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Health Service Use by Community-dwelling Heart Failure Patients in a large urban population in NW London

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Abstract

Background: The complex nature of heart failure (HF) management, often involving multidimensional care, is widely recognised, but overall health service utilisation by HF patients has not previously been described.

Aim: To describe overall health service use by community-dwelling adults with HF.

Design and Setting: Cross-sectional analysis of prevalent HF cases between 2015 and 2018 using an administrative dataset covering primary care, secondary care, and 'other' (community, mental health, and social care) services in North West London (NWL).

Methods: Healthcare use of each service was described overall and by individual components of secondary care (e.g. outpatient appointments) and 'other' services (e.g. nursing contacts). Usage patterns were identified using k-means cluster analysis using all distinct contacts for the whole study period and visualised by a heatmap.

Results: There were 39 301 patients with a prevalent diagnosis of HF between 1 January 2015 and 31 December 2018. 90% used health services during the study period, most commonly outpatient services, GP consultations, unplanned A&E visits and community services. Use of cardiology-specific services ranged from around 3% (cardiology-related community care) to around 20% (outpatient cardiology visits). GP consultations decreased by 11% over our study period. Five clusters of patients were identified, each with significantly different care usage patterns and patient characteristics.

Conclusions: HF patients make heavy but heterogeneous use of services. Relatively low and falling use of GP consultations, and apparently low uptake of community rehabilitation services by patients with HF, is concerning and suggests challenges in primary care access and integration of care.

How this fits in

Heart failure is increasing in prevalence and requires multidisciplinary management including in primary care. Using a linked database for NW London's 2.2 million population, we found that only 60% had seen their GP and 20% had been referred for cardiac rehabilitation during the study period, whilst overall use of unscheduled care by HF patients was high with over 40% using Accident and Emergency. Cluster analysis identified 5 patient groups based on their service use, illustrating for example, that the lowest users of GP services were very high users of all other services, and that the oldest patients with highest mortality were highest users of accident and emergency, with the highest rates of emergency admission. The high rates of unscheduled care use, in all patients with HF but particularly the elderly, and apparently low use of primary care, are concerning and should raise the question of whether HF could be better managed though more integrated care. Findings of cluster analysis, highlighting groups of HF patients that are particularly high and low users of elements of care, may facilitate active case finding and provision of more supportive and preventative care to improve outcomes for these patients.

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Introduction

Heart failure (HF) affects over 900,000 people in the UK(1) and results in significant morbidity and mortality, frequent hospitalisations, and reduced quality of life. Patients with HF are usually older, with comorbidities and may have complex and highly heterogeneous medical and social needs. A multidisciplinary team approach is considered the gold standard model for HF management(2) and is recommended for high-risk patients by both national(3-6) and international(7,8) guidelines. Despite this, there is currently little understanding of the nature of HF care beyond the hospital setting in the UK. In an attempt to begin addressing this, we describe overall health and social service use and care usage patterns by HF patients in Northwest London (NWL).

Methods

Data

We used Whole Systems Integrated Care (WSIC) data, a linked de-identified dataset of individual-level patient records of events from primary, secondary, community, mental health and social care services in NWL, covering over 2 million patients across 360 GP practices(9). It has some similarities with primary care-based research databases like CPRD and THIN (10,11), though with the addition of community, mental health and social care service records.

Definitions

Heart failure cases

We included all adult NWL residents with a diagnosis of HF recorded any time before 31 December 2018 and alive at study entry (1 January 2015). HF diagnoses were identified using primary and secondary care data using Read and ICD-10 codes, respectively (Supplementary Table 1). Patients were included if they had valid patient ID, age, an opt-in flag for WSIC, and if their HF diagnosis date was not later than their death date. Patients were divided into four cohorts, each containing prevalent HF cases for their respective one-year periods between 1 January 2015 and 31 December 2018. Patients were excluded from each cohort if they had died or opted out from WSIC in the preceding year.

Patient characteristics

Age, gender, ethnicity, deprivation level, comorbidities, care status, blood pressure, BMI, and smoking and alcohol drinking statuses were defined using primary care data at the start of each one-year period (looking back 5 years to retrieve data). Socioeconomic status was based on 2015 Index of Multiple Deprivation (IMD) and divided into quintiles (1 – most deprived; 5 – least deprived). Comorbidities were defined as per Khan et al.(12), with some extras defined by us (Supplementary Table 1).

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Health service use

Healthcare use was described for each cohort using data for that one-year period. Primary care use was defined as having a consultation with a general practitioner (GP). Secondary care use included emergency admissions, elective admissions, unplanned accident and emergency (A&E) visits, and outpatient visits. Use of 'other' health services (community, mental health, and social care services) were described overall and by individual components. Variables in these 'other' health service tables were often not in coded form, so contacts were first indexed with keywords (Table 1) arrived at iteratively by manually searching for the most common terms in each table.

Cluster analysis

We sought to discover patterns of healthcare utilisation via k-means cluster analysis(13). Nine healthcare utilisation count variables, reflecting total usage across 2014-2018, were used to define clusters: emergency admissions, elective admissions, unplanned A&E visits not ending in admission, outpatient visits (cardiology), outpatient visits (other), GP consultations, and community, mental health, and social care contacts. Only distinct contacts and attended outpatient visits were included, and extreme high users (in the top 0.1% for any of these variables) were excluded. Data were log-transformed and normalised (min-max method) prior to analysis to give higher weighting to lower values and equal weighting to all variables, respectively. K-means required the number of clusters (k=5) to be pre-specified (Supplementary Box 1).

Statistical analysis

Patient characteristics and prevalence of health service use were summarised for the four yearly cohorts and clusters separately. Usage patterns for each cluster were visualised using a heatmap by comparing the cluster mean usage with the average population usage, taking the percentage difference between these two means. Differences in healthcare utilisation variables and key patient characteristics across clusters were analysed using Kruskal-Wallis tests for continuous variables and Pearson Chi-square tests for categorical variables, with two-tailed testing and significance level 0.05. All analyses were conducted using R version 3.4.0.

Results

Patient characteristics

Between 1 January 2015 and 31 December 2018, 39,301 patients from 359 GP practices had an HF diagnosis recorded and met the inclusion criteria (Supplementary Figure 1), approximately 10 new HF patients per practice per year. The vast majority were present in every cohort.

In 2018, most patients were female (56%), aged 65 or over (58%), and were of White (31%), Asian (26%) or unknown (27%) ethnicity (Table 2). Over 60% were multimorbid (i.e. had

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comorbidity in addition to existing HF), and of these more than half had at least two additional comorbidities, most commonly diabetes (26%) or hypertension (36%). 6 998 (18%) people died and 110 (0.3%) opted out of the WSIC dataset.

Most patient characteristics remained constant during the study period except for an increase in proportion of the underweight (+60%) and the oldest age group (+40%) and a nearly 20% reduction in the prevalence of hypertension.

Health service use

The most commonly used healthcare services in 2018 were outpatients (70%), GP consultations (60%), A&E (41%), community (40%), emergency admissions (27%) and outpatient cardiology (26%) services (Table 3). Community care was the most common 'other' service used, of which the most frequent components were nursing- (23%), podiatry- (16%), and rehabilitation- (8%) related. Few (3%) used community care related to cardiology even though over 1 in 5 had a GP record of referral to cardiac rehabilitation. Around 6% had a referral for echocardiogram, of which half had abnormal results. Both mental health and social care service use were less common (4-5%). When used, mental health contacts were commonly community-related (4%), suggesting a community integrated approach; social care contacts were personal care- (3%), community- (0.7%), domestic- (0.7%), and disability- (0.7%) related.

Only 3,067 (9%) did not use any services, whilst around one-quarter used at least three different types. Services were most commonly used in combination with secondary care and least commonly with 'other' health services (Table 3, Figure 1). Few patients used only primary care and 'other' services (2.3%) or 'other' services alone (2.0%). Over our study period, health service use increased for all elements of secondary care analysed, particularly elective admissions (+37%) and outpatient visits (+24%) but decreased for primary care (-11%). Although many components of the community contacts remained constant, there was a doubling in contacts related to diet and nutrition.

Cluster analysis

318 patients were excluded from the k-means cluster analysis due to extremely high usage. Of the four- and five-cluster solutions identified via preliminary analysis (Supplementary Box 1), we chose five clusters as the extra cluster had distinct usage patterns (Figure 2). Additionally, patient characteristics all differed significantly across clusters (Supplementary Table 2, Supplementary Figure 2). Patients who were younger, female, less comorbid and not living in care homes were generally low users of healthcare (clusters 1 and 2). Perhaps unsurprisingly, those with higher blood pressure and more comorbidities had relatively more GP consultations (cluster 2). Patients who were older, male, and had more comorbidities were generally higher users of healthcare (clusters 3, 4 and 5). The lowest users of GP appointments were very high users of all other services (cluster 3). Those with the most cardiovascular comorbidity (cluster 4) had the highest usage of cardiology-related outpatient services and referrals to echocardiography (42%). The oldest patients with the highest mortality (cluster 5) were the highest users of emergency, A&E, and 'other' services.

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Discussion

Summary

Overall health service utilisation was high. Almost everyone in our HF population used some kind of health service during our study period: outpatients (7 in 10), primary care (6 in 10 saw a GP), community services, especially nursing (2 in 10), and unplanned A&E visits (4 in 10). Community care use related to cardiology was low. Few patients used only primary care and 'other' services, which may reflect modest needs or a lack of community and primary care provision suitable for complex needs.

