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Validity of heart failure diagnoses, treatments, and readmissions in the Danish National Patient Registry

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Abstract

Background
The Danish National Patient Registry (DNPR) is a valuable resource for population-based research, but the validity of routine registration of advanced heart failure (HF) treatments within the registry is unknown. We, therefore, investigated the validity of HF, advanced HF treatments, and HF readmissions in the DNPR.

Methods
We randomly sampled patients registered at a Danish University Hospital during 2017–2021 from the DNPR. We identified 200 patients with first-time HF, 390 patients with one of eight advanced HF treatments, and 133 patients with HF admission after implantable cardioverter-defibrillator (ICD) or cardiac resynchronisation therapy (CRT). Compared with medical record reviews, we calculated positive predictive values (PPVs) with 95% confidence intervals (CIs).

Results
The PPV for first-time HF was 81% (95% CI: 74–86%). For advanced HF treatments, the PPV was 97% (95% CI: 91–99%) for ICD, 96% (95% CI: 86–100%) for CRT-pacemaker, 88% (95% CI: 76–95%) for CRT-defibrillator, 100% (95% CI: 83–100%) for left ventricular assist device, 43% (95% CI: 18–71%) for intra-aortic balloon pump, 38% (95% CI: 25–35%) for impella, 100% (95% CI: 93–100%) for cardiopulmonary support, and 100% (95% CI: 94–100%) for heart transplantation. The PPV for HF admission after ICD was 25% (95% CI: 16–37%) and 18% (95% CI: 9.2–30%) after CRT.

Conclusions
The PPV of routine registrations in the DNPR was moderate for first-time HF, high for most advanced HF treatments, and low for HF admissions after ICD or CRT. Thus, the DNPR is a valuable data source for population-based research on first-time HF and many advanced HF treatments.

Keywords
Cardiac surgical procedures; epidemiology; heart failure; predictive value of tests; validation study

Strengths and limitations

- Large validation study (medical records review of 723 patients).
- Two independent adjudicators ensured accurate validation.
- The results may not necessarily generalise outside the study period (2017–2022).
- Restriction to a single university hospital may limit generalisability to regional hospitals.

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Background

Advanced heart failure (HF) is defined as a condition with severe and persistent symptoms, profound cardiac dysfunction, episodes of pulmonary or systemic congestion, episodes of low cardiac output, and impaired physical capacity despite optimal drug treatment [1]. Up to 10% of patients with HF progress to this advanced stage [2]. Given the increased incidence [3] and improved survival [4] of HF, the prevalence of advanced HF is expected to rise, which emphasises the clinical and public health importance of prognosis studies of patients with advanced HF.

The Danish National Patient Registry (DNPR) is a valuable resource for population-based research, facilitating the identification of patients and their exposures and outcomes [5]. The registry's advantages include its potential for individual-level linkage with other Danish registries, nationwide coverage, long-term follow-up, and precise tracking of vital status [5]. However, the validity of routine registration of advanced HF treatments within the registry is unknown. The same is true for the registration of HF admissions after such treatments. Consequently, it is unclear whether post-treatment HF registrations genuinely indicate HF exacerbations, or if patients are incorrectly registered with an HF diagnosis when admitted for non-HF reasons because of their prior advanced HF treatment.

To address this uncertainty, we validated the routine registration of first-time HF, eight different advanced HF treatments, and HF readmissions within the DNPR.

Methods

Setting

All Danish residents benefit from the tax-financed Danish healthcare system that provides free access to hospitals, general practitioners, and private practice specialists, as well as partial reimbursement for prescription medication expenses [6]. Danish residents receive at birth or upon immigration a unique Civil Personal Registration number that functions as a personal identifier across all health services in Denmark, thereby allowing individual-level linkage between Danish health registries [6]. Danish medical databases, i.e., registries and databases that contain health-related data, are broadly categorised as *administrative databases*, *health databases*, and *clinical quality databases* [6]. The content of each category is described in detail elsewhere [6]. Briefly, administrative databases register people according to geographic area, health insurance program, or attendance at specific hospitals or clinics; health databases register people for surveillance and research; and clinical quality databases register people for clinical quality control [6]. Generally, clinical quality databases [7], such as the Danish Heart Failure Registry [8, 9], contain detailed and valid information due to active enrollment and data collection by clinicians. In contrast, information in administrative databases, such as the DNPR [5], is more dubious due to automated inclusion and data collection. Thus, ongoing validation of the DNPR, as done in this study, is essential to assess its applicability for population-based research.

