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**FAST**TRACK CLINICAL RESEARCH
*Heart failure and cardiomyopathies*

# Telemonitoring for heart failure: a meta-analysis

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**See the editorial comment for this article 'Is telemonitoring for heart failure ready after a journey longer than two decades?', by F. Koehler and G. Hindricks, https://doi.org/10.1093/eurheartj/ehad395.**

## Abstract

**Aims** Telemonitoring modalities in heart failure (HF) have been proposed as being essential for future organization and transition of HF care, however, efficacy has not been proven. A comprehensive meta-analysis of studies on home telemonitoring systems (hTMS) in HF and the effect on clinical outcomes are provided.

**Methods and results** A systematic literature search was performed in four bibliographic databases, including randomized trials and observational studies that were published during January 1996–July 2022. A random-effects meta-analysis was carried out comparing hTMS with standard of care. All-cause mortality, first HF hospitalization, and total HF hospitalizations were evaluated as study endpoints. Sixty-five non-invasive hTMS studies and 27 invasive hTMS studies enrolled 36 549 HF patients, with a mean follow-up of 11.5 months. In patients using hTMS compared with standard of care, a significant 16% reduction in all-cause mortality was observed [pooled odds ratio (OR): 0.84, 95% confidence interval (CI): 0.77–0.93, $I^2$: 24%], as well as a significant 19% reduction in first HF hospitalization (OR: 0.81, 95% CI 0.74–0.88, $I^2$: 22%) and a 15% reduction in total HF hospitalizations (pooled incidence rate ratio: 0.85, 95% CI 0.76–0.96, $I^2$: 70%).

**Conclusion** These results are an advocacy for the use of hTMS in HF patients to reduce all-cause mortality and HF-related hospitalizations. Still, the methods of hTMS remain diverse, so future research should strive to standardize modes of effective hTMS.



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## Structured Graphical Abstract

### Key Question

What is the efficacy of non-invasive and invasive telemonitoring systems on clinical endpoints including all-cause mortality, first heart failure hospitalization, and the total amount of heart failure hospitalizations?

### Key Finding

In 36 549 patients (mean follow-up: 11.5 months), the use of (non-)invasive telemonitoring systems compared to standard of care reduced all-cause mortality by 16%, first heart failure hospitalizations by 19%, and total heart failure hospitalizations by 15%.

### Take Home Message

Home telemonitoring systems can aid in outpatient management and lower all-cause mortality and heart failure hospitalization rates. This type of monitoring should therefore be strongly considered and may be integrated into current heart failure health care systems worldwide.

| All-cause mortality | No. studies | Intervention | Standard of care | Odds ratio [95% CI] | $I^2$ |
|---|---|---|---|---|---|
| **Non-invasive** | **56** | **1337/11 472** | **1365/9985** | 0.85 [0.77, 0.94] | **9%** |
| Telemonitoring | 31 | 656/4998 | 644/4454 | 0.91 [0.79, 1.05] | 7% |
| Structured telephone support | 18 | 375/4033 | 421/3421 | 0.75 [0.63, 0.89] | 9% |
| Complex telemonitoring | 9 | 306/2441 | 329/2355 | 0.88 [0.74, 1.05] | 0% |
| **Invasive** | **24** | **762/7239** | **584/5246** | **0.86 [0.70, 1.06]** | **50%** |
| Cardiac implantable devices | 17 | 429/4732 | 472/4323 | 0.84 [0.65, 1.08] | 56% |
| Invasive haemodynamic monitoring | 7 | 333/2507 | 112/923 | 0.96 [0.72, 1.27] | 0% |
| **Total** | **80** | **2099/18 861** | **1949/15 231** | 0.84 [0.77, 0.93] | **23%** |
| **First heart failure hospitalization** | | | | **Odds ratio [95% CI]** | |
| **Non-invasive** | **39** | **1639/7468** | **1766/6615** | **0.78 [0.70, 0.86]** | **26%** |
| Telemonitoring | 22 | 1008/3826 | 1091/3527 | 0.78 [0.67, 0.92] | 39% |
| Structured telephone support | 15 | 485/2947 | 599/2788 | 0.75 [0.65, 0.86] | 0% |
| Complex telemonitoring | 4 | 146/695 | 128/545 | 0.79 [0.50, 1.23] | 48% |
| **Invasive** | **15** | **562/2884** | **497/2268** | **0.89 [0.77, 1.03]** | **5%** |
| Cardiac implantable devices | 11 | 417/2410 | 440/2128 | 0.92 [0.79, 1.06] | 1% |
| Invasive haemodynamic monitoring | 4 | 145/474 | 57/140 | 0.68 [0.42, 1.09] | 0% |
| **Total** | **54** | **2201/10 352** | **2263/8883** | **0.81 [0.74, 0.88]** | **22%** |
| **Total/recurrent heart failure hospitalization** | | **No. events per person year** | | **Incidence risk ratio [95% CI]** | |
| **Non-invasive** | **21** | **0.363** | **0.389** | **0.82 [0.70, 0.96]** | **70%** |
| Telemonitoring | 13 | 0.446 | 0.472 | 0.83 [0.67, 1.02] | 77% |
| Structured telephone support | 5 | 0.327 | 0.378 | 0.70 [0.46, 1.06] | 66% |
| Complex telemonitoring | 4 | 0.140 | 0.141 | 0.98 [0.79, 1.21] | 0% |
| **Invasive** | **13** | **0.385** | **0.296** | **0.90 [0.74, 1.10]** | **73%** |
| Cardiac implantable devices | 7 | 0.195 | 0.199 | 0.98 [0.76, 1.25] | 67% |
| Invasive haemodynamic monitoring | 6 | 0.605 | 0.584 | 0.75 [0.61, 0.91] | 52% |
| **Total** | **34** | **0.373** | **0.350** | **0.85 [0.76, 0.96]** | **70%** |

Favours intervention — Favours standard of care

Summary results for all-cause mortality, first heart failure hospitalization, and total/recurrent heart failure hospitalizations divided in invasive home telemonitoring systems and non-invasive home telemonitoring systems and total. $I^2$ represents heterogeneity between studies. CI, confidence interval.

**Keywords** Telemonitoring • Heart failure • Non-invasive • Invasive • Mortality • Hospitalization



# Introduction

Heart failure (HF) is a chronic, complex, and progressive syndrome with a significant impact on public health. Globally, >60 million patients are affected by HF, and with the ageing of the general population, its prevalence is expected to increase in the forthcoming years.[1] Despite advances in medical therapy, cardiac implantable electronic devices (CIEDs) and (long-term) mechanical circulatory support, the morbidity and mortality of HF remain high. Moreover, HF places a high burden on healthcare due to frequent outpatient follow-up and recurrent hospitalizations as a result of deterioration of HF.[2] The costs of HF care are projected to further increase, primarily driven by hospitalizations.

Therefore, there is a great need to develop effective strategies to reduce HF (re-)admissions and improve ambulatory HF care. Telemonitoring by means of home telemonitoring systems (hTMS) in this respect seems a promising option, which has gained even more momentum after the COVID-19 pandemic.[3] The hTMS is a system at home, which uses a non-invasive or invasive device to collect health data, such as vital signs and other diagnostic data.[4] While the number of studies—both randomized controlled trials (RCTs) and observational—reporting on hTMS has increased rapidly over the last years, their results and applicability have been uncertain due to heterogeneity. [5–8]

In 2015, a comprehensive Cochrane meta-analysis demonstrated a minor, albeit statistically significant reduction in all-cause mortality (ACM) through the use of structured telephone support (STS) and a significant reduction of both HF hospitalizations (HFH) and ACM by employing other non-invasive telemonitoring solutions.[5] However, the results are hampered by high heterogeneity between the individual studies due to the differences in methodology of the employed systems, some risk of bias, and the lack of a consistent effect in many studies individually. Furthermore, there is a lack of studies pertaining to real-world data and repeated events in this meta-analysis. This conflicting evidence has led to a weak (class IIb, LoE B) recommendation for hTMS in the latest ESC Guidelines on Acute and Chronic HF.[1]

However, medical technology is ever evolving, and newer hTMS have been developed including invasive devices such as CIEDs incorporating new algorithms to detect deterioration of HF (e.g. Heartlogic) and invasive haemodynamic devices measuring the pulmonary artery pressure (e.g. CardioMEMS and Cordella). Also, non-invasive remote monitoring strategies have improved and are now more structured, like the system used in the TIM-HF2 trial.[9] Moreover, the COVID-19 pandemic has further accelerated the process of employing hTMS within the context of HF management.[3] In order to fill in the abovementioned knowledge gaps, it is of great importance to explore the ever-growing body of contemporary literature regarding this subject as the HF community is on the breach of an outbreak of telemonitoring integration in clinical practice. Therefore, we performed a systematic review and meta-analysis of both RCTs and observational studies up to July 2022, comparing hTMS with standard of care (SoC) in patients with HF and describe the efficacy on clinical endpoints.

# Methods

## Protocol and registration

We performed a systematic review and meta-analysis of prospective studies (RCTs and observational studies) following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[10] This review is registered in the International Prospective Register of Systematic Reviews with number CRD42022306677.

## Search strategy and selection criteria

In collaboration with an expert librarian specialized in systematic searches, a literature search was carried out, including studies that were reported during 1996—1 July 2022, using Embase, Medline Ovid, Web of Science, and Cochrane CENTRAL. Keywords used in the search were 'heart failure', 'telemonitoring', 'implantable haemodynamic monitor', 'implantable cardioverter defibrillator', 'home monitoring', 'e-health', 'clinical trial', and 'prospective study'. The full search strategy is presented in the Supplementary material. Only published peer-reviewed original articles in the English language were included in our study. In addition, cross-referencing for any additional eligible studies was performed.

Studies were included if they contained any form of hTMS in chronic HF patients aged 18 years or older. We defined hTMS as a system in the home setting that employs a non-invasive or invasive device to remotely collect vital signs and other biometric or health-status related data (such as weight, blood pressure, heart rate, pulmonary pressure, ECG lead, and signs and symptoms with the exception of physical activity) and remotely transmits the collected data to a healthcare institution for further assessment by a healthcare provider. All other eligibility criteria are presented in Supplementary data online, *Table S1*.

Three reviewers (N.S., M.G., and D.A.) independently performed title and/or abstract screening in order to identify studies that potentially met the inclusion criteria. Results were then discussed, and any disagreement regarding eligibility was resolved by consensus. The full text of these studies was then retrieved and read independently by the same reviewers. Hereafter, each study was discussed in detail to decide upon the eligibility based on the inclusion and exclusion criteria. In case no consensus was reached, the principal investigator (J.B.) had the final say.

If eligible studies described the same population, only the study with the longest follow-up or most recent publication (with an active intervention arm) containing the entire population was included, unless different outcomes of interest were studied in each article. Studies describing a subgroup of the same population were excluded.

## Data extraction, home telemonitoring systems categories, and study endpoints

The following information was extracted from the main study reports: author, year of publication, country, study name, study design, enrollment years, sample size, age, sex, New York Heart Association (NYHA) class, left ventricular ejection fraction (LVEF) cut-off, HF aetiology, medication use, type of telemonitoring solution, comparison group, follow-up duration, and endpoints. If studies presented endpoints at more than one time point, endpoints from the latest time point were extracted. Data extraction was performed by M.G., N.S., and D.A., independently. Categories and definitions of non-invasive and invasive hTMS and subcategories are presented in *Table 1*. Non-invasive hTMS consisted of the following separate subcategories: telemonitoring (TM), structured telephone support (STS), and a combination of TM and STS (complex TM). Invasive hTMS consisted of the following separate subcategories: cardiac implantable electronic devices (CIED), and invasive haemodynamic monitoring (IHM) (*Table 1*). The primary outcomes for this meta-analysis were ACM, first HFH, and total number of HFHs.

## Quality assessment

The Cochrane risk of bias (RoB2) and ROBINS-I were used to assess the risk of bias for RCTs and observational studies, respectively. Each article was assessed independently by at least two authors (N.S., M.G., and/or D.A.). In case no consensus was reached, a third author was available for consultation to give their conclusive opinion.

## Statistical analysis

Continuous variables are presented as means and ± standard deviations (SD) or medians and interquartile ranges (IQR), as appropriate. Categorical variables are presented as counts and percentages. Random-effects methods were used to obtain an estimate of the pooled treatment effect, applying the DerSimonian and Laird procedure. For ACM and first HFH, we present the pooled treatment effect as odds ratio (OR) and corresponding 95% confidence interval (CI). The endpoint total HFHs is presented as incidence rate ratio (IRR) and 95% CI, which required person-years to be calculated. Person-years were calculated by using the mean or median follow-up time. If no mean or median follow-up time was available, the planned follow-up time was used, with the exception of patients who withdrew or died. To calculate person-years for these patients, we used half of the planned follow-up time.

