Variation in hospital performance for heart failure management in the National Heart Failure Audit for England & Wales

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Abstract

Objective: Investigation of variations in provider performance and its determinants may help inform strategies for improving patient outcomes.

Methods: We used the National Heart Failure Audit comprising 68,772 patients with heart failure with reduced left ventricular ejection fraction (HFREF), admitted to 185 hospitals in England and Wales (2007-2013). We investigated hospital adherence to three recommended key performance measures (KPM) for in-hospital care (ACE-inhibitors or ARBs on discharge, beta-blockers on discharge, and referral to specialist follow-up) individually and as a composite performance score. Hierarchical regression models were used to investigate hospital-level variation.

Results: Hospital-level variation in adherence to composite KPM ranged from 50% to 97% (median 79%), but after adjustments for patient characteristics and year of admission, only 8% (CI 7 % to 10%) of this variation was attributable to variations in hospital features. Similarly, hospital prescription rates for ACE-I/ARB and beta-blocker showed low adjusted hospital-attributable variations (7% CI 6% to 9% and 6% CI 5% to 8%, for ACE-I/ARB and beta-blocker, respectively). Referral to specialist follow-up, however, showed larger variations (median 81%; range; 20%, 100%,) with 26% of this being attributable to hospital-level differences (CI 22% to 31%).

Conclusions: Only a small proportion of hospital variation in medication prescription after discharge was attributable to hospital-level features. This suggests that differences in hospital practices are not a major determinant of observed variations in prescription of investigated medications and outcomes. Future healthcare delivery efforts should consider evaluation and improvement of more ambitious KPM.

Key Words: health services, heart failure, quality and outcomes of care

What is already known about this subject?

Quality of care and outcomes for individuals suffering from heart failure are unsatisfactory in many regions of the world. Previous studies have reported wide variations in management of patients with heart failure across different healthcare systems.

What does this study add?

Only 8% of the total variation in the composite performance measure was due to differences in known and unknown hospital features. However, variation in referral for specialist follow-up was substantial and 26% of it was due to hospital-level features.

How might this impact on clinical practice?

Whilst further investment into costly organisational changes for management of HFREF in hospitals in England and Wales may still be useful for changing other important healthcare outcomes across hospitals, our study shows that such investments cannot be expected to lead to large reductions in variability in hospital adherence to heart failure performance measures examined in this study. Future healthcare delivery efforts should consider evaluation and improvement of more ambitious KPM.

Introduction

Over the last few years, substantial effort has been made to ensure that patients with heart failure and reduced left ventricular ejection fraction (HFREF) receive guideline-recommended care that is known to improve outcomes. In many healthcare systems, professional societies and government agencies have formulated and endorsed quality standards for better implementation of recommended care.[1–3] Despite these efforts, the quality of care and outcomes for individuals suffering from heart failure are unsatisfactory in many regions of the world.[4,5]

Investigation of variations in adherence to recommended care among providers can inform decision-makers about the nature and drivers of deficiencies in quality of care, and whether these might be amenable to organisational changes.[6] Given that such changes often require substantial financial and human resource investment, it is prudent to explore the extent to which differences in care practices are responsible for variation in quality of care and to estimate the impact of any proposed changes to service delivery.[7,8]

We set out to measure the amount of variation among hospitals in their adherence to key performance measures (KPM) for management of patients with heart failure with HFREF and the extent to which this can be explained by hospital-level factors.

Methods

This study is a part of the UNVEIL-CHF study (Understanding National Variation and Effects of Interventions at different Levels of Care for Heart Failure), which aims to characterize variation in hospital care and outcomes for patients with heart failure.

Data sources

We used the National Heart Failure Audit for our primary analyses. The audit enrolls patients hospitalised with a primary diagnosis of heart failure in England and Wales.[9] Initially, in 2007, participating hospitals were asked to provide data on at least the first 10 patients with a primary death or discharge diagnosis of heart failure in each month; this requirement has steadily increased and, from 2012, all hospitals in England and Wales were expected to report all unscheduled admissions due to heart failure to the audit. The dataset captures information about patient demographics, clinical characteristics, and follow-up information. The audit was supplemented by a survey of 185 English and Welsh hospitals, included in the National Heart Failure Audit, that provide care for patients with acute heart failure, capturing information on hospital characteristics, including human resources (e.g. number of cardiologists), referral pathways (e.g. heart transplantation) and other organisational features.