Patterns of health service utilisation depended on age and comorbidity but were highly heterogeneous. Younger, less-comorbid patients (clusters 1 and 2) had the lowest usage, which may partly indicate underutilisation and/or lack of access. For instance, those with infrequent GP consultations (clusters 1 and 3) were also more likely to be of mixed ethnicity and living in areas of higher deprivation, demographics known to be associated with poorer primary care access(14,15). These patients also showed the highest levels of unknown values for patient variables (derived from GP data) and lower than average GP consultation rates, which could reflect both poor health management and low engagement of patients in their own health (they were also more likely to be smokers). The oldest and most likely to live in care homes (cluster 5) had the highest usage of emergency, A&E, GP and 'other' services, and had high levels of comorbidity, especially renal disease, and the highest mortality. Higher usage of care is expected for older comorbid patients(16-18) but some use might be excessive and avoidable(16,17).

Strengths and Limitations

We used a linked dataset with near-complete population coverage for the region and employed both descriptive analysis and clustering algorithms to describe health service use by this highly heterogeneous population. The dataset is large and reflective of current medical practice, but our study has several limitations.

Electronic health records are not intended for research, and coding is highly variable(19). Coding in some of the WSIC tables required additional cleaning and processing, which could introduce bias but we provided a transparent coding methodology to mitigate this. Moreover, coded data rely on recorded information, meaning that certain diseases or service components may have been underestimated (e.g. cardiac rehabilitation) or certain primary care data coding may be affected by pay-for-performance schemes. We were unable to tell what the community care or mental health consultations were for as diagnosis coding was irregular. It is also likely that the fall in GP consultations during the study period was offset by more practice nurse appointments, which we did not include.

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Lastly, although our dataset is based on community-dwelling adults from a large and ethnically diverse area in England, our findings may not be generalisable to the wider HF population.

Comparison with existing literature

Few studies have attempted to quantify individual patterns of care in real-world settings beyond the hospital. Robertson et al.(20) described the burden of HF on the Australian healthcare system but were only able to assess hospitalisation data, as was the case for our previous work(21,22). Similarly, other studies have described a single dimensional aspect of health service use by the HF population(23,24). Our findings are consistent with these, showing that secondary care use is high(20), participation in cardiac rehabilitation in the community is low (23,25) and that requirement for personal care such as nursing and homecare services is relatively common(24).

We observed an increase over time in most healthcare services, especially outpatient visits, but a surprising decrease of 11% in GP consultations. Furthermore, only 60% of patients had GP appointments during the study period, which contrasts with the national GP Patient Survey of 2019(26) where 85% of patients reported having had a GP appointment in the past year. Potential explanations include the increasing workload and workforce pressures on primary care, changes in primary care practice with more frequent contacts with practice nurses and allied health professionals, a significant problem of access to care, and/or differences in casemix.

Another surprising finding is the apparently limited uptake of community cardiac rehabilitation. The National Audit of Cardiac Rehabilitation 2018 report(25) suggests that half of eligible patients take up cardiac rehabilitation. The report did indicate significant regional variation. However, it seems likely that differences in coding of data are responsible for the very low uptake in this analysis ('rehabilitation' events may be recorded elsewhere and currently unavailable in WSIC, and "community cardiology" may also include HF nurse domiciliary care).

We further report low use of mental health and social care services by HF patients. A general absence of mental health professionals in integrated HF care has been previously noted(27), but whether this observed level is appropriate is unclear without further assessment.

Implications for research and/or practice

Our finding of increased secondary and urgent care service use, low GP appointment use and apparently limited cardiac rehabilitation is of concern and suggests a lack of multidisciplinary HF care. NICE guidelines recommend a multidisciplinary team (MDT) approach, but there is no standard definition besides who should be involved and what should be achieved(1). Each local area has unique challenges and requiring tailored solutions; research is needed to establish the nature, location, timing, and intensity of the support needed by HF patients. In an ethnically diverse area with a relatively young population like NWL, where deprivation level and ethnicity may affect a person's access to healthcare, creating a strong MDT embedded in primary care may be very pertinent. For example, practice nurses may target recently diagnosed patients in primary care, i.e. younger patients with fewer comorbidities,

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on early education and management, which may include additional telephone and/or specialist community support for those with lower socioeconomic status. This, in conjunction with hospital-based solutions like early supported discharge plans for the elderly, i.e. the highest users of secondary care, may provide significant and long-term benefits for NWL area. Local solutions like these have been shown not only to reduce utilisation of health services, but also to improve patient wellbeing and result in large cost savings for the NHS(28).

Although our data could not establish whether a MDT approach was implemented in the NWL area, it may well be that MDTs exist but their solutions are not translating into reduced secondary care use.. Successful MDTs will require co-operation, co-ordination, and communication across health services. Reasons for an ineffective multidisciplinary care could be posited through the following questions: is there an overarching coordinating unit for multidisciplinary care? Are the IT systems compatible for such care? Is information exchange readily available and safe? Is communication across settings both smooth and frequent? Is the approach sustainable? These questions illustrate how successful solutions will require sustained financial investments and the solid backing of all relevant stakeholders, and the sheer challenge of this may explain why many MDTs have had only neutral effects(2).

Conclusion

Health service use was high and heterogeneous in our community-dwelling HF population. However, overall apparently relatively low GP service use, which decreased over our study period, and high use of emergency and other unscheduled care in these vulnerable patients is of significant concern and may suggest challenges in access to primary care services. These findings warrant further investigation to ensure equity of access and appropriate integrated care provision for patients with HF.

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Ethical Approval

WSIC is a dataset of NWL residents who have consented to the anonymous data in their online health records for research purposes. Additionally, this specific study was approved by the Discover Research Advisory Group (DRAG), which is a nominated body that provides a governance mechanism for evaluating project applications requesting the WSIC de-identified dataset.

Competing Interests Statement

AB, DK and PA had financial support through a research grant from Dr Foster® for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work. BH is a general practitioner working in the NHS.

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Table 1. Key terms used to index individual components in 'other' services in order to describe the types of services used by HF patients in these respective settings.

Table	Component	Index terms
Community	Nursing	*nursing*
	Rehabilitation	*rehab**
	Urgent	*rapid, acute, urgent, emergency, A&E, unplanned, admit*, hospital adm*, inpatient, ambulance*
	Intermediate	*intermediate, CIS (stands for Community Independence Service)*
	Cardiology	*heart, cardi*, stroke*
	Diabetes	*diabet*, endocri**
	Physio- or occupational therapy	*occupation*, physio**
	Podiatry	*foot, pod**
	Respiratory	*pulmon*, respir*, COPD, TB, tubercul*, thorac**
	Neurology	*musculo*, MSK, neuro*, parkinson**
	Urinary	*genito*, bladder, bowel, continenc*, urinary*
	Speech Language Therapy	*SLT, speech, language*
	Falls	*falls*
	Diet & nutrition	*diet, nutrition**
	Memory & cognition	*memory, cognition*
	Home	*home*
	Phone	*phone*
	Unknown	*(none of the above key terms)*
Mental health	Outpatient	*outpatient, day case*
	Community	*community*
	Urgent	*rapid, acute, urgent, emergency, A&E, unplanned*
	Specialist	*special*, nurs*, *ist*
	Dementia	*dementi*, memory, cogni**
	Learning disability	*learning*
	Eating disorder	*eating, anorexi**
	Psychiatric	*psy**
	Review	*review**
	Consultation	*consult**
	Treatment	*treat**
	Assessment	*assess**
	Unknown	*(none of the above key terms)*
Social care	Nursing	*nursing*
	Rehabilitation	*rehab**
	Urgent	*rapid, acute, urgent, emergency, A&E, unplanned*
	Personal care	*personal care, home care, day care, bathing, extra care, reable*, care service*
	Food	*food, meal*
	Domestic	*domiciliary, domestic, housework, laundry, shopping, cleaning, washing*
	Transport	*transfer, transport, migration, trip, mobil**
	Disability	*dis'y, disabilit*, disable**
	Occupational therapy	*occupational therapy*
	Memory & cognition	*dementia, memory, cognition*
	Assisted Equipment Technology	*assistive tech*, assisted equipment, equipment, technology*
	Nursing home	*nursing home, residential home, residential care, care home*
	Mental Health	

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	Community Social Carer Housing & living Unknown	*mental, CMHT (stands for Community Mental Health Team)* *community* *social* *carer* *housing, living* *(none of the above key terms)*

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Table 2 Patient characteristics for each cohort

Patient characteristics		Year							
		2015		2016		2017		2018	
		N	%	N	%	N	%	N	%
Total		23828		27443		31554		34651	
Gender	Female	13,178	55.3	15,246	55.6	17,506	55.5	19,463	56.2
Age group	<45	3,293	13.8	3,958	14.4	4,619	14.6	5,227	15.1
	45-<65	6,760	28.4	7,661	27.9	8,600	27.3	9,295	26.8
	65-<75	5,542	23.3	5,957	21.7	6,601	20.9	7,007	20.2
	75-<85	6,002	25.2	6,952	25.3	7,948	25.2	8,470	24.4
	85+	2,231	9.4	2,915	10.6	3,786	12.0	4,652	13.4
Deprivation level	1 (most)	3,166	13.3	3,883	14.1	4,656	14.8	5,205	15.0
	2	6,568	27.6	7,673	28.0	9,001	28.5	9,954	28.7
	3	5,869	24.6	6,833	24.9	7,875	25.0	8,759	25.3
	4	4,089	17.2	4,596	16.7	5,197	16.5	5,653	16.3
	5 (least)	3,430	14.4	3,636	13.2	3,866	12.3	3,975	11.5
	Unknown	706	3.0	822	3.0	959	3.0	1,105	3.2
Ethnicity	White	7,712	32.4	8,741	31.9	9,963	31.6	10,793	31.1
	Asian	6,237	26.2	7,147	26.0	8,161	25.9	8,905	25.7
	Black	1,721	7.2	1,990	7.3	2,245	7.1	2,412	7.0
	Mixed	1,767	7.4	2,162	7.9	2,630	8.3	3,087	8.9
	Unknown	6,391	26.8	7,403	27.0	8,555	27.1	9,454	27.3
Care status	Care home	619	2.6	682	2.5	732	2.3	686	2.0
	Have carer	125	0.5	162	0.6	191	0.6	219	0.6
Status	Died	1,294	5.4	1,543	5.6	1,811	5.7	2,351	6.8
	Opted out	-	0.0	21	0.1	92	0.3	5	0.0
Smoking status	Non	9,612	40.3	11,455	41.7	13,395	42.5	14,955	43.2
	Current	2,290	9.6	2,648	9.6	3,174	10.1	3,377	9.7
	Former	7,626	32.0	8,390	30.6	9,267	29.4	9,685	28.0