**Table 1 Categories of telemonitoring modalities and abbreviations used**

| Home Telemonitoring System | | Definitions |
|---|---|---|
| **Non-invasive hTMS** | | |
| – TM | Telemonitoring (individual) | Modality in which biometric data and/or health-related questionnaires are collected and sent to an HF clinic. |
| – STS | Structural telephone support | Modality in which HF patients are called by a HF nurse or cardiologist on a frequent basis. |
| – Complex TM | Complex telemonitoring | Modality in which multiple TM is combined with STS and/or 24-h call center or mix of other sub-modalities. |
| **Invasive hTMS** | | |
| – CIED | Cardiac implantable electronic devices | Modality in which PM/ICD systems (optionally with impedance leads) are used to monitor the patient. |
| – IHM | Invasive haemodynamic monitoring | Modality in which invasive haemodynamic parameters are used, e.g. (pressure) sensors. |

hTMS, home telemonitoring system; TM, telemonitoring; STS, structural telephone support; HF, heart failure; CIED, cardiac implantable electronic device; PM, pacemaker; ICD, implantable cardiac defibrillator; IHM, invasive haemodynamic monitoring.

Sensitivity analyses were performed based on the specified categories of hTMS (*Table 1*). In this meta-analysis, we use ORs as the key effect measure, since the data that are required to obtain this measure can be directly derived from the study reports. It is true that in scenarios where the time varies, the hazard ratio (HR) is the preferred effect measure. However, HRs are only presented in 30% (endpoint hospitalization) to 37% (endpoint mortality) of studies, and must thus be estimated for the other studies. Therefore, we decided to present the (pooled) HRs as a sensitivity analysis and not as main analysis. Furthermore, another sensitivity analysis was carried out, dividing studies in short- (<3 months), mid- (3 to 12 months) and long-term (>12 months) follow-up time with respect to ACM and first HFH. Heterogeneity was assessed using the $I^2$-statistic and classified as not important ($I^2$: ≤25%), moderate, ($I^2$: 26%–50%), substantial ($I^2$: 51%–75%), and considerable ($I^2$: >75%).[11] Funnel plots were generated and Egger regression tests performed to assess publication bias. All analyses were carried out using R Studio version 3.0 with the Metafor 3.4–0 package. A two-sided *P*-value of ≤0.05 was considered as statistically significant.

# Results

## Study characteristics

The literature search exposed, after duplicate removal, 6112 studies. A total of 91 studies that met all the eligibility criteria were included. In addition, one study was added from cross-referencing, resulting in a total of 92 studies.[9,12–102] The full PRISMA-flow diagram is shown in *Figure 1*. Within the 92 included studies, 36 549 HF patients were included, with a mean follow-up of 11.5 (range: 1.0–34.9) months. A total of 23 610 HF patients were included from 65 non-invasive hTMS studies, with a mean follow-up of 9.9 (range: 1.0–32.4) months (*Table 2*; Supplementary data online, *Table S2*). In 27 invasive hTMS studies, 12 939 HF patients were included and had a mean follow-up of 15.3 (range: 5.4–34.9) months (*Table 3*; Supplementary data online, *Table S3*). In non-invasive hTMS and invasive hTMS, 8 and 11 studies, respectively, were observational (either pre–post studies, matched studies, or single arm studies). All other studies were RCTs.

## Patient characteristics

The mean age of patients in the non-invasive hTMS studies was 68 ± 13 years; 67.8% were men; 46.6% were classified as NYHA classes III–IV. Of the non-invasive studies, 10 359, 8571, and 4680 patients were included in the TM, STS, and Complex TM categories, respectively (*Table 2*). In the invasive hTMS studies, the mean age was 66 ± 12 years. Of these patients 75.8% were men, and 47.6% were classified as NYHA classes III–IV. In the invasive hTMS, 9445 and 3494 patients were included in CIED or IHM, respectively (*Table 3*). Details regarding the prescription of guideline-directed medical therapy (GDMT) for HF are presented in Supplementary data online, *Tables S4* and *S5*.

## Clinical efficacy of telemonitoring

### All-cause mortality

In 80 studies (both non-invasive and invasive) reporting ACM, 11.1% (2099/18 711) of the patients died in the hTMS group compared with 12.8% (1949/15 231) in the SoC group. Overall, hTMS showed a significant 16% reduction in ACM (OR: 0.84, 95% CI: 0.77–0.93) (*Figure 2*). Within the treatment effect, the degree of heterogeneity across all studies was considered as not important however, significant ($I^2 = 24\%$). The funnel plot and Egger's regression test showed no evidence of publication bias for this endpoint (see Supplementary data online, *Figure S1-S6*). Non-invasive hTMS showed a 15% reduction in ACM (OR: 0.85, 95% CI: 0.77–0.94, $I^2 = 9\%$). This effect was primarily driven by the effect of STS. Invasive hTMS showed no significant reduction in mortality (OR: 0.86, 95% CI: 0.70–1.06, $I^2 = 50\%$) (*Figure 2*). These results were consistent for both CIED and IHM studies. The results of the sensitivity analyses, in which HRs are obtained, showed similar results compared with the main analyses based on ORs (see Supplementary data online, *Figure S7*). Results dividing articles based on follow-up times are presented in Supplementary data online, *Figure S8*.

### First heart failure hospitalization

In 54 studies reporting first HFH, 21.3% (2201/10 352) of the patients receiving hTMS and 25.5% (2263/8883) receiving SoC had at least one

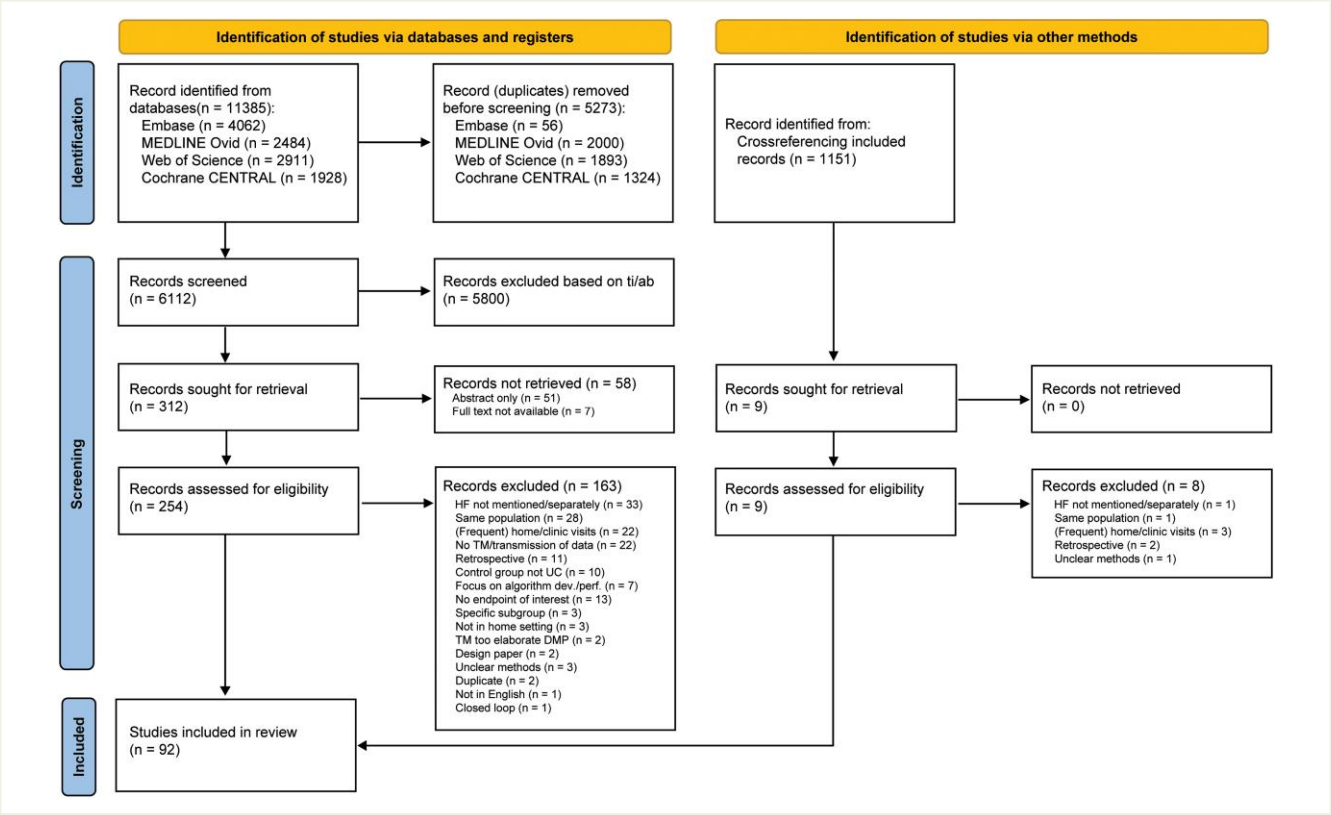


**Figure 1** Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow-chart.[103]

HF admission. The pooled non-invasive and invasive studies showed a 19% reduction in first HFHs in patients using hTMS (OR: 0.81, 95% CI 0.74–0.88) (*Figure 3*). The degree of heterogeneity of these studies was considered to be not important and non-significant ($I^2 = 22\%$). The funnel plot and Egger's regression test showed a significant asymmetry (see Supplementary data online, *Figure S9–S13*). The HF patients using non-invasive hTMS showed a 22% reduction in first HFH compared with SoC, with a moderate degree of heterogeneity (OR: 0.78, 95% CI: 0.70–0.86, $I^2 = 26\%$). This effect was primarily driven by the STS and TM studies. In contrast, invasive hTMS showed no significant reduction compared with SoC, with a low degree of heterogeneity (OR: 0.89, 95% CI: 0.77–1.03, $I^2 = 5\%$). These results were consistent within for both CIED and IHM studies. The results of the sensitivity analysis, in which HRs are obtained, showed similar results compared with the main analyses based on ORs (see Supplementary data online, *Figure S14*). Results dividing articles based on follow-up times are presented in Supplementary data online, *Figure S15*.

### Total heart failure hospitalizations

In 34 studies reporting total HFHs, 3839 HFHs occurred over the course of 10 280 patient-years in patients receiving hTMS compared with 2929 HFHs over the course of 8358 patient-years in the control group. Receiving hTMS was found to be significantly associated with a 15% reduction in the occurrence of HFHs over time (IRR: 0.85, 95% CI 0.76–0.96) (*Figure 4*). Within the non-invasive studies, the use of hTMS was associated with an 18% reduction in the occurrence of HFH over time (IRR: 0.82, 95% CI 0.70–0.96). In contrast, in invasive studies, no significant effect in the occurrence of HFH was shown (IRR: 0.90, 95% CI 0.74–1.10). Within all invasive studies, the IHM studies showed a significant reduction in the occurrence of HFH, whereas the CIED studies showed no effect. The degree of heterogeneity of both non-invasive and invasive studies was classified as substantial (non-invasive: $I^2 = 70\%$, invasive: $I^2 = 73\%$). The funnel plot and Egger's regression test showed no evidence of publication bias for this outcome (see Supplementary data online, *Figure S16–S21*).

## Risk of bias assessment

Quality assessment was performed using the RoB2 tool and ROBINS-I tool in 73 and 19 studies, respectively. A total of 20.5% of the RCTs were classified as high risk of bias. This was most frequently due to risk of bias in the domain 'missing outcome data' and 'deviations from the intervention' (see Supplementary data online, *Figure S22*). A total of 62.5% of the observational articles were classified as serious or critical risk of bias. This was frequently due to the high risk of confounding bias (see Supplementary data online, *Figure S23*).

# Discussion

In this state-of-the-art meta-analysis of 92 studies encompassing 36 549 patients with HF, we show that the use of hTMS modalities in HF patients is associated with a reduction in the risk of mortality, first HFH, and the total HFHs (Structured Graphical Abstract). We found a strong and consistent overall efficacy in reducing all clinical endpoints, with less heterogeneous results than previous meta-analyses on telemonitoring in chronic HF.[5] Overall, with our findings, the body of evidence for the use of hTMS in the management of these patients is further growing.