The Danish national patient registry

The DNPR is an administrative database with the primary aim of providing a tool for health care planning for the Danish Health and Medicines Authority by monitoring hospital and health service use [5]. However, the registry is also used for other purposes such as for population-based research [5]. The DNPR contains information on all non-psychiatric inpatient contacts in Denmark back to 1977 and all inpatient psychiatric, outpatient clinic, and emergency room contacts back to 1995 [5]. Information on diagnoses, treatments, and procedures from such contacts is routinely reported from all Danish hospitals to the DNPR [5]. Diagnoses are recorded as one primary and optional secondary diagnoses according to the International Classification of Diseases 8^{th} edition before 1994 and 10^{th} edition after 1994 [5]. The diagnosis code is registered at the time of hospital discharge or immediately after an outpatient clinic contact by the discharging or treating physician [5]. Treatments and procedures are recorded according to the Danish Classification of Surgical Procedures and Therapies before 1996 and the Nordic Medico-statistical Committee's Classification of Surgical Procedures after 1996 [5]. The treatment or procedure code is registered immediately after the treatment or procedure by the treating physician [5].

Study sample

From the DNPR, we randomly sampled patients registered at a Danish University Hospital (Aarhus University Hospital) from 1 January 2017 to 31 December 2022. First, we sampled 200 patients with a first-time in or outpatient, primary or secondary diagnosis code for HF. The 200 patients were selected by sampling 50 patients from each of the following categories: inpatient primary diagnosis, inpatient secondary diagnosis, outpatient primary diagnosis, and outpatient secondary diagnosis. Second, we aimed to sample at least 50 patients with a procedure code for each of eight advanced HF treatments. However, because of the rarity of some treatments, achieving a sample size of 50 for each treatment was not feasible. Consequently, we sampled patients with a procedure code for ICD (n = 100), CRT-pacemaker (CRT-P) (n = 50), CRT-defibrillator (CRT-D) (n = 50), left ventricular assist device (LVAD) (n = 20), intra-aortic balloon pump (IABP) (n = 14), impella (n = 50), cardiopulmonary support (CPS) (n = 50), and heart transplantation (HTx) (n = 56). The sampling of the procedures was conducted exclusively based on the specific procedure codes without the requirement of an HF diagnosis during the same admission. Third, we aimed to sample at least 50 patients with an inpatient, primary diagnosis code for HF during an admission after each of the treatments. Because of a limited sample size, we were only able to identify patients with an HF diagnosis code after ICD (n = 71) and CRT (n = 62). Supplementary Table 1 presents all codes used for the validation. The codes used for defining HF diagnoses were aligned with a previous validation [10]. The codes used for defining the advanced HF treatments were based on clinical practice.

Medical record review

Two adjudicators (KB and CTW) independently compared data on HF diagnoses and advanced HF treatments from the DNPR with the patient's medical record review as the reference. HF was confirmed if the medical record indicated signs of HF (e.g., reduced left ventricular ejection fraction, clinical signs of congestion, or biochemical markers of HF). Advanced HF treatments were confirmed if the medical record described the specific treatment. The adjudicators first reviewed the discharge summaries (for the diagnosis) or procedure descriptions (for the procedures) and when still unclear the full medical record. Disagreements between the adjudicators were resolved through consensus.

Statistical analyses

As a measure of validity, we calculated the positive predictive value (PPV) as the number of diagnoses or treatments retrieved from the DNPR confirmed by the medical record review. We used the Wilson Score method to calculate 95% confidence intervals (CIs) [11]. We calculated percent agreement and kappa statistics to estimate the adjudicators' agreement [12]. We stratified all analyses by sex and age ($\leq$59 years, 60–79 years, or $\geq$80 years). Comparisons between strata were done using Fisher's exact test [13]. Lastly, we calculated the PPV for the overall HF diagnosis code (DI50). All analyses were performed using Stata statistical software version 17 (Stata Corporation, College Station, Texas, U.S.).

