CONTEMPORARY REVIEW

Advancing telemedicine in cardiology: A comprehensive review of evolving practices and outcomes in a postpandemic context

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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 a health care provider. As telemedicine infrastructure has changed since the coronavirus disease 2019 (COVID-19) pandemic, this review provides an overview of telemedicine use and effectiveness in cardiology, with emphasis on coronary artery disease in the postpandemic context. Prepandemic studies tend to report statistically insignificant or modest improvements in cardiovascular disease outcome from telemedicine use to usual care. In contrast, postpandemic studies tend to report positive outcomes or comparable acceptance of telemedicine use to usual care. Today, telemedicine can effectively replace in person follow-up visits to produce comparable (but not necessarily superior) outcomes in cardiovascular disease management. A benefit of telemedicine is the potential reduction in follow-up time or time to intervention, which may lead to earlier detection and prevention of adverse events. Nonetheless, barriers remain to effective telemedicine implementation in the postpandemic context. Ensuring accessible and user-friendly telemedicine devices, maintaining adherence to remote rehabilitation procedures, and normalizing use of telemedicine in routine follow-up visits are examples. Current knowledge gaps include the true economic cost of telemedicine infrastructure, feasibility of use in specific cardiology contexts, and sex/gender differences in telemedicine use. Future telemedicine developments will need to address these concerns before acceptance of telemedicine as the new standard of care.

KEYWORDS Cardiology; Cardiovascular medicine; e-Health; mHealth; Myocardial infarction; Telehealth; Telemedicine

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Introduction

Telemedicine refers to the exchange of medical information or medical care from one site to another through electronic communication between a patient and a health care provider.[1] This includes consultations via virtual conferencing (eg, Zoom, Microsoft Teams), phone calls, or text messages. Major improvements to telemedicine infrastructure during the coronavirus disease 2019 (COVID-19) pandemic have now positioned telemedicine as a safe, efficient, convenient, and accessible method of accessing care. Many health care providers and patients are willing to embrace telemedicine as the primary method ("the new normal") of health care delivery in hospitals, long-term care facilities, and outpatient settings.[2] Commonly cited benefits of telemedicine include lowering health system costs, increasing access to care, decreasing time for scheduled visits, reducing cancellation rates, fewer hospitalizations, increasing patient satisfaction, decreasing emergency department use, and improving social connectedness.[2]

Telemedicine use has seen a sharp increase since the pandemic, with a 154% increase in telemedicine visits in the United States (U.S.) in 2020 compared to the same week in 2019, with similar trends seen globally.[3] After the pandemic, telemedicine usage has remained higher than prepandemic levels, with an average of 22.0% of U.S. adults using telemedicine within a 4-week span in 2022.[4] Nonetheless, there remain social and logistical barriers that prevent widespread and lasting adoption of this technology, issues that are unique to each medical speciality. For example, in the context of cardiology in which patients often are older, health care providers may believe telemedicine is not ideal because it is more difficult to discern medically complex issues or establish a relationship with the patient virtually.[2] The cognitive or physical impairments suffered by some patients receiving cardiac care also may make telemedicine use unrealistic.[2] General concerns revolve around accessibility of telemedicine platforms, digital literacy, proficiency in care delivery,

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KEY FINDINGS

- Prepandemic studies tend to report statistically insignificant or modest improvements in cardiovascular disease outcome from telemedicine use to usual care. In contrast, postpandemic studies tend to report positive outcomes or comparable acceptance of telemedicine use to usual care.
- A benefit of telemedicine is the potential reduction in follow-up time or time to intervention, which may lead to earlier detection and prevention of adverse events.
- Barriers to effective telemedicine implementation in the postpandemic context include providing accuracy and ease of use of telemedicine devices, ensuring adherence to remote rehabilitation procedures, and implementing widespread telemedicine infrastructure.
- 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.

and health data privacy concerns with virtual doctor–patient communication.[5] In cardiology, physical examination including auscultation is greatly hindered (or not possible) through virtual encounters, which may delay the detection of health conditions.[6]

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 outcomes in a postpandemic context from 2020–2022 and onward. We present peer-reviewed evidence on telemedicine for diseases such as coronary artery disease and reviews articles, and briefly discuss ongoing clinical trials using telemedicine for cardiovascular care.

