points such as time of symptom onset, first medical contact, first ECG, ECG diagnosis, arrival and discharge from the non-PCI hospital, arrival at the PCI hospital, catheterization laboratory activation and wire-crossing, within 9 months follow-up. It was revealed that pre-hospital electrocardiography transfer via a WeChat group resulted in earlier reperfusion of ST-elevation myocardial infarction. The median time between symptom onset to first medical contact time was slightly shorter (129 min. telemedicine vs 150 min. control, $p > 0.05$), but the median time for medical contact and medical intervention such as catheterization laboratory activity was significantly shorter in the WeChat group by 30-40 minutes ($p < 0.001$).

In Singapore, a multicenter randomized clinical trial conducted by Chan et al. evaluated the safety and efficacy of allied health care practitioner-led remote intensive management (RIM) with cardiologist-led standard care (SC) for post-acute MI patients (the IMMACULATE Randomized Clinical Trial).[8] A total of 301 participants were randomized equally to RIM or SC. A baseline cardiac MRI was taken 5-10 days within admission and repeated at 6 months. Participants received RIM transmitted blood pressure and heart rate measurements two times a day using a Bluetooth-enabled device immediately after imaging. Weekly consultations were conducted via telephone for 2 months and then every 2 weeks for 4 months by nurse practitioners who remotely adjusted medication to a standardized algorithm. Measurements of serum creatinine and potassium concentration were performed at 30 days unless needed earlier. Participants receiving SC received regular face-to-face consultations with their cardiologists who provided the medication adjustment. The primary endpoint was an evaluation of hypotension, bradycardia, hyperkalemia, or acute kidney injury requiring hospitalization. Results revealed that among low-risk patients, RIM use was feasible and safe - there were no differences in achieved medication doses or indices of left ventricular remodeling. After 6-months post-discharge, RIM participants had an equally low number of safety events and achieved similar β-blocker and ACE-I/ARB doses but did not improve LV remodeling outcomes compared to the control arm.

In Germany, a randomized control trial by Osteresch et al. evaluated the effectiveness between a telemedicine-based intensive prevention program (IPP) and usual care (UC) for 12 months.[9] Post-MI patients after 3-weeks of acute cardiac rehabilitation were randomly assigned to a 12-months IPP (136 patients) or UC (139 patients). IPP involved group education sessions every month, personal telephone contacts with prevention assistants every 3 weeks, telemetric devices with online

documentation of physical activity, and clinical visits to intervene if risk factors did not meet the guideline-recommended targets. The primary outcome was global cardiovascular risk factor control, assessed by the IPP Prevention Score. Further study endpoints were single risk factors, medical treatment, serious clinical events, costs, and quality of life. IPP resulted in a significantly better risk factor control with less serious clinical events (12.5% vs 20.9%, log-rank p = 0.06) compared to UC after 24 months. The usage of re-interventions occurring 24 months after MI further improved risk factor control, such as LDL cholesterol and blood pressure lowering. Additionally, after 24 months, the costs of IPP were lower than UC (cost per patient 1,070 € in IPP vs 1,170 € in UC), making telemedicine-based care a more economically feasible option.

Looking at other aspects of telemedicine feasibility, a U.S. multi-center, prospective study evaluated whether sociodemographic characteristics influence use of a digital health intervention (DHI) in 30-day readmission reduction after acute MI.[10] A total of 133 patients from 4 U.S. hospitals (Johns Hopkins Hospital, Johns Hopkins Bayview Medical Center, Reading Hospital, and Massachusetts General Hospital) were given a telemedicine iPhone application to report symptoms and an Apple Watch at hospitalization, followed by a Bluetooth-enabled blood pressure monitor on enrollment. Patients used these interventions while hospitalized and for 30 days post-discharge. Demographic data (age, sex, race, marital status, and insurance status), clinical data, digital health characteristics, and patient self-report questionnaires were collected remotely. The primary outcome was use of the vital sign monitoring and medication tracking features. Age, sex, and race were not significantly associated with DHI use before or after covariate adjustment (fully adjusted OR 0.98 (95%CI: 0.95-1.01), 0.6 (95%CI: 0.29-1.25), and 1.22 (95% CI: 0.60-2.48), respectively). Being married was associated with high DHI use (OR 2.12; 95% CI 1.02-4.39), indicating that the presence of a spouse may act as a proxy for enhanced caregiver support and encourage DHI use.