Study population and outcomes

Only hospital admissions in which the patient survived to discharge were eligible for inclusion in the study because collection of treatment variables was not mandated for patients who died in hospital. We restricted our analysis to patients with HFREF, diagnosed using echocardiogram, because clearly defined and evidence-based treatment recommendations exist only for this subgroup. Contra-indications to ACE-I/ARB and beta-blockers were recorded and patients with any contra-indications were classified as missing for these variables. For patients with more than one reported hospital admission (10,280, 14.4%), we randomly selected one admission.

The primary analyses of variation among hospitals in their adherence to key performance measures used patient-level outcomes for three key performance measures for HFREF: provision of an ACE-I/ARB, provision of a beta-blocker and referral for follow-up with a heart failure specialist (either referral for follow up with a cardiologist or with a heart failure specialist nurse), and their composite performance score (described below). We chose these KPMs as they were recommended by the American Heart Association's Task Force on Performance Measures in 2012 and the UK National Institute for Health and Care Excellence (NICE) in 2014.[3,10]

To generate the composite performance score, a mean of the provision of an ACE-I/ARB, provision of a beta-blocker and specialist follow-up was generated for each patient. This was averaged at the hospital level across all patients to generate a hospital level composite performance score (continuous score, ranging from 0 to 1, or 0% to 100%).[11] We chose to use process outcomes as our primary endpoint, rather than mortality, because the process outcomes selected represent established clinical standards and such outcomes are better suited than mortality or metrics with limited evidence-base for comparing performances between hospitals.[12]

In a secondary analyses, we investigated variation among hospitals for risk-adjusted death at 30 days and at one-year after discharge (adjusted for age, sex, NYHA class [I, II, III or IV], peripheral oedema [none, mild, moderate or severe], history of diabetes, history of ischemic heart disease, history of hypertension, history of valve disease, atrial fibrillation, left bundle block, previous myocardial infarction, concomitant diastolic dysfunction, left ventricular hypertrophy and valve disease).

Statistical analysis

We used multiple imputation using chained equations to impute missing covariates; five imputation sets were generated. No covariate was missing at a rate that exceeded 15%. Although multiple imputation relies upon the missing at random assumption (that is, that missing covariates and outcomes are missing at random conditional on other covariates), simulation studies have suggested that multiple imputation provides equivalent or better coverage and bias than complete case analysis, even when missingness is not at random.[13,14] We therefore used multiple imputation rather than a complete case analysis.

Continuous data were summarised using the mean and standard deviation or median and interquartile interval while categorical data were summarised using percentages. Hierarchical Poisson and normal regression models were used to examine time trends in the individual components of the composite score and the patient level composite score, respectively, with yearly rates modeled through the inclusion of calendar year as a categorical covariate. As the patient level composite score was not symmetric (2.3% of participants received a score of 0 while 58.1% received a score of 1), normal approximation condition for the patient level composite score was verified by bootstrapping. We conducted bootstrapping using 10000 replications and examined the distribution of the mean ICC. The mean ICC followed a normal distribution and the bootstrapped confidence intervals were identical to those derived using a normal approximation.

Time trends in risk-adjusted 30-day mortality and one-year mortality were similarly examined through hierarchical Poisson models adjusted for patient case-mix (clinical characteristics listed below). These models were then used to predict 30-day and one-

year risk-adjusted mortality for each year at the means of patient covariates. Statistical significance of changes in rates was determined by including year as a continuous covariate.

To examine associations between hospital characteristics and their composite performance score, we divided hospitals into fifths based on their respective composite performance score (with the bottom fifth containing hospitals with the lowest composite score and the top fifth containing hospitals with the highest composite score). Hospital characteristics by fifth of composite performance score were summarized using proportions for categorical data and means for continuous variables. To examine whether hospital characteristics differed across fifths, continuous and categorical covariates at the hospital level were tested for trend using linear regression with hospital fifths as a continuous outcome. To further determine which hospital characteristics were associated with a better performance score, backwards stepwise regression was performed with the inclusion of all hospital characteristics and a p-value for exit of 0.01.

