



## ORIGINAL ARTICLE

# The validity of heart failure diagnoses in the Finnish Hospital Discharge Register

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## Abstract

**Background:** Contemporary validation studies of register-based heart failure diagnoses based on current guidelines and complete clinical data are lacking in Finland and internationally. Our objective was to assess the positive and negative predictive values of heart failure diagnoses in a nationwide hospital discharge register. **Methods:** Using Finnish Hospital Discharge Register data from 2013–2015, we obtained the medical records for 120 patients with a register-based diagnosis for heart failure (cases) and for 120 patients with a predisposing condition for heart failure, but without a heart failure diagnosis (controls). The medical records of all patients were assessed by a physician who categorized each individual as having heart failure (with reduced or preserved ejection fraction) or no heart failure, based on the definition of current European Society of Cardiology heart failure guidelines. Unclear cases were assessed by a panel of three physicians. This classification was considered as the clinical gold standard, against which the registers were assessed. **Results:** Register-based heart failure diagnoses had a positive predictive value of 0.85 (95% CI 0.77–0.91) and a negative predictive value of 0.83 (95% CI 0.75–0.90). The positive predictive value decreased when we classified patients with transient heart failure (duration <6 months), dialysis/lung disease or heart failure with preserved ejection fraction as not having heart failure. **Conclusions:** Heart failure diagnoses of the Finnish Hospital Discharge Register have good positive predictive value and negative predictive value, even when patients with pre-existing heart conditions are used as healthy controls. Our results suggest that heart failure diagnoses based on register data can be reliably used for research purposes.

**Keywords:** Heart failure, validation, sensitivity, specificity, hospital discharge register, drug purchase register, echocardiography

## Introduction

Heart failure (HF) is a significant global health problem, with national prevalence estimates varying between 0.12 and 6.7%. The economic burden of HF on society is enormous as yearly worldwide costs exceeded US\$108 billion in 2012 [1,2]. This is attributed to several factors, including an ageing population, nevertheless there remains much interest in

identifying risk factors of HF. Administrative registers, such as hospital discharge registers, are an important source of epidemiological data for investigating a wide spectrum of diseases at a population level. To verify data quality, the completeness and validity of the hospital discharge register-based epidemiological data need to be assessed at regular intervals. Prior validation studies from North America, the Netherlands,

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Denmark, Sweden and the UK have found a relatively low sensitivity and high specificity for HF diagnoses [3–8,9]. A systematic review and meta-analysis reported similar results [10] with sensitivity and specificity estimates exceeding 69% and 95%, respectively. However, the diverse validation procedures of different studies and patients often render between-study comparisons challenging [11].

A previous study on the validity of HF diagnoses in the Finnish Hospital Discharge Register demonstrated a specificity of 99.7% with a relatively low sensitivity of 48.5% [3]. However, this study from 2013 was based mainly on the use of brain natriuretic peptide levels for the diagnosis of HF, instead of combining the single marker with detailed clinical data including echocardiography, which is the gold standard to which register-based HF diagnoses should be compared to [12]. The diagnostic techniques of echocardiographic imaging have improved, and it has become an easily available bedside assessment method in clinical practice in recent years. In addition, this previous validation is somewhat outdated due to the following.

1. The use of echocardiography in diagnosing HF has increased drastically over the past 10 years.
2. New European guidelines for diagnosing HF have been introduced [12].
3. Register-based diagnoses from secondary and tertiary care outpatient clinics were not available at the time.

The aim of the present study was to assess the contemporary validity of the Finnish Hospital Discharge Registers for HF diagnoses. We used full clinical data from both in- and outpatient clinics and adhered to the most recent European Society of Cardiology (ESC) guidelines when assessing the potential presence of clinical HF in patients with a register-based diagnosis.

## Materials and methods

### *Study sample and data collection*

We used data from the Finnish Cardiovascular Disease Register to identify register-based cases and controls. The Finnish Cardiovascular Disease Register [13] contains information on Finnish individuals with a nationwide hospital discharge register-based diagnosis of coronary heart disease, stroke or HF after the year 1994. We chose a sample size of 120 cases and controls as this provided a statistical power of 0.80, 0.93 and 0.99 for specificity and sensitivity when specificity was set at 0.8, 0.9 and 0.95 [14]. We randomly drew 120 patients with a first

hospital discharge register-based diagnosis of HF (cases) and another 120 patients with a first register-based diagnosis of a cardiac condition predisposing to HF from the Finnish Hospital Discharge Register [15], but without a diagnosis of HF (controls). These first diagnoses occurred between 2013 and 2015. After identifying these individuals, we then applied and received permission from the two hospital districts' chiefs of medicine and/or research to access relevant electronic health records of these individuals. Sixty patients with and without HF were drawn from both the Finland Proper and Central Finland health care districts for a total of 240 secondary and tertiary care patients. We excluded patients with a first diagnosis at age under 30 or over 80 years to avoid the possible confounding effects of substance use in the young and multimorbidity in the elderly.

