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A systematic review of mHealth-based heart failure interventions

Maan Isabella Cajita, BSN, RN-BC [PhD Student],
Johns Hopkins University School of Nursing, Baltimore, Maryland, USA

Kelly T. Gleason, BSN, RN [PhD Student], and
Johns Hopkins University School of Nursing, Baltimore, Maryland, USA

Hae-Ra Han, PhD, RN, FAAN [Associate Professor]
Johns Hopkins University School of Nursing, Baltimore, Maryland, USA

Abstract

Background—The popularity of mobile phones and similar mobile devices makes it an ideal medium for delivering interventions. This is especially true with heart failure (HF) interventions, in which mHealth-based HF interventions are rapidly replacing their telephone-based predecessors.

Purpose—This systematic review examined the impact of mHealth-based HF management interventions on HF outcomes. The specific aims of the systematic review are to: (1) describe current mHealth-based HF interventions and (2) discuss the impact of these interventions on HF outcomes.

Methods—PubMed, CINAHL Plus, Embase, PsycINFO, and Scopus were systematically searched for randomized controlled trials or quasi-experimental studies that tested mHealth interventions in people with HF using the terms *Heart Failure*, *Mobile Health*, *mHealth*, *Telemedicine*, *Text Messaging*, *Texting*, *Short Message Service*, *Mobile Applications*, and *Mobile Apps*.

Conclusions—Ten articles, representing nine studies, were included in this review. Majority of the studies utilized mobile health technology as part of a HF monitoring system, which typically included a blood pressure measuring device, weighing scale, and an ECG recorder. The impact of the mHealth interventions on all-cause mortality, cardiovascular mortality, HF-related hospitalizations, length of stay, NYHA functional class, LVEF, quality of life, and self-care were inconsistent at best.

Implications—Further research is needed to conclusively determine the impact of mHealth interventions on HF outcomes. The limitations of the current studies (e.g. inadequate sample size, quasi-experimental design, use of older mobile phone models, etc.) should be taken into account when designing future studies.

Keywords

Heart failure; mHealth; mobile health; telemedicine; text messaging

Corresponding Author: Maan Isabella Cajita, (Telephone) 443-570-7329; (Fax) 410-203-2685, mcajita1@jhu.edu.

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Background

In the United States, 5.1 millions adults have heart failure (HF)[1] and approximately $31 billion are spent annually in HF-related costs[2]. The majority of HF-related costs are attributed to hospitalizations,[2] which are most often the result of poor HF self-management. The complexity of HF self-management contributes to the poor adherence to recommended HF treatment plans and, ultimately, to frequent hospitalizations.

Telemedicine, or the use of information and communication technology to bridge the distance barrier in order to improve health outcomes, was first coined in the 1970s.[3] In cardiology, early forms of telemedicine involved the transmission of electrocardiograph data over telephone lines.[4] In HF management, the use of technology in monitoring patients' conditions remotely or telemonitoring, were first tested in the late 1990s.[5] Eventually, as technology evolved so did its health-related applications.

As mobile phones became more ubiquitous, researchers started to turn their attention to the utility of mobile phones and similar portable devices in health-related interventions. It is estimated that 90% of adult Americans have mobile phones and 58% have smartphones.[6] The popularity of the mobile phone and its rapidly increasing computing capabilities, makes it an ideal tool for delivering health care. mHealth, or the use of mobile technologies in the delivery of healthcare services to support the achievement of health objectives,[7] first appeared in publication in 2003 and has since seen an exponential increase in usage.[8] mHealth has been utilized in managing other chronic diseases such diabetes,[9,10] hypertension,[11,12] and chronic obstructive pulmonary disease[13]; wherein, it has been shown to decrease HbA1c,[9,10] decrease blood pressure,[11,12] and increase exercise capacity,[13] respectively.

While there have been several systematic reviews of the use of technology in HF management they were focused on older telephone-based technology, [5,14–17] which, with the advent of the mobile phone, has been rendered near obsolete.[18] Therefore a systematic review focusing on current mobile health technology is warranted. The purpose of this systematic review is to examine the impact of HF management interventions using mHealth technology on HF outcomes. Specifically, this systematic review aims to (1) describe current mHealth-based HF interventions and (2) discuss the impact of these interventions on HF outcomes.

Methods

Five databases (PubMed, CINAHL Plus, Embase, PsycINFO, and Scopus) were systematically searched for relevant studies with the help of a medical librarian. The following search terms were used: *Heart Failure, Cardiac Failure, Heart Decompensation, Myocardial Failure, Congestive Heart Failure, Mobile Health, mHealth, Telemedicine, Text Messaging, Texting, Short Message Service, Text Messages, Mobile Applications, Mobile Apps, and Mobile App.* Studies were included if they met the following criteria: (1) used a randomized control trial or a quasi-experimental design, (2) tested an intervention using a mobile device (by itself or as part of a system), (3) included HF patients ≥18 years, and (4)

published in English. Studies were excluded if they tested a traditional telephone-based HF intervention and only had abstracts or study protocols available. Only relevant articles published before June 5, 2015 were included in this systematic review.