**Table 2 Trial characteristics non-invasive studies**

| Author, year (study) | Country | Design | Enrollment | *n* | Age, years | Men, % | NYHA III–IV, % | LVEF cut-off | Ischaemic aetiology, % |
|---|---|---|---|---|---|---|---|---|---|
| Angermann **et al.**, 2012 (INH)[15] | DE | RCT | 2004–2007 | 715 | 68.6 ± 12.2 | 71 | 40 | ANY | 58 |
| Antonicelli **et al.**, 2008[16] | IT | RCT | *NA* | 57 | 78 ± 8.5 | 61 | 42 | ANY | 67 |
| Baker **et al.**, 2011[17] | US | RCT | 2007–2009 | 605 | 60.7 ± 13.1 | 52 | 31 | ANY | *NA* |
| Balk **et al.**, 2008[18] | NL | RCT | 2005–2006 | 214 | 66 (33–87)[a] | 70 | 52 | ANY | 57 |
| Bento **et al.**, 2009[19] | BR | RCT | *NA* | 40 | 57.5 ± 9.4 | 70 | 38 | ANY | 25 |
| Blum **et al.**, 2014 (MCCD)[20] | US | RCT | 2001–2005 | 203 | 72.5 ± 9 | 71 | 86 | ANY | 65 |
| Boyne **et al.**, 2012 (TEHAF)[13] | NL | RCT | 2007–2008 | 382 | 71.4 ± 11.2 | 59 | 43 | ANY | 50 |
| Capomolla **et al.**, 2004[25] | IT | RCT | 2000–2001 | 133 | 57 ± 10 | 88 | 33 | ANY | 41 |
| Chaudhry **et al.**, 2010 (Tele-HF)[26] | US | RCT | *NA* | 1653 | 61 (51–73) | 58 | 57 | ANY | 51 |
| Chen **et al.**, 2010[27] | TW | NRCT | 2003–2005 | 550 | 68.2 ± 15.5 | 71 | *NA* | <45% | 58 |
| Cichosz **et al.**, 2018 (Danish telecare north)[29] | DK | RCT | *NA* | 299 | 70.5 | 81 | *NA* | ANY | *NA* |
| Cleland **et al.**, 2005 (TEN-HMS)[30] | NL/UK/DE | RCT | 2000–2002 | 426 | 67.2 ± 11.6 | 77 | 34 | <40% | 78 |
| Copeland **et al.**, 2010[32] | US | RCT | 2005 | 458 | 70.0 ± 10.8 | 99 | 44 | ANY | 35 |
| Comin-Colet **et al.**, 2016 (iCOR)[31] | ES | RCT | 2010–2012 | 178 | 74 ± 11 | 59 | 54 | ANY | 35 |
| Dar **et al.**, 2009 (Home HF)[34] | UK | RCT | 2006–2007 | 182 | 71.0 ± 11.7 | 66 | *NA* | ANY | 55 |
| De Lusignan **et al.**, (2001)[35] | UK | RCT | *NA* | 20 | 75.2 | NA | NA | ANY | *NA* |
| DeBusk **et al.**, 2004[37] | US | RCT | 1998–2001 | 462 | 72 ± 11 | 51 | 50 | ANY | 51 |
| Delaney **et al.**, 2013[38] | US | RCT | 2011–2012 | 100 | *NA* | 32 | 100 | ANY | *NA* |
| Dendale **et al.**, 2012 (TEMA-HF)[39] | BE | RCT | 2008–2010 | 160 | 75.8 ± 9.7 | 65 | *NA* | ANY | *NA* |
| DeWalt **et al.**, 2006[40] | US | RCT | 2001–2003 | 127 | 62.5 ± 10.1 | 49 | 50 | ANY | *NA* |
| Domingues **et al.**, 2010[42] | BR | RCT | 2005–2008 | 120 | 63 ± 13 | 58 | *NA* | <45% | *NA* |
| Galbreath **et al.**, 2004[43] | US | RCT | 1999–2003 | 1069 | 70.9 ± 10.3 | 71 | 24 | ANY | *NA* |
| Galinier **et al.**, 2020 (OSICAT)[44] | FR | RCT | 2013–2016 | 990 | 70 ± 12.4 | 72 | 49 | ANY | *NA* |
| Gambetta **et al.**, 2007[45] | US | NRCT | *NA* | 282 | 74.6 ± 13 | 56 | NA | ANY | 46 |
| Gattis **et al.**, 1999 (PHARM)[46] | US | RCT | 1996–1997 | 181 | *NA* | 68 | 33 | <45% | *NA* |
| GESICA, Grancelli **et al.**, 2005 (DIAL) | AR | RCT | 2000–2001 | 1518 | 65 ± 13.3 | 71 | 49 | ANY | *NA* |
| Giordano **et al.**, 2009[47] | IT | RCT | 2002–2004 | 460 | 57 ± 10 | 85 | 40 | <40% | 53 |
| Gjeka **et al.**, 2021[48] | US | RCT | 2016–2018 | 62 | 68.6 | 49 | *NA* | *NA* | *NA* |
| Goldberg **et al.**, 2003 (WHARF)[49] | US | RCT | 1998–2000 | 280 | 59.1 ± 15.3 | 68 | 100 | ≤35% | 43 |
| Ho **et al.**, 2007[52] | TW | OBS (pre-post) | 2004 | 247 | 60 ± 17 | 68 | 33 | ≤40% | 49 |
| Kalter-Leibovici **et al.**, 2017[55] | IL | RCT | 2007–2012 | 1360 | 70.7 ± 11.3 | 73 | 85 | ANY | *NA* |
| Kashem **et al.**, 2008[56] | US | RCT | *NA* | 48 | 53.7 ± 10.5 | 74 | 58 | ANY | 41 |
| Köberich **et al.**, 2015[57] | DE | RCT | 2011–2013 | 110 | 61.7 ± 12.0 | 83 | 34 | ≤40% | 53 |
| Koehler **et al.**, 2011 (TIM-HF)[58] | DE | RCT | 2008–2009 | 710 | 66.9 ± 10.6 | 81 | 50 | ≤35% | 56 |
| Koehler **et al.**, 2018 (TIM-HF2)[9] | DE | RCT | 2013–2017 | 1538 | 70.0 ± 10.5 | 70 | 48 | ANY | 41 |

*Continued*

**Table 2** ***Continued***

| Author, year (study) | Country | Design | Enrollment | *n* | Age, years | Men, % | NYHA III–IV, % | LVEF cut-off | Ischaemic aetiology, % |
|---|---|---|---|---|---|---|---|---|---|
| Kotooka ***et al.***, 2018 (HOMES-HF)[59] | JP | RCT | 2012–2013 | 181 | 66.2 ± 14.2 | 59 | 22 | ANY | 30 |
| Krum ***et al.***, 2013 (CHAT)[60] | AU | RCT | 2003 -? | 405 | 73.0 ± 10.5 | 63 | 41 | <40% | *NA* |
| Laramee ***et al.***, 2003[63] | US | RCT | 1999–2001 | 287 | 70.7 ± 11.8 | 54 | 36 | <40% | 71 |
| Lyngå ***et al.***, 2012 (WISH)[67] | SE | RCT | *NA* | 319 | 73.6 ± 10.1 | 75 | 100 | <50% | 46 |
| Mo ***et al.***, 2021[68] | CN | OBS | 2019 | 300 | 53.1 ± 11.4 | 67 | 52 | <40% | *NA* |
| Morguet ***et al.***, 2008[70] | DE | OBS (matched) | 2004–2006 | 128 | 60.8 ± 10.2 | 88 | 25 | ≤60% | 69 |
| Mortara ***et al.***, 2009 (HHH)[71] | UK/IT/PL | RCT | 2002–2004 | 461 | 60 ± 12 | 85 | 40 | ≤40% | 56 |
| Negarandeh ***et al.***, 2019[73] | IR | RCT | 2016 | 80 | *NA* | 60 | *NA* | *NA* | *NA* |
| Nouryan ***et al.***, 2019[74] | US | RCT | *NA* | 89 | 83.2 | 32 | *NA* | *NA* | *NA* |
| Nunes-Ferreira ***et al.***, 2020[75] | PT | OBS (matched) | 2016–2018 | 125 | 65.9 ± 11.9 | 68 | 8 | ≤40% | 38 |
| Olivari ***et al.***, 2018 (RENEWING HEALTH)[76] | EU | RCT | 2011–2014 | 339 | 80.0 ± 7.0 | 63 | 52 | ANY | 43 |
| Ong ***et al.***, 2016 (BEAT-HF)[77] | US | RCT | 2011–2013 | 1437 | 73 | 54 | 75 | ANY | *NA* |
| Pedone ***et al.***, 2015[78] | IT | RCT | *NA* | 96 | 80 ± 7 | 39 | 68 | ANY | *NA* |
| Pekmezaris ***et al.***, 2019[79] | US | RCT | 2014–2016 | 104 | 59.9 ± 15.1 | 57 | 70 | ANY | *NA* |
| Pérez-Rodríguez ***et al.***, 2015 | MX | RCT | 2011–2012 | 40 | 68.2 ± 7.5 | 65 | 100 | *NA* | *NA* |
| Ramachandran ***et al.***, 2007[80] | IN | RCT | 2005 | 50 | 44.6 ± 11.9 | 78 | 26 | <40% | 12 |
| Riegel ***et al.***, 2002[81] | US | RCT | *NA* | 358 | 73.8 ± 12.4 | 51 | 97 | ANY | 49 |
| Ritchie ***et al.***, 2016[82] | US | RCT | 2010–2011 | 346 | 63.3 ± 13.1 | 51 | *NA* | *NA* | *NA* |
| Roth ***et al.***, 2004[84] | IL | OBS | *NA* | 118 | 74 ± 9 | 70 | 78 | <50% | *NA* |
| Scherr ***et al.***, 2009[86] | AU | RCT | 2003–2008 | 120 | NA | 73 | 87 | *NA* | *NA* |
| Schwarz ***et al.***, 2008[87] | US | RCT | *NA* | 102 | 78.1 ± 7.1 | 48 | 79 | ANY | *NA* |
| Seto ***et al.***, 2012[88] | CA | RCT | 2009–2010 | 100 | 53.7 ± 13.7 | 79 | 46 | <40% | 33 |
| Soran ***et al.***, 2008 (HFHC trial)[92] | US | RCT | 2002–2005 | 315 | 76 ± 7 | 35 | 42 | ≤40% | 55 |
| Villani ***et al.***, 2014[96] | IT | RCT | NA | 80 | 72 ± 3 | 74 | *NA* | <40% | *NA* |
| Völler, ***et al.***, 2022[97] | DE | RCT | 2010–2013 | 621 | 63.0 ± 11.5 | 88 | 31 | <40% | 59 |
| Vuorinen ***et al.***, 2014 (Heart at Home)[98] | FI | RCT | 2010–2012 | 94 | 58.1 ± 11.8 | 83 | 62 | ≤35% | *NA* |
| Wagenaar ***et al.***, 2019 (e-VITA HF)[99] | NL | RCT | 2013–2014 | 450 | 66.8 ± 11.0 | 74 | 20 | *NA* | *NA* |
| Wakefield ***et al.***, 2008[100] | US | RCT | 2002–2005 | 148 | 69.3 ± 9.6 | 99 | 72 | *NA* | *NA* |
| Ware ***et al.***, 2020[101] | CA | OBS (pre-post) | 2016–2019 | 315 | 58.3 ± 15.5 | 78 | 31 | ANY | *NA* |
| Wita ***et al.***, 2022[102] | PL | RCT | 2014–2017 | 63 | 66.1 ± 10.5 | 87 | *NA* | *NA* | 29 |

SD, standard deviation; IQR, interquartile range; NYHA, New York Heart Association classification; LVEF, left ventricular ejection fraction; DE, Germany; IT, Italy; US, United States; NL, The Netherlands; BR, Brazil; TW, Taiwan; DK, Denmark; UK, United Kingdom; ES, Spain; BE, Belgium; FR, France; AR, Argentina; IL, Israel; JP, Japan; AU. Australia; SE, Sweden; CN, China; PL, Poland; IR, Iran; PT, Portugal; EU, Europe; MX, Mexico; IN, India; CA, Canada; TH, Thailand; FI, Finland; RCT, randomized controlled trial; OBS, observational study; NRCT, non-randomized controlled trial; NA, not available.
[a]Median (range).