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	Unknown	4,300	18.0	4,950	18.0	5,718	18.1	6,634	19.1
Drinking status	Non	1,607	6.7	1,934	7.0	2,079	6.6	2,197	6.3
	Current	382	1.6	439	1.6	485	1.5	578	1.7
	Former	43	0.2	58	0.2	70	0.2	83	0.2
	Unknown	21,796	91.5	25,012	91.1	28,920	91.7	31,793	91.8
BMI category	Underweight	423	1.8	526	1.9	714	2.3	1,000	2.9
	Ideal	5,210	21.9	6,000	21.9	7,032	22.3	7,814	22.6
	Overweight	6,296	26.4	7,089	25.8	7,959	25.2	8,503	24.5
	Obese	6,255	26.3	7,213	26.3	8,323	26.4	8,891	25.7
	Unknown	5,644	23.7	6,615	24.1	7,526	23.9	8,443	24.4
Systolic blood pressure	<110 mm Hg	1,109	4.7	1,303	4.7	1,535	4.9	1,789	5.2
	110-119 mm Hg	2,386	10.0	2,886	10.5	3,497	11.1	3,966	11.4
	120-139 mm Hg	10,943	45.9	12,768	46.5	14,820	47.0	16,465	47.5
	140-159 mm Hg	5,925	24.9	6,540	23.8	7,270	23.0	7,623	22.0
	160+ mm Hg	510	2.1	570	2.1	627	2.0	609	1.8
	Unknown	2,955	12.4	3,376	12.3	3,805	12.1	4,199	12.1
Diastolic blood pressure	<80 mm Hg	13,969	58.6	16,434	59.9	19,215	60.9	21,261	61.4
	80-89 mm Hg	5,586	23.4	6,195	22.6	6,959	22.1	7,536	21.7
	90-99 mm Hg	962	4.0	1,053	3.8	1,159	3.7	1,219	3.5
	100+ mm Hg	134	0.6	148	0.5	166	0.5	179	0.5
	Unknown	3,177	13.3	3,613	13.2	4,055	12.9	4,456	12.9
Comorbidities	Acute MI	1,006	4.2	1,123	4.1	1,309	4.1	1,398	4.0
	Atrial fibrillation	2,700	11.3	3,362	12.3	4,018	12.7	4,549	13.1
	Chronic pulmonary disease	3,346	14.0	3,928	14.3	4,623	14.7	5,084	14.7
	Congenital heart disease	73	0.3	91	0.3	122	0.4	135	0.4
	Coronary heart disease	1,516	6.4	1,658	6.0	1,856	5.9	1,965	5.7
	Diabetes	6,116	25.7	7,102	25.9	8,208	26.0	9,053	26.1
	Hypertension	10,474	44.0	11,352	41.4	12,241	38.8	12,507	36.1
	Myocardial infarction	1,034	4.3	1,146	4.2	1,331	4.2	1,444	4.2

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	Myocarditis	614	2.6	697	2.5	797	2.5	868	2.5
	Other arrhythmias	2,181	9.2	2,680	9.8	3,266	10.4	3,782	10.9
	Peripheral vascular disease	563	2.4	634	2.3	681	2.2	771	2.2
	Renal diseases	1,048	4.4	1,129	4.1	1,301	4.1	1,400	4.0
	Stroke	667	2.8	762	2.8	933	3.0	1,052	3.0
Number of comorbidities	0	7,793	32.7	9,329	34.0	11,073	35.1	12,559	36.2
	1	7,155	30.0	7,978	29.1	8,950	28.4	9,667	27.9
	2	4,976	20.9	5,640	20.6	6,264	19.9	6,659	19.2
	3	2,291	9.6	2,632	9.6	3,082	9.8	3,363	9.7
	4+	1,613	6.8	1,864	6.8	2,185	6.9	2,403	6.9

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Table 3 Health service ever used by NWL HF patients between 2015 and 2018

Service Use		Year							
		2015		2016		2017		2018	
		N	%	N	%	N	%	N	%
Total		23828		27443		31554		34651	
Secondary Care	Emergency admission	5,163	21.7	6,592	24.0	8,276	26.2	9,257	26.7
	Elective admission	910	3.8	1,495	5.4	1,803	5.7	1,798	5.2
	Unplanned A&E	8,238	34.6	10,697	39.0	12,250	38.8	14,145	40.8
	Outpatient (any specialty)	13,492	56.6	18,560	67.6	22,115	70.1	24,283	70.1
	Outpatient (Top 1) (cardiology)	4,117	17.3	6,518	23.8	8,040	25.5	8,231	23.8
	Outpatient (Top 2)†	2,645	11.1	4,662	17.0	5,600	17.7	6,049	17.5
	Outpatient (Top 3)†	1,992	8.4	3,444	12.5	4,127	13.1	5,053	14.6
	Outpatient (Top 4)†	1,645	6.9	3,156	11.5	4,018	12.7	4,500	13.0
	Outpatient (Top 5)†	1,563	6.6	2,554	9.3	3,220	10.2	3,383	9.8
Primary Care	GP consultation	16,014	67.2	17,573	64.0	19,494	61.8	20,741	59.9
	Echocardiogram	1,826	7.7	2,016	7.3	2,156	6.8	2,178	6.3
	Echocardiogram abnormal	1,010	4.2	1,066	3.9	1,150	3.6	1,113	3.2
Community	Any	8,801	36.9	9,869	36.0	11,195	35.5	13,762	39.7
	Nursing	6,590	27.7	5,893	21.5	6,311	20.0	8,052	23.2
	Rehabilitation	2,052	8.6	2,489	9.1	2,065	6.5	2,861	8.3
	Urgent	918	3.9	811	3.0	999	3.2	1,203	3.5
	Intermediate	1,841	7.7	1,754	6.4	1,397	4.4	1,526	4.4
	Cardiology	859	3.6	578	2.1	797	2.5	1,005	2.9
	GP referral to cardiac rehabilitation	4,333	18.2	5,465	19.9	6,585	20.9	7,187	20.7
	Diabetes	1,011	4.2	955	3.5	1,171	3.7	1,654	4.8
	Physio-/Occupational therapy	1,091	4.6	1,160	4.2	1,148	3.6	1,853	5.3
	Foot	3,760	15.8	4,076	14.9	4,404	14.0	5,397	15.6
	Respiratory	217	0.9	163	0.6	206	0.7	302	0.9
	Neurological	1,054	4.4	1,427	5.2	1,481	4.7	2,138	6.2
	Urinary	452	1.9	597	2.2	747	2.4	1,374	4.0
	Speech language therapy	108	0.5	68	0.2	60	0.2	102	0.3
	Falls	165	0.7	332	1.2	365	1.2	450	1.3
	Diet & nutrition	644	2.7	1,399	5.1	1,696	5.4	2,197	6.3

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	Home	1,229	5.2	1,411	5.1	1,738	5.5	1,654	4.8
	Phone	949	4.0	317	1.2	418	1.3	393	1.1
	Unknown	178	0.7	203	0.7	206	0.7	248	0.7
Mental health	Any	1,064	4.5	1,421	5.2	1,718	5.4	1,557	4.5
	Outpatient	354	1.5	360	1.3	428	1.4	169	0.5
	Community	964	4.0	1,305	4.8	1,589	5.0	1,489	4.3
	Urgent	387	1.6	695	2.5	950	3.0	631	1.8
	Specialist	62	0.3	197	0.7	253	0.8	78	0.2
	Dementia	527	2.2	585	2.1	706	2.2	732	2.1
	Learning disability	33	0.1	39	0.1	48	0.2	29	0.1
	Psychology	91	0.4	236	0.9	279	0.9	261	0.8
	Review	109	0.5	159	0.6	214	0.7	92	0.3
	Consultation	51	0.2	82	0.3	118	0.4	951	2.7
	Treatment	61	0.3	84	0.3	110	0.3	117	0.3
	Assessment	151	0.6	254	0.9	309	1.0	267	0.8
	Unknown	<5	0.0	<5	0.0	-	0.0	-	0.0
Social care	Any	1,042	4.4	1,236	4.5	1,912	6.1	1,350	3.9
	Nursing	89	0.4	109	0.4	169	0.5	128	0.4
	Personal care	709	3.0	890	3.2	1,485	4.7	1,057	3.1
	Food	68	0.3	82	0.3	44	0.1	10	0.0
	Domestic	165	0.7	238	0.9	350	1.1	253	0.7
	Transport	78	0.3	78	0.3	99	0.3	70	0.2
	Disability	181	0.8	230	0.8	277	0.9	248	0.7
	Occupational therapy	8	0.0	15	0.1	18	0.1	28	0.1
	Memory & cognition	53	0.2	76	0.3	104	0.3	63	0.2
	Assisted equipment technology	129	0.5	28	0.1	47	0.1	7	0.0
	Nursing home	58	0.2	76	0.3	123	0.4	80	0.2
	Mental health	43	0.2	49	0.2	95	0.3	36	0.1
	Community	250	1.0	122	0.4	198	0.6	232	0.7
	Social	64	0.3	87	0.3	165	0.5	88	0.3
	Carer	127	0.5	125	0.5	142	0.5	159	0.5
	Housing & living	119	0.5	66	0.2	98	0.3	41	0.1
	Unknown	68	0.3	110	0.4	119	0.4	66	0.2
Service count	0	2,602	10.9	2,567	9.4	2,891	9.2	3,067	8.9