The initial database search yielded 1882 citations. After the predefined filters (i.e. age, language) were applied, 706 citations remained. 488 abstracts remained after duplicates were removed and were then subsequently reviewed for their relevance. Following the abstract review, full-text evaluations of the remaining 77 articles were conducted, which resulted in the inclusion of 9 articles. A manual search of the references of the included articles yielded 1 additional relevant study. A total of 10 articles, representing 9 studies (i.e. two articles[19,20] were on the same intervention but reported on different outcomes), were included in this systematic review (Figure 1).

The Cochrane Collaboration's tool for assessing risk of bias was used to appraise the rigor of the included studies.[21] The tool assesses for risk of selection bias, performance bias, detection bias, attrition bias, and reporting bias. Risk assessments can be presented in the form of a pictograph and/or a table containing the risk ratings (high risk, low risk, or unclear risk) alongside the reviewers' rationales.[21] Two reviewers independently assessed the rigor of the included studies with a 91% agreement rate (Kappa 0.86, $P<0.001$); discrepancies were discussed then reconciled. Inter-rater agreement was calculated using Stata 13 (StataCorp LP, College Station, Texas, USA). The first author performed the data extraction and the second author reviewed the data extraction table for accuracy. The heterogeneity of the mHealth interventions and the measured outcomes (i.e. all-cause/cardiovascular mortality, HF hospitalizations, length of stay, New York Heart Association (NYHA) functional class, left ventricular ejection fraction (LVEF), quality of life, and self-care) precluded the conduct of a meta-analysis; hence, a systematic review with descriptive synthesis was performed and quantitative results from the individual studies are presented to support the narrative.

Results

Key characteristics of the included studies are summarized in Table 1. Six of the nine studies included in this review were randomized control trials and the remaining studies utilized a quasi-experimental design. Only three of the studies reported the racial composition of their study sample (overall, 68% White, 18% Black, 14% other race) and all were conducted in North America.[22–24] The remaining 6 studies were conducted in Europe and Australia. Study duration ranged from 4 weeks to 24 months. The number of study participants ranged from 6 to 710 totaling 1777 participants. The mean age of the study participants was 61.3 years. The majority of the study participants (81.1%) were male. The mean LVEF of the study samples was 29.1%. On average, <1% of the study participants were in NYHA functional class I, 44.5% were in class II, 53.7% were in class III, and the remaining 1.5% were in class IV.

The results of the bias risk assessments are depicted in Figure 2 and Figure 3. Overall, the methodological rigor of the included studies was moderate. Although two studies[19,20,25] had low risk of bias in all categories, majority of the studies had a high risk for bias in at least

one bias category. Additionally, majority of the studies failed to provide enough information to allow for a complete assessment of their risk of bias (i.e. unclear risk of bias).

Characteristics of Current mHealth Interventions

Key characteristics of the mHealth interventions are summarized in Table 2. The majority of the studies (8 of 9) used mobile devices as part of a larger HF monitoring system, which typically included a blood pressure measuring device, [16,18,20–22,26] weighing scale,[24,26,19,20] electrocardiogram (ECG) recorder, [24,19,27] or an implantable defibrillator equipped with a heart rhythm monitoring function[25]. Only one study used mHealth as a stand-alone intervention.[23] Nundy et al. used the mobile phone to deliver daily HF education messages to their study participants via text messaging.[23] In the studies, various mediums were used to transmit data including mobile phones (n=5),[23,24,28,29] small wireless devices (n=2),[19,25] or tablets (n=2).[22,26]

Seven of the eight mHealth monitoring systems utilized a central monitoring center/ platform; five allowed for automatic data transfer between the participants and the monitoring center,[22,24,19,27,25] while the remaining two required the participants to manually input and transfer their data to the monitoring center.[28,29] Four of the monitoring systems utilized algorithms to determine whether the patients' values were outside their predefined limits,[22,24,28,29] which would then trigger an alert message to be sent to the participants' physicians.[24,28,29] Meanwhile, two of the studies had trained nurses and physicians in their central monitoring centers who regularly monitored the participants' status.[19,25] The remaining study did not specify who/what performed the data monitoring.[27] Additionally, only three of the studies utilized a structured approach in contacting participants regarding their status,[22,19,27] the remaining studies made it optional for the physicians to contact their patients.[24,28,29,25]