Methods

Given the heterogeneous usage of telemedicine in cardiology, a comprehensive narrative review of high-quality studies was conducted to present the current state of the field and highlight emerging knowledge gaps.

Search strategy and selection criteria

Pilot studies were conducted on January 2023 in multiple databases (PubMed, MEDLINE, Scopus, Google Scholar) to define the initial search parameters. A set of detailed searches was conducted in February 2023 in 2 peer-reviewed databases (PubMed, Ovid MEDLINE^{R} ALL) and ClinicalTrials.gov, using Medical Subject Headings (MeSH) terms where appropriate (see Supplemental 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/or study descriptions were screened to include studies that pertained to the feasibility of telemedicine in cardiology. For example, studies were included if they measured "feasibility" according to empirical or clinical parameters, or described feasibility of telemedicine usage alongside clinical, practical, or social determinants of health considerations. Published and completed clinical 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 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 ultimately were chosen. The studies start from 2011, although most studies were published 2020 or after.

Results

Articles included peer-reviewed published clinical research, ongoing clinical trials, and reviews on the effectiveness of telemedicine in cardiology. Articles were stratified into research conducted before the pandemic (before 2019) and research conducted during or after the pandemic (2020 and after). Summaries of the major findings from each included study are given in Tables 1, 2, and 3.

Published clinical research

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

Prepandemic studies

Of the 2 studies published before 2019, the oldest study by Shah et al[7] in 2011 evaluated the effect of virtual telemedicine interventions compared to usual care (UC) and nurse-administered care on risk factor modification and outcomes of long-term cardiovascular disease management. A total of 450 patients in the United States with recent MI and hypertension were enrolled in a 3-arm randomized controlled trial—SPRITE (Secondary Prevention Risk Interventions via Telemedicine and tailored patient Education). The telemedicine intervention itself was HealthVault, a Web-based data tracking system of home blood pressure (BP) measurements. A total of 150 participants were randomized to one of each arm: (1) standard of care (SC) (control group); (2) nurse-administered behavioral and education self-management intervention plus the use of HealthVault; or (3) a Web-based behavioral and education self-

Table 1 Summary of published clinical studies

Author (year)	Aim	Disease	Study design	Interventional population (n)	Control population (n)	Outcomes	Main findings
Prepandemic							
Shah et al (2011)	To evaluate the effect of 2 tele-interventions compared with UC 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 SBP, LDL cholesterol, body weight, and HbA_{1c} (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 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 HbA_{1c}, 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.	MI	Nonrandomized 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, return to work was significantly greater only in men.
Postpandemic							
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.	MI	Single-center, nonblinded, 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 SC. Such an intervention is feasible in clinical practice and is accepted by patients.
Osteresch et al (2021)	To evaluate the effects of a 12-month IPP, based on repetitive contacts between nonphysician "prevention assistants" and patients.	MI	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 toward less serious clinical events with minimal cost.

(*Continued*)

Table 1 (*Continued*)

Author (year)	Aim	Disease	Study design	Interventional population (n)	Control population (n)	Outcomes	Main findings
Shah et al (2021)	To evaluate whether sociodemographic characteristics influence use of a DHI targeting 30-day readmission reduction after AMI.	MI	Multicenter prospective study	133	-	(1) Use of 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.
Chan et al (2021)	To compare the safety and efficacy of allied health care practitioner-led RIM with cardiologist-led SC.	MI	Randomized controlled trial	301	152	(1) Hypotension, bradycardia, hyperkalemia, or acute kidney injury requiring hospitalization (2) Six-month indexed LVESV adjusted for baseline LVESV	Among low-risk patients with revascularization after MI, 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 teleECG services via the WeChat group application, to reduce the time taken for diagnosis and treatment of ST-elevation MI.	MI	Controlled before and after Study	70	70	(1) Reperfusion time comparison between 2 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	Median symptom onset to FMC time was similar between WeChat and control groups, but median FMC to wire, door to wire, and FMC to catheterization laboratory activity were significantly shorter in the WeChat group. Prehospital ECG transfer via WeChat resulted in earlier reperfusion of transferred MI 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.	Nonspecific	Observational study	100	—	Acceptance of teleconsultation	Teleconsultation acceptance rate was rated 8 among patients and 10 for physicians. More than 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 prepandemic period, as teleconsultations took place instead of regular visits.