In our main analysis, to investigate the degree to which patient case-mix, year of investigation and hospital features accounted for the variation in hospital performances, we used hierarchical logistic regression models. We first fitted an unconditional (null) model with only a hospital random intercept to quantify the amount of between-hospital variation. In the second model, we added 24 patient characteristics: demographic characteristics (age, sex); clinical characteristics (NYHA class [I, II, III or IV], peripheral oedema [none, mild, moderate or severe], history of diabetes, history of ischemic heart disease, history of hypertension, history of valve disease, atrial fibrillation, left bundle block, previous myocardial infarction, diastolic dysfunction, left ventricular hypertrophy

and valve disease) and dummy variables for year of admission (2007, 2008, 2009, 2010, 2011, 2012, 2013) to investigate the extent to which differences in performance between hospitals was accounted for by patient case-mix and year of admission. In the third model, we added hospital characteristics independently associated with the composite performance score to determine whether the variation among hospitals could be accounted for by known hospital characteristics: tertiary hospital, number of full time equivalent consultant cardiologists, a multidisciplinary team with a cardiologist, a multidisciplinary team with a consultant with an interest in heart failure, a multidisciplinary team with a pharmacist, a multidisciplinary team with a psychologist, a multidisciplinary team with a social workers, coronary angiography capabilities, cardiac MRI capabilities, an outpatient service with a cardiologist and an outpatient service with a heart failure specialist nurse. We used the intraclass correlation coefficient (ICC) to estimate the proportion of variance in performance that was attributable to the between-hospital variation. We calculated the ICC from these hierarchical logistic models using the following equation: ICC=se^2/(se^2 + (π^2)/3), where se is the standard error of the random hospital intercept.[15] This was supported by the median odds ratio (MOR), which reports between-hospital variation that is not explained by patient characteristics. The MOR works on the principle that, if two patients with 'identical patient-level characteristics', from two randomly selected hospitals are compared, any odds ratio greater than 1 would represent differences in the hospital (as the patients are identical). The MOR is calculated using the formula: MOR=exp(0.95*se), where se is the standard error of the random hospital intercept.[15] We also calculated ICC for key performance measures by year, and tested for trend across years using inverse variance weighted linear regression, to examine whether variation in outcomes has changed across years.

All analyses were performed using Stata IC, version 12. Study findings are reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) recommendations.[16] No ethics approval was required for this analysis; the National Heart Failure Audit was conducted with the approval of the NHS Information Centre.

Results

In total, 68,772 patients with HFREF were discharged with a primary diagnosis of heart failure from 185 hospitals, between 2007 and 2013. The median (interquartile interval) age was 75 (68, 84) and 36.5% were female.

From 2007 to 2013, no significant improvement in rates of prescription of ACE-I or referral for specialist follow-up was observed (Table 1). However, rates of prescription of beta-blockers increased from 56% to 82% (p trend < 0.001), which drove an increase in the composite score from 73% to 84% (p trend <0.001). Risk-adjusted one-year mortality decreased from 27% in 2007 to 23% in 2011 (p trend < 0.001), although no appreciable change was observed in risk-adjusted 30-day mortality (Table 1).

The composite performance score at the hospital level showed modest variation (median 79%, range 50% to 97%; Figure 1A and Supp. Figure 1). Amongst the three individual components of the composite performance score, prescription of ACE-I /ARB at discharge had the highest adherence and lowest variation in its prescription among hospitals (median 84%, range 62% to 99%; Figure 1B). The prescription of beta-blockers at discharge was lower but with similar variability among hospitals (median 75%, range

45% to 96%; Figure 1C); while follow-up with a specialist had the largest variation (median 81%; range; 20%, 100%; Figure 1D).