### *Hospital discharge register*

The National Institute for Health and Welfare maintains a nationwide hospital discharge register that covers information on all hospitalizations in Finland after 1967 [15]. Outpatient diagnoses from secondary and tertiary care have been available since 1998. In this study, we used data from in- and outpatient care diagnoses from secondary and tertiary care to define register-based cases and controls. The hospital discharge register includes data on admission and discharge dates, performed procedures and up to four different diagnoses for each discharge, coded in our study period with ICD-10 (International Classification of Diseases, 10th Revision) [16].

### *Definition of register-based HF (i.e. cases) and register-based other cardiac disease without HF (i.e. controls)*

Patients with ICD-10 codes I50, I110, I130 or I132 in the hospital discharge register for the first admission were defined as having register-based HF (cases). Main and secondary diagnoses from secondary and tertiary care for inpatient and outpatient admissions were accepted. Patients with a diagnostic ICD-10 code for a condition predisposing to HF; that is, coronary heart disease (I20–I25 or coronary revascularization), cardiomyopathy (I42) or valvular heart disease (I34–I37) in the hospital discharge register without a diagnosis for HF were defined as controls.

### *Diagnosis of HF based on clinical assessment*

We used a modified diagnostic algorithm based on the ESC Acute and Chronic Heart Failure Guidelines

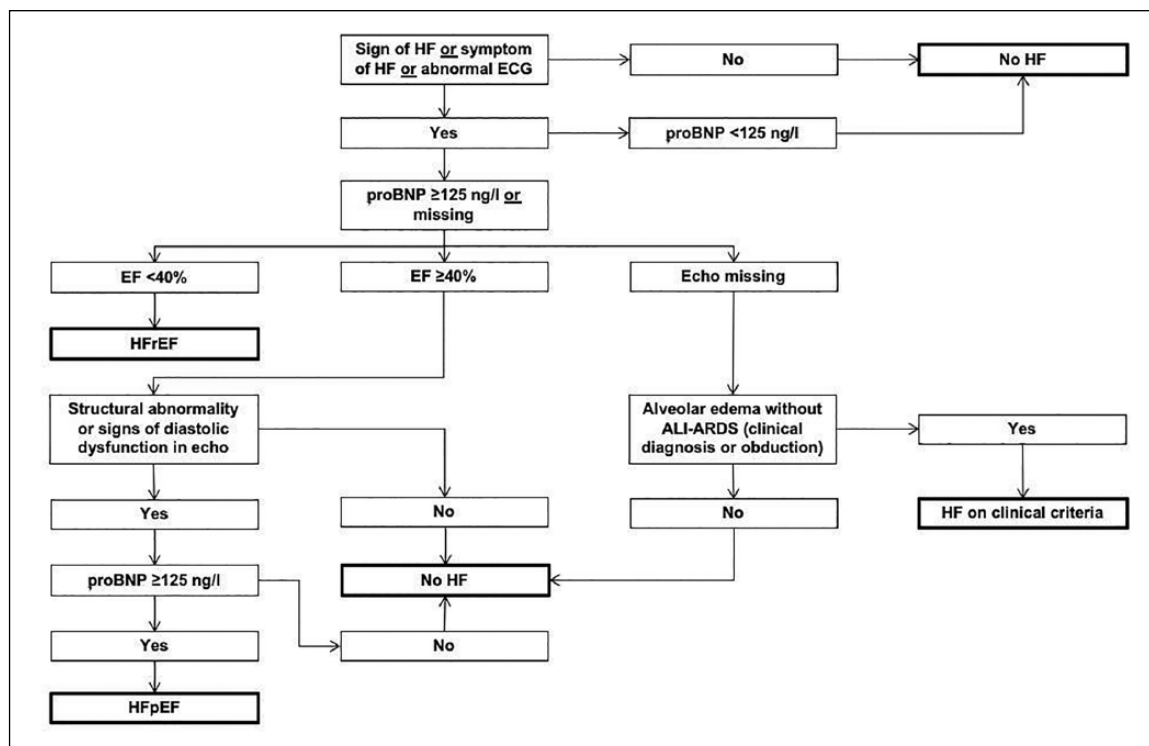


Figure 1. Diagnostic algorithm adapted from the European Society of Cardiology (ESC) heart failure guidelines 2016.