Finally, the study by Kołtowski et al. in Poland assessed how teleconsultations are received by physicians and patients - whether all medical issues can be addressed during a teleconsultation, and the type of consultation patients would be willing to have in the future.[11] Through an observational, non-invasive, and non-randomized study, investigators conducted interviews with 100 patients and their physicians in the Department of Cardiology at the University Hospital of the Medical University of Warsaw in Poland from March to June 2020 (2 months). After the initial teleconsultation, physicians were interviewed about their attitude to telemedicine, any technical difficulties, and the efficiency of communication with the patient. Patients were interviewed about their acceptance of the teleconsultation, whether all medical issues were addressed, and the type of consultation they would prefer next time. Acceptance evaluation was assessed based on a scale from 1 to 10, where 1 point meant no acceptance and 10 meant full acceptance. The median (IQR) acceptance rate with teleconsultation was 8 (range: 7–10) among patients, and 10 (range: 8–10) for physicians (r = –0.03, P = 0.81). Over half (57%) of the patients preferred teleconsultation to traditional home visits. Most patients (85%) stated all medical issues were addressed. All patients received an electronic prescription when needed. The time frame between follow-ups was identical with the pre-pandemic period, as teleconsultations took place instead of regular visits.

Overall, the 8 published clinical studies exemplify positive use of telemedicine in cardiology, particularly for follow-up of post-MI patients.

(ii) Ongoing Clinical Trials

Of the 4 ongoing clinical trials posted from clinicaltrials.gov, 2 studies were conducted before the pandemic and 2 were conducted after. The pre-pandemic studies are completed (1 with results) while the post-pandemic studies are currently recruiting participants. These trials exemplify promising research on the feasibility and effectiveness of various telemedicine uses in large populations.

The oldest trial was a U.S. pilot interventional study started in July 2010 to compare the accuracy of surgeons' decisions in post-operative follow-up visits using video-teleconference versus traditional face-to-face visits for patients with coronary artery disease.[12] A total 40 patients were invited to participate in virtual assessments followed by in-person follow-up within a 1 month time frame. The primary outcome was accuracy of diagnosis (measured by comparing virtual to face-to-face

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diagnosis), while secondary outcomes were acceptability (measured by the Likert-scale questionnaire) and feasibility (via questionnaire). Of the 40 participants, only 24 completed the study, with 12 participants withdrawing due to facing barriers with teleconference access. The mean age was 64 (S.D. 8.3) and all were male. Most (16) participants were White. Of the 24 total participants, there was high agreement (89%) in accuracy between virtual and in-person diagnosis. According to participants, 68% were agreeable to the use of telemedicine. Participants were followed up after one year with no adverse events or mortality reported. The study had no associated publications.

Another U.S. and India multi center trial which started in August 2014 assessed the feasibility, utility and impact of new mobile health devices on health outcomes among patients with rheumatic and structural heart disease.[13] These patients were located in resource-limited areas and disproportionately received low allocation of health services and interventions. The aim was to assess if mobile health assessments accelerate medical-decision-making and shorten the time to therapy. A total of 253 participants were randomized to either the mHealth arm with smartphone-connected devices (e.g. smart-ECG, activity monitors, connected blood pressure devices, handheld ultrasounds) or standard care in-person cardiology evaluations. The primary outcome was time to definitive treatment with valvuloplasty or valve replacement within 12 months, with secondary outcomes of cardiovascular hospitalization and/or death within 12 months. According to published results[14], mHealth use was associated with a shorter time to referral for valvuloplasty and/or valve replacement (83 ± 79 days vs. 180 ± 101 days; $p < 0.001$) with increased probability for valvuloplasty/valve replacement compared to standard-care (34% vs. 32%; adjusted hazard ratio: 1.54; 95% CI: 0.96 to 2.47; $p = 0.07$). mHealth patients were also associated with a lower risk of a hospitalization and/or death on follow-up (15% vs. 28%, adjusted hazard ratio: 0.41; 95% CI: 0.21 to 0.83; $p = 0.013$).