Impact of mHealth Interventions on HF Outcomes

Table 3 summarizes the impact of the mHealth interventions on HF outcomes assessed in two or more studies including mortality (all-cause and cardiovascular specific), HF hospitalizations, length of stay, NYHA functional class, LVEF, quality of life, and self-care. Outcomes that were measured in only one study (e.g. walked distance, perceived exertion, b-type natriuretic peptide level) were not selected due to the limitation in comparing findings across studies. The impact of the mHealth interventions on all-cause mortality was mixed. One study reported a lower mortality rate for the intervention group (hazard ratio 0.36, 95% confidence interval 0.17–0.74, P=0.004),[25] while another study had no difference in mortality rates between their study groups (hazard ratio 0.97, 95% confidence interval 0.67–1.41, P=0.87).[19] It should be noted that the study by Hindricks et al. utilized an invasive monitoring system (implantable defibrillator with monitoring function)[25] while the study by Koehler et al. utilized a non-invasive, daily monitoring system.[19] Similarly, the impact of the mHealth interventions on cardiovascular mortality was mixed, with the invasive monitoring system resulting in a lower mortality rate for the intervention group (hazard ratio 0.37, 95% confidence interval 0.16–0.83, P=0.012)[25] while the non-invasive monitoring system showed no difference in cardiovascular mortality rates between the study groups (hazard ratio 0.86, 95% confidence interval 0.56–1.31, P=0.49)[19]. Meanwhile, both invasive and non-invasive

monitoring systems showed no significant difference in the number of HF-related hospitalizations between their study groups.[22,19,25] Four of the six studies that examined the impact of their interventions on the length of hospital stay reported no significant differences between their study groups,[22,24,19,25] while the remaining two studies reported significantly shorter lengths of stay for the intervention group compared to the control group.[26,29]

The impact of mHealth interventions on the patients' NYHA functional class was inconclusive. Three studies reported no significant differences in NYHA class composition between their study groups post-intervention.[24,19,25] Two studies reported significant improvements in mean/median NYHA class for their intervention groups.[29,27] In the study by Piotrowicz et al., the mean NYHA class for the intervention group post-intervention was 2.1 vs. 2.3 for the control group (P=0.007).[27] Similarly, in the study by Scherr et al. (2009) the median NYHA class improved from 3 to 2 in the intervention group only (P< 0.001).[29] Finally, the quasi-experimental study by Scherr et al. (2006), reported an improvement in mean NYHA class from 2.3 to 1.8.[28] However, the lack of a control group makes it difficult to ascertain whether this improvement is the result of the mHealth intervention or an unidentified confounder. Similarly, the same study[28] reported an improvement in the mean LVEF of their study participants, while two other studies found no significant difference in the improvements in LVEF between their study groups.[24,29]

Two of the five studies that measured quality of life used the Short Form (SF) 36 Health Survey,[19,27] two studies used the Minnesota Living with Heart Failure Questionnaire (MLHFQ),[22,24] and the remaining study used the SF-36 and the Kansas City Cardiomyopathy Questionnaire (KCCQ) to measure quality of life.[26] Koehler et al. reported an improved score for the SF-36 physical functioning in the intervention group (*P*=0.01).[19] Similarly, Seto et al. found a significant improvement in overall quality of life for their intervention group (−8.9 vs. −0.5, P=0.05).[24] On the other hand, Hagglund et al. reported no significant difference in QOL between their study groups using the SF-36; however, they found a significant improvement in quality of life for their intervention group using the KCCQ.[26] Piotrowicz et al. found no significant difference in the improvement in quality of life between the home-based cardiac rehabilitation group and the standard cardiac rehabilitation group (−8.8 vs. −12.4, P=0.0001).[27] Finally, Zan et al. also found no significant difference in the pre- and post-intervention quality of life scores (*P*= .55).[22]

Finally, the impact of mHealth interventions on HF self-care was also mixed. Two[23,24] of the three studies that measured self-care used the Self-Care of Heart Failure Index, while the remaining study[26] used the European Heart Failure Self-Care Behavior Scale. One randomized controlled study reported no significant difference between their study groups,[24] while another randomized controlled trial reported significant improvement in self-care in their intervention group.[26] Similarly, a quasi-experimental study found significant improvements in self-care maintenance (+28 points, 95%CI 15–42, P=0.003) and self-care management (+30 points, 95%CI 17–42, P=0.002). However, the quasi-experimental study lacked a control group, which makes it difficult to conclusively associate the improvement in self-care with the mHealth intervention.

Discussion

Majority of the studies used mHealth technology to monitor the patients' HF status. The most commonly used monitoring intervention consisted of a mobile communication device, a blood pressure measuring device, a weighing scale, and an ECG recorder. While most of the monitoring systems utilized a central monitoring center, how the monitoring was done and to what intensity greatly varied among the interventions. Two studies employed trained health professionals (nurses and physicians) to monitor the patients' data while four studies used algorithms to generate alert messages in case the patients' values were outside their predefined limits. Finally, most of the interventions were limited to monitoring the patients' HF status and left the actual care of the patients (i.e. responding to the patients' change in status) to their own physicians.

Similar to traditional telemonitoring interventions,[16] the impact of an mHealth-based monitoring system on HF outcomes was inconclusive. A systematic review of multi-modal telemonitoring technologies also found inconsistent evidence on the impact of telemonitoring on HF outcomes (e.g. HF hospitalizations, length of stay, quality of life, self-care), which precluded a definitive conclusion of their positive impact.[17] On the other hand, another systematic review focused on HF telemanagement concluded that the use of telehealth technologies in remotely managing HF patients had a positive impact on healthcare utilization, care costs, and quality of life.[14] Taking these opposing review findings into consideration, one can infer that simply using these technologies to remotely monitor HF patients may not be as effective as using them to remotely manage the patients' HF symptoms. Hence, mHealth technology could potentially see similar positive results if utilized beyond simple remote monitoring.