AMI = acute myocardial infarction; CABG = coronary artery bypass graft; CR = cardiac rehabilitation; DBP = diastolic blood pressure; DHI = digital health intervention; ECG = electrocardiogram; FMC = first medical contact; HbA_{1c} = glycosylated hemoglobin; HR = heart rate; IPP = intensive prevention program; LDL = low-density lipoprotein; LVESV = left ventricular end-systolic volume; MI = myocardial infarction; PCI = percutaneous coronary intervention; RIM = remote intensive management; SBP = systolic blood pressure; SC = standard of care; UC = usual care.

Table 2 Summary of unpublished clinical studies

Study name	Date started	Date completed	Aim	Condition	Phase	Study design	Participants (n)	Randomization	Interventions	Status	Trial no.
Prepandemic											
Telemedicine in Cardiac Surgery: A Pilot Study	July 2010	January 2015	To compare the accuracy of surgeons' decisions during follow-up visits via V-Visit to surgeons' decisions during traditional FTF-Visits.	Coronary artery disease	Early phase 1	Interventional (clinical trial)	40	Nonrandomized	Evaluate video clinic visit before face-to-face usual care visit	Completed with results	NCT01163474
Mobile Health in Structural Heart Disease (ASEF-VALUES)	August 2014	January 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 shorten the time to definitive therapy.	Rheumatic heart disease	Phase 2, phase 3	Interventional (clinical trial)	253	Randomized	mHealth, SC	Completed	NCT02881398
Postpandemic											
Mobile App and Digital System for Patients After Myocardial Infarction (afterAMI)	December 2020	—	To study the impact of application-supported model of care with comparison to SC, 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 Hybrid Cardiac Rehabilitation Among Acute Coronary Syndrome Survivors	March 2022	-	To investigate the feasibility of conducting a randomized controlled trial of THCR compared with traditional CR among ACS survivors.	Acute Coronary Syndrome, Myocardial Infarction	N/A	Interventional (Clinical Trial)	40	Randomized	Behavioral: THCR, traditional CR	Recruiting	NCT05328375

ACS = acute coronary syndrome; FTF-Visit= face-to-face follow-up visit; THCR = telehealth-enhanced hybrid cardiac rehabilitation; V-Visit = video-teleconference; other abbreviations as in Table 1.

management intervention plus the use of HealthVault. Both interventional groups received ambulatory BP monitors and HealthVault. The primary outcome was reduction in systolic blood pressure (SBP) at 12 months compared to control. Secondary outcomes were reductions in low-density lipoprotein (LDL) cholesterol, body weight, and glycosylated hemoglobin, with adherence to preventative care and improvement in health behaviors. 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-up visits within 14 months of enrollment. The main outcomes were not statistically significant for changes over time by treatment groups for glycated hemoglobin (HbA_{1c}), SBP, diastolic BP, or LDL. Behavioral 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 mm Hg ($P = .11$) in SBP in the nurse-administered arm.

A 2015 study in Poland by Korzeniowska-Kubacka et al[8] evaluated a hybrid model of cardiac rehabilitation in men and women after MI. The study compared the effect of usual outpatient care vs tele-electrocardiogram (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 outpatient clinic; the remaining training was completed at home via teleECG monitoring. Patients underwent a symptom-limited exercise stress test while the ECG was monitored, and heart rate (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.