**Table 3 Trial characteristics invasive studies**

| Author, year (study) | Country | Design | Enrollment | *n* | Age, years | Men % | NYHA III–IV, % | LVEF cut-off | Ischaemic aetiology, % |
|---|---|---|---|---|---|---|---|---|---|
| Abraham ***et al.***, 2016 (CHAMPION)[12] | US | RCT | 2007–2009 | 550 | 61.6 ± 12.8 | 73 | 100[a] | ANY | 61 |
| Adamson ***et al.***, 2011 (REDUCEhf)[13] | US | RCT | *NA* | 400 | 55 ± 15 | 69 | 51 | ANY | 45 |
| Angermann ***et al.***, 2020 (MEMS-HF)[14] | NL/DE/IE | NRCT | 2016–2018 | 234 | 67.9 ± 10.7 | 78 | 100 | ANY | 53 |
| Böhm ***et al.***, 2016[21] | DE | RCT | 2008–2013 | 1002 | 66.3 ± 10.4 | 80 | 87[a] | <35% | 54 |
| Boriani ***et al.***, 2016 (MORE-CARE) | IT | RCT | 2009–2014 | 918 | 66 ± 10 | 76 | 62 | ANY | 44 |
| Bourge ***et al.***, 2008 (COMPASS-HF)[23] | US | RCT | *NA* | 274 | 58 ± 13.5 | 65 | 100 | <50% | 81 |
| Chiu ***et al.***, 2021 (REMOTE-CIED) | NL/DK | RCT | 2013–2016 | 595 | 65 (59–73) | 78 | 33[a] | ANY | 55 |
| Cowie ***et al.***, 2022 (COAST)[33] | UK | OBS | 2017–2018 | 100 | 69 ± 11.9 | 70 | 100 | ANY | 39 |
| De Simone ***et al.***, 2015 (EFFECT)[36] | IT | NRCT | 2011–2013 | 987 | 66 ± 12.5 | 77 | 44 | ANY | 55 |
| Domenichini ***et al.***, 2015 (LIMIT-CHF)[41] | UK | RCT | 2010–2013 | 80 | 67.9 ± 11.4 | 94 | NA | <50% | NA |
| Hansen ***et al.***, 2018 (InContact)[50] | DE | RCT | 2010–2014 | 210 | 63.8 ± 11.1 | 84 | 43 | ≤35% | 59 |
| Hindricks ***et al.***, 2014 (IN-TIME)[51] | AU/EU/IL | RCT | 2007–2010 | 664 | 65.5 ± 9.4 | 81 | 57 | ≤35% | *NA* |
| Jermyn ***et al.***, 2017[54] | US | OBS | 2014–2016 | 66 | *NA* | *NA* | 100 | *NA* | *NA* |
| Kurek ***et al.***, 2017 (COMMIT-HF)[61] | PL | OBS (matched) | 2009–2013 | 574 | *NA* | 84 | 41 | ≤35% | 71 |
| Landolina ***et al.***, 2012 (EVOLVO)[62] | IT | RCT | 2008–2009 | 200 | *NA* | 79 | 88 | ≤35% | 46 |
| Liberska ***et al.***, 2016[64] | PL | OBS | 2006–2012 | 305 | 62.6 | 76 | *NA* | ≤35% | 57 |
| Lindenfeld ***et al.***, 2021 (GUIDE-HF)[65] | US | RCT | 2018–2019 | 1000 | *NA* | 63 | 70 | ANY | 40 |
| Lüthje ***et al.***, 2015[66] | DE | RCT | 2007–2011 | 176 | 65.9 ± 12.0 | 77 | 43 | ANY | 51 |
| Morgan ***et al.***, 2017 (REM-HF)[69] | UK | RCT | 2011–2014 | 1650 | 69.5 ± 10.17 | 86 | 31 | ANY | *NA* |
| Mullens ***et al.***, 2010[72] | BE/US | OBS | 2007–2007 | 194 | 62.0 ± 14.0 | 59 | *NA* | *NA* | 45 |
| Sardu ***et al.***, 2016[85] | IT | RCT | 2010–2014 | 191 | 72.2 ± 7.2 | 76 | 55 | <35% | *NA* |
| Sharif ***et al.***, 2022 (SIRONA 2)[89] | BE | OBS | 2019–2021 | 70 | 71.0 ± 10.0 | 71 | 100 | ANY | *NA* |
| Shavelle ***et al.***, 2020[90] | US | OBS (pre-post) | 2014–2017 | 1200 | 69 ± 12 | 62 | *NA* | ANY | 41 |
| Smeets ***et al.***, 2017[91] | BE | OBS (registry) | 2010–2013 | 282 | 71 ± 12 | 82 | 18 | ANY | 61 |
| Tajstra ***et al.***, 2020 (RESULT)[93] | PL | RCT | 2015–2017 | 608 | *NA* | 81 | 22 | <35% | 64 |
| Treskes ***et al.***, 2021[94] | BE/NL/CH | NRCT (pre-post) | 2018–2019 | 74 | 67.2 ± 10.3 | 84 | 32 | ANY | 36 |
| Van Veldhuisen ***et al.***, 2011 (DOT-HF)[95] | EU/AF/ME/AS | RCT | *NA* | 335 | 64 ± 10 | 86 | 37 | ≤ 35% | 56 |

SD, standard deviation; IQR, interquartile range; NYHA, New York Heart Association classification; LVEF, Left Ventricular Ejection Fraction; US, United States; NL, The Netherlands; DE, Germany; IE, Ireland; IT, Italy; DK, Denmark; AU, Australia; EU, Europe; PL, Poland; UK, United Kingdom; BE, Belgium; AT, Austria; CH, Switzerland; AF, Africa; ME, Middle East; AS, Asia; RCT, randomized controlled trial; OBS, Observational study; NRCT, non-randomized controlled trial; NA, not available.
[a]Only NYHA III patients.

## Non-invasive home telemonitoring systems

This comprehensive meta-analysis is the first to demonstrate a significant consistent benefit of non-invasive hTMS in HF patients on reducing ACM, first HFH, and the total HFHs. However, considering the separate modalities within non-invasive hTMS, limited power precluded the robustness that is needed to evaluate if each individual modality would reduce total HFHs. When dissecting the results of the different non-invasive hTMS modalities, we demonstrate that TM had a significant reduction in first HFH, while a tendency towards a reduced risk of ACM and total HFHs was observed. This is in contrast to a

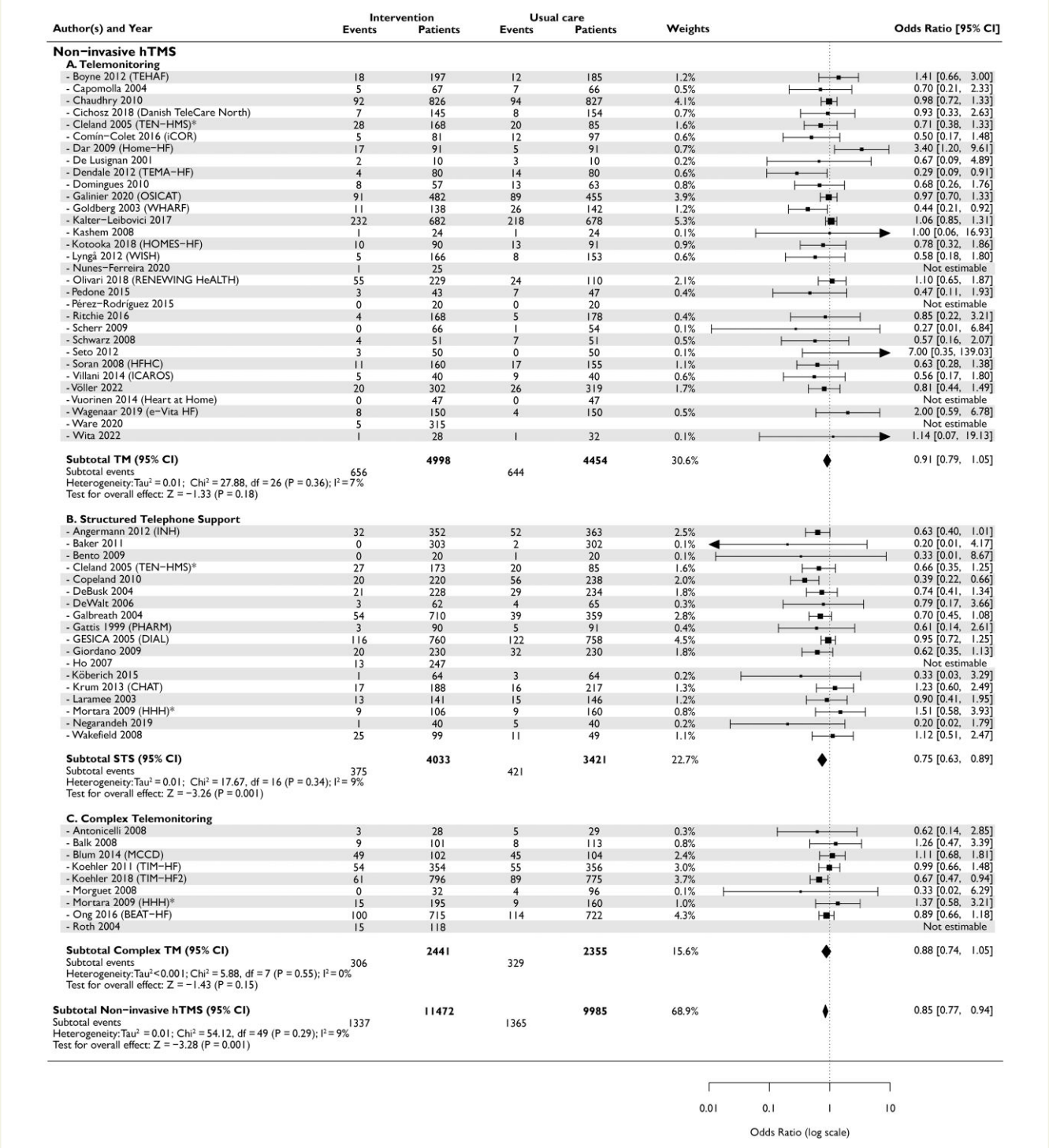


**Figure 2** Forest plot all-cause mortality. TM, telemonitoring; STS, structured telephone support; complex TM, complex telemonitoring; hTMS, home telemonitoring systems; CIED, cardiac implantable electronic devices; IHM, invasive haemodynamic monitoring. *The studies of Mortara *et al.*[71] and Cleland *et al.*[30] have multiple intervention arms. Therefore, those articles are presented more than once in the forest plot. In the subtotal non-invasive home telemonitoring systems and the total pooled analysis, event rates of each study arm are added together. **From the article of Lindenfeld *et al.*, the post-COVID analysis was used, to avoid bias in observed outcomes due to the COVID pandemic.

Cochrane review,[5] which demonstrated a significant benefit for both ACM and HFH. This difference could be explained by the reclassification of the Tele-HF study from STS to TM.[26] The benefits on first HFHs are in line with Inglis *et al.*[5] For complex TM, this review was not able to demonstrate a clear benefit, which may be due to the lower number of studies in this category. Nevertheless, complex TM systems may prove beneficial as shown in the TIM-HF2 trial.[9] Within this RCT, patients were monitored using a combination of TM and STS and

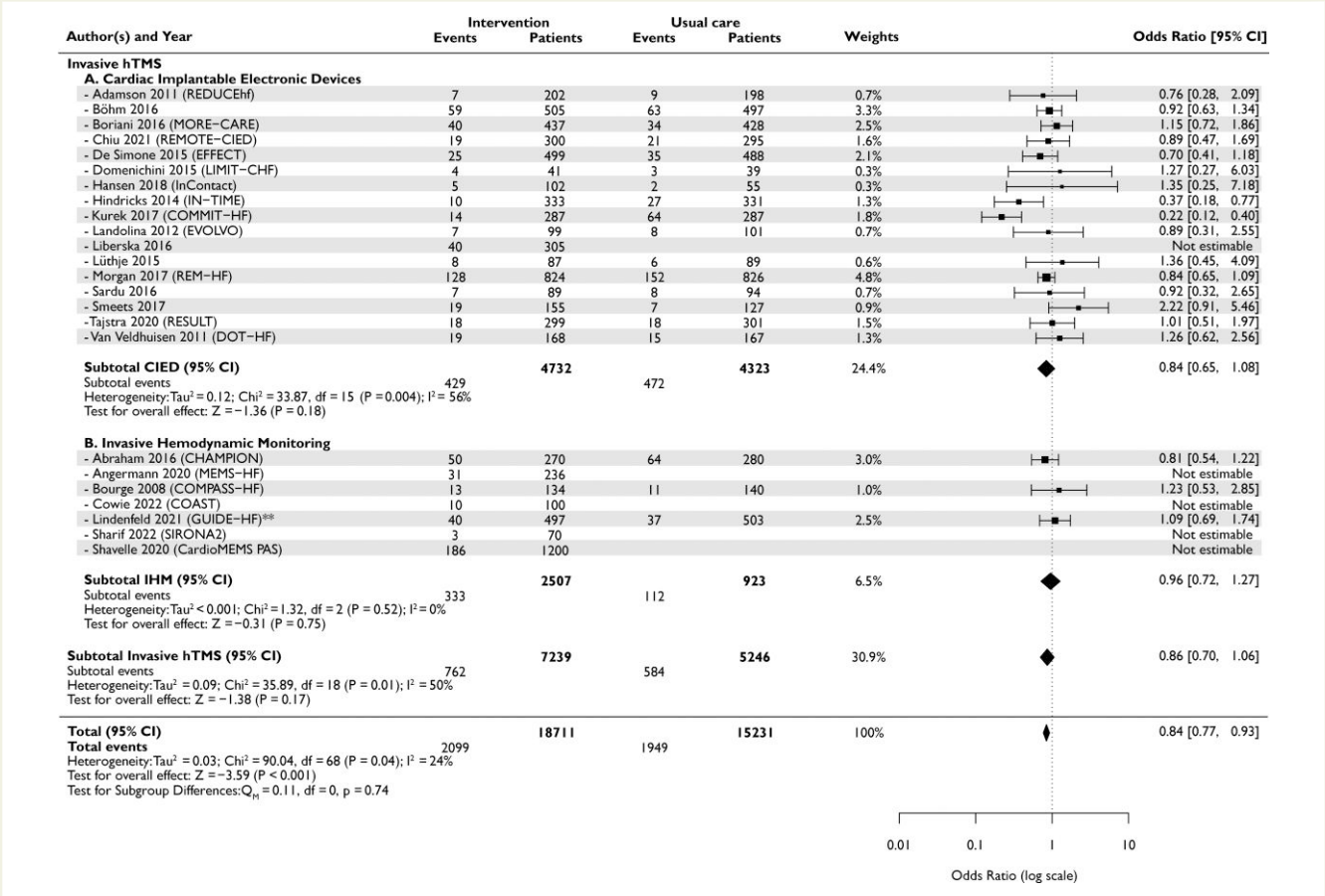


**Figure 2** Continued

provided with 24/7 telemedical support. This complex intervention led to a reduction in the percentage of days lost due to HFH and ACM. Nevertheless, one potential limitation of complex TM systems is that they are labour-intensive and therefore probably not feasible in every healthcare system. The modality described in the TIM-HF2 study requires extra personnel due to the large amount of provided data in combination with continuous accessibility of telemedical support. A desirable solution to this would be automated interpretation of such data, which, obviously, is challenging. In addition, the effects of less labour-intensive alternatives as STS and TM were overall stronger than complex TM. This observation might be explained by differences in the healthcare system and therefore the SoC of the included studies. The CHAMP-HF and CHECK-HF registries, both containing quality-of-care data from two developed western countries (USA and the Netherlands), show substantial differences regarding guideline adherence, prescription levels, and target dose levels of GDMT and devices, which can be related to differences in healthcare system, insurance, and care access.[104]

Our results show a significant overall reduction in the incidence of endpoints in patients with HF through the use of non-invasive hTMS. There is, however, some heterogeneity present between studies. On the other hand, the degree of heterogeneity, regarding ACM and first HFH, of the studies included in this meta-analysis is considerably lower as compared with previous meta-analyses. Interestingly, the effect on the outcomes attenuates in the period after publication of Inglis *et al.*[5] A potential explanation for this heterogeneity is that studies that include chronic 'stable' HF patients (NYHA classes I–II), who experience less events and have a better overall prognosis, will show a smaller effect size on the short term than studies including unstable HF patients who recently had an HF admission and therefore are at a greater risk of a recurrent event. Unfortunately, as these data were not always presented in detail, we were unable to analyse these differences in the context of the current study. Also, we selected many new studies (up to July 2022) especially from the last 5 years with a more structured and integrated approach of hTMS, and this time window is important with the expansion of GDMT between guidelines.