Furthermore, the inconclusive study findings could be attributed, in part, to the varying ranges of methodological rigor. For example, in the Koehler et al. study, the authors noted lack of power and the characteristics of their study sample (relatively stable with optimal treatment) as possible reasons for no intervention effect on all-cause and cardiovascular-related mortality rates.[30] Therefore, they recommended that future studies should target HF sub-populations that would most likely benefit from this intervention.[20] Hindricks et al., whose study sample was similar to that of Koehler et al. in terms of baseline HF status and medication regimen, found significantly lower mortality rates in their intervention group. However, it should be noted that Hindricks et al. used an invasive monitoring intervention (implantable defibrillator), which allowed for a much earlier detection of heart arrhythmias and worsening symptoms. Such finding suggests that monitoring HF symptoms once a day might not be sufficient to detect a worsening HF status, particularly among HF patients with higher acuity.

Another important aspect of interventions that needs to be taken into consideration is the response to the alerts generated by the systems. Among the three studies that provided data on the number of alerts generated and the subsequent response taken, a total number of 3278 alerts were generated; however, patients were contacted only 39% (range: 29% – 52%) of the time.[24,29,25] Additionally, only one study reported their median reaction time (median: 1 day, interquartile range: 0–6). [23] It is not known how many of these alerts were false

positives. However, the low response rate to the alerts could be a potential factor as to why no significant differences were seen in HF outcomes between those that received the intervention and those in the control group.

Lastly, among the studies that reported participant adherence only one study achieved 100% adherence to their mHealth-based intervention.[27] One study had over 20% of their intervention group fail to even start the intervention due to difficulties in operating their mobile phone's Internet browser[29] and another study reported a 60% attrition rate, the majority (57%) of which were lost due to technology issues.[23] Among the studies that saw better adherence rates, one study still lost participants in their intervention group due to technical difficulties.[24] The variability in participant adherence could be another potential contributor to the non-significant differences in HF outcomes between the study groups.

As with any systematic reviews, the quality of this review is dependent upon the quality of the included studies. Additionally, the small number of studies included could be seen as a limitation; however, this was unavoidable considering the novelty of mHealth interventions in HF management. Finally, the heterogeneity of the interventions and the measured outcomes precluded the performance of a meta-analysis; thus, limiting the rigor of this review. However, the critical assessment of the quality of the included studies using the Cochrane tool and the extensive, systematic search process conducted under the guidance of an expert medical librarian strengthened the quality of this review.

Conclusion

Majority of the mHealth-based HF interventions used mobile health technology to remotely monitor the patients' HF status. The typical remote monitoring system included a mobile communication device, a blood pressure measuring device, a weighing scale, and an ECG recorder. The impact of the mHealth-based HF interventions on HF-related outcomes was mixed, highlighting the need for further research.

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Implications for Practice and Future Research

Currently, the inconsistent impact of mHealth-based interventions on HF outcomes limits their utility in clinical practice. Findings from this systematic review suggest that further studies are critically needed to conclusively determine the impact of mHealth interventions on HF outcomes. Researchers should consider the limitations of the current studies (e.g. inadequate sample size, quasi-experimental design, use of older mobile phone models, etc.) when designing future studies. Additionally, researchers should involve representatives of their target population (i.e. people with HF) in the development stage in order to inform the design of their patient-device interface considering that a number of participants still had difficulties with the interventions despite the reported acceptable overall adherence to the current mHealth interventions. Furthermore, ease of use is just one factor that can affect adherence; other facilitators and barriers that influence adoption of mHealth interventions should also be examined. Lastly, studies should also consider performing cost-benefit analyses in order to determine whether mHealth HF interventions are cost-effective.

What's New?

- Current mHealth-based interventions, which typically include a mobile communication device, a blood pressure measuring device, a weighing scale, and an ECG recorder, were utilized to remotely monitor HF patients.
- Overall, the impact of current mHealth interventions on HF outcomes, such as mortality, HF-related hospitalizations, length of hospital stay, NYHA functional class, LVEF, quality of life, and HF self-care, was inconclusive, which underscores the need for further research.