HF: heart failure of any kind; EF: ejection fraction; proBNP: N-terminal pro b-type natriuretic peptide; ALI-ARDS: acute lung injury and adult respiratory distress syndrome; HFrEF: heart failure with reduced ejection fraction; HFpEF: heart failure with preserved ejection fraction.

from 2016 as the definition of clinical HF (Figure 1) [11]. Based on this algorithm, all hospital discharge register-based cases and controls were categorized as having: (1) HF with reduced ejection fraction (HFrEF); (2) HF with preserved ejection fraction (HFpEF); (3) HF based on clinical criteria if no echocardiography was available; and (4) no HF. The same algorithm was used for both cases and controls. The diagnostic procedure in depth and additional details are reported in the Supplemental Methods. The ESC guidelines also include a definition of HF with mildly reduced ejection fraction (HFmrEF). In this study, we classified these patients as having HFpEF.

#### The validation procedure

An internist examined all relevant electronic hospital patient records prior to, and for 6 months after, the register-based index date for information related to HF (Supplemental Table). Information on history of risk factors for HF was also collected (Supplemental Table), although it was not used as a part of our algorithm. The register-based diagnoses were based on an in- or outpatient visit to secondary or tertiary care. We used the electronic patient

records to review all relevant patient charts, echocardiography reports, laboratory tests, ECGs and radiology reports for relevant information (Supplemental Table). Patient records were available from all secondary and tertiary care public sector hospitals from both regions and were available for all study patients. All uncertain and borderline cases were reviewed by a panel of two internists (TN and MV) and one cardiologist (JL), and diagnosis was based on consensus.

#### Sensitivity analyses

In addition to the main analyses in which all patients with HFpEF, HFrEF and clinical HF were considered as having HF, we also performed sensitivity analyses with three alternative definitions of HF. First, we considered only cases of chronic HF and excluded those with transient HF (resolving of signs and symptoms and normalization of ejection fraction within 6 months). Second, we classified patients on dialysis or with chronic hypoxemic pulmonary conditions (Supplemental Table) as not having HF, as these patients almost always had congestive findings. Third, we considered only patients with HFrEF as having HF.

Table I. Study sample characteristics.

Characteristic	N with data	Overall	No register-based HF	Register-based HF	P value
N	240	240	120	120	
Women	240	76 (31.7)	38 (31.7)	38 (31.7)	0.99
Age, mean (SD)	240	64.8 (8.9)	64.3 (8.6)	65.4 (9.2)	0.36
Medical history					
Coronary artery disease	234	150 (64.1)	94 (79.0)	56 (48.7)	<0.001
Arrhythmia	238	86 (36.1)	23 (19.5)	63 (52.5)	<0.001
Hypertension	239	145 (60.7)	70 (58.8)	75 (62.5)	0.65
Perimyocarditis	240	4 (1.7)	3 (2.5)	1 (0.8)	0.61
Cardiomyopathy	240	25 (10.4)	2 (1.7)	23 (19.2)	<0.001
Diabetes mellitus	240	85 (35.4)	33 (27.5)	52 (43.3)	0.015
Inflammatory heart disease	240	3 (1.2)	1 (0.8)	2 (1.7)	0.99
Dialysis	240	3 (1.2)	1 (0.8)	2 (1.7)	0.99
Cardiac metastases	240	5 (2.1)	0 (0.0)	5 (4.2)	0.07
Severe lung disease	240	5 (2.1)	0 (0.0)	5 (4.2)	0.07
Any symptom of HF	239	158 (66.1)	49 (41.2)	109 (90.8)	<0.001
Any sign of HF	235	100 (42.6)	18 (15.1)	82 (70.7)	<0.001
Pulmonary oedema	225	19 (8.8)	2 (2.0)	17 (14.5)	<0.001
Highest proBNP, mean (SD)	164	5822 (8841)	2583 (5297)	7502 (9813)	0.001
Echocardiography					
Lowest EF, mean (SD)	199	47.6 (16.4)	56.2 (12.1)	40.4 (16.1)	<0.001
Diastolic dysfunction	64	41 (64.1)	14 (45.2)	27 (81.8)	0.005
Structural abnormality	176	161 (91.5)	67 (85.9)	94 (95.9)	0.04
Clinical diagnosis					
HF <sub>r</sub> EF	240	64 (26.7)	11 (9.2)	53 (44.2)	<0.001
HF <sub>p</sub> EF	240	51 (21.2)	8 (6.7)	43 (35.8)	<0.001
Clinical HF	240	7 (2.9)	1 (0.8)	6 (5.0)	<0.001
No HF	240	118 (49.2)	100 (83.3)	18 (15.0)	<0.001
Transient HF	240	34 (14.2)	6 (5.0)	28 (23.3)	<0.001
Chart review by physician committee	240	41 (17.1)	12 (10.0)	29 (24.2)	0.006