Postpandemic studies

Of the studies occurring during or postpandemic, 1 study was published in 2020, and 5 studies were published in 2021. The 2020 Netherlands study by Treskes at al[9] evaluated the feasibility of whether smart technology in clinical practice can improve BP regulation through a single-center, nonblinded, randomized clinical trial. A total of 200 patients were randomized 1:1 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

Table 3 Summary of review findings

Year	Title	Author	Aim	Review type	Main findings
Prepandemic					
2016	eHealth in cardiovascular medicine: A clinical update	Hugo Saner, Enno van der Velde	To describe opportunities and challenges of e-Health and telemedicine in the framework of our health systems and, in particular, in the context of today's cardiology services.	Narrative review	The most promising applications of e-Health and telemedicine include • Prevention and lifestyle interventions • Chronic disease management (eg, hypertension, diabetes, heart failure) • Arrhythmia detection (eg, early detection of atrial fibrillation and telemonitoring via devices such as pacemaker, internal cardioverter-defibrillator, and implantable rhythm monitoring device) • 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

Postpandemic					
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 health care 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 • Pharmacist-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

CVD = cardiovascular disease.

performed at 3 months. A 24-hour Holter 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 nonfatal adverse cardiac events. After 1 year, 79% of telemedicine patients had controlled BP vs 76% of control patients ($P = .64$). Overall satisfaction with SC was the same between groups (mean SD scores 82.6 [14.1] vs 82.0 [15.1]; $P = .88$). All-cause mortality rate was 2% in both groups ($P > .99$). A total of 20 hospitalizations for nonfatal adverse cardiac events occurred (8 in the intervention group and 12 in the control group). Within the telemedicine arm, 90.3% of patients were satisfied with smart technology intervention. The investigators concluded that smart technology yields similar patient outcomes of regulated BP compared with SC, 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[10] evaluated the effectiveness of providing 24-hour teleECG services via WeChat (a popular mobile app messaging platform) for patients who were transferred from a hospital without percutaneous coronary intervention (PCI) capability to a hospital capable of PCI. The goal was to reduce the time taken for diagnosis and treatment of ST-elevation myocardial infarction (STEMI). Through a controlled pre–post study within a 9-month sampling time frame, 70 STEMI postincidence PCI patients had ECGs recorded from the non-PCI hospital and pretransmitted to the PCI hospital via WeChat. The control group had 70 patients who did not pretransmit ECGs, who subsequently were 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 during acute care. It was revealed that re-hospital ECG transfer via a WeChat group resulted in earlier reperfusion of STEMI. Median time between symptom onset to first medical contact time was slightly shorter (129 minutes for telemedicine vs 150 minutes for control; $P > .05$), but median time for medical contact and medical intervention such as catheterization laboratory activity was significantly shorter in the WeChat group by 30–40 minutes ($P < .001$).

In Singapore, a multicenter randomized clinical trial conducted by Chan et al[11] evaluated the safety and efficacy of allied health care practitioner-led remote intensive management (RIM) with cardiologist-led SC for post–acute MI patients (IMMACULATE [IMproving reModeling in Acute myoCardial Infarction Using Live and Asynchronous Telemedicine]). A total of 301 participants were randomized 1:1 to RIM or SC. Baseline cardiac magnetic resonance imaging was performed within 5–10 days of hospital admission and repeated at 6 months. Participants received RIM-transmitted BP and HR measurements 2 times per day using a Bluetooth-enabled device immediately after baseline cardiac magnetic resonance 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 concentrations were performed at 30 days unless needed earlier. Participants in the SC arm received regular face-to-face consultations with their cardiologists, who provided the medication adjustment. The primary endpoint was 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 postdischarge, RIM participants had an equally low number of safety events and used similar dosages of β-blockers, angiotensin-converting enzyme inhibitors, and angiotensin II receptor blockers, with no differences in left ventricular remodeling outcomes compared to the control arm.

In Germany, a randomized control trial by Osteresch et al[12] evaluated the effectiveness between a telemedicine-based intensive prevention program (IPP) and UC for 12 months. Post-MI patients after 3 weeks of acute cardiac rehabilitation were randomly assigned to 12-month 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 score. Further study endpoints were single risk factors, medical treatment, serious clinical events, costs, and quality of life. IPP resulted in a slight improvement in risk factor control with less serious clinical events (12.5% vs 20.9%; log-rank $P = .06$) compared to UC after 24 months. Usage of IPP 24 months after MI further improved risk factor control, such as LDL cholesterol and BP lowering. In addition, after 24 months, the costs of IPP were lower than those of UC (cost per patient 1070 € for IPP vs 1170 € for UC), making telemedicine-based care an economically comparable option.