Trials which started during the pandemic showcase future directions of telemedicine use in cardiology. A clinicaltrials.gov study beginning December 2020 will comprehensively assess the impact of telemedicine in comparison to standard care.[15] A proposed 100 participants will be randomized into either the virtual arm or the standard care control arm, with end points collected 1 and 6 months after discharge from hospital. Participants in the virtual arm will have access to a mobile application which tracks vital signs, provides educational content, and coordinates rehabilitation therapy. Primary outcomes will measure cardiovascular risk factor control (hypertension, body mass, nicotinism, dyslipidemia), and rate/reason for rehospitalization. Secondary outcomes include patient's knowledge regarding risk factor control, return to work time frame, depression/anxiety/stress assessment via the DASS 21 (Depression Anxiety Stress Scales) scale, and quality of life via the MacNew questionnaire and EQ-5D-5L questionnaire. The estimated project completion date is July 2023.

Finally, a key trial which started in March 2022 will compare the feasibility of telehealth-enhanced hybrid cardiac rehabilitation (THCR) with traditional cardiac rehabilitation (CR) among acute coronary syndrome (ACS) survivors. THCR is an increasingly popular hybrid model which combines traditional therapy (e.g. exercise training, patient education, and risk factor management) with telehealth, clinic, and home-based activities.[16] All 40 proposed participants will attend a total of 24 CR sessions (either 5 in-clinic + 19 remote sessions or 24 standard in-clinic control sessions) over a 12-week period. The primary outcome is completion rate of each arm, with secondary outcomes of feasibility based on the Feasibility of Intervention Measure (FIM) score, pre-to-post program change in functional capacity (using the six-minute walk test (6MWT), and pre-to-post program change in health-related quality of life via Duke health profile questionnaire. The estimated project completion date is December 2023.

(iii) Reviews

Of the 3 reviews, each one focuses on a single aspect of telemedicine use in cardiology, while this review integrates findings from different sources to provide an overview of telemedicine development. The oldest article dating back to 2016 is a European review which describes the benefits and challenges of telemedicine in the pre-pandemic context of cardiology.[17] Global benefits of

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telemedicine include: (1) improvement of tracking & treatment for demographics like elderly and chronic disease populations; (2) ease-of-use to track or alter negative life-style habits; (3) mitigating access barriers in providing healthcare to low density populations; and (4) optimization of data transfer and treatment processes. The most promising applications of telemedicine in cardiology include: (1) prevention and lifestyle interventions; (2) chronic disease management such as hypertension, diabetes, and heart failure; (3) early arrhythmia detection; and (4) rehabilitation. On the other hand, pre-pandemic obstacles preventing widespread integration of telemedicine into daily clinical practice include (1) limited evidence on technical potential, cost-effectiveness, or clinical outcome; (2) lack of interoperability due to inadequate technical or legal frameworks; and (3) lack of support, reimbursement, or financial compensation for implementing such processes. Finally, the authors emphasize that the focus of telemedicine should be on the patient's needs.

For studies after the pandemic, a September 2021 U.S. review presented the latest literature on mobile health applications in cardiovascular disease management, and provided insight on barriers to effective implementation.[18] Although there is widespread support on the supposed efficacy of mHealth, the extant published literature is heterogeneous with inconsistent results on its true efficacy. Within cardiovascular medicine, there was reported benefit in areas such as risk factor modification in diabetes, cigarette smoking cessation, physical activity/weight loss, and multi risk factor modification in cardiac rehabilitation. Socioeconomic status and age remain significant factors to successful mHealth use, while lack of reimbursement structures and application heterogeneity represent existing challenges to telehealth infrastructure. It appears the future of cardiovascular disease management can greatly benefit from the integration of mHealth applications with multimedia platforms such as wearable data-collecting devices and Electronic Health Record interfaces.

Finally, a 2022 US scoping review of 17 articles examined the benefits of using pharmacist-led telehealth services in medication adherence for patients with hypertension.[19] Results revealed that medication adherence increased when pharmacists were involved with the patient's management of hypertension. Randomized controlled trials further demonstrated that pharmacist intervention can significantly lower and improve in blood pressure lowering in patients with hypertension. Nonetheless, there are limitations in the accuracy of telehealth management, such as monitoring blood pressure and identifying symptoms of hypertensive crises from home, which can apply beyond the hypertension context.