## Invasive home telemonitoring systems

This meta-analysis was not able to demonstrate an overall benefit of invasive hTMS on all outcomes. Sensitivity analysis of the different invasive hTMS modalities showed no benefit of CIED monitoring on ACM and HFHs, while IHM showed a significant reduction in total HFHs. The lack of effect of CIED monitoring is important to note. In our meta-analysis, we did not differentiate between CIED with or without impedance measurements to investigate the potential differences in effect. However, a recent meta-analysis by Zito *et al.*[105] showed no reduction in risk of ACM and HFH using CIED with or without impedance measurements. Additionally, this meta-analysis presented similar results regarding IHM, with several studies showing a remarkably strong result especially those with specifically designed sensors. These findings can be explained by the pathogenesis of HF deterioration. It is well known that increasing filling pressures is one of the first parameters for deterioration of HF, even before overt clinical

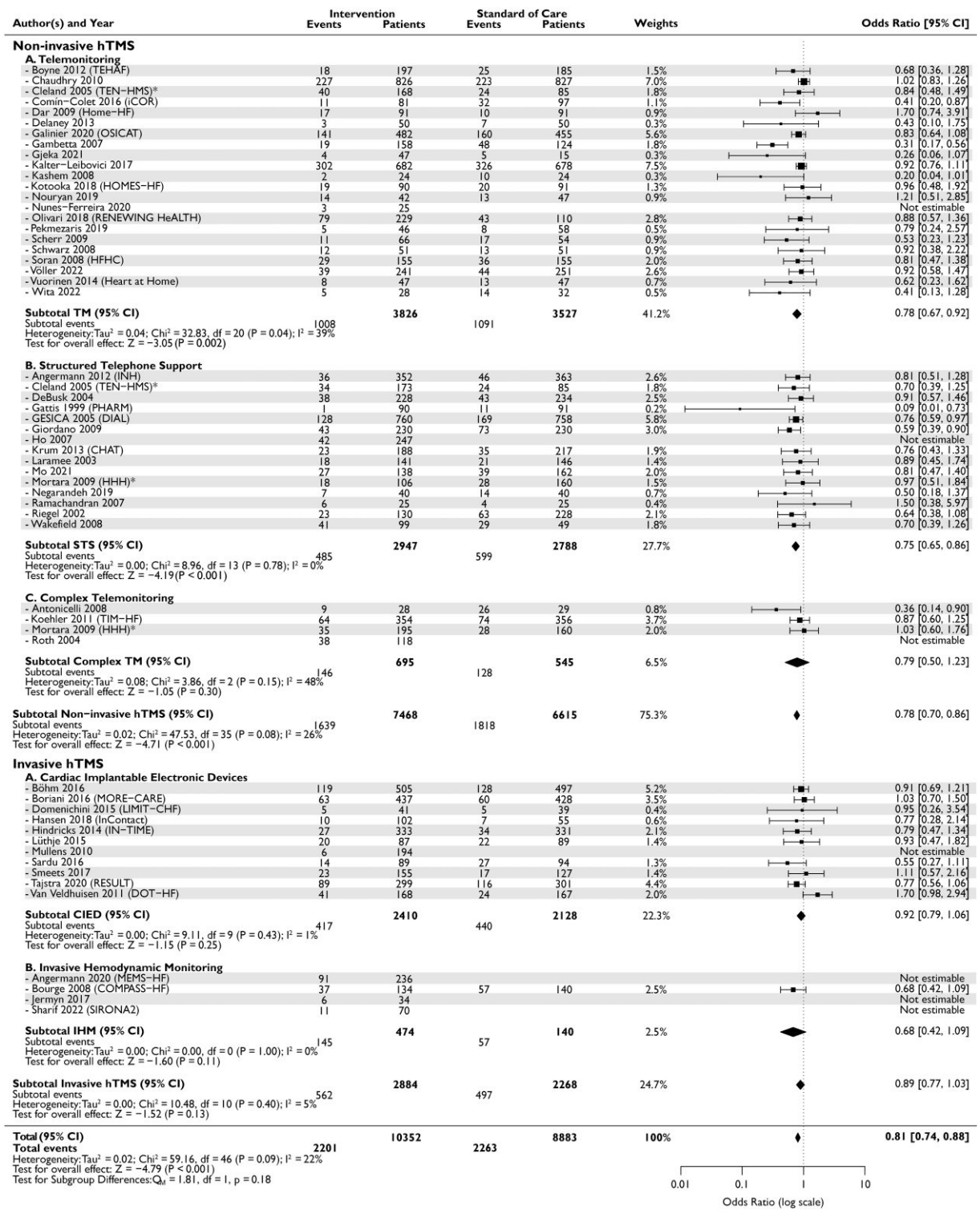


**Figure 3** Forest plot first hospitalization. TM, telemonitoring; STS, structured telephone support; complex TM, complex telemonitoring; hTMS, home telemonitoring systems; CIED, cardiac implantable electronic devices; IHM, invasive haemodynamic monitoring. *The studies of Mortara *et al.*[71] and Cleland *et al.*[30] have multiple intervention arms. Therefore, those articles are presented more than once in the forest plot. In the subtotal non-invasive home telemonitoring systems and the total pooled analysis, event rates of each study arm are added together.

symptoms are present.[106] By measuring this clinically intuitive parameter (which leads to proactive early interventions), hospitalizations due to HF deterioration can be avoided.[12] These haemodynamic-guided monitoring techniques are very promising. Still, due to their costs, these devices are most likely targeted for those patients who are at higher risk of (re-)admission due to HF and require more intensive monitoring.

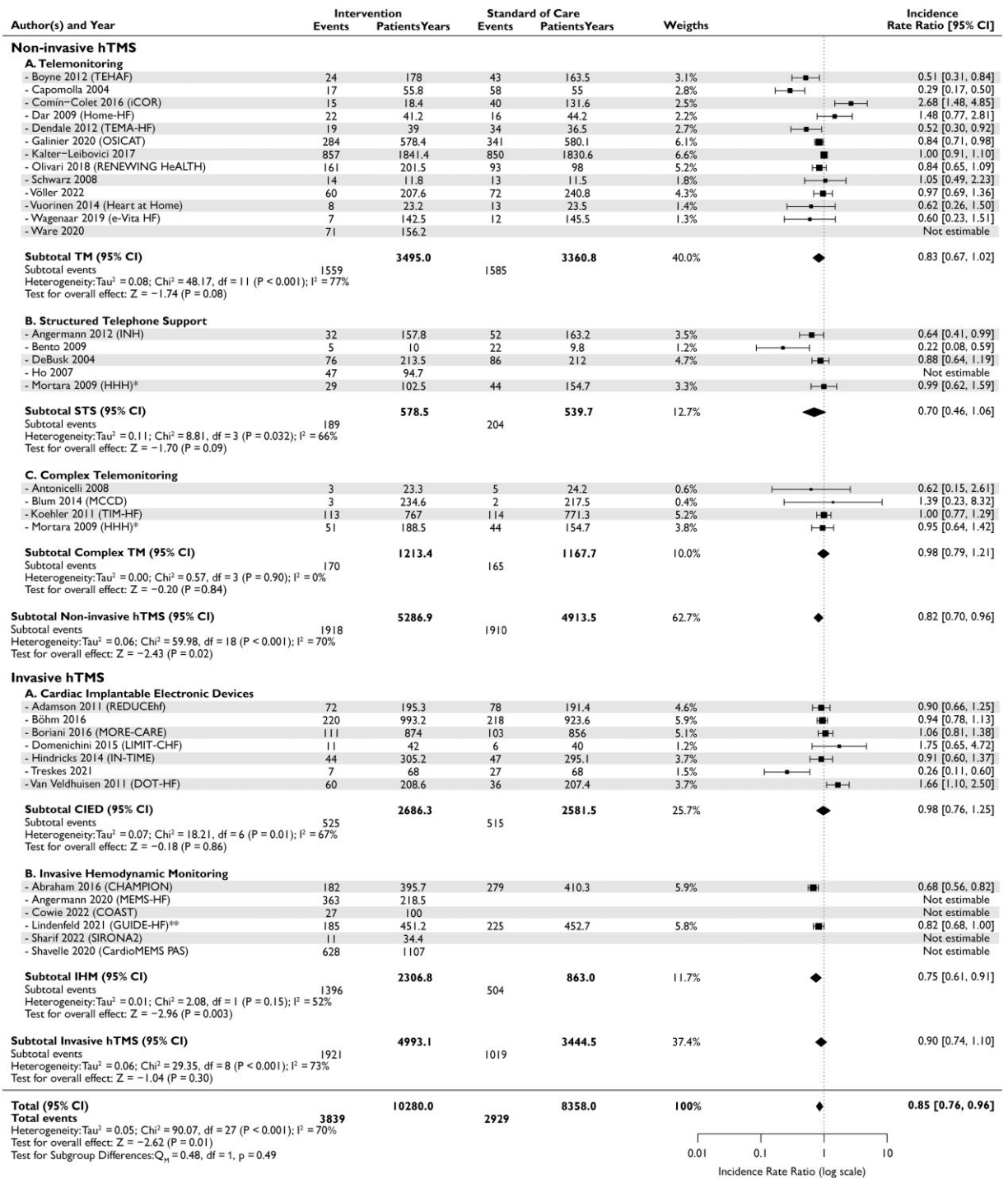


**Figure 4** Forest plot total hospitalizations. TM, telemonitoring; STS, structured telephone support; complex TM, complex telemonitoring; hTMS, home telemonitoring systems; CIED, cardiac implantable electronic devices; IHM, invasive haemodynamic monitoring. *The studies of Mortara *et al.*[71] have multiple intervention arms. Therefore, those articles are presented more than once in the forest plot. In the subtotal non-invasive home telemonitoring systems and the total pooled analysis, event rates of each study arm are added together. **From the article of Lindenfeld *et al.*, the post-COVID analysis was used, to avoid bias in observed outcomes due to the COVID pandemic.

Furthermore, there is not only a variation in the identification of distinct pathological parameters between IHM and CIED, but the method of monitoring is often different as well. Pulmonary artery pressures are frequently measured daily to weekly with the use of IHM, and treatment is changed accordingly, while CIED are frequently operated on an alarm basis rather than frequent data monitoring. In addition, alarms are frequently based on less intuitive measurements, such as impendence or algorithms, compared to clinically relevant pressure data.