In stratified analyses of the composite performance score, hospitals in the top fifth of composite performance score (Q5), compared to those in the bottom fifth (Q1), had a higher proportion of tertiary hospitals and consultant cardiologists (Table 2). The presence and composition of the multidisciplinary heart failure teams also differed between hospital fifth scores, with hospitals in the top fifth being more likely to have a multidisciplinary heart failure team. There were no statistically significant differences across fifths of hospitals with regard to referral pathways, including referral for heart transplantation or for cardiac rehabilitation.

With the composite performance score as a continuous outcome, we performed backward stepwise regression and included all hospital characteristics. We found two statistically significant predictors of higher adherence to KPMs and retained these in the final model; the number of consultant cardiologists working in the hospital and the presence of a multidisciplinary heart failure team with a pharmacist (Table 3). However, their absolute effect on the composite performance score was small; on average, the presence of a multidisciplinary team with a pharmacist was associated with an increase of 3.9% (CI 1.1%, 6.8%; p=0.003) in performance score. The addition of ten more full-time equivalent cardiologists was associated with an increase of 3.5% (CI 1.2%, 5.8%; p=0.007) in performance score.

In an unadjusted (null) linear multilevel model, the ICC for the composite performance score was 9% (CI 7%, 11%), suggesting that only 9% of the total national variation in

adherence to the composite performance score was related to differences amongst hospitals (Table 4). Thus, variability within hospitals (related to patient factors, random variation, or other known or unknown factors within hospitals) greatly exceeded the variability amongst hospitals (due to known or unknown hospital features). When year of admission and patient features were added to the model, the ICC decreased from 9% to 8%, indicating that variation in the type of patient managed by different hospitals and year of admission explained only 1% of the total variability amongst hospitals (Table 4). Addition of known organisational features reduced this variability by another 1%, suggesting that these features had a small absolute and relative influence on the variability in the composite performance score (proportion of residual variability explained by known organisational features was 12.7%, Table 4). No evidence of change in the ICC for any of the five performance measures across years was observed (Supp. Table 1) Estimates were similar when a propensity score was adjusted for rather than adjusting for covariates (Supp. Table 2).

The variability in prescription of ACE-I/ARB and beta-blockers was concordant with the overall composite performance score. Of the total variability in prescription of ACE-I/ARB and beta-blockers, only 8% and 7% were attributable to differences amongst hospitals (ICC 0.08, CI 0.06, 0.10 and 0.07, CI 0.06, 0.09, respectively). However, hospital-level variation in the rate of referral for specialist follow-up was 26%, even after adjustment for patient characteristics (ICC 0.26, CI 0.22, 0.31). The median odds ratio for referral for specialist follow-up was 2.94 (CI 2.63, 3.33), suggesting that, on average, the odds of a patient being referred for specialist follow-up after discharge would differ approximately three fold from one randomly selected hospital to another hospital with higher odds (Table 4).

In our secondary analyses of mortality following discharge, we found that at the hospital level, mortality at 30-days ranged from 2.1% to 14.3% and for one year from 10.4% to 43.6%. In an unadjusted multilevel model, the ICC for death at 30-days and one year after discharge were 2% (CI 1%, 3%), and 1% (CI 1%, 2%), respectively, suggesting that only 1 to 3% of the total national variation in death rates were related to variations in known or unknown hospital-level features (Table 4).

Discussion

This analysis of the National Heart Failure Audit shows substantial variation in hospital adherence to a composite of key performance measures for management of patients hospitalized with HFREF. However, only a small fraction of this variation was attributable to between-hospital differences in care provision. This overall low hospital-attributable variation was mainly driven by high rates of ACE-i/ARB and beta-blocker prescription with small degrees of hospital-attributable variations (7% and 6% of the total variability, respectively). However, variation in referral for specialist follow-up was substantial and 26% of it was due to hospital-level features.

Previous studies have reported wide variations in management of patients with heart failure across different healthcare systems [4,17,18] and others have shown certain hospital-level features to be associated with better clinical outcomes.[19] The present study goes beyond these earlier findings. By quantifying the extent to which variation in KPM can be attributed to hospital-level features, this study raises important questions about the potential impact of further organisational changes that target individual hospitals.