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	1	7,036	29.5	7,438	27.1	8,572	27.2	9,267	26.7
	2	8,200	34.4	10,549	38.4	12,211	38.7	13,710	39.6
	3+	5,990	25.1	6,889	25.1	7,880	24.9	8,607	24.8
Service type	None	2,602	10.9	2,567	9.4	2,891	9.2	3,067	8.9
	Secondary care only	2,508	10.5	3,569	13.0	4,586	14.5	5,020	14.5
	Primary care only	4,134	17.3	3,443	12.5	3,538	11.2	3,600	10.4
	Other services only	460	1.9	467	1.7	486	1.5	682	2.0
	Secondary care & Primary care	5,298	22.2	7,331	26.7	8,465	26.8	8,606	24.8
	Secondary care & Other services	2,244	9.4	3,267	11.9	4,097	13.0	5,141	14.8
	Primary care & Other services	1,133	4.8	606	2.2	614	1.9	781	2.3
	All three	5,449	22.9	6,193	22.6	6,877	21.8	7,754	22.4

†The top five outpatient specialties by year

Rank/Year	**2015**	**2016-2018**
1	Cardiology	
2	General surgery	Ophthalmology
3	Ophthalmology	General surgery
4	Trauma & orthopaedics	Allied health professional episode
5	Allied health professional episode	Radiology

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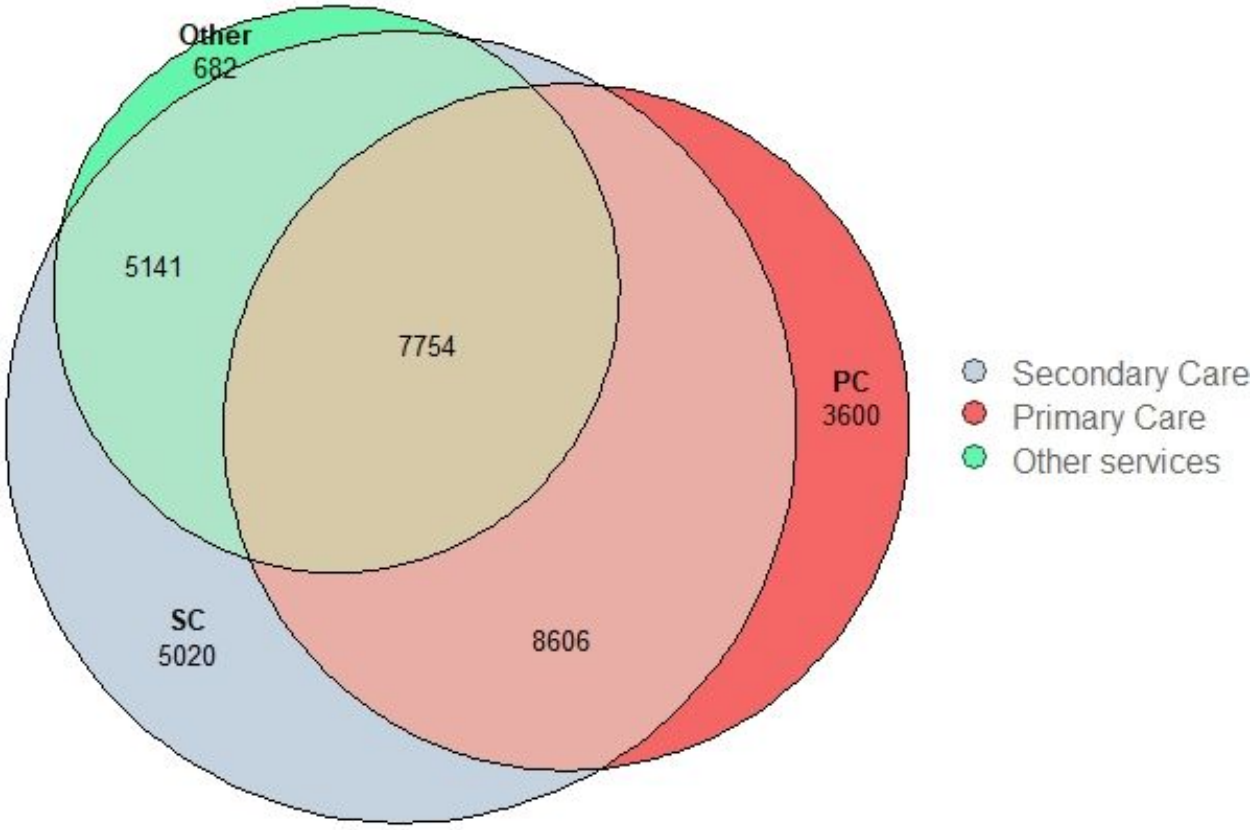
Figure 1 Venn diagram* of service use in 2018



*Venn diagram shows an approximation of group sizes. An intersection is missing between PC & Other services (2.3%) – documentation of R eulerr package states that “with three or more sets intersecting, exact Euler diagrams are often impossible. For such cases eulerr attempts to provide a good approximation

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Figure 2 Heatmap of service utilisation by cluster. Numbers represent percentage difference between cluster mean and population mean values of each health utilisation variable.