The IHM was not able to show a benefit on short-term mortality. This is most likely caused by the low power considering the small number of studies and events with a higher level of uncertainty of our data as well as the relative short follow-up time. The type of patients selected is generally sicker or has more advanced HF with NYHA class III and a previous HF hospitalization, with a reduced life expectancy. Several recent drug and device trials could not show a benefit of treatment on mortality in advanced stages of HF and/or against high levels of background therapies. The IHM studies primarily target congestion with modifications in diuretic dosages to prevent decompensation, which potentiates primarily the effects on recurrent HFH. It is unknown whether this translates to indirect benefits on mortality at long term. In the future, the long-term data on IHM will be expanded e.g. with the MONITOR-HF trial.[65,107]

## Clinical impact and future perspective

This meta-analysis provides support for telemonitoring to be incorporated in HF care. A tailored approach seems necessary in order to lead to a maximal benefit of hTMS with various determinants such as the type of healthcare system, funding, and also characteristics of the patients such as disease severity and symptoms. Patients with more advanced HF (NYHA class III) appear to benefit of a more intensive form of (invasive) monitoring, which could be achieved through IHM with main effects on recurrent HF hospitalizations (targeting congestion), while a patient with a more 'stable' HF (NYHA classes I–II) would suffice with the use of non-invasive hTMS, which is simpler and less costly, also considering the enormous patient volumes. This clearly makes sense from a cost-effectiveness perspective, where the most costly method is reserved for the sickest patients who have most to profit from it. In addition, such systems ideally should be adaptable over time, i.e. to intensify when the patient is in a more unstable phase and taper off when the patient is stable. The latter will most likely lead to a higher adherence during prolonged follow-up. Future research should focus on defining these subgroups of patients (based on age, gender, LVEF, NYHA class, stable/unstable aetiology, or other factors) and the effect of the different hTMS modalities on these subgroups. Moreover, the approach will also largely depend on the compatibility with the healthcare system that is already in place. It may also be important to not only focus on detecting HF deterioration, but also to implement a health maintenance strategy.[108]

The evidence provided by this meta-analysis supports non-invasive hTMS and invasive hTMS using IHM (but not CIED). Considering IHM, as the CIs of treatment effects are quite wide, more evidence is needed before widespread use of IHM is to be broadly advocated in specific target populations. Still, there is an urge of wider implementation of remote monitoring strategies within clinical practice and healthcare systems. This requires facilities and personnel, which needs to be funded by the healthcare insurances, and also significant advances in IT development and support in hospitals to reduce workload (e.g. with digital technology and artificial intelligence). Many hTMS studies are on top of care, and the field must also work on replacing standard care components by hTMS, self-management at home, and further reduce face-to-face contacts, such as shown by the EVITA-HF study.[99] To effectuate this, wider implementation needs to be facilitated by the international HF community and guidelines that speak out about their position on hTMS modalities, with the increasing number of studies and data now provided. Also, we need to study and invest in patients, e.g. self-management and involvement in their disease and remote monitoring strategies, which can help in diet, lifestyle, and treatment adherence and close the loop between hospital and patient.

## Strengths and limitations

This meta-analysis has several major strengths. The current meta-analysis is the most comprehensive, contemporary, and largest overview of hTMS (with all available modalities) in chronic HF to date including both clinical trial and real-world observational data. To the best of our knowledge, this is the first systematic review and meta-analysis that focuses on both non-invasive and invasive hTMS in contrast to the Cochrane review of 2015,[5] which only described non-invasive solutions. While we were unable to directly compare non-invasive with invasive hTMS, this study does offer insights into the effectiveness of both modalities. Furthermore, in this meta-analysis, opposed to earlier meta-analyses, we now also differentiated between first HFH and the total HFHs. In our opinion, this manner of analysing the hTMS data is crucial, since both outcomes have different implications and economic impacts.

Several limitations should be mentioned. Firstly, there was still some heterogeneity across studies. Albeit the heterogeneity is decreasing as compared with previous studies, we can specifically observe heterogeneity in the results on the total number of HFHs. The $I^2$-index as a relative measure of heterogeneity, which is not to be considered as an absolute number but as relative categories ranging from <25%, might not be important and >75% considerable heterogeneity. Possible explanations for this degree of heterogeneity are the large variety of hTMS, patient characteristics, and the large variety of HF management between studies. For IHM, the number of studies and events was low, which relates to the $I^2$-index. Attempts were made to minimize this heterogeneity and investigate the effects of the major categories distinguishing between non-invasive and invasive hTMS. The treatment algorithm used in TM strategies could differ across studies, which may have led to the effects demonstrated. As standard care is the comparator, we should acknowledge that the level of standard care varies between studies and in time-period with expanding GDMT. Compared with the Inglis analysis, we observe a decline in heterogeneity of included studies especially in the last 5 years, with many new structured telemonitoring projects.[5] Secondly, the follow-up times used in the meta-analysis of the total number of HFH were limitedly available across studies. These were calculated, as stated in the methods, which may introduce some bias. Thirdly, distortion of results may be present due to publication bias. However, based on our funnel plots, we assume the risk of publication bias to be low for the majority of the analyses.

# Conclusions

Our meta-analysis revealed that overall hTMS are effective in reducing HFH and improve survival. Non-invasive hTMS reduce all endpoints, whereas in invasive hTMS, only IHM reduces recurrent HFHs significantly. Therefore, telemonitoring should be strongly considered and may be integrated in current HF healthcare systems worldwide. For optimal impact, the implementation of hTMS should ultimately be tailored to the individual HF patient and based on compatibility with current healthcare systems.

## Acknowledgements

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# Supplementary data

Supplementary data is available at *European Heart Journal* online.

# Data availability

The data underlying this article can be shared on reasonable request to the corresponding author.

# Conflict of interest

D.T. received research grants from Boston Scientific and Biotronik. O.M. received consulting fees from Abbott, AstraZeneca, and Boehringer-Ingelheim. R.d.B. has received research grants and/or fees from AstraZeneca, Abbott, Boehringer-Ingelheim, Cardior Pharmaceuticals GmbH, Ionis Pharmaceuticals, Inc., Novo Nordisk, and Roche; and has had speaker engagements with Abbott, AstraZeneca, Bayer, Bristol Myers Squibb, Novartis, and Roche. R.v.d.B. received an independent research grant and speaker fee from Abbott. J.B. received independent research grant from Abbott for ISS and has had speaker engagement or advisory boards in the past 5 years with Astra Zeneca, Abbott, Boehringer-Ingelheim, Bayer, Daiichi Sankyo, Novartis and Vifor. All other authors declared to have no conflict of interest.

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# References

1. McDonagh TA, Metra M, Adamo M, Gardner RS, Baumbach A, Bohm M, *et al.* 2021 ESC guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J* 2021;**42**:3599–3726. https://doi.org/10.1093/eurheartj/ehab368
2. Farre N, Vela E, Cleries M, Bustins M, Cainzos-Achirica M, Enjuanes C, *et al.* Real world heart failure epidemiology and outcome: a population-based analysis of 88,195 patients. *PLoS One* 2017;**12**:e0172745. https://doi.org/10.1371/journal.pone.0172745
3. Tersalvi G, Winterton D, Cioffi GM, Ghidini S, Roberto M, Biasco L, *et al.* Telemedicine in heart failure during COVID-19: a step into the future. *Front Cardiovasc Med* 2020;**7**:612818. https://doi.org/10.3389/fcvm.2020.612818
4. Craig J, Patterson V. Introduction to the practice of telemedicine. *J Telemed Telecare* 2005;**11**:3–9. https://doi.org/10.1177/1357633X0501100102
5. Inglis SC, Clark RA, Dierckx R, Prieto-Merino D, Cleland JG. Structured telephone support or non-invasive telemonitoring for patients with heart failure. *Cochrane Database Syst Rev* 2015;**10**:CD007228.
6. Radhoe SP, Veenis JF, Brugts JJ. Invasive devices and sensors for remote care of heart failure patients. *Sensors (Basel* 2021;**21**:2014. https://doi.org/10.3390/s21062014
7. Theuns D, Radhoe SP, Brugts JJ. Remote monitoring of heart failure in patients with implantable cardioverter-defibrillators: current status and future needs. *Sensors (Basel)* 2021;**21**:3763. https://doi.org/10.3390/s21113763
8. Veenis JF, Radhoe SP, Hooijmans P, Brugts JJ. Remote monitoring in chronic heart failure patients: is non-invasive remote monitoring the way to go? *Sensors (Basel)* 2021;**21**:887. https://doi.org/10.3390/s21030887
9. Koehler F, Koehler K, Deckwart O, Prescher S, Wegscheider K, Kirwan BA, *et al.* Efficacy of telemedical interventional management in patients with heart failure (TIM-HF2): a randomised, controlled, parallel-group, unmasked trial. *Lancet* 2018;**392**:1047–1057. https://doi.org/10.1016/S0140-6736(18)31880-4
10. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD *et al.* The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021;**392**:n71. (http://dx.doi.org/10.1136/bmj.n71)
11. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ* 2003;**327**:557–560. https://doi.org/10.1136/bmj.327.7414.557
12. Abraham WT, Stevenson LW, Bourge RC, Lindenfeld JA, Bauman JG, Adamson PB, *et al.* Sustained efficacy of pulmonary artery pressure to guide adjustment of chronic heart failure therapy: complete follow-up results from the CHAMPION randomised trial. *Lancet* 2016;**387**:453–461. https://doi.org/10.1016/S0140-6736(15)00723-0
13. Adamson PB, Gold MR, Bennett T, Bourge RC, Stevenson LW, Trupp R, *et al.* Continuous hemodynamic monitoring in patients with mild to moderate heart failure: results of the reducing decompensation events utilizing intracardiac pressures in patients with chronic heart failure (REDUCEhf) trial. *Congest Heart Fail* 2011;**17**:248–254. https://doi.org/10.1111/j.1751-7133.2011.00247.x
14. Angermann CE, Assmus B, Anker SD, Asselbergs FW, Brachmann J, Brett ME, *et al.* Pulmonary artery pressure-guided therapy in ambulatory patients with symptomatic heart failure: the CardioMEMS European monitoring study for heart failure (MEMS-HF). *Eur J Heart Fail* 2020;**22**:1891–1901. https://doi.org/10.1002/ejhf.1943
15. Angermann CE, Stork S, Gelbrich G, Faller H, Jahns R, Frantz S, *et al.* Mode of action and effects of standardized collaborative disease management on mortality and morbidity in patients with systolic heart failure: the interdisciplinary network for heart failure (INH) study. *Circ Heart Fail* 2012;**5**:25–35. https://doi.org/10.1161/CIRCHEARTFAILURE.111.962969
16. Antonicelli R, Testarmata P, Spazzafumo L, Gagliardi C, Bilo G, Valentini M, *et al.* Impact of telemonitoring at home on the management of elderly patients with congestive heart failure. *J Telemed Telecare* 2008;**14**:300–305. https://doi.org/10.1258/jtt.2008.071213
17. Baker DW, Dewalt DA, Schillinger D, Hawk V, Ruo B, Bibbins-Domingo K, *et al.* The effect of progressive, reinforcing telephone education and counseling versus brief educational intervention on knowledge, self-care behaviors and heart failure symptoms. *J Card Fail* 2011;**17**:789–796. https://doi.org/10.1016/j.cardfail.2011.06.374
18. Balk AH, Davidse W, Dommelen P, Klaassen E, Caliskan K, van der Burgh P, *et al.* Tele-guidance of chronic heart failure patients enhances knowledge about the disease. A multi-centre, randomised controlled study. *Eur J Heart Fail* 2008;**10**:1136–1142. https://doi.org/10.1016/j.ejheart.2008.08.003
19. Bento VF, Brofman PR. Impact of the nursing consultation on the frequency of hospitalizations in patients with heart failure in Curitiba, Parana State. *Arq Bras Cardiol* 2009;**92**:454–460. 473–9, 490–6.
20. Blum K, Gottlieb SS. The effect of a randomized trial of home telemonitoring on medical costs, 30-day readmissions, mortality, and health-related quality of life in a cohort of community-dwelling heart failure patients. *J Card Fail* 2014;**20**:513–521. https://doi.org/10.1016/j.cardfail.2014.04.016
21. Bohm M, Drexler H, Oswald H, Rybak K, Bosch R, Butter C, *et al.* Fluid status telemedicine alerts for heart failure: a randomized controlled trial. *Eur Heart J* 2016;**37**:3154–3163. https://doi.org/10.1093/eurheartj/ehw099
22. Boriani G, Da Costa A, Quesada A, Ricci RP, Favale S, Boscolo G, *et al.* Effects of remote monitoring on clinical outcomes and use of healthcare resources in heart failure patients with biventricular defibrillators: results of the MORE-CARE multicentre randomized controlled trial. *Eur J Heart Fail* 2017;**19**:416–425. https://doi.org/10.1002/ejhf.626
23. Bourge RC, Abraham WT, Adamson PB, Aaron MF, Aranda JM Jr, Magalski A, *et al.* Randomized controlled trial of an implantable continuous hemodynamic monitor in patients with advanced heart failure: the COMPASS-HF study. *J Am Coll Cardiol* 2008;**51**:1073–1079. https://doi.org/10.1016/j.jacc.2007.10.061
24. Boyne JJ, Vrijhoef HJ, Crijns HJ, De Weerd G, Kragten J, Gorgels AP, *et al.* Tailored telemonitoring in patients with heart failure: results of a multicentre randomized controlled trial. *Eur J Heart Fail* 2012;**14**:791–801. https://doi.org/10.1093/eurjhf/hfs058
25. Capomolla S, Pinna G, La Rovere MT, Maestri R, Ceresa M, Ferrari M, *et al.* Heart failure case disease management program: a pilot study of home telemonitoring versus usual care. *Eur Heart J Suppl* 2004;**6**:F91–FF8. https://doi.org/10.1016/j.ehjsup.2004.09.011
26. Chaudhry SI, Mattera JA, Curtis JP, Spertus JA, Herrin J, Lin ZQ, *et al.* Telemonitoring in patients with heart failure. *N Engl J Med* 2010;**363**:2301–2309. https://doi.org/10.1056/NEJMoa1010029
27. Chen YH, Ho YL, Huang HC, Wu HW, Lee CY, Hsu TP, *et al.* Assessment of the clinical outcomes and cost-effectiveness of the management of systolic heart failure in Chinese patients using a home-based intervention. *J Int Med Res* 2010;**38**:242–252. https://doi.org/10.1177/147323001003800129
28. Chiu CSL, Timmermans I, Versteeg H, Zitron E, Mabo P, Pedersen SS, *et al.* Effect of remote monitoring on clinical outcomes in European heart failure patients with an implantable cardioverter-defibrillator: secondary results of the REMOTE-CIED randomized trial. *Europace* 2022;**24**:256–267. https://doi.org/10.1093/europace/euab221
29. Cichosz SL, Udsen FW, Hejlesen O. The impact of telehealth care on health-related quality of life of patients with heart failure: results from the Danish TeleCare North heart failure trial. *J Telemed Telecare* 2020;**26**:452–461. https://doi.org/10.1177/1357633X19832713
30. Cleland JG, Louis AA, Rigby AS, Janssens U, Balk AH, Investigators T-H. Noninvasive home telemonitoring for patients with heart failure at high risk of recurrent admission and death: the Trans-European Network-Home-Care Management System (TEN-HMS) study. *J Am Coll Cardiol* 2005;**45**:1654–1664. https://doi.org/10.1016/j.jacc.2005.01.050
31. Comin-Colet J, Enjuanes C, Verdu-Rotellar JM, Linas A, Ruiz-Rodriguez P, Gonzalez-Robledo G, *et al.* Impact on clinical events and healthcare costs of adding telemedicine to multidisciplinary disease management programmes for heart failure: results of a randomized controlled trial. *J Telemed Telecare* 2016;**22**:282–295. https://doi.org/10.1177/1357633X15600583
32. Copeland LA, Berg GD, Johnson DM, Bauer RL. An intervention for VA patients with congestive heart failure. *Am J Manag Care* 2010;**16**:158–165.