Broadly consistent with previous suggestions, we found several in-hospital organisational features to be significantly associated with hospital-level performances. However, we further show that the absolute effect of these organisational features on explaining variability in adherence to key performance measures, particularly ACE-inhibitor/ARB and beta-blocker prescription, is small. Although the number of consultant cardiologists working in the hospital and the presence of a multidisciplinary heart failure team with a pharmacist were strongly associated with the hospital performances, they collectively accounted for only 1% of the total hospital variation.

These findings indicate that the majority of remaining variability in prescription of ACE-i/ARB and beta-blocker is randomly distributed among hospital providers and is not determined by differences in organisational features among hospitals. Whilst further investment into costly organisational changes for management of HFREF in hospitals in England and Wales may still be useful for changing other important healthcare outcomes across all hospitals, our study shows that such investments cannot be expected to lead to large reductions in variability in hospital adherence to these performance measures. Even if we assume that the observed associations between hospital preferences (e.g., presence of multi-disciplinary teams) and hospital performances (e.g., prescription rates for beta-blocker) are causally related, additional changes to such hospital preferences for in-hospital care would only be expected to reduce the absolute between-hospital variability in the ACE-i/ARB or beta-blocker prescription by less than 5%. Whether such modest reductions in the process outcomes are worthwhile require formal health economic evaluation before any recommendations can be made about additional changes to service delivery in the UK hospitals.[20] These results also suggest that research should be undertaken to characterize hospital-level variation in key performance measures for

heart failure in other countries. The modest effects of quality improvement programs on heart failure care in the United States [21]may be due to limited variation in key performance measures, as observed in this analysis.

The only key performance measure for which we observed large variation amongst hospitals was referral to specialist follow-up (either to a heart failure nurse or cardiologist). After case-mix adjustment, there was still an almost three times difference in the odds of a patient being referred for specialist follow-up between two randomly selected hospitals. Twenty percent of this variation was explained by known differences in hospital practices and overall the average adherence to specialist follow-up after discharge did not change from 2007 to 2013. If specialist follow-up influences outcomes in heart failure, as has been suggested by prior studies, such high levels of variation may partially explain differences in risk of death among hospitals. There are several potential explanations for this observation. First, it is likely that adherence to this key performance measure is more difficult and resource-intensive than making changes to prescription of evidence-based therapies. Second, it may be that there is less professional agreement about this performance measure because the level of evidence for it is less strong than pharmacological interventions.[22] Randomised evidence on the effect of early specialist follow-up after discharge is limited [23,24] and findings from non-randomised comparisons have been inconsistent.[25–27]

This study has several strengths. First, recommended performance measures were selected as the primary outcome,[3,10] as opposed to clinical endpoints, thus avoiding the risk of uncontrolled residual confounding when mortality or hospitalisation are

chosen.[12,28] Second, we separated the evaluation of in-hospital performance from post-discharge performance to take account of differences in recommended care during these very different phases of care. Third, we linked a survey of organisational features to hospital processes and used multi-level analysis to quantify the impact of such features on quality of care, thus extending previous studies which have been criticized for largely investigating associations between structural hospital features, such as number of beds or volume of patients, which are not amenable to change.[29] Finally, we included a large number of confirmed cases of HFREF with linked databases and hence were able to investigate the quality of care in a more accurate and detailed manner than previous reports.

However, this study also has several potential limitations. First, many other aspects of heart failure care, in addition to prescription of ACE-I/ARBs, beta-blockers and specialist follow-up, may influence outcomes after hospitalization for HFREF. However, other evidence-based interventions, such as mineralocorticoid receptor antagonists or cardiac resynchronization therapy are currently not recommended as the minimum performance measures for in-hospital care. These results therefore suggest that future research should examine whether these evidence-based interventions would be better suited as performance measures, considering the relatively high prescription rates and modest hospital level variation of ACE-inhibitor/ARBs and beta-blockers observed. Second, we lacked information on the dosage of prescribed medications, which are an important determinant of outcomes in heart failure and may exhibit greater variation among hospitals than prescription rates.[30] Third, the small between-hospital variation observed in this study may not be generalisable to health systems which are more diverse than the NHS in terms of organisation and delivery of care for patients with acute heart failure[4].