Looking at other aspects of telemedicine feasibility, a U.S. multicenter, prospective study evaluated whether sociodemographic characteristics influence use of a digital health intervention (DHI) in 30-day readmission reduction after acute MI.[13] 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 BP monitor on enrollment. Patients used these interventions while hospitalized and for 30 days postdischarge. Demographic data (age, sex, race, marital status, and

insurance status), clinical data, digital health characteristics, and patient self-report questionnaires were collected remotely. 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 odds ratio [OR] 0.98, 95% confidence interval [CI] 0.95–1.01; 0.6, 95% CI 0.29–1.25; and 1.22, 95% CI 0.60–2.48, respectively). However, this may be due to the small sample size (n = 133) with imprecise CIs. In contrast, 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[14] 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. Through an observational, noninvasive, nonrandomized 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 (3 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. Median interquartile range of acceptance rate with teleconsultation was 8 (range 7–10) among patients and 10 (range 8–10) for physicians (r = –0.03; P = .81). More than half of the patients (57%) preferred teleconsultation to traditional home visits as the SC. Most patients (85%) stated all medical issues were addressed. All patients received an electronic prescription when needed. The time frame between follow-up visits was identical with the prepandemic period, with teleconsultations taking place instead of regular in-person visits.

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

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. Most prepandemic studies have been completed (1 with results), whereas the postpandemic studies currently are 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 dating back to July 2010, which compared the accuracy of surgeons' decisions in postoperative follow-up visits using video teleconference vs traditional face-to-face visits for patients with coronary artery disease.[15] A total of 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 diagnosis). Secondary outcomes were acceptability (measured by the Likert scale questionnaire) and feasibility (via questionnaire). Of the 40 participants, only 24 completed the study; 12 participants withdrew because of barriers with teleconference access. Mean age was 64 ± 8.3 year, and all participants were male. Most participants (n = 16) were White. Of the 24 total participants, there was high agreement (89%) in accuracy between virtual and in-person diagnoses. According to participants, 68% were agreeable to the use of telemedicine. Participants were followed up after 1 year, with no adverse events or mortality reported. The study had no associated publications.

Another U.S. and Indian multicenter 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.[16] These patients were located in resource-limited areas and disproportionately received low allocations of health services and interventions. The aim was to assess whether 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 (eg, smart-ECG, activity monitors, connected BP devices, handheld ultrasounds) or SC in-person cardiology evaluations. Primary outcome was time to definitive treatment with valvuloplasty or valve replacement within 12 months. Secondary outcomes were cardiovascular hospitalization and/or death within 12 months. According to published results, mHealth use was associated with a shorter time to referral for valvuloplasty and/or valve replacement (83 ± 79 days vs 180 ± 101 days; P <.001), with no significant difference for valvuloplasty/valve replacement rates compared to SC (34% vs 32%; adjusted hazard ratio 1.54; 95% CI 0.96–2.47; P = .07).[17] mHealth patients were also associated with a lower risk of hospitalization and/or death on follow-up (15% vs 28%, adjusted hazard ratio 0.41; 95% CI 0.21–0.83; P = .013).

Trials that started during the pandemic showcase future directions of telemedicine use in cardiology. A clinical trial that began in December 2020 aims to comprehensively assess the impact of telemedicine use for 6 months after MI hospitalization discharge compared to in-person SC follow-up visits.[18] A proposed 100 participants will be randomized to either the virtual arm or the SC control arm, with endpoints collected 1 and 6 months after discharge from the hospital. Participants in the virtual arm will have access to a mobile application that tracks vital signs, provides educational content, and coordinates rehabilitation therapy. Primary outcomes will measure cardiovascular risk factor control (hypertension, body mass, nicotine use, 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 Depression Anxiety Stress Scales, and quality of life via the MacNew questionnaire and 5-level EuroQol–5D version questionnaire. The estimated project completion date was July 2023.