Numbers are presented as *n* (%) unless otherwise indicated.

EF: ejection fraction; HF: heart failure; HF<sub>r</sub>EF: heart failure with reduced ejection fraction; HF<sub>p</sub>EF: heart failure with preserved ejection fraction; proBNP: N-terminal pro b-type natriuretic peptide; SD, Standard Deviation.

### *Additional assessment of validity of HF diagnoses based on furosemide purchases*

Every prescription drug purchase in Finland is stored in the nationwide Prescribed Drug Purchase Register [17]. We assessed the validity of HF diagnoses that were based solely on repeated furosemide purchases. Because furosemide purchase data were not available for individuals included in the Finnish Cardiovascular Disease Register, we used information from 75,081 participants who took part in nationwide FINRISK population surveys between 1972 and 2012 [18]. Of these individuals, we identified 2967 30- to 80-year-old persons who had purchased furosemide and/or furosemide combined with a potassium sparing diuretic (ATC codes C03CA01 and C03EB01) three or more times. All FINRISK participants have given consent to use their yearly collected register data for research purposes. We then assessed the proportion of persons that developed a hospital discharge register-based diagnosis of HF (defined above) or hepatic or renal insufficiency over

3- and 5-year follow-up periods. Additional details are reported in the Supplemental Methods.

### *Statistical methods*

We compared characteristics of patients with and without a register-based diagnosis of HF using regular ANOVA with equal variance assumption for continuous variables and chi-squared tests with continuity correction for categorical variables, with means and standard deviations provided with *p*-values. We calculated the positive predictive values and negative predictive values (PPVs and NPVs) and positive likelihood ratios and negative likelihood ratios (PLRs and NLRs) for the hospital discharge register for diagnosing clinical HF along with 95% confidence intervals (CI) [19]. In addition, we assessed the agreement between register-based and clinical diagnoses of HF using Cohen's kappa statistic. All statistical analyses were performed using R v.3.5.0.

Table II. Agreement between clinical and register-based diagnoses with varying criteria for clinical diagnosis.

	Definition of positive clinical diagnosis							
	Main analysis		Sensitivity analyses					
	Chronic and transient (<6 months) HF		Chronic HF		Chronic and transient (<6 months) HF (excluding dialysis and lung patients)		Chronic and transient HFrEF	
Register-based HF diagnosis	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Positive	102	18	76	44	99	21	53	67
Negative	20	100	15	105	20	100	11	109
Measure								
PPV	0.85 (0.77, 0.91)		0.63 (0.54, 0.72)		0.82 (0.75, 0.89)		0.44 (0.35, 0.54)	
NPV	0.83 (0.75, 0.90)		0.88 (0.80, 0.93)		0.83 (0.75, 0.90)		0.91 (0.84, 0.95)	
PLR	5.48 (3.56, 8.45)		2.83 (2.17, 3.68)		4.79 (3.22, 7.13)		2.18 (1.75, 2.71)	
NLR	0.19 (0.13, 0.29)		0.23 (0.15, 0.38)		0.20 (0.14, 0.31)		0.28 (0.16, 0.48)	
Kappa	0.68 (0.56, 0.81)		0.50 (0.39, 0.63)		0.66 (0.53, 0.78)		0.35 (0.24, 0.46)	
Accuracy	0.84 (0.79, 0.89)		0.75 (0.69, 0.81)		0.83 (0.78, 0.87)		0.68 (0.61, 0.73)	

HF: heart failure; HFrEF: heart failure with reduced ejection fraction; HFpEF: heart failure with preserved ejection fraction.