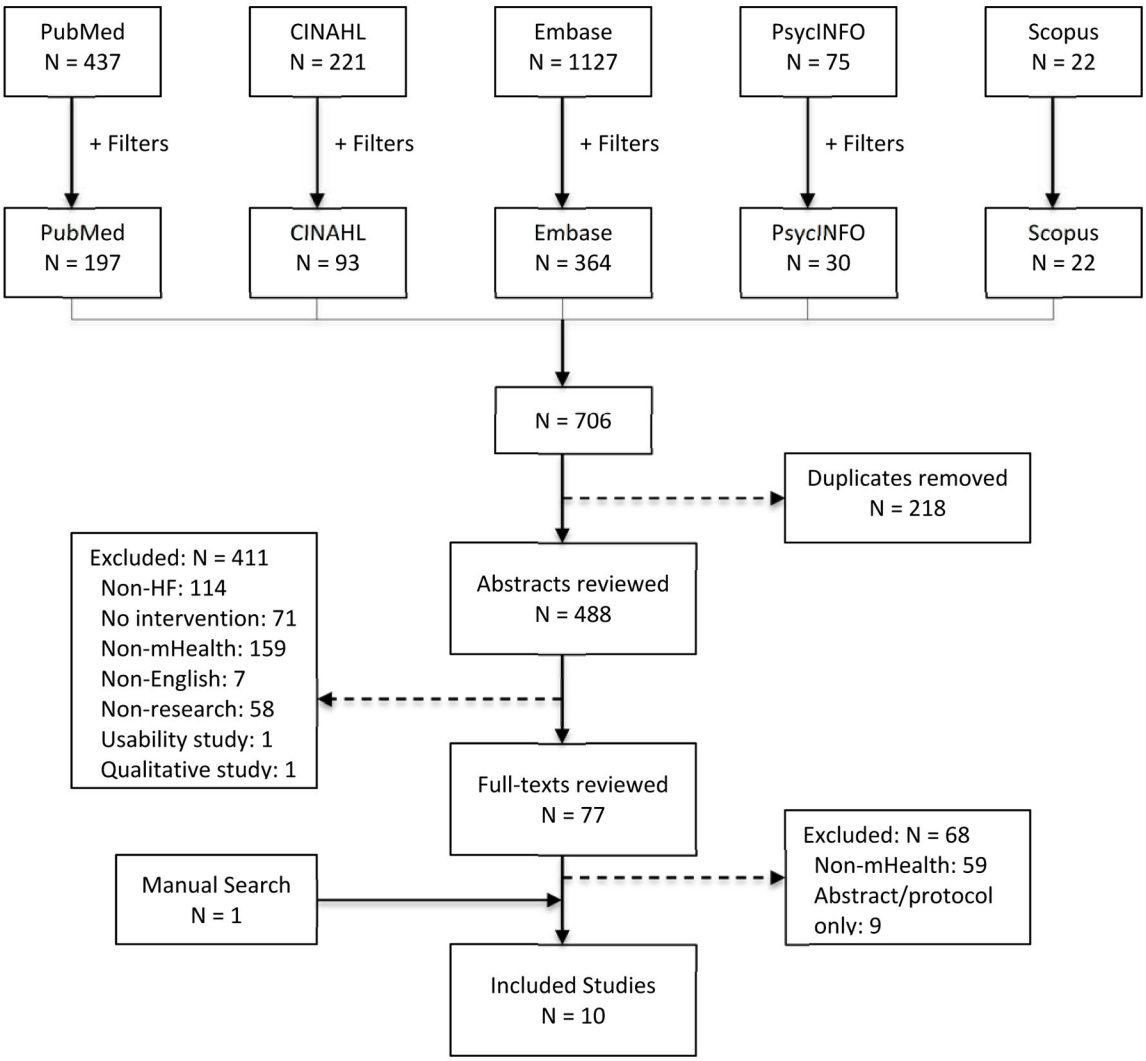

Figure 1.
Diagram of search and retrieval process. HF indicates heart failure

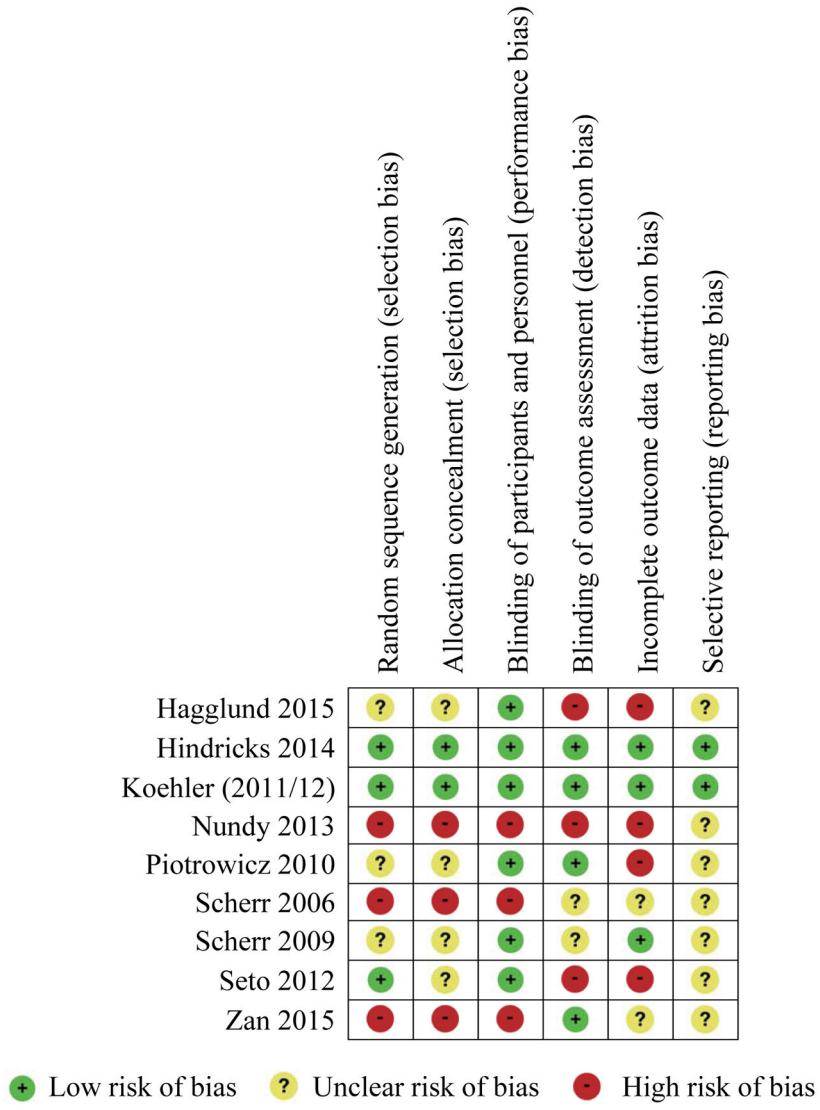

Figure 2.
Risk of Bias Assessment

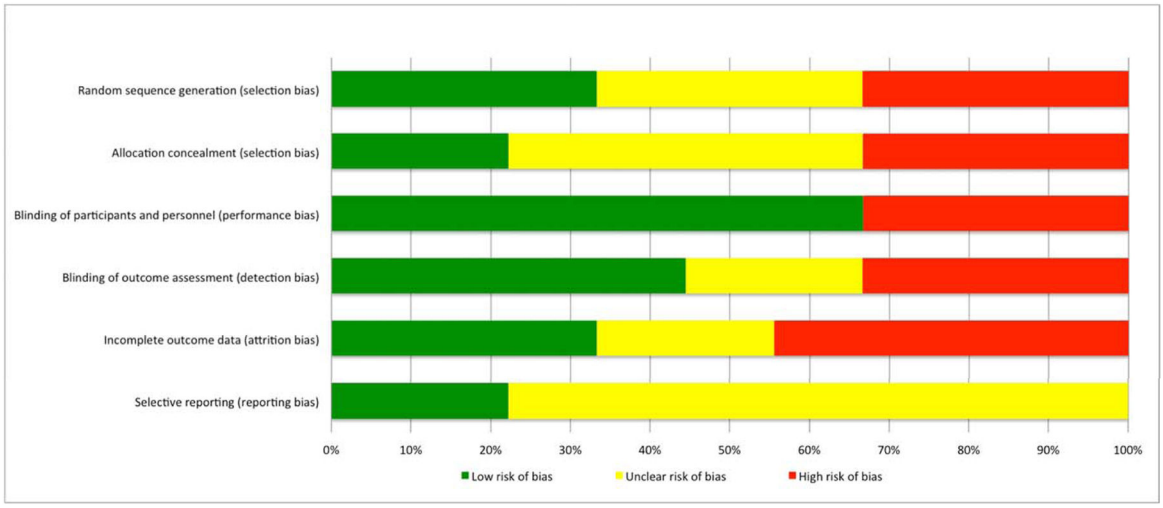

Figure 3.
Risk of Bias Assessment Summary

Table 1

Study Characteristics

First Author (Year) Country	Study Design Study Duration	Sample (Size & Description)	Intervention/ Control Group	Limitations
Hagglund (2015) Sweden	RCT, multicenter 3 months	**N** = 72 (IG: 32, CG: 40) Mean: **Age**: IG 75y; CG 76y **Male**: IG 21 (66%) CG 28 (70%) **LVEF**: IG 34%; CG 38% **NYHA**: **II:** IG 12 (38%) CG 7 (18%) **III:** IG 20 (62%) CG 33 (82%)	**IG:** Self monitoring of weight and symptoms; HF information sheet; support access **CG:** HF information sheet; support access	• 23.8% attrition in the IG, which was not included in the analyses
Hindricks (2014) Australia, Israel, *Europe*	RCT, multicenter 12 months	**N**= 664 (IG: 333, CG: 331) Mean: **Age**: IG 65y; CG 66y **Male**: IG 274 (82%), CG 262 (79%) **LVEF**: IG 26%; CG 26% **NYHA**: **II**: IG 150 (45%); CG 135 (41%) **III**: IG 182 (55%); CG 196 (59%)	**IG:** Remote monitoring of heart rhythms **CG:** standard of care according to European guidelines	• No blinding to treatment allocation • Treatment after remote monitoring observations were not standardized nor were the clinical actions recorded