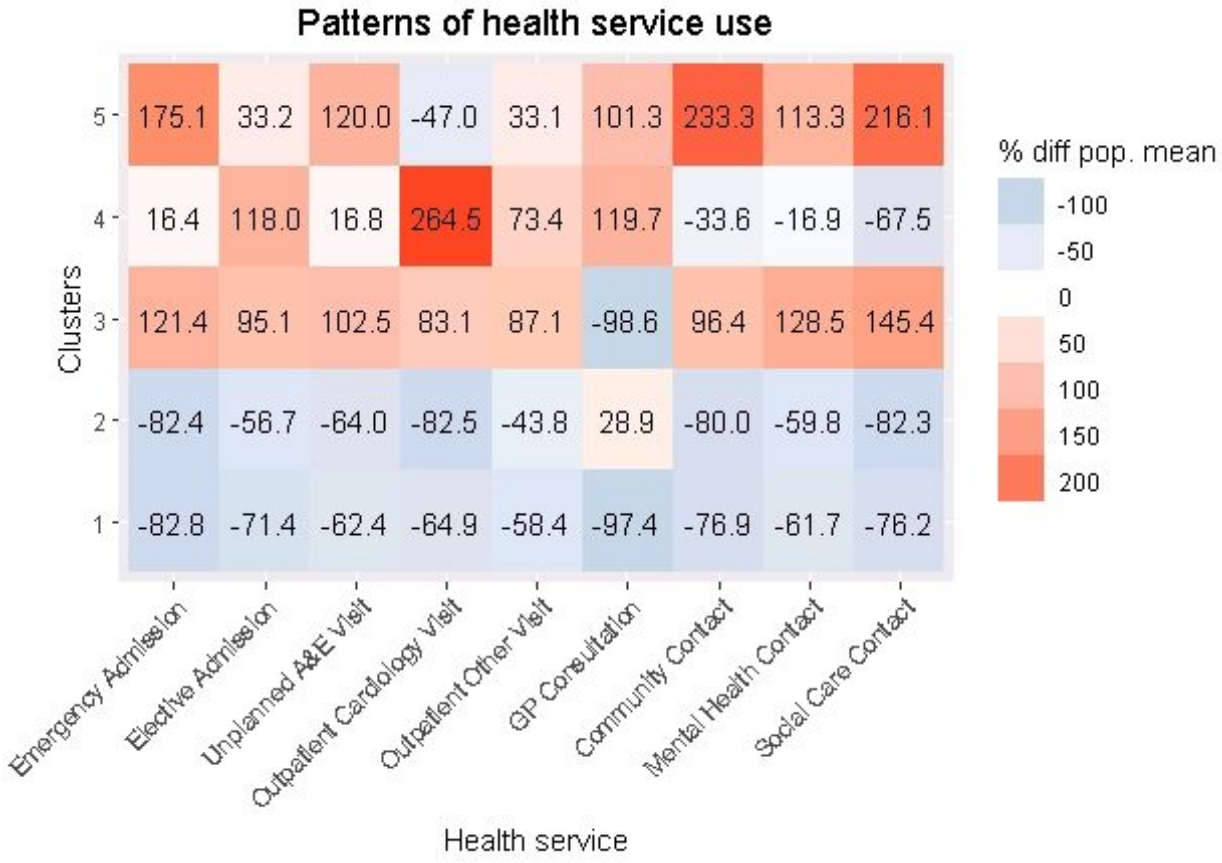

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Table S1. Code list

Variable/Diagnosis	Read codes	Timeframe
Heart failure	14A6.00, 14AM.00, G58..00, G58..11, G580.00, G580.11, G580.12, G580.13, G580.14, G580000, G580100, G580200, G580300, G580400, G581.00, G581.13, G581000, G582.00, G583.00, G583.11, G584.00, G58z.00, G58z.12, G5yy900, G5yyA00, G5y4z00, 1O1..00, G580.12, G232.00, 8B29.00, 662W.00, 8H2S.00, 8CL3.00, SP11111, 585f.00, 585g.00, 662T.00, 9N0k.00, 662g.00, 8HBE.00, 662f.00, 9N2p.00, 662h.00, 662i.00, G211100, G234.00, G21z100, 9N6T.00, 8IB8.00, G210100, 8CMK.00, 679W100, 8CeC.00, 8CMW800, 661M500, G583.12, ZRad.00, 388D.00 & ICD10 codes: I50.0, I50.1, I50.9, I11.0, I13.0, I13.2, J81X	Historic GP data, and SUS data (1 January 2015 – 31 December 2018)
Smoking status	1371, 1371.11, 1372, 1372.11, 1373, 1374, 1375, 1376, 1377, 1378, 1379, 137..00, 137..11, 137a.00, 137A.00, 137b.00, 137B.00, 137C.00, 137c.00, 137D.00, 137d.00, 137e.00, 137f.00, 137F.00, 137G.00, 137h.00, 137H.00, 137J.00, 137j.00, 137K.00, 137K000, 137L.00, 137l.00, 137M.00, 137m.00, 137N.00, 137o.00, 137O.00, 137P.00, 137P.11, 137Q.00, 137Q.11, 137R.00, 137S.00, 137T.00, 137V.00, 137X.00, 137Y.00, 137Z.00, 8CdB.00, 8HkQ.00, 8IEK.00, 8IEM.00, 8IEo.00, 8T08.00, 9km..00, 9km..11, 9kn..00, 9kn..11, 9ko..00, 9ko..11, 9NS0200, 9OO1.00, 6791, 13p..00, 13p5.00, 67H1.00, 745H.00, 745H400, 745Hy00, 8CA6.00, 8H7i.00, 8HBM.00, 8HTK.00, 945Hz00, 9CAL.00, 9kc..00, 9OO..12, 9OO.00, 9OO3.00, 9OO4.00, 9OO5.00, 9OO6.00, 9OO7.00, 9OO8.00, 9OOA.00, 13p0.00, 13p5000, 13p8.00, 67H6.00, 8IAj.00, 9N2k.00, 9N4M.00, 9OO2.00, H310100, ZG23300	Up to 5 years before start of study year
Drinking status	ZV4KC00, ZV6D600, ZV57A00, ZV11300, Eu10211, Eu10212, 136..00, 136Z.00, 68S..00, 6892, 1368, E23..00, E23z.00, 8BA8.00, 136K.00, 136L.00, E23..12, 9k13.00, 9k17.00, 9k15.00, 9k18.00, 9k16.00, 136X.00, 136V.00, E01y000, E23..11, 136G.00, 136R.00, E231.00, E231z00, 136M.00, 136e.00, 136H.00, 1362.12, 1362.11, 136I.00, 136D.00, 136B.00, 136C.00, 136A.00, 136E.00, 388u.00, 1462, 136T.00, 136S.00, 136P.00, 1365, 136N.00, 1363, 136O.00, 1364, 1361.11, E250.00, E250z00, E250200, E250000, 1361.12, 38D2.00, 136J.00, 136F.00, 1367, 1369, 1362, 136Q.00, 1366, 1361, 1D19.00, 2577, 2577.11, 136W.00, 13ZY.00, E250100, E250300, ZV11311, E250.11, E250.12, E250.13, E250.14, R103.00, U81..00	As above
BMI	22A..00, 229..00, 22A6.00, C380.00, 22A4.11, 22A5.11, 22K..00, C380300, 22K4.00, C38z000, R034800, 22K5.00, 1444, 22A4.00, 6878.11, 22AZ.00, 22K7.00, 22A3.00, 22K6.00, C380500, 22A1.00, 22K2.00, 22K1.00, 22A2.00, 22K3.00, 22A5.00, C380200, 229Z.00, 22K8.00, 22Z..00, 222A.00, C38..00, Cyu7000, C38z.00, 22AA.00, C380600, C380700	As above
Blood pressure	246..00, 2461, 246..11, 246..12, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 246a.00, 246A.00, 246b.00, 246B.00, 246c.00, 246C.00, 246d.00, 246D.00, 246e.00, 246E.00, 246f.00, 246F.00, 246G.00, 246J.00, 246N.00, 246P.00, 246Q.00, 246R.00, 246S.00, 246T.00, 246V.00, 246W.00, 246X.00, 246Y.00, 246Z.00, 6623, 662B.00, 662C.00, 662L.00, R1y2.00, R1y3.00, ZV70B00, G20..11, 662Q.00, 315B.00, 662V.00, 8HR8.00, 8HRH.00	As above
Acute MI	G30..00, G30..14, G30..15, G308.00, G301.00, G307100, G30X000, G30z.00, G301z00, G305.00, G304.00, G30X.00, G30B.00, G30y.00, G30yz00, G306.00, Gyu3400, 14AH.00, 14AT.00	As above
Atrial fibrillation	G573000, G573.00, G573200, 662S.00, 14AN.00, 3272, 9Os..00, 6A9..00, 9hF1.00, G573z00, 9Os0.00, 9hF..00, G573500, 7936A00, 9Os1.00, G573300, 9Os2.00, G573400, 9Os3.00, 9Os4.00	As above
Chronic pulmonary disease	114 PF, 14B4.00, 173A.00, 173c.00, 1761, 1780, 1O2..00, 466 BC, 466 D, 490, 490 T, 491, 491 AC, 491 BS, 491 BT, 491 E, 491 R, 492, 493, 493 A, 493 AA, 493 AB, 493 AC, 493 AD, 493 AI, 493 AJ, 493 BD, 493 BG, 493 BI, 493 BR, 493 D, 493 EA, 493 EB,	As above

	493 EP, 493 GR, 493 GS, 493 HR, 493 HT, 493 JC, 493 KA, 493 KB, 493 NA, 5151, 5152, 5161F, 518, 5192BY, 5192CM, 5199CL, 663e.00, 663, 6.6299999999999997E+102, 663f.00, 663h.00, 663N.00, 663N000, 663N100, 663p.00, 663P.00, 663q.00, 663r.00, 663s.00, 663t.00, 663u.00, 663v.00, 663V000, 663V100, 663V200, 663V300, 663w.00, 663W.00, 66YC.00, 66YP.00, 691 TM, 7832AB, 8H2P.00, 9OJ1.00, 9OJA.11, H30..00, H300.00, H30..11, H30z.00, H31..00, H310.00, H310000, H310100, H310z00, H311.00, H311000, H311100, H311z00, H312.00, H312000, H312011, H312100, H312z00, H313.00, H31y.00, H31y100, H31yz00, H31z.00, H32..00, H320.00, H320000, H320200, H320z00, H321.00, H322.00, H32y.00, H32y000, H32y100, H32y200, H32yz00, H32z.00, H33..00, H330.00, H330000, H330011, H330111, H330.12, H330.13, H330.14, H330z00, H331.00, H331000, H33..11, H331100, H331.11, H331111, H331z00, H332.00, H333.00, H334.00, H33z.00, H33z000, H33z011, h33z100, H33z111, H33z200, H33zz11, H33zz12, H33zz13, H34..00, H340.00, H341.00, H34z.00, H35..00, H350.00, H351.00, H352.00, H352000, H352100, H352z00, H353.00, H354.00, H355.00, H356.00, H35y.00, H35y300, H35y500, H35y600, H35y700, H35yz00, H35z.00, H35z100, H35zz00, H3z..11, H40..00, H41..00, H410.00, H41z.00, H42..00, H420.00, H423.00, H42z.00, H43..00, H430.00, H431.00, H432.00, H434.00, H435.00, H43z.00, H440.00, H441.00, H442.00, H45..00, H460.00, H460z00, H464000, H464100, H464200, H47y000, H4y1000, H4z..00, H57y.00, H57yz00, H581.00, H582.00, Hyu3000, Hyu4000, Hyu4100, Hyu4300, K3441B, L4930LO, L5161B, SK07.00	
Congenital heart disease	P5...00, P5...11, P5...12, P5...13, P50..00, P50..11, P50..12, P500.00, P500.11, P500.12, P501.00, P501.11, P501.12, P502.00, P502.11, P50z.00, P51..00, P510.00, P511.00, P511100, P511200, P511300, P511z00, P512.00, P51y.00, P51y.11, P51z.00, P51z.11, P52..00, P520.00, P520.11, P520.12, P521.00, P52z.00, P53..00, P54..00, P540.00, P541.00, P542.00, P543.00, P544.00, P545.00, P54y.00, P54z.00, P55..00, P550.00, P550.11, P550.12, P550.13, P551.00, P552.00, P552.11, P553.00, P55y.00, P55y.11, P55z.00, P56..00, P561.00, P561.11, P56y.00, P56z.00, P56z000, P56z011, P56z100, P56z200, P56zz00, P58..00, P59..00, P5X..00, P5y..00, P5z..00, P6...00, P60..00, P600.00, P601.00, P601000, P601z00, P602.00, P602100, P602z00, P603.00, P603.11, P60z.00, P60z000, P60z100, P60zz00, P61..00, P610.00, P611.00, P61z.00, P62..00, P63..00, P64..00, P640.00, P641.00, P64z.00, P65..00, P65..11, P650.00, P651.00, P652.00, P65z.00, P66..00, P67..00, P68..00, P69..00, P6W..00, P6X..00, P6y..00, P6y0.00, P6y1.00, P6y2.00, P6y3.00, P6y3000, P6y3100, P6y3z00, P6y4.00, P6y4000, P6y4100, P6y4300, P6y4400, P6y4411, P6y4500, P6y4600, P6y4z00, P6y5.00, P6y5000, P6y5100, P6y5200, P6y5z00, P6y6.00, P6y6.11, P6y6000, P6y6100, P6y6111, P6y6200, P6y6300, P6y6400, P6y6z00, P6y7.00, P6y8.00, P6yy.00, P6yy.11, P6yy.12, P6yy000, P6yy100, P6yy200, P6yy300, P6yy400, P6yy411, P6yy500, P6yy600, P6yy700, P6yy900, P6yyA00, P6yyC00, P6yyz00, P6z..00, P6z..11, P6z0.00, P6z1.00, P6z1000, P6z1100, P6z2.00, P6z3.00, P6z3.11, P6zz.00	As above
Coronary heart disease	G340.12, G33z300, G33..00, G311.13, G30..12, G311.11, 792..00, 7929y00, 7920y00, G311100, 7920200, 7921z00, 7920100, 7920000, G302.00, 7929400, 7921, G307000, G33z500, 7921200, 792z.00, G331.11, 7920300, G300.00, G33z700, G331.00, 662K.00, G30..16, 662K200, 662Kz00, 662K100, 7N41300, G30A.00, G311200, G301100, G311400, G330000, 7920, G34z000, 7923z00, 7923, 7921100, 662K000, G311.14, 792B000, G310.00, 7929, G33z.00, G33z600, 3234, G33zz00, G30y000, G303.00, G330z00, G30..13, 7925100, 7924200, 7922, 792y.00, 792B.00, 7925000, G311300, 792A.00, G332.00, 7925y00, G312.00, Gyu3000, G301000, G30y200, 7927z00, 7929500, 7921300, 7921000, 792Bz00, 7922300, 7922200, 8B27.00, 7927, 7922z00, ZRBN.00, 7925300, 7920z00, 7927400, P6y7.00, 792C000, G311011, 792C.00, 792Ay00, 7922100, 7922y00, 7926300, G311000, 792Az00, 7921y00, 7927200, 7926000, G30y100, 7923200, 7929200, 7923100, 7924100, 7926200, 7923300, 7925400, 792By00, 7922000, 792Cz00, 7926z00, 7923000, 7929600, 792Cy00, 792B100, 7927y00, 7926	As above