Measures: PPV: positive predictive value – the probability of having HF in a subject with a register-based diagnosis; NPV: negative predictive value – the probability of not having HF in a subject without a register-based diagnosis for HF; PLR: positive likelihood ratio – ratio of a positive result in subjects with HF to the subjects without HF; NLR: negative likelihood ratio – ratio of a negative result in subjects with HF to the subjects without HF; Kappa: the proportion of responses in which the two (positive or negative) responses agree. Numbers in parentheses represent 95% confidence intervals.

## Results

Characteristics of the study sample are presented in Table I. Out of 240 patients, 76 were women (31.7%). The mean age of the whole sample was 64.8 (Standard Deviation [SD] = 8.9) years. Despite a lack of matching, the age- and sex-distributions of the cases and controls were similar. The most common comorbidities were coronary heart disease (150 patients, 64.1%) and hypertension (145 patients, 60.7%). The echocardiographic coverage of our sample was good, with 199 (82.9%) of patients having echocardiographic data available. The indices on diastolic dysfunction were available for only 27% during the given study period (Table I). The mean ejection fraction was 40.4 (SD = 16.1) % in the register-based HF group and 56.2 (SD = 12.1) % in the group without register-based HF diagnosis. In total, our physician committee reviewed 41 unclear cases (17.1%).

We observed 20 false negative cases (16.7%) in the control group and 18 false positive cases (15.0%) (Table II). The most common reasons for a false positive diagnosis were dyspnoea (6 patients) and fluid retention (3 patients) due to reasons other than HF. The reasons for false negative diagnoses were the use of only the ICD-code of the underlying cause of HF (9 patients), a missed diagnosis (6 patients) or a properly coded HF diagnosis in the patient records that was not transmitted to the Finnish Hospital Discharge Register (5 patients). In the main analysis, register-based diagnoses had a PPV of 0.85 (95% CI 0.77–0.91) and a NPV of 0.83 (95% CI 0.75–0.90)

for HF. Positive likelihood ratio was 5.48 for all cases of HF. The scatterplot of peak proBNP versus lowest ejection fraction in groups by HF status is depicted in Figure 2.

When HF was defined as only chronic HF, PPV fell to 0.63 (0.54–0.72) but NPV improved slightly to 0.88 (0.80–0.93), and the positive likelihood ratio was also lower at 2.83 (2.17–3.68) (Table II). Excluding chronic obstructive pulmonary disease and dialysis patients from HF patients lowered PPV slightly to 0.82 (0.75–0.89) and NPV to 0.83 (0.75–0.90) compared with the main definition, but PLR improved to 4.79 (3.22–7.13). When HF was defined strictly as only HFrEF, this resulted in a significantly poorer PPV of 0.44 (0.35–0.54), but an improved NPV of 0.91 (0.84, 0.95).

The prognosis of individuals who received a tentative diagnosis based on repeated furosemide purchases is shown in Table III. A total of 2477 individuals had data available for a 3-year follow-up after receiving a tentative diagnosis and 2059 individuals had data for a full 5-year follow-up. Of these persons, 1024 (41.3%) and 1054 (51.2%) were diagnosed with HF during the follow-up, respectively. Lone HF (without hepatic or renal insufficiencies) was the only diagnosis in 885 (35.7%) and 903 (43.9%) patients in 3-year and 5-year follow-up groups, respectively. A notable number of individuals used furosemide without any register-based diagnosis for HF, renal insufficiency or hepatic insufficiency, 1189 (48.0%) and 808 (39.2%) in 3-year and 5-year follow-up groups.