Fourth, although hospitals were asked to provide information from the first unselected 10 or 20 patients admitted to their hospital each month, we cannot entirely rule out that patients included differ in some respects from those that have not been included in the reports. Finally, we focused our analysis on quantification of differences in natural variation among hospitals in order to estimate the impact of variation in hospital preferences on key performance measures. In theory, it is, however, possible that interventions that equally target all hospitals could lead to an average increase (or decrease) in hospital performances across all hospitals even when there is not much between-hospital variability but average performance is uniformly low (or high).

In conclusion, we observed an improvement in hospital performances for management of patients with HFREF over time. Although substantial variation in adherence to key performance measures was observed, only a small proportion of this could be attributed to between-hospital differences. These results suggest that further organisational changes that would specifically target low performing hospitals will have limited impact on reducing variation in prescription rates of ACE-inhibitors/ARBs and beta-blockers for patients with HFREF in the UK. Future hospital-level organisational changes should consider focusing on improving rates of referral to specialist follow-up after discharge, for which there is substantial variation. Future research should also examine whether other evidence-based interventions, such as prescription of mineralocorticoid receptor antagonists or cardiac resynchronization therapy or prescription of recommended dosages of medications, should be used as performance measures for in-hospital care.

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Contributors

Connor Emdin and Kazem Rahimi involved in the design, implementation, and analysis of the study, and in writing the final manuscript. All authors were involved in revision of the manuscript for important intellectual content.

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Disclosures

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Data Sharing Statement

Data and code is available from the lead author upon request.

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Figure Legend

Figure 1. Variation in (A) the composite performance score (B) prescription of ACE-inhibitors/ARBs (C) prescription of beta-blockers and (D) referral for specialist follow up performance measures among 185 hospitals.

Tables

Table 1. Temporal trends in hospital adherence to key performance measures and risk of death after discharge in 185 hospitals in England and Wales

	Year							
	2007 (n=320)	**2008 (n=3380)**	**2009 (n=8622)**	**2010 (n=14656)**	**2011 (n=17466)**	**2012 (n=19071)**	**2013 (n=5257)**	**Test for trend**
Composite performance score	73% (CI 70%, 76%)	77% (CI 76%, 78%)	78% (CI 78%, 79%)	79.0% (CI 79%, 80%)	81% (CI 80%, 81%)	83% (CI 82%, 83%)	84% (CI 83%, 85%)	p<0.001
ACE-I/ARB	79% (CI 69%, 90%)	83% (CI 80%, 87%)	84% (CI 82%, 86%)	83% (CI 82%, 85%)	83% (CI 82%, 85%)	84% (CI 83%, 86%)	84% (CI 82%, 86%)	p=0.556
Beta-blockers	56% (CI 47%, 67%)	63% (CI 60%, 66%)	67% (CI 65%, 69%)	70% (CI 68%, 72%)	75% (CI 73%, 77%)	80% (CI 78%, 81%)	82% (CI 79%, 85%)	p<0.001
Specialist follow-up	79% (CI 68%, 92%)	78% (CI 75%, 82%)	79% (CI 76%, 82%)	79% (CI 77%, 82%)	79% (CI 77%, 82%)	80% (CI 78%, 83%)	81% (CI 78%, 84%)	p=0.081
Risk-adjusted 30-day mortality	3.5% (CI 2.0%, 6.0%)	5.4% (CI 4.7%, 6.3%)	5.4% (CI 4.9%, 5.9%)	4.8% (CI 4.5%, 5.2%)	5% (CI 4.7%, 5.4%)	5.1% (CI 4.7%, 5.4%)	5.1% (CI 4.5%, 5.7%)	p=0.663
Risk-adjusted one-year mortality	27% (CI 22%, 33%)	28% (CI 26%, 30%)	26% (CI 25%, 27%)	25% (CI 24%, 26%)	23% (CI 22%, 24%)	-	-	p<0.001

Table 2. Key performance measures and hospital characteristics across fifths of composite performance score