33. Cowie MR, Flett A, Cowburn P, Foley P, Chandrasekaran B, Loke I, *et al.* Real-world evidence in a national health service: results of the UK CardioMEMS HF system post-market study. *ESC Heart Fail* 2022;**9**:48–56. https://doi.org/10.1002/ehf2.13748
34. Dar O, Riley J, Chapman C, Dubrey SW, Morris S, Rosen SD, *et al.* A randomized trial of home telemonitoring in a typical elderly heart failure population in North West London: results of the Home-HF study. *Eur J Heart Fail* 2009;**11**:319–325. https://doi.org/10.1093/eurjhf/hfn050
35. de Lusignan S, Wells S, Johnson P, Meredith K, Leatham E. Compliance and effectiveness of 1 year's home telemonitoring. The report of a pilot study of patients with chronic heart failure. *Eur J Heart Fail* 2001;**3**:723–730. https://doi.org/10.1016/S1388-9842(01)00190-8
36. De Simone A, Leoni L, Luzi M, Amellone C, Stabile G, La Rocca V, *et al.* Remote monitoring improves outcome after ICD implantation: the clinical efficacy in the management of heart failure (EFFECT) study. *Europace* 2015;**17**:1267–1275. https://doi.org/10.1093/europace/euu318
37. DeBusk RF, Miller NH, Parker KM, Bandura A, Kraemer HC, Cher DJ, *et al.* Care management for low-risk patients with heart failure: a randomized, controlled trial. *Ann Intern Med* 2004;**141**:606–613. https://doi.org/10.7326/0003-4819-141-8-200410190-00008
38. Delaney C, Apostolidis B, Bartos S, Morrison H, Smith L, Fortinsky R. A randomized trial of telemonitoring and self-care education in heart failure patients following home care discharge. *Home Health Care Manag Pract* 2013;**25**:187–195. https://doi.org/10.1177/1084822312475137
39. Dendale P, De Keulenaer G, Troisfontaines P, Weytjens C, Mullens W, Elegeert I, *et al.* Effect of a telemonitoring-facilitated collaboration between general practitioner and heart failure clinic on mortality and rehospitalization rates in severe heart failure: the TEMA-HF 1 (TElemonitoring in the MAnagement of heart failure) study. *Eur J Heart Fail* 2012;**14**:333–340. https://doi.org/10.1093/eurjhf/hfr144
40. DeWalt DA, Malone RM, Bryant ME, Kosnar MC, Corr KE, Rothman RL, *et al.* A heart failure self-management program for patients of all literacy levels: a randomized, controlled trial [ISRCTN11535170]. *BMC Health Serv Res* 2006;**6**:30. https://doi.org/10.1186/1472-6963-6-30
41. Domenichini G, Rahneva T, Diab IG, Dhillon OS, Campbell NG, Finlay MC, *et al.* The lung impedance monitoring in treatment of chronic heart failure (the LIMIT-CHF study). *Europace* 2016;**18**:428–435. https://doi.org/10.1093/europace/euv293
42. Domingues FB, Clausell N, Aliti GB, Dominguez DR, Rabelo ER. Education and telephone monitoring by nurses of patients with heart failure: randomized clinical trial. *Arq Bras Cardiol* 2011;**96**:233–239. https://doi.org/10.1590/S0066-782X2011005000014
43. Galbreath AD, Krasuski RA, Smith B, Stajduhar KC, Kwan MD, Ellis R, *et al.* Long-term healthcare and cost outcomes of disease management in a large, randomized, community-based population with heart failure. *Circulation* 2004;**110**:3518–3526. https://doi.org/10.1161/01.CIR.0000148957.62328.89
44. Galinier M, Roubille F, Berdague P, Brierre G, Cantie P, Dary P, *et al.* Telemonitoring versus standard care in heart failure: a randomised multicentre trial. *Eur J Heart Fail* 2020;**22**:985–994. https://doi.org/10.1002/ejhf.1906
45. Gambetta M, Dunn P, Nelson D, Herron B, Arena R. Impact of the implementation of telemanagement on a disease management program in an elderly heart failure cohort. *Prog Cardiovasc Nurs* 2007;**22**:196–200. https://doi.org/10.1111/j.0889-7204.2007.06483.x
46. Gattis WA, Hasselblad V, Whellan DJ, O'Connor CM. Reduction in heart failure events by the addition of a clinical pharmacist to the heart failure management team: results of the Pharmacist in Heart Failure Assessment Recommendation and Monitoring (PHARM) study. *Arch Intern Med* 1999;**159**:1939–1945. https://doi.org/10.1001/archinte.159.16.1939
47. Giordano A, Scalvini S, Zanelli E, Corra U, Longobardi GL, Ricci VA, *et al.* Multicenter randomised trial on home-based telemanagement to prevent hospital readmission of patients with chronic heart failure. *Int J Cardiol* 2009;**131**:192–199. https://doi.org/10.1016/j.ijcard.2007.10.027
48. Gjeka R, Patel K, Reddy C, Zetsche N. Patient engagement with digital disease management and readmission rates: the case of congestive heart failure. *Health Informatics J* 2021;**27**:14604582211030959. https://doi.org/10.1177/14604582211030959
49. Goldberg LR, Piette JD, Walsh MN, Frank TA, Jaski BE, Smith AL, *et al.* Randomized trial of a daily electronic home monitoring system in patients with advanced heart failure: the weight monitoring in heart failure (WHARF) trial. *Am Heart J* 2003;**146**:705–712. https://doi.org/10.1016/S0002-8703(03)00393-4
50. Hansen C, Loges C, Seidl K, Eberhardt F, Troster H, Petrov K, *et al.* INvestigation on routine follow-up in CONgestive HearT FAilure patients with remotely monitored implanted cardioverter defibrillators SysTems (InContact). *BMC Cardiovasc Disord* 2018;**18**:131. https://doi.org/10.1186/s12872-018-0864-7
51. Hindricks G, Taborsky M, Glikson M, Heinrich U, Schumacher B, Katz A, *et al.* Implant-based multiparameter telemonitoring of patients with heart failure (IN-TIME): a randomised controlled trial. *Lancet* 2014;**384**:583–590. https://doi.org/10.1016/S0140-6736(14)61176-4
52. Ho YL, Hsu TP, Chen CP, Lee CY, Lin YH, Hsu RB, *et al.* Improved cost-effectiveness for management of chronic heart failure by combined home-based intervention with clinical nursing specialists. *J Formos Med Assoc* 2007;**106**:313–319. https://doi.org/10.1016/S0929-6646(09)60258-8
53. Investigators G. Randomised trial of telephone intervention in chronic heart failure: dIAL trial. *BMJ* 2005;**331**:425. https://doi.org/10.1136/bmj.38516.398067.E0
54. Jermyn R, Alam A, Kvasic J, Saeed O, Jorde U. Hemodynamic-guided heart-failure management using a wireless implantable sensor: infrastructure, methods, and results in a community heart failure disease-management program. *Clin Cardiol* 2017;**40**:170–176. https://doi.org/10.1002/clc.22643
55. Kalter-Leibovici O, Freimark D, Freedman LS, Kaufman G, Ziv A, Murad H, *et al.* Disease management in the treatment of patients with chronic heart failure who have universal access to health care: a randomized controlled trial. *BMC Med* 2017;**15**:90. https://doi.org/10.1186/s12916-017-0855-z
56. Kashem A, Droogan MT, Santamore WP, Wald JW, Bove AA. Managing heart failure care using an internet-based telemedicine system. *J Card Fail* 2008;**14**:121–126. https://doi.org/10.1016/j.cardfail.2007.10.014
57. Koberich S, Lohrmann C, Mittag O, Dassen T. Effects of a hospital-based education programme on self-care behaviour, care dependency and quality of life in patients with heart failure–a randomised controlled trial. *J Clin Nurs* 2015;**24**:1643–1655. https://doi.org/10.1111/jocn.12766
58. Koehler F, Winkler S, Schieber M, Sechtem U, Stangl K, Bohm M, *et al.* Impact of remote telemedical management on mortality and hospitalizations in ambulatory patients with chronic heart failure: the telemedical interventional monitoring in heart failure study. *Circulation* 2011;**123**:1873–1880. https://doi.org/10.1161/CIRCULATIONAHA.111.018473
59. Kotooka N, Kitakaze M, Nagashima K, Asaka M, Kinugasa Y, Nochioka K, *et al.* The first multicenter, randomized, controlled trial of home telemonitoring for Japanese patients with heart failure: home telemonitoring study for patients with heart failure (HOMES-HF). *Heart Vessels* 2018;**33**:866–876. https://doi.org/10.1007/s00380-018-1133-5
60. Krum H, Forbes A, Yallop J, Driscoll A, Croucher J, Chan B, *et al.* Telephone support to rural and remote patients with heart failure: the chronic heart failure assessment by telephone (CHAT) study. *Cardiovasc Ther* 2013;**31**:230–237. https://doi.org/10.1111/1755-5922.12009
61. Kurek A, Tajstra M, Gadula-Gacek E, Buchta P, Skrzypek M, Pyka L, *et al.* Impact of remote monitoring on long-term prognosis in heart failure patients in a real-world cohort: results from all-comers COMMIT-HF trial. *J Cardiovasc Electrophysiol* 2017;**28**:425–431. https://doi.org/10.1111/jce.13174
62. Landolina M, Perego GB, Lunati M, Curnis A, Guenzati G, Vicentini A, *et al.* Remote monitoring reduces healthcare use and improves quality of care in heart failure patients with implantable defibrillators: the evolution of management strategies of heart failure patients with implantable defibrillators (EVOLVO) study. *Circulation* 2012;**125**:2985–2992. https://doi.org/10.1161/CIRCULATIONAHA.111.088971
63. Laramee AS, Levinsky SK, Sargent J, Ross R, Callas P. Case management in a heterogeneous congestive heart failure population: a randomized controlled trial. *Arch Intern Med* 2003;**163**:809–817. https://doi.org/10.1001/archinte.163.7.809
64. Liberska A, Kowalski O, Mazurek M, Lenarczyk R, Jedrzejczyk-Patej E, Przybylska-Siedlecka K, *et al.* Day by day telemetric care of patients treated with cardiac resynchronisation therapy: first Polish experience. *Kardiol Pol* 2016;**74**:741–748. https://doi.org/10.5603/KP.a2016.0019
65. Lindenfeld J, Zile MR, Desai AS, Bhatt K, Ducharme A, Horstmanshof D, *et al.* Haemodynamic-guided management of heart failure (GUIDE-HF): a randomised controlled trial. *Lancet* 2021;**398**:991–1001. https://doi.org/10.1016/S0140-6736(21)01754-2
66. Luthje L, Vollmann D, Seegers J, Sohns C, Hasenfuss G, Zabel M. A randomized study of remote monitoring and fluid monitoring for the management of patients with implanted cardiac arrhythmia devices. *Europace* 2015;**17**:1276–1281. https://doi.org/10.1093/europace/euv039
67. Lynga P, Persson H, Hagg-Martinell A, Hagglund E, Hagerman I, Langius-Eklof A, *et al.* Weight monitoring in patients with severe heart failure (WISH). A randomized controlled trial. *Eur J Heart Fail* 2012;**14**:438–444. https://doi.org/10.1093/eurjhf/hfs023
68. Mo Y, Chu M, Hu W, Wang H. Association between the nurse-led program with mental health status, quality of life, and heart failure rehospitalization in chronic heart failure patients. *Medicine (Baltimore* 2021;**100**:e25052. https://doi.org/10.1097/MD.0000000000025052
69. Morgan JM, Kitt S, Gill J, McComb JM, Ng GA, Raftery J, *et al.* Remote management of heart failure using implantable electronic devices. *Eur Heart J* 2017;**38**:2352–2360. https://doi.org/10.1093/eurheartj/ehx227
70. Morguet AJ, Kuhnelt P, Kallel A, Jaster M, Schultheiss HP. Impact of telemedical care and monitoring on morbidity in mild to moderate chronic heart failure. *Cardiology* 2008;**111**:134–139. https://doi.org/10.1159/000119701
71. Mortara A, Pinna GD, Johnson P, Maestri R, Capomolla S, La Rovere MT, *et al.* Home telemonitoring in heart failure patients: the HHH study (home or hospital in heart failure). *Eur J Heart Fail* 2009;**11**:312–318. https://doi.org/10.1093/eurjhf/hfp022
72. Mullens W, Oliveira LP, Verga T, Wilkoff BL, Tang WH. Insights from internet-based remote intrathoracic impedance monitoring as part of a heart failure disease