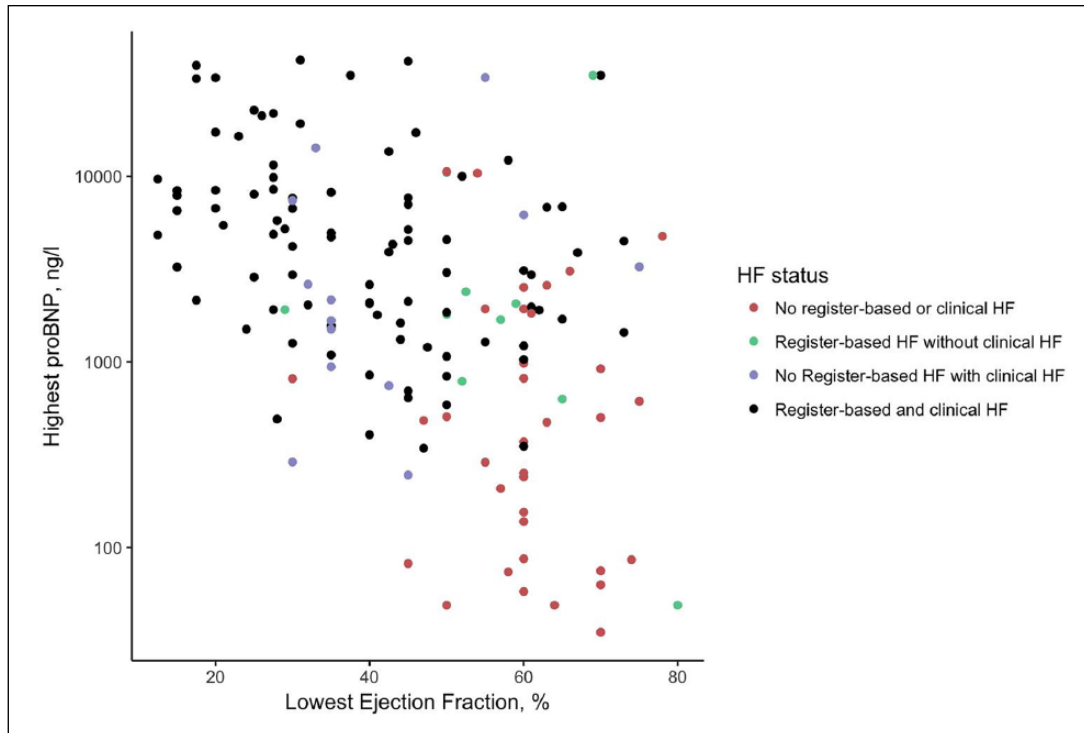


Figure 2. Scatterplot of brain natriuretic peptides and cardiac ejection fraction in patients classified by heart failure status ( $N=147$  with data available).

proBNP: brain natriuretic peptide; HF: heart failure.

Table III. Three- and five-year prognosis of individuals with an initial furosemide-purchase-based diagnosis of heart failure.

Register-based diagnoses of HF, CKD and liver disease after repeated furosemide purchases	3-year follow-up ( $N=2477$ )	5-year follow-up ( $N=2059$ )
No HF	1453 (58.7)	1005 (48.8)
No diagnoses for HF, CKD or liver disease	1189 (48.0)	808 (39.2)
CKD	210 (8.5)	160 (7.8)
Liver disease	42 (1.7)	31 (1.5)
CKD and liver disease	12 (0.4)	6 (0.3)
HF	1024 (41.3)	1054 (51.2)
HF as only diagnosis	885 (35.7)	903 (43.9)
HF and CKD	112 (4.5)	120 (5.8)
HF and liver disease	20 (0.8)	20 (1.0)
HF, CKD and liver disease	7 (0.3)	11 (0.5)

HF: heart failure; CKD: chronic kidney disease.

## Discussion

In this study, we validated the HF diagnoses of the Finnish Hospital Discharge Register that occurred in 2013–2015. Even when using patients with pre-existing heart conditions as the controls, we observed a PPV of 0.85 and a NPV of 0.83 for HF. When compared to a gold standard test, the ESC guideline, for HF diagnosis with a PPV of 1.0, this study showed that the Finnish Hospital Discharge Register has a high predictive value for discriminating HF cases from non-HF cases, even if individuals with prevalent heart disease were used as the controls.

The previous Finnish Hospital Discharge Register validation study of HF by Mähönen et al. reported a high specificity of 99.7% and a moderate sensitivity of 48.5% [3]. As prevalence of HF in the general population affects these measures, we chose to include only the predictive values and likelihood ratios. The contrast between our current findings and the previous study [3] from Finland may be explained by several factors. First, the sample of the prior study was drawn from population survey participants thus increasing its sensitivity, whereas in our study, both cases and controls were secondary or tertiary care

patients. Another key difference is that the previous study used brain natriuretic peptide levels without a thorough cardiovascular clinical examination or echocardiography data, which may have explained the lower observed sensitivity [20,21]. Other alternative definitions with stricter criteria for HF led to improved NPV and lower PPV in our validation study, as was expected.