Finally, a key trial that started in March 2022 will compare the feasibility of telehealth-enhanced hybrid cardiac rehabilitation with traditional cardiac rehabilitation among survivors of acute coronary syndrome. Telehealth-enhanced hybrid cardiac rehabilitation is an increasingly popular hybrid model that combines traditional therapy (eg, exercise training, patient education, and risk factor management) with telemedicine, clinic, and home-based activities.[19–21] All 40 proposed participants will attend a total of 24 cardiac rehabilitation sessions (either 5 in-clinic + 19 remote sessions or 24 standard in-clinic control sessions) over a 12-week period. The primary outcome is the completion rate of each arm, with secondary outcomes of feasibility based on the Feasibility of Intervention Measure score, pre-to-post program change in functional capacity using the 6-minute walk test, and pre-to-post program change in health-related quality of life via the Duke health profile questionnaire. The estimated project completion date was December 2023.

Reviews

Each of the 3 selected reviews focuses on a different aspect of telemedicine use in cardiology. The oldest article from 2016 describes the benefits and challenges of telemedicine in the prepandemic context of cardiology.[22] Global benefits of telemedicine include (1) improved access to follow-up visits, leading to better chances of altering negative lifestyle habits; (2) mitigating access barriers for low-density, elderly, or chronic disease populations; and (3) optimization of data transfer and treatment processes. The most promising applications of telemedicine in cardiology are (1) prevention and lifestyle interventions; (2) chronic disease management such as hypertension, diabetes, and heart failure; (3) early arrhythmia detection; and (4) rehabilitation. Prepandemic obstacles to implementing widespread telemedicine infrastructure were described as (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.

After the pandemic, a September 2021 U.S. review presented an update on mobile health application use in cardiovascular disease management and provided insight on barriers to effective implementation.[23] Although there is widespread support for 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 multirisk factor modification in cardiac rehabilitation. Socioeconomic status and age remain significant factors to successful mHealth use, whereas lack of reimbursement structures and application heterogeneity represent existing challenges to telemedicine infrastructure. It was speculated that 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 U.S. scoping review of 17 articles examined the benefits of using pharmacist-led telemedicine services in medication adherence for patients with hypertension.[24] 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 BP lowering in patients with hypertension. Nonetheless, there are limitations to the accuracy of telemedicine management, such as monitoring BP and identifying symptoms of hypertensive crises from home, which can apply beyond the hypertension context. Thus far, the studies presented provide a multifaceted portrayal of telemedicine in cardiovascular medicine, for its feasibility in diagnosis, follow-up, and preventative care.

Discussion

Here we highlight notable themes that emerged from the collection of telemedicine studies, particularly for coronary artery disease.

Pre- and Postpandemic differences in telemedicine use

The comparably higher number of publications released 2020 or afterward reflects the booming interest in telemedicine brought forth by the pandemic. Among the included studies, prepandemic studies tended to report statistically insignificant or modest improvements in cardiovascular disease outcome when using telemedicine over UC.[7,8] In comparison, most postpandemic studies reported either a clear positive benefit or comparable acceptance of telemedicine to in-person controls.[10,12,14] 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 whether telemedicine can be used as a standalone service for all primary care interactions. The major barriers today preventing effective telemedicine implementation are mitigating access barriers to telemedicine devices, ensuring adherence to remote rehabilitation procedures, and implementing widespread telemedicine infrastructure.[23,24]

The extant evidence suggests that mobile health use can be used to replace in-person follow-up visits to produce comparable (but not necessarily superior) outcomes in cardiovascular disease management.[9] 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.[10] However, many earlier studies reported limited statistical significance in outcomes, which can allude to practical challenges in effective telemedicine implementation.[7] For example, ensuring patients follow through on long-term rehabilitation regimens via telemedicine remains a challenge in the postpandemic context. The decreased oversight from an in-person follow-up visit can be a reason for this finding, 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 postpandemic 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 economic cost or clinical outcomes.[13,14] This is a reflection of the changing discourses surrounding the receptibility of telemedicine use postpandemic—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 process since the pandemic. A variety of terms were used to describe virtual or remote interventions before the pandemic, whereas studies more explicitly and consistently use unified terms such as "telemedicine" or "telehealth" after the pandemic—a trend seen internationally regardless of native English language.