management program. *Congest Heart Fail* 2010;**16**:159–163. https://doi.org/10.1111/j.1751-7133.2010.00149.x
73. Negarandeh R, Zolfaghari M, Bashi N, Kiarsi M. Evaluating the effect of monitoring through telephone (tele-monitoring) on self-care behaviors and readmission of patients with heart failure after discharge. *Appl Clin Inform* 2019;**10**:261–268. https://doi.org/10.1055/s-0039-1685167
74. Nouryan CN, Morahan S, Pecinka K, Akerman M, Lesser M, Chaikin D, *et al.* Home telemonitoring of community-dwelling heart failure patients after home care discharge. *Telemed J E Health* 2019;**25**:447–454. https://doi.org/10.1089/tmj.2018.0099
75. Nunes-Ferreira A, Agostinho JR, Rigueira J, Aguiar-Ricardo I, Guimaraes T, Santos R, *et al.* Non-invasive telemonitoring improves outcomes in heart failure with reduced ejection fraction: a study in high-risk patients. *ESC Heart Fail* 2020;**7**:3996–4004. https://doi.org/10.1002/ehf2.12999
76. Olivari Z, Giacomelli S, Gubian L, Mancin S, Visentin E, Di Francesco V, *et al.* The effectiveness of remote monitoring of elderly patients after hospitalisation for heart failure: the renewing health European project. *Int J Cardiol* 2018;**257**:137–142. https://doi.org/10.1016/j.ijcard.2017.10.099
77. Ong MK, Romano PS, Edgington S, Aronow HU, Auerbach AD, Black JT, *et al.* Effectiveness of remote patient monitoring after discharge of hospitalized patients with heart failure: the better effectiveness after transition—heart failure (BEAT-HF) randomized clinical trial. *JAMA Intern Med* 2016;**176**:310–318. https://doi.org/10.1001/jamainternmed.2015.7712
78. Pedone C, Rossi FF, Cecere A, Costanzo L, Antonelli Incalzi R. Efficacy of a physician-led multiparametric telemonitoring system in very old adults with heart failure. *J Am Geriatr Soc* 2015;**63**:1175–1180. https://doi.org/10.1111/jgs.13432
79. Pekmezaris R, Nouryan CN, Schwartz R, Castillo S, Makaryus AN, Ahern D, *et al.* A randomized controlled trial comparing telehealth self-management to standard outpatient management in underserved Black and Hispanic patients living with heart failure. *Telemed J E Health* 2019;**25**:917–925. https://doi.org/10.1089/tmj.2018.0219
80. Ramachandran K, Husain N, Maikhuri R, Seth S, Vij A, Kumar M, *et al.* Impact of a comprehensive telephone-based disease management programme on quality-of-life in patients with heart failure. *Natl Med J India* 2007;**20**:67–73.
81. Riegel B, Carlson B, Kopp Z, LePetri B, Glaser D, Unger A. Effect of a standardized nurse case-management telephone intervention on resource use in patients with chronic heart failure. *Arch Intern Med* 2002;**162**:705–712. https://doi.org/10.1001/archinte.162.6.705
82. Ritchie CS, Houston TK, Richman JS, Sobko HJ, Berner ES, Taylor BB, *et al.* The E-coach technology-assisted care transition system: a pragmatic randomized trial. *Transl Behav Med* 2016;**6**:428–437. https://doi.org/10.1007/s13142-016-0422-8
83. Robinson S, Stroetmann K, Stroetmann V. Tele-homecare for chronically-ill patients: improved outcomes and new developments. *J Inf Technol Healthcare* 2004;**2**:251–262.
84. Roth A, Kajiloti I, Elkayam I, Sander J, Kehati M, Golovner M. Telecardiology for patients with chronic heart failure: the 'SHL' experience in Israel. *Int J Cardiol* 2004;**97**:49–55. https://doi.org/10.1016/j.ijcard.2003.07.030
85. Sardu C, Santamaria M, Rizzo MR, Barbieri M, di Marino M, Paolisso G, *et al.* Telemonitoring in heart failure patients treated by cardiac resynchronisation therapy with defibrillator (CRT-D): the TELECART study. *Int J Clin Pract* 2016;**70**:569–576. https://doi.org/10.1111/ijcp.12823
86. Scherr D, Kastner P, Kollmann A, Hallas A, Auer J, Krappinger H, *et al.* Effect of home-based telemonitoring using mobile phone technology on the outcome of heart failure patients after an episode of acute decompensation: randomized controlled trial. *J Med Internet Res* 2009;**11**:e34. https://doi.org/10.2196/jmir.1252
87. Schwarz KA, Mion LC, Hudock D, Litman G. Telemonitoring of heart failure patients and their caregivers: a pilot randomized controlled trial. *Prog Cardiovasc Nurs* 2008;**23**:18–26. https://doi.org/10.1111/j.1751-7117.2008.06611.x
88. Seto E, Leonard KJ, Cafazzo JA, Barnsley J, Masino C, Ross HJ. Mobile phone-based telemonitoring for heart failure management: a randomized controlled trial. *J Med Internet Res* 2012;**14**:e31. https://doi.org/10.2196/jmir.1909
89. Sharif F, Rosenkranz S, Bartunek J, Kempf T, Assmus B, Mahon NG, *et al.* Safety and efficacy of a wireless pulmonary artery pressure sensor: primary endpoint results of the SIRONA 2 clinical trial. *ESC Heart Fail* 2022;**9**:2862–2872. https://doi.org/10.1002/ehf2.14006
90. Shavelle DM, Desai AS, Abraham WT, Bourge RC, Raval N, Rathman LD, *et al.* Lower rates of heart failure and all-cause hospitalizations during pulmonary artery pressure-guided therapy for ambulatory heart failure: one-year outcomes from the CardioMEMS post-approval study. *Circ Heart Fail* 2020;**13**:e006863. https://doi.org/10.1161/CIRCHEARTFAILURE.119.006863
91. Smeets CJ, Vranken J, Van der Auwera J, Verbrugge FH, Mullens W, Dupont M, *et al.* Bioimpedance alerts from cardiovascular implantable electronic devices: observational study of diagnostic relevance and clinical outcomes. *J Med Internet Res* 2017;**19**:e393. https://doi.org/10.2196/jmir.8066
92. Soran OZ, Pina IL, Lamas GA, Kelsey SF, Selzer F, Pilotte J, *et al.* A randomized clinical trial of the clinical effects of enhanced heart failure monitoring using a computer-based telephonic monitoring system in older minorities and women. *J Card Fail* 2008;**14**:711–717. https://doi.org/10.1016/j.cardfail.2008.06.448
93. Tajstra M, Sokal A, Gadula-Gacek E, Kurek A, Wozniak A, Niedziela J, *et al.* Remote Supervision to Decrease Hospitalization Rate (RESULT) study in patients with implanted cardioverter-defibrillator. *Europace* 2020;**22**:769–776. https://doi.org/10.1093/europace/euaa072
94. Treskes RW, Beles M, Caputo ML, Cordon A, Biundo E, Maes E, *et al.* Clinical and economic impact of HeartLogic compared with standard care in heart failure patients. *ESC Heart Fail* 2021;**8**:1541–1551. https://doi.org/10.1002/ehf2.13252
95. van Veldhuisen DJ, Braunschweig F, Conraads V, Ford I, Cowie MR, Jondeau G, *et al.* Intrathoracic impedance monitoring, audible patient alerts, and outcome in patients with heart failure. *Circulation* 2011;**124**:1719–1726. https://doi.org/10.1161/CIRCULATIONAHA.111.043042
96. Villani A, Malfatto G, Compare A, Della Rosa F, Bellardita L, Branzi G, *et al.* Clinical and psychological telemonitoring and telecare of high risk heart failure patients. *J Telemed Telecare* 2014;**20**:468–475. https://doi.org/10.1177/1357633X14555644
97. Völler H, Bindl D, Nagels K, Hofmann R, Vettorazzi E, Wegscheider K, *et al.* The first year of noninvasive remote telemonitoring in chronic heart failure is not cost saving but improves quality of life: the randomized controlled CardioBBEAT trial. *Telemed J E Health* 2022;**28**:1613–1622. https://doi.org/10.1089/tmj.2022.0021
98. Vuorinen AL, Leppanen J, Kaijanranta H, Kulju M, Helio T, van Gils M, *et al.* Use of home telemonitoring to support multidisciplinary care of heart failure patients in Finland: randomized controlled trial. *J Med Internet Res* 2014;**16**:e282. https://doi.org/10.2196/jmir.3651
99. Wagenaar KP, Broekhuizen BDL, Jaarsma T, Kok I, Mosterd A, Willems FF, *et al.* Effectiveness of the European Society of Cardiology/Heart Failure Association website 'heartfailurematters.org' and an e-health adjusted care pathway in patients with stable heart failure: results of the 'e-Vita HF' randomized controlled trial. *Eur J Heart Fail* 2019;**21**:238–246. https://doi.org/10.1002/ejhf.1354
100. Wakefield BJ, Ward MM, Holman JE, Ray A, Scherubel M, Burns TL, *et al.* Evaluation of home telehealth following hospitalization for heart failure: a randomized trial. *Telemed J E Health* 2008;**14**:753–761. https://doi.org/10.1089/tmj.2007.0131
101. Ware P, Ross HJ, Cafazzo JA, Boodoo C, Munnery M, Seto E. Outcomes of a heart failure telemonitoring program implemented as the standard of care in an outpatient heart function clinic: pretest–posttest pragmatic study. *J Med Internet Res* 2020;**22**:e16538. https://doi.org/10.2196/16538
102. Wita M, Orszulak M, Szydło K, Wróbel W, Filipecki A, Simionescu K, *et al.* The usefulness of telemedicine devices in patients with severe heart failure with an implanted cardiac resynchronization therapy system during two years of observation. *Kardiol Pol* 2022;**80**:41–48. https://doi.org/10.33963/KP.a2021.0175
103. Page MJ, Moher D, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, *et al.* PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *BMJ* 2021;**372**:n160. http://dx.doi.org/10.1136/bmj.n160
104. Greene SJ, Felker GM. The urgency of doing: addressing gaps in use of evidence-based medical therapy for heart failure. *JACC Heart Fail* 2019;**7**:22–24. https://doi.org/10.1016/j.jchf.2018.11.006
105. Zito A, Princi G, Romiti GF, Galli M, Basili S, Liuzzo G, *et al.* Device-based remote monitoring strategies for congestion-guided management of patients with heart failure: a systematic review and meta-analysis. *Eur J Heart Fail* 2022;**24**:2333–2341. https://doi.org/10.1002/ejhf.2655
106. Adamson PB. Pathophysiology of the transition from chronic compensated and acute decompensated heart failure: new insights from continuous monitoring devices. *Curr Heart Fail Rep* 2009;**6**:287–292. https://doi.org/10.1007/s11897-009-0039-z
107. Brugts JJ, Veenis JF, Radhoe SP, Linssen GCM, van Gent M, Borleffs CJW, *et al.* A randomised comparison of the effect of haemodynamic monitoring with CardioMEMS in addition to standard care on quality of life and hospitalisations in patients with chronic heart failure: design and rationale of the MONITOR HF multicentre randomised clinical trial. *Neth Heart J* 2020;**28**:16–26
108. Cleland JGF, Clark RA, Pellicori P, Inglis SC. Caring for people with heart failure and many other medical problems through and beyond the COVID-19 pandemic: the advantages of universal access to home telemonitoring. *Eur J Heart Fail* 2020;**22**:995–998. https://doi.org/10.1002/ejhf.1864