In summary, the studies presented provide a multi-faceted portrayal of telemedicine in cardiovascular medicine, for its feasibility in diagnosis, follow-up, and preventative care.

Discussion

Here we highlight notable themes which emerged from the collection of telemedicine studies.

Pre- and Post-Pandemic Differences in Telemedicine Use

The comparably higher number of publications released 2020 or afterwards reflect the booming interest in telemedicine brought forth by the pandemic. Amongst the included studies, pre-pandemic studies tended to report statistically insignificant or modest improvements in cardiovascular disease outcome when using telemedicine over usual care.[4,5] In comparison, most post-pandemic studies reported a clear positive benefit or comparable acceptance of telemedicine to in-person controls.[7,9,11] The studies show that that telemedicine, particularly in hybrid models, is particularly useful in reducing diagnosis time or barriers to accessing regular care. However, it is unclear if telemedicine can be used as a standalone service for all primary care interactions. The major barriers to effective telemedicine implementation in the post-pandemic are accuracy and ease-of-use of telemedicine devices, ensuring adherence to remote rehabilitation procedures, and implementing widespread telemedicine infrastructure.[18,19]

The extant evidence suggests that mobile health use can be used to replace in-person follow-ups to produce comparable (but not necessarily superior) outcomes in cardiovascular disease management.[6] A major benefit of telemedicine is the significant reduction in follow-up time or time-

to-intervention which may lead to earlier detection and prevention of adverse events.[7] However, many earlier studies report limited statistical significance in outcomes, which can allude to practical challenges in effective telemedicine implementation.[4] For example, ensuring patients follow through on long-term rehabilitation regimens via telemedicine remains a challenge in the post-pandemic context. The lessened pressure to report to a physician in person can be a reason for this, although more novel studies are needed to elucidate all the potential factors that give rise to this observation.

Changing Paradigms in Telemedicine Literature

A notable shift observed in the post-pandemic context is that feasibility studies are more comprehensive and measure more facets of telemedicine use (such as return to work, mental wellbeing, and receptiveness to telemedicine use), rather than simple measurements of economical cost or clinical outcomes.[10,11] This is a reflection of the changing discourses surrounding the receptibility of telemedicine use post-pandemic - its normalization in clinical routine would naturally lead researchers to investigate many different aspects of telemedicine. In parallel, the language used while describing telemedicine has changed over the years, signifying a more unified understanding of the idea since the pandemic. A variety of terms were used to describe virtual or remote interventions before the pandemic, while studies more explicitly and consistently used the terms like "telemedicine" or "smart technology" after the pandemic - a trend seen internationally regardless of native English language.

Additionally, there may be a gender difference in telemedicine use. The study by Korzeniowska-Kubacka et al. also revealed that telemedicine has more greatly benefited men than women in the management of cardiovascular disease when evaluating its effectiveness on restoring the wellbeing of patients post-MI.[5] A plausible explanation for this may be the gendered differences in healthcare management, where women may be more likely to minimize symptoms and delay treatment, in combination with a greater burden of caretaking responsibilities and withstanding psychosocial issues.[20,21] Although recent studies have focused on the apparent gender difference in cardiovascular health outcomes[22], more studies need to assess if there is potentially a sex/gender difference in telemedicine use within cardiovascular medicine.

Recommendations

Overall, there has been significant increase in telemedicine usage, receptibility, and funding since the COVID-19 pandemic, leading to improved feasibility and access in its use within a cardiology context. However, there remain issues to address such as ensuring secure telecommunication platforms or obtaining informed consent through virtual means. Cardiologists may have issues obtaining accurate BP, HR, or other cardiovascular metrics, while medication use, dosage, and well-being of patients may not be effectively communicated virtually, especially in elderly patients. Cardiologists are also not able to perform physical exams which is a critical step to detect underlying issues. On the other hand, routine physical exams are unlikely to change in stable patients, and some patients can send pictures of physical symptoms - making these situations more likely to be replaced by telemedicine. Telemedicine also eliminates transportation time, which makes it safer and more accessible for older patients to receive follow-up appointments.