Additionally, gender differences remain in telemedicine use. The study by Korzeniowska-Kubacka et al[8] revealed that telemedicine has more greatly benefited men than women in the management of cardiovascular disease when evaluating its effectiveness in restoring the wellbeing of patients post-MI. A plausible explanation for this may be the gendered differences in health care management, in which women may be more likely to minimize symptoms and delay treatment, in combination with a greater burden of caretaking responsibilities and withstanding psychosocial issues.[25,26] However, the study sample of women was comparatively smaller than the men, thereby compromising the strength of the findings. Although recent studies have focused on the apparent gender difference in cardiovascular health outcomes,[27] more studies need to assess whether there is potentially a sex/gender difference in telemedicine use within cardiovascular medicine.

Cardiology-specific benefits and barriers to effective telemedicine implementation

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. For example, telemedicine eliminates transportation time, which makes it safer and more accessible for older patients to receive follow-up appointments. More importantly, it offers significant, but often underrecognized, advantages, particularly for refugees, displaced populations, or patients in occupied territories or temporary shelters. In these contexts, telemedicine can greatly reduce wait times for consultation and provide ease of access to diagnose conditions, leading to improved access for otherwise vulnerable populations. Cardiologists, who may be displaced themselves, are able to follow up with patients as well. Patients can send data from wearable devices to provide additional health data to cardiologists who may otherwise be unavailable for detailed monitoring. Telemedicine can also help facilitate faster and direct communication between primary care practitioners and cardiologists for specialized treatment in situations where only a primary care practitioner may be available.

Nonetheless, there remain issues to address with telemedicine implementation, particularly along the socioeconomic front. Inequitable access to telemedicine has been noted in patients who are of the female sex, are older, are located in rural/remote areas without broadband Internet access, are of lower socioeconomic status (median household income under $50,000), do not have private health insurance, or are non-English speakers in English-speaking countries.[6,28] Black, Hispanic, and Asian populations were also noted to have lower rates of telemedicine use during the early stages of the pandemic.[6,28] These inequities point to the ongoing barriers in establishing universal access to telemedicine, namely, that significant improvements to technological infrastructure (particularly Internet connection) and financial compensation are needed to promote access for underrepresented communities.

Due to technological limitations of mobile health devices, cardiologists may have issues obtaining detailed BP, HR, or other cardiovascular metrics, while medication use, dosage, and well-being of patients may not be effectively communicated virtually, especially from elderly patients.[29] Thus, the feasibility and effectiveness of telemedicine in cardiology are dependent on the ease of use and accuracy of wearable health devices. Cardiologists are unable to perform physical examinations for visits that require close follow-up, which is a critical step to detection of underlying issues such as heart failure. A proposed middle ground can be the promotion of telemedicine use for in-person initial visits with virtual follow-up visits for stable patients. The use of digital tools for monitoring weight, ECG readings, and BPs can partially supplement the workflow of cardiologists in follow-up visits, although the long-term benefits and effectiveness of digital monitoring remain to be discerned. It is important to note that routine physical examinations are unlikely to change in stable patients, making these situations more likely to be replaced by telemedicine.

Recommendations

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. Second, because feasibility is unique to the specific field of medicine and greatly differs among various forms of telemedicine usage (eg, mobile health apps, virtual clinics, virtual rehabilitation therapy), future studies will need to explore the feasibility of telemedicine use in specific cardiology contexts. Finally, more controlled retrospective studies or interviews should be conducted to measure the extent of sex or gender differences, such as health behavior, health communication, clinical outcomes, and barriers to telemedicine access.

Conclusion

This review has presented an overview of 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 SC.

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Authorship

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Appendix

Supplementary data

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