Koehler (2011) Koehler (2012) Germany	RCT, multicenter 24 months	**N** = 710 (IG: 354, CG: 356) Mean: **Age**: IG 67y, CG 67y **Male**: IG 285 (81%), CG 292 (82%) **LVEF**: IG 27 %; CG 27% **NYHA**: **II:** IG 176 (50%); CG 180 (51%) **III:** IG 178 (50%); CG 176 (49%)	**IG**: Remote monitoring of ECG, blood pressure, and body weight **CG**: usual care according to current treatment guidelines for heart failure	• Low statistical power to detect clinically significant difference in mortality • No information were collected on the number of patients who were prescreened and who were not enrolled in the trial
Nundy (2013) USA	Quasi-experimental (no control group), single center 4 weeks	**N**=15 enrolled → 6 completed study Mean: (N=15) **Age**: 50y **Male**: 9 (60%) **Race**: Black 14 (93%) **LVEF**: 22%	Heart failure education and reminders via text messages	• Very small sample size with high attrition rate • No control group • Lack of CG precludes the determination of whether the improvements could be from clinic visits during the course of the intervention and/or simply improvement in health status
Piotrowicz (2010) Poland	RCT, single center 8 weeks	**N** = 152 (IG: 77, CG: 75) → 131 (IG: 75, CG: 56) Mean: (N=131)	**IG**: Home-based remotely monitored cardiac rehabilitation; patient education; psychological support	• Small sample size • Relative short duration of the study