	Hospital-Level Composite Performance Score (n, range)					
	Q1 (n=37, 49.8% - 71.6%)	**Q2 (n=37, 71.7% - 77.3%)**	**Q3 (n=37, 77.4%, 81.6%)**	**Q4 (n=37, 81.8%, 86.6%)**	**Q5 (n=37, 86.7%, 97.0%)**	**Test for Trend**
Composite Performance Score	**66.6%**	**74.5%**	**79.3%**	**84.2%**	**89.3%**	p<0.001
ACE-I/ARB	76.2%	80.3%	83.7%	86.4%	90.8%	p<0.001
Beta-blockers	63.4%	69.0%	75.7%	77.2%	84.5%	p<0.001
Specialist Follow-up	60.2%	74.2%	78.5%	89.1%	92.7%	p<0.001
Hospital Characteristics						
Tertiary Hospital	9.2%	12.4%	5.4%	22.7%	34.1%	p=0.002
General Hospital	88.1%	87.6%	91.9%	75.1%	65.4%	p=0.004
Other Hospital	2.7%	0%	2.7%	2.2%	0.5%	p=0.75
Heart Failure Specialist Nurse FTEs, No.	3.4	4.4	4.5	4.7	4.3	p=0.18
Consultant Cardiologist FTEs, No.	4.1	4.6	4.7	5.7	8.5	p<0.001
Consultant HF Specialist Cardiologist	89.2%	77.8%	84.9%	88.1%	95.1%	p=0.21
Other HF Specialist Consultant	27.6%	16.8%	18.4%	26.5%	35.1%	p=0.28
Multidisciplinary Team (% of hospitals)	69.7%	71.9%	78.9%	80.5%	96.2%	p=0.003
With a Consultant Cardiologist	69.7%	71.9%	78.9%	80.5%	93.5%	p=0.008
With a Heart Failure Nurse	69.7%	71.9%	78.9%	80.5%	96.2%	p=0.003
With another Consultant	21.6%	24.3%	16.8%	25.4%	44.3%	p=0.045
With a District Nurse	10.8%	10.8%	3.8%	13.0%	7.6%	p=0.78
With a Pharmacist	8.1%	14.1%	19.5%	33.5%	33.0%	p=0.001
With a Dietician	5.4%	8.1%	6.5%	11.9%	16.8%	p=0.09
With a Physiotherapist	21.1%	21.6%	12.4%	19.5%	36.2%	p=0.20
With a Psychologist	13.5%	4.9%	11.4%	18.9%	35.1%	p=0.003
With a Primary Provider	14.1%	8.6%	23.8%	23.8%	32.4%	p=0.01
With a Social Worker	0%	0%	2.7%	5.4%	8.1%	p=0.02
Diagnostic Capabilities						
ECG	100%	100%	100%	100%	100%	p=1.0
BNP	54.6%	68.6%	62.7%	68.6%	75.1%	p=0.10
Exercise Testing	97.3%	100%	100%	97.3%	94.6%	p=0.29
Echocardiography	97.3%	100%	100%	100%	100%	p=0.16
Coronary Angiography	63.2%	82.2%	84.3%	82.7%	84.9%	p=0.04
Cardiac MRI	24.9%	21.1%	48.6%	43.2%	51.4%	p=0.003
Referral Pathways						
Internal Defibrillator	98.4%	98.9%	100%	100%	100%	p=0.30
Cardiac Resynchronization Therapy	95.7%	96.2%	100%	100%	97.3%	p=0.37
Transplantation	87.0%	88.6%	83.8%	93.5%	90.3%	p=0.50
Left Ventricular Assistive Device	84.3%	80%	67.0%	78.4%	76.8%	p=0.46
Palliative Care	100%	100%	93.5%	98.4%	100%	p=0.81
Cardiac Rehabilitation	74.6%	81.6%	74.6%	80%	89.2%	p=0.19
Outpatient Services						
HF Clinic	86.4%	80%	79.5%	87.6%	96.2%	p=0.14
Cardiologist	61.1%	61.6%	60%	75.1%	82.7%	p=0.02
Heart Failure Specialist Nurse	76.2%	67.6%	58.9%	84.9%	93.5%	p=0.02
Physician with HF Interest	7.0%	12.4%	11.9%	14.6%	16.2%	p=0.24
Primary Care	6.5%	1.6%	8.1%	4.9%	5.9%	p=0.86
Geriatrician	8.1%	2.7%	0%	5.4%	10.8%	p=0.49
Pharmacist	2.7%	3.8%	10.8%	9.7%	8.1%	p=0.22
Telemonitoring	32.4%	25.9%	45.9%	35.7%	51.9%	p=0.057
Cardiac Surgery	86.5%	95.1%	88.6%	91.9%	100%	p=0.09