Diabetes	C10EC11, C10EC12, C11y000, C10FJ11, C10FP11, C104y00, C109K00, C10E111, C10A.00, 66AR.00, C108F11, C109600, C10EH00, C10E100, C10FA00, C108A11, C10E200, 9OLA.11, 1434, 67IJ100, C10..00, C109D12, C10EM00, C10E600, C10FL00, 9OLM.00, C10E000, C10E511, 8HgC.00, C10E912, ZV13F00, C106100, C10FF00, C109312, C10z.00, C10yy00, C108B11, C10F211, C10EN11, 9OLB.00, C108F00, C102000, C10E400, 8Hj0.00, C108500, C108A00, C109500, C10F400, C106y00, C103z00, C101z00, C10E.11, C10C.12, C10C.11, C10FJ00, C107100, C108012, C10P000, C107.00, 66AQ.00, 9N0n.00, C10E500, ZC2CA00, C109J00, C10M.00, C10FB11, C10EE12, C10FK11, C10B.00, C10N.00, C108600, C10F.00, C10D.00, C109G00, C106.12, C106.13, C10EC00, C10FP00, C10FM00, C10ED00, C108H11, C109611, C109612, C10zz00, C10FA11, F372.00, 66AX.00, C135.12, 14F4.00, C10FS00, L180500, C10E611, C10E612, C10z000, C109D11, C109111, C10EA11, 66AU.00, C108B00, C10F200, C109400, 9h4..00, C104000, C10FQ00, C10F900, C108511, C101y00, C107z00, C105z00, 8CE0000, C10P100, C108811, C108812, C10FD11, 66An.00, 66A8.00, F171100, C10P.00, L180400, Cyu2.00, C10ED12, C10E311, C10E312, C108000, C135000, C107.12, C107.11, C108700, C10FG00, 66Ay.00, C10E800, C10EB00, C10FK00, C109J11, C109J12, C109100, C10FB00, Q441.00, C10EE00, 9NN9.00, 8CS0.00, C10E012, C10E011, C109E11, C10EP00, C108D00, C106.00, C103100, C109112, L180.00, C108D11, C10F011, 9OL6.00, C109C11, C109C12, C10z100, C10FM11, 9OLZ.00, C108H00, L180z00, 8B3l.00, C10N100, C135.00, L180600, C109200, C10EL00, C10F300, Kyu0300, C104100, C10EA00, C105.00, 2G5C.00, C103.00, 2BBF.00, C105100, 8HTE100, 661N400, C109300, 1253, C105y00, 9OL5.00, Cyu2300, C109412, C109411, C108C00, C108211, C100011, 66Ao.00, ZC2CB00, C10F911, C10EA12, 12G2.00, C10N000, 8CP2.00, C10EF12, Cyu2000, 8Hl4.00, 9OL4.00, L180700, C108100, C10E900, C108800, C10FD00, L180300, C10E300, C102100, C10FC00, C108J12, C108J11, C109E12, C108712, C108711, C10FG11, C109F11, C109F12, C10E812, C10E811, 46Z0.00, 9OL1.00, ZL62500, 66A9.00, C109912, C109911, C10E412, C10E411, C10A000, L180800, C10EK00, C10F000, C109C00, C10F500, C10A100, C10EG00, K01x100, C109H12, C109H11, C105000, C109211, C109212, C10EL11, 2G51000, C10F311, C107200, 8H4e.00, K081.00, 679L000, ZC2C800, C10F611, C10FN11, L180900, C108200, C108900, C10FE00, C109.00, C100000, C10F100, 661M400, C101.00, ZC2C911, C104.00, C106z00, C100z00, L180811, C10zy00, C108512, C10F711, C10H.00, C10F511, C108212, C109711, C109712, C108.12, C108.13, C108.11, C109A11, C10FC11, L180X00, ZRB5.11, C109E00, C10E711, C10E712, Q44B.00, 66AJ100, C109000, C10EJ00, C108E00, C109900, C109B00, ZRbH.00, C10EF00, 7276, C103y00, C10E512, ZRB4.00, C10P011, C107000, C108411, C10y100, C101000, L180100, C10EQ11, C10EP11, C108300, C108y00, C109512, C100100, C10F600, C102.00, C109011, C10FN00, 679R.00, 8H7f.00, C10E.12, 9Nl4.00, 8CR2.00, C100.00, C104z00, C102z00, C108911, C108912, C10FE11, C109.11, C109.13, C109.12, C10F111, C108011, C10E112, C10y.00, C10E212, 9OLC.00, C109D00, ZC2C900, C10EM11, C10FL11, 9OLF.00, C10A500, C109700, C108.00, C109A00, C10FH11, C10ER00, C101100, C10G000, C10FR00, C103000, C108412, C10EN00, 66Af.00, 66AH200, C100112, C109012, 8HTe.00, C108E11, C108E12, C109B11, C109B12, K27y700, C10yz00, C109511, 8BL2.00, L180000, 8Hg4.00, C10F411, C10B000, 9NM0.00, C108400, C10E700, C108z00, C10G.00, C10E.00, C10C.00, C10F700, C314.11, C10D.11, C10EQ00, 8CMW700, C109G11, 66AJ.11, 9OLN.00, 9OL..00, C108311, 1JL..00, C106000, C108112, 3882, C100111, C10FH00, C10FF11, C10F.11, C109G12, C10E911	As above
Hypertension	G20..00, 662..12, G2...00, 662P.00, G20..11, G20z.00, 662d.00, G20z.11, 662c.00, 8BL0.00, 662O.00, 6627, G2z..00, 6628, 662G.00, G201.00, G2...11, G202.00, 9N1y200, 8B26.00, 662F.00, 9OIA.11, F421300, G21..00, G200.00, 662b.00, 1JD..00, G24..00, 8CR4.00, G22..00, G21z011, 6629, G22z.11, G24z.00, G2y..00, G21zz00, G672.00, TJC7.00, G24z100, TJC7z00,	As above