The following recommendations are provided to further improve the infrastructure of telemedicine and absolve existing knowledge gaps on the effectiveness of its use. First, more studies on cost analysis should be conducted to evaluate the long-term economic value of implementing telemedicine in different contexts. It should consider the projected cost of maintaining technological infrastructure, particularly for remote communities. Secondly, as feasibility is unique to the specific field of medicine and greatly differs between various forms of telemedicine usage (e.g., mobile health apps, virtual clinics, virtual rehabilitation therapy), future studies will need to explore feasibility of telemedicine use in specific cardiology contexts. Finally, more controlled retrospective studies or interviews should be conducted to identify specific sex or gender differences - such as health behaviour, health communication, clinical outcomes, and barriers to telemedicine access.

Conclusion

In summary, this review has presented an overview on telemedicine use and effectiveness in cardiology, spanning evidence from primary research, clinical trials, and review. With the surge in popularity during the COVID-19 pandemic, telemedicine has now become an integrated and essential component of cardiovascular medicine. Nonetheless, this review has also highlighted existing knowledge gaps with telemedicine use, such as technical limitations ensuring accurate diagnoses or gendered differences in telemedicine usage and health outcomes. Future telemedicine developments will need to address these issues to achieve widespread acceptance as the new standard of care.

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Appendix: Summary of Search Strategy

Date of Search:
- PubMed: February 2, 2023
- Ovid MEDLINE: February 3, 2023
- Clinicaltrials.gov: February 3, 2023

Source	Search String	Results
PubMed	**With All Terms** ("Telemedicine"[Mesh] NOT "Wearable Electronic Devices"[Mesh]) AND ("Cardiology"[Mesh]) AND ("Patient Satisfaction"[Mesh] OR "Patient Outcome Assessment"[Mesh] OR "Hospitalization"[Mesh] OR "Risk Factors"[Mesh] OR "Blood Pressure"[Mesh] OR "Cholesterol"[Mesh])	18
	General Cardiology ("Telemedicine"[Mesh] NOT "Wearable Electronic Devices"[Mesh]) AND ("Cardiology"[Mesh])	287
	NOT Pediatrics ("Telemedicine"[Mesh] NOT "Wearable Electronic Devices"[Mesh]) AND ("Cardiology"[Mesh] NOT "Pediatrics"[Mesh])	257
	Applied Filter: Clinical Trials	9
	General Cardiology with Heart Attacks ("Telemedicine"[Mesh] NOT "Wearable Electronic Devices"[Mesh]) AND ("Cardiology"[Mesh] OR "Myocardial Infarction"[Mesh]) AND ("Patient Satisfaction"[Mesh] OR "Patient Outcome Assessment"[Mesh] OR	60

Ovid	"Hospitalization"[Mesh] OR "Risk Factors"[Mesh] OR "Blood Pressure"[Mesh] OR "Cholesterol"[Mesh])	
	Applied Filter: Clinical Trials	15
	With All Terms (exp Telemedicine/) AND (exp Cardiology/ OR exp Cardiology Service, Hospital/ OR exp Myocardial Infarction/) AND (exp Patient Satisfaction/ OR exp Outcome Assessment, Health Care/ OR exp Hospitalization/ OR exp Risk Factors/ OR exp Blood Pressure/ OR exp Cholesterol/)	102
	Applied Filter: Clinical Trials	7
	Applied Filter: Evaluation Studies	7
Clinicaltrials.gov	**Keyword**: Telemedicine/Telehealth/e-Health	765
	Keyword: telehealth telemedicine e-health effectiveness feasibility	104
	Condition: coronary disease **Keyword**: telemedicine, clinic	11
	Condition: heart attack **Keyword**: telemedicine, clinic	3