Abbreviations: ACE-I/ARB: Angiotensin-converting enzyme inhibitor/angiotensin receptor blocker; FTE: Full time equivalents; ECG: electrocardiography; BNP: B-type natriuretic peptide; Cardiac MRI: Cardiac magnetic resonance imaging

Note that multiple imputation results in different hospitals being assigned to different fifths in the five imputations. As a result, some percentages are not fractions of 37.

Table 3. Hospital characteristics associated with better composite performance score after stepwise regression.[1]

	% Change in Composite Score (95% CI)	p-value
Number of FTEs of Consultant Cardiologists (units of 10 cardiologists) [2]	3.5% (CI 1.2%, 5.8%)	p=0.003
Presence of a Multidisciplinary Heart Failure Team with a Pharmacist	3.9% (CI 1.1%, 6.8%)	p=0.007

[1]Mutually adjusted for number of FTEs of consultants cardiologist and presence of a multidisciplinary heart failure team with a pharmacist, after stepwise elimination with a p-value for elimination of 0.01.
[2] Full time equivalents

Table 4. Inter-hospital variability in adherence to individual key performance measures, their composite performance score and mortality at 30 days and at one year after discharge

	Null Model		**Adjusted for Patient Characteristics + Year**			**Adjusted for Hospital + Patient Characteristics + Year**		
Key Performance Measure	ICC[1]	Median Odds Ratio	ICC	Median Odds Ratio	Proportion of Variance Explained[4]	ICC	Median Odds Ratio	Proportion of Variance Explained[5]
Composite Performance Score[2]	0.09 (CI 0.07, 0.11)	-	0.08 (CI 0.07, 0.10)	-	12.1%	0.07 (CI 0.06, 0.09)	-	12.7%
ACE-I/ARB[3]	0.08 (CI 0.06, 0.10)	1.70 (CI 1.60, 1.82)	0.07 (CI 0.06, 0.09)	1.67 (CI 1.57, 1.79)	5.2%	0.07 (CI 0.06, 0.09)	1.66 (CI 1.56, 1.77)	3.3%
Beta-blocker	0.07 (CI 0.06, 0.09)	1.65 (CI 1.56, 1.76)	0.06 (CI 0.05, 0.08)	1.59 (CI 1.51, 1.68)	13.7%	0.06 (CI 0.04, 0.07)	1.56 (CI 1.48, 1.65)	7.6%
Specialist Follow-up	0.27 (CI 0.23, 0.31)	2.99 (CI 2.67, 3.40)	0.26 (CI 0.22, 0.31)	2.94 (CI 2.63, 3.33)	2.3%	0.21 (CI 0.18, 0.25)	2.55 (CI 2.31, 2.85)	19.4%
30-day mortality	0.02 (CI0.01, 0.03)	1.29 (CI 1.23, 1.36)	0.02 (CI 0.01, 0.02)	1.25 (CI 1.20, 1.32)	20.0%	0.01 (CI 0.01, 0.02)	1.24 (CI 1.18, 1.30)	12.2%
1-year mortality	0.01 (CI 0.01, 0.02)	1.25 (CI 1.21, 1.29)	0.01 (CI 0.01, 0.01)	1.18 (CI 1.15, 1.22)	41.3%	0.01 (CI 0.01, 0.01)	1.17 (CI 1.14, 1.21)	10.8%

[1]ICC denotes intra-class correlation coefficient
[2]As a continuous variable, a median odds ratio is not calculable.
[3]Provision of an angiotensin-converting enzyme inhibitor or angiotensin receptor blocker
[4]Relative to the null model.
[5]Relative to the model adjusted for patient characteristics