	8I3N.00, G22z.00, G203.00, G24z000, G24zz00, G220.00, G672.11, G244.00, G241000, G21z.00, G222.00, G241.00, G233.00, G241z00, G240.00, F404200, U60C511, G232.00, G221.00, Gyu2.00, G211.00, G21z000, G23..00, G21z100, G210.00, U60C51A, G211100, G240000, G23z.00, G211000, G240z00, G230.00, 7Q01.00, G231.00, G210000, G210100, Gyu2100	
Myocardial infarction	G305.00, G380.00, G384.00, G32..00, G310.00, G30yz00, G30z.00, G306.00, G353.00, G30X.00, G304.00, G30..00, G381.00, G383.00, G38..00, G35..00, G30y.00, Gyu3400, 323..00, G308.00, 14AH.00, G30B.00, G35X.00, G38z.00, 3232, G30X000, G32..11, G32..12, Gyu3600, G30..17, G30..15, G30..13, G351.00, G350.00, Gyu3500, 14AT.00, G307100, G301z00, G301.00, G30..00, G30..14, G30..15, G308.00, 323..00, G30..11, G30z.00, G301z00, G305.00, G32..11, G30..17, G35..00, G30X.00, G38z.00, G353.00, G306.00, G301.00, G307100, G30X000, G38..00, G30B.00, G30y.00, G351.00, G30yz00, G384.00, G380.00, G35X.00, G381.00, G350.00, G304.00	As above
Myocarditis	A32y100, A364300, A742300, A93y100, G012.00, G1y0.00, G52..00, G520100, G520300, G520500, G520600, G520700, G520z00, G52y.00, G52y000, G52y111, G52y200, G52y300, G52y400, G52y600, G52y700, G52yz00, G52z.00, G5y0.00, G5y7.00, G5y8.00, Gyu5F00, Gyu5J00, F391B00, G343.00, G55..00, G551.00, G552.00, G554.00, G554000, G554011, G554100, G554200, G554300, G554400, G554500, G554511, G554z00, G555.00, G557.00, G557z00, G558.00, G558000, G558100, G558200, G558400, G558z00, G559.00, G55A.00, G55A.11, G55y.00, G55y.11, G55y000, G55z.00, Gyu5M00, Gyu5N00, Gyu5P00, L186500	As above
Other arrhythmias	G573100, G576300, G57y800, G572100, G57y200, G57..11, G57z.00, G57..00, G576.00, G576z00, G576000, G572000, G576011, G57y.14, G576400, G57y600, G57yz00, G57y.00, G573600, G570000, G570100, G570200, G570300, G570.00, G570z00, G572z00, G572.00, G571.00, G57y000, G576.11, G57y.12, G57y.11, G57yA00, G57y100, G57y300, G57y400, G577.00, G57y700, G57y.13, G576100, G57y900, G576200, G574000, G574.00, G574z00, G574100, G576500, G571.11, G57y500, 2426, 2426.11, 14AP.00, 14AQ.00, 14AR.00, R050.00, R050.11, R050.12, 1814, 3262, 3263, 3264, 3273, 3274, 3281, 3282, 181..12, 793M100, 793M300, Gyu5a00, R059.00, R05W.00, Ryu0600, 326..00, 326Z.00, 327..00, 327Z.00, 328..00, 328Z.00, R05X.00, Ryu0000, 2432, 2433, 2435, 2447	As above
Peripheral vascular disease	14AE.00, 14NB.00, 4410N, 4419, 4439A, 4439GD, 7A11211, 7A11311, 7A13.11, 7A13411, 7A14.11, 7A14411, g71..00, G71..00, G710.00, G711.00, G711.11, G712.00, G713.00, G713000, G713.11, G714.00, G714000, G714100, G714.11, G715.00, G715000, G716.00, G716000, G718.00, G71z.00, G73..00, G73..11, G73y.00, G73yz00, G73z.00, G73z000, G73z011, G73zz00, Gyu7100, Gyu7200, Gyu7400	As above
Renal disease	14D1.00, 1Z10.00, 1Z11.00, 1Z12.00, 1Z13.00, 1Z14.00, 582 N, 583 A, 583 GC, 583 MA, 583 MN, 583 MP, 5930A, 5930AR, 5930R, 5932A, 5932E, 5932EC, 5932KH, 5932MN, 7598A, K0...00, K001.00, K012.00, K019.00, K02..00, K021.00, K02..11, K02..12, K022.00, K023.00, K02y000, K02y200, K02y300, K02yz00, K02z.00, K03..00, K03..11, K032.00, K032000, K032y00, K032y13, K032y14, K032z00, K034.00, K035.00, K041.00, K042.00, K04y.00, K04z.00, K05..00, K050.00, K06..00, K060.11, K080.00, K080000, K080100, K080200, K080300, K080z00, K081.00, K08y000, K08yz00, K08z.00, K0A3200, K0A3300, K0A3400, K0A3500, K0A3700, K0A5500, K100000, K100100, K101000, K101100, Kyu2.00, Kyu2000, Kyu2100	As above
Stroke	G63y000, G63y100, G63z.00, G64..00, G64..11, G64..12, G64..13, G640.00, G640000, G641.00, G641.11, G641000, G64z.00, G64z.11, G64z.12, G64z000, G64z200, G64z300, G64z400, G65..00, G65..11, G65..12, G65..13, G655.00, G65z100, G65zz00, G65y.00, G65z.00, G660.00, G661.00, G662.00, G663.00, G664.00, G665.00, G666.00, G667.00, G668.00, G671.00, G671000, G677000, G677100, G677200, G677300, G677400, 14A7.12, 14AB.00, 14AB000, 14AK.00	As above

Cardiac rehabilitation	9N0k.00, 8HBE.00, 9N2p.00, 8HHb.00, 8HTL.00, 9N6T.00, 8HHz.00, 8Hk0.00, 8Hg8.00, 8HgD.00, 8HTL000, 9N1P.00, 8H44.00, 9N1P.11, ZL9A300, 8F9..00, ZL5A100, 8H7v.00, ZL18300, ZLE6300, 9Oa..00, 8HVJ.00, 9NM2.00, Z677.00, ZLD3300, ZLA2200, ZL22200, 66f..00, ZLD7200, ZV57900, 8H4R.00, ZLEQ400, 9N6W.00, 8H3V.00, 8F90.00, 8F91.00, ZL62200, 8F92.00, 9NJK.00, 9N6V.00, 9NJL.00, 8F93.00, 9N2x.00, 9Nl1.00, Z1E2.00, 8Hkk.00, 8Hkl.00, 7P24000, 8Hkt.00, 8F97.00, 9NNf300, 8H44000, 8CMWB00	During study year
Echocardiogram	8HQ7.00, 33BD.00, 5853000, 5853100, R132000, 585f.00, 585g.00, 585k.00, 585R.00, 9Ee0800, 9EV7.00, 5853.11, 7P0Hz00, 7P0H.00, 8A54400, 7935200, 7P0H100, 7P0H000, 7P0H400, 7935500, 7P0H300, 7P0Hy00, 7P0H600, 8A58.00, 5C20.00, 8H7o000	During study year

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Box S1. Selection of number of clusters

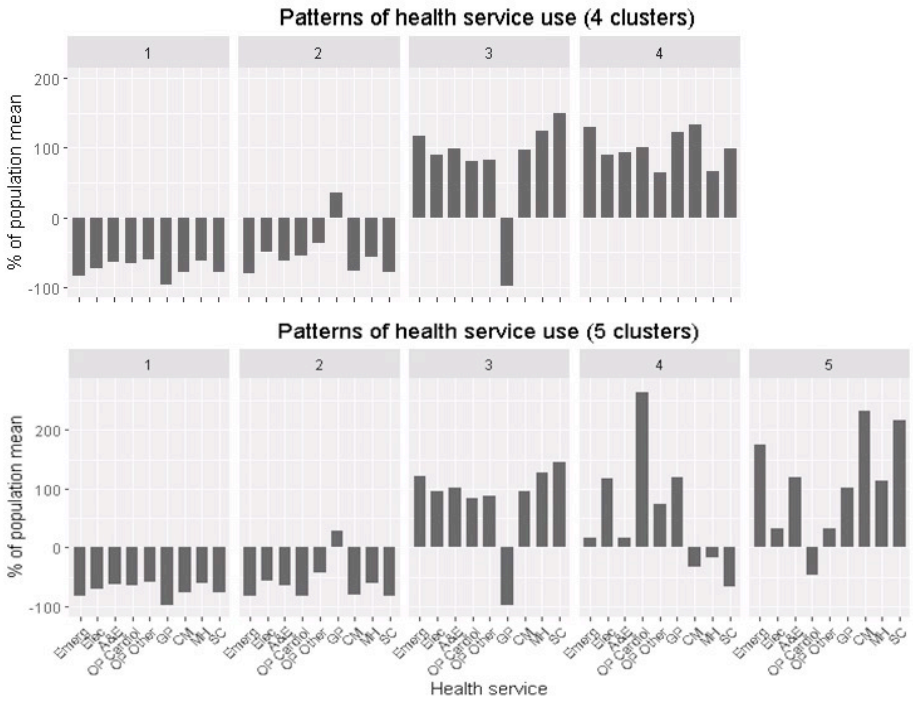
To identify the appropriate number of clusters for k-means analysis, the 'elbow method' and hierarchical cluster analysis were employed using the Euclidian distance measures.

For the elbow method, the k-means clustering was applied to a range of values for 'k', and cluster variability was examined using the within-cluster sums of squares where lower values represent clusters of higher similarity. The highest 'k', at which point there is diminishing returns, was selected by identifying the "elbow-point" in the plot of within-cluster sums of squares against 'k'. From a range of 2 to 15 cluster solutions, this method identified four clusters as optimal 'k'.

Although there is no consensus on the best method of clustering, hierarchical cluster analysis is thought to be more flexible and have fewer assumptions about the distribution of the data, e.g. does not require pre-specified number of clusters, but works poorly with large data sets. We applied hierarchical agglomerative clustering to 10 samples of 3,000 patients using Ward's method, which aims to minimise total within-cluster variance and is considered to be the hierarchical equivalent of k-means. This method identified mostly four and five clusters, so both were explored using k-means.

The 4- and 5-cluster solutions resulted in three very similar clusters. The fourth and fifth clusters in the 5-cluster model, however, provided additional information, splitting the last cluster in the 4-cluster model into two distinct clusters with very contrasting care usage patterns. Therefore, our main analyses present the 5-cluster solution.