References

1. MEDICARE TELEMEDICINE HEALTH CARE PROVIDER FACT SHEET | CMS. https://www.cms.gov/newsroom/fact-sheets/medicare-telemedicine-health-care-provider-fact-sheet.
2. Wardlow, L. *et al.* Perceptions and Uses of Telehealth in the Care of Older Adults. *Telemedicine and e-Health* tmj.2022.0378 (2022) doi:10.1089/tmj.2022.0378.
3. Vimarlund, V., Koch, S. & Nøhr, C. Advances in E-Health. *Life* **11**, 468 (2021).
4. Shah, B. R. *et al.* Secondary Prevention Risk Interventions Via Telemedicine and Tailored Patient Education (SPRITE): A Randomized Trial to Improve Postmyocardial Infarction Management. *Circ: Cardiovascular Quality and Outcomes* **4**, 235–242 (2011).
5. Korzeniowska-Kubacka, I., Bilińska, M., Dobraszkiewicz-Wasilewska, B. & Piotrowicz, R. Hybrid model of cardiac rehabilitation in men and women after myocardial infarction. *Cardiol J* **22**, 212–218 (2015).
6. Treskes, R. W. *et al.* Effect of Smartphone-Enabled Health Monitoring Devices vs Regular Follow-up on Blood Pressure Control Among Patients After Myocardial Infarction: A Randomized Clinical Trial. *JAMA Netw Open* **3**, e202165 (2020).
7. Liu, H. *et al.* Can WeChat group-based intervention reduce reperfusion time in patients with ST-segment myocardial infarction? A controlled before and after study. *J Telemed Telecare* **26**, 627–637 (2020).
8. Chan, M. Y. *et al.* Remote Postdischarge Treatment of Patients With Acute Myocardial Infarction by Allied Health Care Practitioners vs Standard Care: The IMMACULATE Randomized Clinical Trial. *JAMA Cardiol* **6**, 830 (2021).
9. Osteresch, R. *et al.* Long-Term Effects of an Intensive Prevention Program After Acute Myocardial Infarction. *The American Journal of Cardiology* **154**, 7–13 (2021).
10. Shah, L. M. *et al.* Sociodemographic Characteristics Predicting Digital Health Intervention Use After Acute Myocardial Infarction. *J. of Cardiovasc. Trans. Res.* **14**, 951–961 (2021).
11. Kołtowski, Ł. *et al.* Cardiological teleconsultation in the coronavirus disease 2019 era: patient's and physician's perspective. *Kardiol Pol* **79**, 76–78 (2021).
12. Telemedicine in Cardiac Surgery: A Pilot Study. *ClinicalTrials.gov* https://clinicaltrials.gov/ct2/show/NCT01163474.
13. Mobile Health in Structural Heart Disease. *ClinicalTrials.gov* https://clinicaltrials.gov/ct2/show/NCT02881398.
14. Bhavnani, S. P. *et al.* A Randomized Trial of Pocket-Echocardiography Integrated Mobile Health Device Assessments in Modern Structural Heart Disease Clinics. *JACC Cardiovasc Imaging* **11**, 546–557 (2018).

15. Mobile App and Digital System for Patients After Myocardial Infarction. *ClinicalTrials.gov* https://clinicaltrials.gov/ct2/show/NCT04793425.
16. Telehealth-enhanced Hybrid Cardiac Rehabilitation Among Acute Coronary Syndrome Survivors. *ClinicalTrials.gov* https://clinicaltrials.gov/ct2/show/NCT05328375.
17. Saner, H. & van der Velde, E. eHealth in cardiovascular medicine: A clinical update. *Eur J Prev Cardiol* **23**, 5–12 (2016).
18. Kozik, M., Isakadze, N. & Martin, S. S. Mobile health in preventive cardiology: current status and future perspective. *Current Opinion in Cardiology* **36**, 580–588 (2021).
19. Velázquez Fuentes, M. N., Shah, P. & Hale, G. M. Improving medication adherence in patients with hypertension through pharmacist-led telehealth services. *J Telemed Telecare* **28**, 613–617 (2022).
20. Understanding the heart attack gender gap. *Harvard Health* https://www.health.harvard.edu/blog/understanding-heart-attack-gender-gap-201604159495 (2016).
21. Mosca, L., Barrett-Connor, E. & Kass Wenger, N. Sex/Gender Differences in Cardiovascular Disease Prevention: What a Difference a Decade Makes. *Circulation* **124**, 2145–2154 (2011).
22. Dreyer, R. P. *et al.* Gender Differences in the Trajectory of Recovery in Health Status Among Young Patients With Acute Myocardial Infarction: Results From the Variation in Recovery: Role of Gender on Outcomes of Young AMI Patients (VIRGO) Study. *Circulation* **131**, 1971–1980 (2015).