Previous validation studies for register-based cardiovascular disease diagnoses have been performed also in Sweden, Denmark, the UK and the Netherlands [4-8,9]. Ingelsson et al. reviewed the validity of 321 HF register-based diagnoses observed in a cohort of 2322 middle-aged Swedish men [4]. The validity of these diagnoses was 82% in all cases, with echocardiographic examinations increasing the validity to 88%. In patients who were treated at internal medicine or cardiology clinics, the respective validities were 86% and 91% [4]. These validity estimates correspond to the predictive values observed in our study, although direct comparisons are not possible as Ingelsson et al. did not compare HF cases with non-HF cases. Kümler et al. examined all patients who were hospitalized during a 12-month period due to any cause in a single hospital in Denmark and observed a specificity of 99% and sensitivity of 29% for all patients, and they concluded that HF is severely underreported in Danish hospitalized patients [7]. Delekta et al. validated HF diagnoses by reviewing 500 patient records in northern Denmark from 2007 and reported a PPV of 83.6% (95% CI 80.1–86.7%) for definite and probable HF [8]. Khand et al. performed a comparable study with similar findings in Glasgow, using a cohort of atrial fibrillation (AF) patients as a control group [9]. The authors concluded that the use of hospital discharge codes substantially underestimates hospital events related to HF in the UK, as 54% of AF cases with true HF did not receive a discharge code for HF during a 3-month follow-up period. In Maastricht, the Netherlands, Merry et al. performed a study of hospital discharge register diagnoses by validating hospital discharge register diagnoses of coronary heart disease, acute myocardial infarction, unstable angina pectoris and HF against diagnoses from the cardiovascular disease register of the Maastricht cohort study [5]. The authors reported a low sensitivity of 43% and a PPV of 0.80 for HF. In addition, a previous meta-analysis concluded that the specificity of hospital discharge registers is high for HF (>90%), but sensitivity is usually much lower ( $\geq 69\%$ ) [9]. Based on available HF validation studies, hospital discharge registers tend to underestimate the number of hospitalizations for HF with substantial differences between countries [3-9]. However, direct

head-to-head comparisons between the national hospital discharge registers of various countries have not been performed, as individual-level data would be best suited for this. This is also the reason why most studies report different epidemiological measures.

The main reasons for the differing results of prior national studies are the highly variable study settings; that is, differences in study samples and diagnostic criteria. Additionally, the diagnosis of HF can often be challenging [11]; chronic, stable HFpEF remains a difficult entity to diagnose even for an experienced physician. First, the assessment of diastolic dysfunction and diagnosis of HFpEF have also been a subject of change recently, as technological and diagnostic progress has made it possible to more precisely diagnose these patients; however, the diastolic indices were available for only a minority (27%) of patients in our study as well. Second, infections, renal failure or chronic obstructive pulmonary disease exacerbation, etc. can present with HF-like symptoms such as breathlessness, cough, reduced exercise tolerance and peripheral swelling or weight gain, which all may be difficult to differentiate from common HF symptoms. Third, there may be various coexisting disease symptoms at the same time [22]. When another parallel disease process triggers an episode of decompensation in patients with a prior diagnosis of chronic HF, sometimes only the underlying cause for HF may have been coded in the hospital discharge register. In our study, this occurred quite commonly with decompensations triggered by acute myocardial infarctions. Fourth, mild or asymptomatic HF events can more often be left uncoded compared to HF patients with active, recurring disease. One challenge of the Finnish Hospital Discharge Register is that it relies on ICD-10 coding, which does not differentiate between acute and chronic HF as they are different clinical entities [23]. The use of ICD-11 or ICD-10-CM (Clinical Modification) could be beneficial, as these medical classifications have a wide spectrum of HF diagnosis codes available, including acute, chronic and acute-on-chronic HF.

A recent article by Cainzos-Achirica et al. (2018) reviewed the many challenges of evaluating chronic and acute HF events in large health care databases [11]. For the gold standard diagnosis, they recommended the 2016 ESC guideline criteria jointly with BNP levels, cardiac imaging and echocardiographic data, highlighting the need of a documented structural abnormality for the development and diagnosis of HF [12]. Unfortunately, diagnosing chronic HF is often more difficult than diagnosing acute HF, because cardiac structural abnormalities may asymptotically precede the clinical syndrome [24] in

contrast to a more clearly manifesting onset with an acute myocardial injury [25,26]. In most cases the structural abnormalities related to HF are permanent, whereas HF symptoms may occur periodically as the failing heart leads to many phases of acute decompensations before chronic HF. In validation studies, however, the study period may overlap with any of the aforementioned parts: the asymptomatic compensated structural abnormality stage, a clinical decompensation period, or a chronic stable or unstable stage later in the disease progression [11].