First Author (Year) Country	Study Design Study Duration	Sample (Size & Description)	Intervention/ Control Group	Limitations
		Age: IG 56y, CG 61y **Male**: IG 64 (85%), CG 53 (95%) **LVEF**: IG 30%; CG 31% **NYHA**: **II**: IG 37 (49%), CG 31 (55%) **III**: IG 38 (51%), CG 25 (45%)	**CG**: standard cardiac rehabilitation; patient education; psychological support	• Lack of real-time ECG monitoring during remotely monitored rehabilitation
Scherr (2006) Austria	Quasi-experimental (no comparison group), single center 90 days	**N** = 14 Mean: **Age**: 53y **Male**: 13 (93%) **LVEF**: 32% **NYHA**: **II:** 10 (71%) **III:** 4 (29%)	Remote automated monitoring of blood pressure and body weight	• Small sample size • No control group
Scherr (2009) Austria	RCT 6 months	**N** = 120 (IG: 66, CG 54) → 78 (IG: 42, CG: 36) Mean: (N=108) **Age**: IG 65y, CG 67y **Male**: IG 40 (74%), CG 39 (72%) **LVEF**: IG 25%, CG 29% **NYHA**: **II**: IG 7 (13%), CG 7 (13%) **III**: IG 33 (61%), CG 37 (69%) **IV**: IG 14 (26%), CG 10 (19%)	**IG**: Remote automated monitoring of blood pressure and body weight; pharmacological treatment **CG**: pharmacological treatment	• Small sample size • Premature termination of randomization because of relevant technological issues • 12 “never beginners”
Seto (2012) Canada	RCT, single center 6 months	**N**= 100 (IG 50, CG 50) Only 82 returned pre-post questionnaires Mean: **Age**: IG 55y, CG 52y **Male**: IG 41 (82%), CG 38 (76%) **LVEF**: IG 27%, CG 27% **NYHA**: **II**: IG 21 (42%), CG 22(44%) **II/III:** IG 6 (12%), CG 5 (10%) **III**: IG 21 (42%), CG 21 (42%) **IV**: IG 2 (4%), CG 2 (4%)	**IG**: Remote automated monitoring of ECG, blood pressure, and body weight; standard care **CG**: standard care (clinic visits once every 2 weeks to once every 3 to 6 months, heart failure education)	• Small sample size • 1/3 of the IG used the intervention for a number of weeks before completing baseline questionnaire • Potential for recall bias and obsequiousness bias
Zan (2015) USA	Quasi-experimental (using a 1:1 matched control group by age, gender, race, and diagnosis), single center 90 days	**N** = 21 (20 analyzed) Mean: **Age**: IG 53y; CG: 53y **Male**: IG 15 (71%), CG 14 (70%) **LVEF**: IG 35% **NYHA**: **I:** 5 (24%) **II:** 9 (43%) **III:** 7 (33%)	**IG:** Remote monitoring of weight, blood pressure, and heart rate	• Small sample size • Potential selection bias due to purposeful sampling • Predominantly married, white male sample

RCT- Randomized Control Trial, IG- Intervention Group, CG- Control Group, LVEF- Left Ventricular Ejection Fraction, NYHA – New York Heart Association