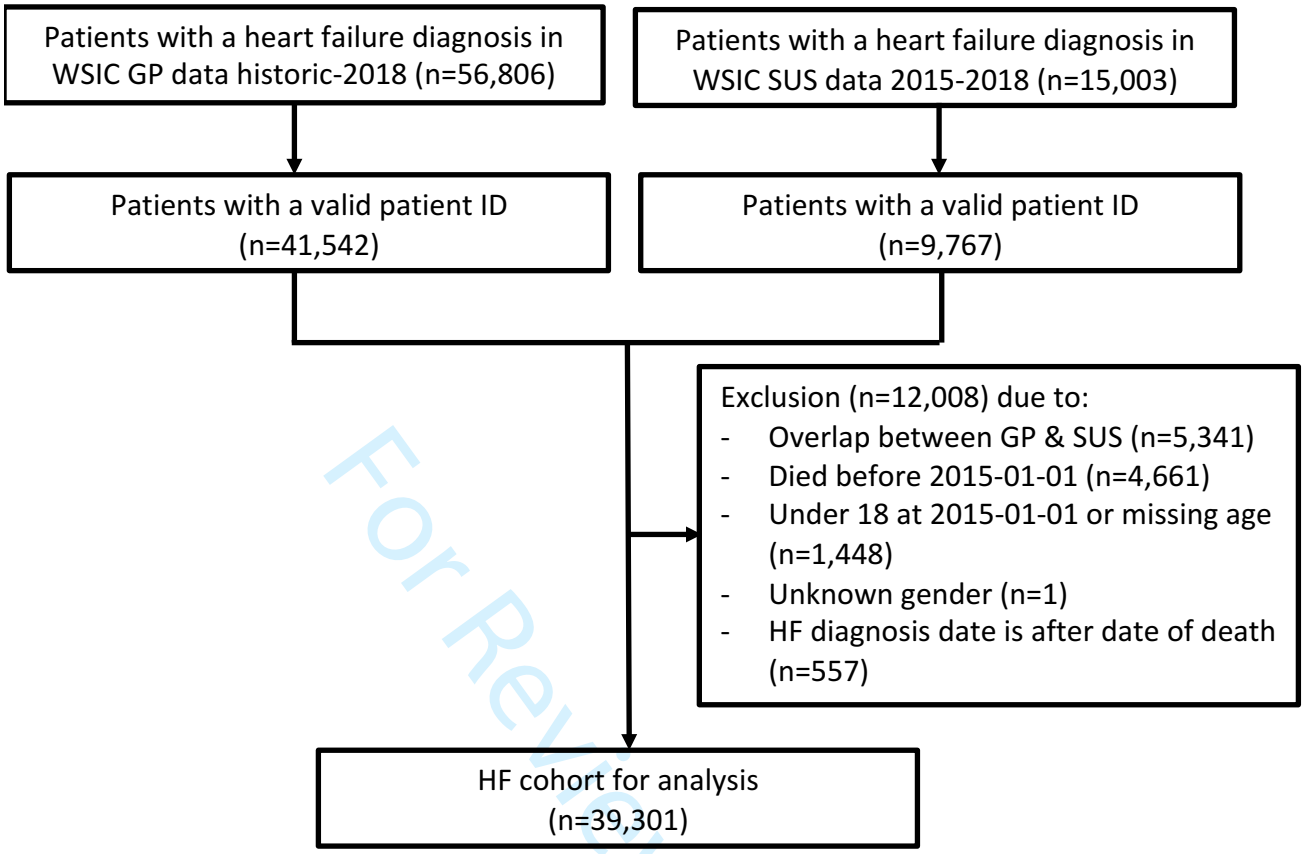
Figure S1: Comparison of 4- and 5-cluster solutions



Reference

Uc-r.github.io. (2019). Hierarchical Cluster Analysis · UC Business Analytics R Programming Guide. [online] Available at: https://uc-r.github.io/hc_clustering [Accessed 25 Jun. 2019].

Figure S1. Flow chart of study population



Our heart failure study population is relatively young (42% are under 65 years old, Table 2 in main manuscript). This may be due to the fact that we used all historic GP data but only 4 years (2015-2018) of SUS (hospitalisations) data to identify HF cases. Unfortunately, WSIC did not have SUS data for any years prior. This means we miss patients who are initially diagnosed with HF in secondary care prior to 2015 and only later, if at all, managed in primary care. These patients tend to be older than those who are diagnosed in primary care, and their exclusion may explain why our cohort is younger.

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Table S2. Service utilisation and patient characteristics by cluster

Cluster		1	2	3	4	5	Population
Size of cluster (%)		9838 (25.2)	12124 (31.1)	6070 (15.6)	5293 (13.6)	5658 (14.5)	38983
Health service use (median, IQR)							
Secondary care	Number of emergency admissions	0 (0-0)	0 (0-0)	3 (1-5)	1 (0-3)	4 (2-6)	0 (0-2)
	Number of elective admissions	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-1)	0 (0-0)	0 (0-0)
	Number of unplanned A&E visits	1 (0-2)	1 (0-2)	6 (3-9)	3 (2-6)	6 (4-10)	2 (0-5)
	Number of outpatient cardiology visits	0 (0-0)	0 (0-0)	2 (0-7)	7 (4-13)	0 (0-2)	0 (0-3)
	Number of outpatient other specialty visits	2 (0-8)	4 (0-10)	18 (9-34)	18 (8-31)	12 (4-24)	7 (2-18)
Primary care	Number of GP consultations	0 (0-0)	21 (12-33)	0 (0-0)	38 (23-57)	32 (18-53)	11 (0-31)
Other	Number of community contacts	0 (0-3)	0 (0-2)	10 (2-30)	3 (0-11)	23 (8-57)	2 (0-11)
	Number of mental health contacts	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
	Number of social care contacts	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-1)	0 (0-0)
Patient characteristics (%)		**1**	**2**	**3**	**4**	**5**	**Population**
Gender	Female	57.5	60.7	51.1	42.8	57.5	55.5
Age group	<45	25.7	17.6	5.3	3.9	3.0	13.8
	45-<65	30.8	31.7	19.6	22.6	10.9	25.3
	65-<75	16.8	21.1	22.0	25.0	17.2	20.1
	75-<85	17.1	20.1	33.3	35.4	37.6	26.0
	85+	9.6	9.5	19.8	13.1	31.3	14.8
Deprivation level	1 (most)	20.3	9.5	23.1	9.7	12.3	14.8
	2	29.4	26.7	31.1	27.6	30.2	28.7
	3	25.5	24.9	25.6	26.7	24.4	25.3
	4	15.1	18.1	12.1	18.1	17.5	16.3
	5 (least)	5.6	18.1	4.2	15.5	12.9	11.7
	Unknown	4.1	2.6	3.9	2.3	2.7	3.2
Ethnicity	White	27.7	33.6	27.4	34.2	39.7	32.1

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	Asian	18.9	30.3	19.2	33.2	25.4	25.4
	Black	5.1	8.6	4.8	7.1	8.8	7.0
	Mixed	13.5	5.2	13.3	5.0	5.3	8.6
	Unknown	34.8	22.2	35.3	20.5	20.8	27.0
Status	Have carer	1.3	0.3	0.9	0.1	0.2	2.6
	Care home	1.1	2.2	1.9	1.2	7.8	0.6
	Died	15.3	13.7	19.6	14.2	44.5	19.6
Tests	Echocardiogram	11.2	12.3	23.7	42.3	24.5	19.9
	Echocardiogram abnormal	4.9	5.6	10.2	25.2	14.4	10.1
Smoking status	Non	37.7	49.9	30.4	48.0	45.6	42.9
	Current	11.7	9.5	8.5	7.8	9.1	9.6
	Former	23.4	27.6	28.8	35.7	36.2	29.1
	Unknown	27.2	12.9	32.2	8.4	9.2	18.4
Drinking status	Non	7.1	5.8	7.1	5.8	6.0	6.4
	Current	1.7	2.0	1.0	1.7	1.2	1.6
	Former	0.4	0.1	0.2	0.2	0.1	0.2
	Unknown	90.8	92.0	91.7	92.3	92.7	91.8
BMI category	Underweight	3.7	2.1	3.2	1.1	3.3	2.7
	Ideal	24.5	26.2	19.4	24.6	28.7	24.8
	Overweight	21.6	31.2	20.5	34.1	27.2	26.9
	Obese	21.2	27.9	23.7	32.4	28.8	26.3
	Unknown	29.1	12.7	33.1	7.8	12.1	19.3
Systolic blood pressure	<110 mm Hg	7.1	6.0	2.9	3.6	2.6	5.0
	110-119 mm Hg	13.3	13.0	7.5	10.1	8.6	11.2
	120-139 mm Hg	39.7	52.6	38.6	56.6	54.4	48.0
	140-159 mm Hg	16.8	25.0	20.9	27.2	30.3	23.4
	160+ mm Hg	1.9	1.8	1.8	1.9	2.9	2.0
	Unknown	21.2	1.6	28.4	0.7	1.2	10.6
	<80 mm Hg	53.0	63.1	53.9	74.3	78.5	62.9

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Diastolic blood pressure	80-89 mm Hg	20.9	28.9	15.0	20.9	17.0	21.9
	90-99 mm Hg	4.1	4.6	2.4	2.6	2.0	3.5
	100+ mm Hg	0.7	0.7	0.3	0.5	0.2	0.5
	Unknown	21.4	2.7	28.4	1.8	2.2	11.2
Comorbidities (%)		**1**	**2**	**3**	**4**	**5**	**Population**
Disease	Acute MI	2.3	2.5	4.9	9.2	7.9	4.5
	Atrial fibrillation	7.7	7.5	17.5	27.5	24.4	14.3
	Chronic pulmonary disease	10.4	13.3	16.5	19.5	21.2	15.1
	Congenital heart disease	0.3	0.2	0.6	0.8	0.3	0.4
	Coronary heart disease	3.2	3.7	7.0	13.3	7.8	6.0
	Diabetes	15.1	26.1	26.0	39.0	41.6	27.3
	Hypertension	21.4	43.8	27.8	49.6	48.7	37.1
	Myocardial infarction	2.4	2.6	5.1	9.5	8.0	4.7
	Myocarditis	1.8	1.3	2.9	7.4	1.3	2.5
	Other arrhythmias	6.4	7.9	13.2	21.3	15.5	11.3
	Peripheral vascular disease	1.0	1.7	3.4	4.4	4.7	2.6
	Renal diseases	2.7	2.4	6.4	7.0	9.0	4.7
	Stroke	1.8	1.9	4.0	4.8	6.8	3.3
Count	0	56.1	32.6	40.7	11.4	14.8	34.3
	1	24.2	36.1	19.9	25.4	26.7	27.8
	2	11.6	20.6	18.1	27.8	27.1	19.9
	3	4.8	7.1	11.8	18.6	17.8	10.4
	4+	3.3	3.6	9.5	16.7	13.6	7.7

All variables are significantly different across clusters at <0.001 significance level using Kruskal-Wallis or Chi Square tests.
Appendix 5 depicts the standardised residuals from the Chi-square test of association between cluster and each patient characteristics as a heatmap.

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Figure S2. Heatmap visualising standardised residuals from the Chi-square test of association between cluster and each patient characteristics.