In addition to assessing the validity of hospital discharge register-based diagnoses for HF, we also assessed whether the Finnish Prescribed Drug Register data could be used to reliably diagnose HF. Previous clinical data of these patients have been lacking, and we observed that approximately half of the individuals with repeated furosemide purchases did not receive a hospital discharge register-based diagnosis for HF, liver disease or renal insufficiency over a 5-year follow-up. It is conceivable that furosemide is quite commonly prescribed by primary care doctors as a potential therapy for lower extremity swelling from any cause, even in spite of clinical and research evidence against the use of furosemide for venous insufficiency [27]. We therefore conclude that although furosemide use is likely to increase sensitivity of register-based HF diagnoses, it leads to decreased specificity.

We tried to address many of the shortcomings of prior validation studies [11]. Indeed, we used the ESC diagnostic algorithm for HF as the gold standard and included a control group, thus enabling us to perform different analyses for alternative definitions of HF. We adhered to the Standards for Reporting of Diagnostic accuracy (STARD) initiative for reporting all measures as described by the initiative [28]. As a study limitation, the HF patients were not classified as having possible, probable or definite HF to facilitate interpretation of our results [5,9]. In addition, echocardiography and proBNP levels were not accessible for all patients, and we did not have access to primary care data (including furosemide usage data) where follow-up visits sometimes occurred. However, data may not be completely reliable, as echocardiography is rarely performed at local health care centres. For unclear cases, we used an alternative approach – a panel of physicians to review the clinical data to reach consensus. In general, echocardiographic data and its quality is highly dependent on the individual investigators and hospital protocols, and especially the diastolic parameters are not even measured in many hospital protocols yet, so we could not use register data to fully evaluate the distinction between definitive non-cardiac congestion and HFpEF. Right-side catheterization or

other invasive stress tests for precise cardiopulmonary assessment would have been optimal for this [29], but unfortunately no testing had been done on any of our study patients either. Indeed, in real-world clinical practice, the detailed evaluation of diastolic function is not often performed for patients with HF symptoms during the hospital admission.

We conclude that the Finnish Hospital Discharge Register reliably discriminates between HF cases and non-HF cases, and better with acute cases than with chronic ones, even if individuals with prevalent heart disease were used as the controls. However, the predictive values of HF diagnosis could be further improved through proper coding of mild and chronic HF cases and reduction of clerical errors that lead to improper coding. Additional diagnostic codes not present in ICD-10, such as acute, acute-on-chronic and chronic HF, are also needed. All clinicians in countries with nationwide health care registers should become increasingly aware of the clinical and research benefits of a structurally unified register and its coding system. Treating physicians should pay attention to correct coding of all diagnoses during patient encounters, as high-quality register data benefit both the clinician and the researcher.

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### Conflict of interest

VS has participated in a conference trip sponsored by Novo Nordisk and received an honorarium from the same source for participating in an advisory board meeting. He also has research collaboration with Bayer Ltd.

### Authors' contributions

MV contributed to design; contributed to acquisition, analysis and interpretation; drafted manuscript; critically revised manuscript; gave final approval and agrees to be accountable for all aspects of work, ensuring integrity and accuracy.

AP contributed to acquisition, analysis and interpretation; critically revised manuscript; gave final approval and agrees to be accountable for all aspects of work, ensuring integrity and accuracy.

JL contributed to conception and design; contributed to interpretation; drafted manuscript; critically



revised manuscript; gave final approval and agrees to be accountable for all aspects of work, ensuring integrity and accuracy.

AH contributed to design; contributed to acquisition, analysis and interpretation; critically revised manuscript; gave final approval and agrees to be accountable for all aspects of work, ensuring integrity and accuracy.

MK contributed to interpretation; critically revised manuscript; gave final approval and agrees to be accountable for all aspects of work, ensuring integrity and accuracy.


TJ contributed to conception and design; contributed to acquisition, analysis and interpretation; drafted manuscript; critically revised manuscript; gave final approval and agrees to be accountable for all aspects of work, ensuring integrity and accuracy.

VS contributed to design; contributed to acquisition, analysis and interpretation; critically revised manuscript; gave final approval and agrees to be accountable for all aspects of work, ensuring integrity and accuracy.

### Supplemental material

Supplemental material for this article is available online.

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