Table 2

Intervention Characteristics

First Author (Year)	Devices						Information Transfer	Central Monitoring Center	Monitoring Intensity	Monitoring Personnel	Patient Callback
	Mobile Device	Wireless Data Receiver	ECG Recorder	BP Device	Weighing Scale	Implantable Defibrillator					
Hagglund (2015)	✓				✓*		Automatic	No	Daily	Patient	NA
Hindricks (2014)		✓				✓	Automatic	Yes	Not specified	Nurses, Physicians	Optional[1]
Koehler (2011, 2012)		✓	✓*	✓*	✓*		Automatic	Yes	24/7	Physician-led	Structured[2]
Nundy (2013)	✓						NA	NA	NA	NA	NA
Piotrowicz (2010)	✓		✓*				Automatic	Yes	Not specified	Not specified	Structured[3]
Scherr (2006)	✓			✓	✓		Manual-input	Yes	Not specified	NA (Computer)	Optional[4]
Scherr (2009)	✓			✓	✓		Manual-input	Yes	Not specified	NA (Computer)	Optional[4]
Seto (2012)	✓		✓*	✓*	✓*		Automatic	Yes	Not specified	NA (Computer)	Optional[5]
Zan (2015)	✓			✓*	✓*		Automatic/Manual	Yes	“regular business hours”	Study staff	Structured[1]

*Wireless-enabled for automatic data transfer

[1]Initiated by the study investigators

[2]Initiated by the monitoring center, monthly and as needed per protocol; patient’s own physician also receives notifications from the monitoring center

[3]Patients were given immediate feedback after transmittal of ECG data to the monitoring center (i.e. permission to start exercise training session)

[4]Patients’ physicians are notified thru text message/email if the patients’ values exceeded predefined limits. Physicians have the option to contact their patients.

[5]Clinic cardiologists were emailed alerts if the patients’ values were outside target range; they then had the option to contact the patients if warranted.

Table 3

Impact of mHealth Interventions on Selected Heart Failure Outcomes

First Author (Year)	Outcomes								
	All-cause mortality	**CV mortality**	**HF-related admissions**	**LOS**	**NYHA class**	**LVEF**	**QOL**	**Self-Care**	**Composite (CV mortality /HF admission)**
Hagglund (2015)				Shorter LOS in IG (Risk ratio .38, *P*< .05)			• Improved HF-specific QOL (*P*< .05) and physical limitation (*P*< .05) in IG (based on KCCQ) • No difference between groups (based on SF-36) (physical component: *P*= .40, mental component: *P*= .90)	Significant improvement in self-care (*P*< .05)	
Hindricks (2014)	Lower mortality rate in IG (hazard ratio .36, *P*= .004)	Lower mortality rate in IG (hazard ratio .37, *P*= .012)	No difference between groups (*P*= .38)	No difference between groups (*P*= .21)	No difference between groups (*P*= .43)				
Koehler (2011, 2012)	No difference between groups (hazard ratio .97, *P*= .87)[19]	• No difference between groups (hazard ratio .86, *P*= .49)[19] • Lower mortality in the IG (sub-group analysis) (*P*= .03)[20]	No difference between groups (hazard ratio .84, *P*= .32)[19]	No difference between groups (Cohen's *d*= .03, *P*= .71)[19]	No difference between groups (*P*> .05)[19]		Improved physical function in IG (*P*< .05)[19]		No difference between groups (*P*= .44)[19]
Nundy (2013)								• Significant improvement in self-care maintenance (Cohen's d_z= 1.66, *P*= .003) • Significant improvement in self-care management (Cohen's d_z= 1.92, *P*= .002) • No change in self-care confidence (Cohen's d_z= .62, *P*= .11)	

First Author (Year)	Outcomes								
	All-cause mortality	**CV mortality**	**HF-related admissions**	**LOS**	**NYHA class**	**LVEF**	**QOL**	**Self-Care**	**Composite (CV mortality /HF admission)**
Piotrowicz (2010)					Greater improvement in NYHA class in IG (*P*= .007)		No difference between groups in improvement in QOL (*P*> .05)		
Scherr (2006)					NYHA class (# before → after) I: 0 → 3 II: 10 → 11 III: 4 → 0	Improved LVEF			
Scherr (2009)				Shorter LOS in IG (*P*= .04)	Median improved from III to II in the IG only (*P*< .001)	No difference between groups (*P*>.05)			No difference between groups per intention to treat (*P*= .06)
Seto (2012)				No difference between groups (Cohen's *d*= .21, *P*= .20)	No difference between groups (Cohen's *d*= −.16, *P*=. 90)	No difference between groups (Cohen's *d*= .09, *P*= .10)	• No difference between groups in physical (Cohen's *d*= −.20, *P*= .10), emotional (Cohen's *d*= −.24, *P*= .07) • Improved overall QOL (Cohen's *d*= − .24, *P*= .05)	No difference between groups in self-care maintenance (Cohen's *d*= .56, *P*= .60), management (Cohen's *d*= −.04, *P*= .90), and confidence (Cohen's *d*= .07, *P*=. 80)	
Zan (2015)			No difference between groups (*P*= .99)	No difference between groups (*P*= .30)			No difference between pre- and post-intervention QOL scores in the IG (Cohen's d_z= −.13, *P*= .55)		

CV – cardiovascular, HF – heart failure, LOS – length of stay (hospital), NYHA – New York Heart Association, LVEF – left ventricular ejection fraction, QOL – quality of life, IG – intervention group