Results

For the sampled patients, all medical records were available for review. Tables 1–3 provide the results. Most of the sampled patients were men aged 60–79 years. Among the 200 patients with first-time HF in the DNPR, 161 were confirmed by the medical record review, yielding a PPV of 81% (95% CI: 74–86%) (Table 1). For inpatient diagnoses, the PPVs for first-time HF were 80% (95% CI: 66–90%) for primary diagnoses and 76% (95% CI: 62–87%) for secondary diagnoses. For outpatient diagnoses, the corresponding PPVs were 80% (95% CI: 66–90%) for primary diagnoses and 86% (95% CI: 73–94%) for secondary diagnoses. We observed no noteworthy differences within subgroups of sex (Supplementary Table 2). The overall PPV for first-time HF was lower in patients aged $\geq$80 years (72%; 95% CI: 57–84%) compared with patients aged $<$59 years (91%; 95% CI: 78–97%) (p-value = 0.03) or those aged 60–79 years (80%; 95% CI: 71–87%) (p-value = 0.03) (Supplementary Table 3). Among the 91 patients receiving a primary DI50 code, HF was confirmed in 75 cases (PPV = 82%, 95% CI: 73–90%).

For the advanced HF treatments, the PPVs were as follows: 97% (95% CI: 91–99%) for ICD, 96% (95% CI: 89–100%) for CRT-P, 88% (95% CI: 76–95%) for CRT-D, 100% (95% CI: 83–100%) for LVAD, 43% (95% CI: 18–71%) for IABP, 38% (95% CI: 25–53%) for impella, 100% (95% CI: 93–100%) for CPS, and 100% (95% CI: 94–100%) for HTx (Table 2). Patients recorded with IABP, but without medical record confirmation, were primarily found to have received other advanced HF treatments such as LVAD, impella, or CPS. For the 50 patients recorded with impella, the medical record showed that 22 (44%) had received CPS and eight (16%) had received LVAD. The PPVs for the advanced HF treatments were not noteworthily different within subgroups of sex or age (Supplementary Tables 4, 5).

For HF admissions after ICD, the PPVs were 25% (95% CI: 16–37%) for in or outpatient diagnoses, 38% (95% CI: 16–62%) for inpatient diagnoses, and 20% (95% CI: 10–34%) for outpatient diagnoses (Table 3). For HF admissions after CRT, the PPVs were 18% (95% CI: 9.2–30%) for in or outpatient diagnoses, 38% (95% CI: 14–68%) for inpatient diagnoses, and 33% (95% CI: 20–48%) for outpatient diagnoses (Table 3). For the majority of patients without medical record confirmation of HF admission after ICD or CRT, their hospital contact was not related to HF treatment; instead, it was typically associated with planned pacemaker follow-up or the management of other medical conditions. We observed no noteworthy differences for the PPVs of HF admission after ICR or CRT within subgroups of sex or age (Supplementary Tables 6, 7).

The adjudicator agreement ranged from 82–94% for first-time HF, 94–100% for advanced HF treatments, and 94–100% for HF admissions after ICD or CRT (Supplementary Table 8).

Discussion

We validated routine registration of first-time HF, eight advanced HF treatments, and HF admissions after ICD or CRT in the DNPR. Comparing the registration with patients' medical records, we found moderate validity for first-time HF, with PPVs ranging from 76% to 86%, depending on the algorithm used for contact and diagnosis type. The registration of advanced HF treatments showed generally high validity, with PPVs of 88% or above for ICD, CRT-P, CRT-D, LVAD, CPS, and HTx. However, IABP and Impella were poorly registered with PPVs of 43% or below. Finally, the registration of HF admissions after advanced HF treatments was only possible to examine for ICD or CRT. Here, the very low PPVs (equal to or below 40%) indicated severe misclassification of their registration.

Previous literature

Our observed PPVs for first-time HF align with those reported in previous studies validating HF within the DNPR. Two studies comparing *first-time* HF registration with the patients' medical records reported PPVs of 76% [10] and 100% [14]. Another two studies comparing HF registration during *any admission* with the patients' medical records both reported PPVs of 84% [15, 16]. A study comparing HF registration with a clinical evaluation based on the European Society of Cardiology guidelines reported a PPV of 81% [1, 17].

Our finding of no notable differences in the validity of first-time HF based on whether primary or secondary diagnosis codes were used corresponds with a previous Danish validation study [10]. In that study, the PPV for first-time HF was 79% (95% CI: 64–89%) when primary diagnoses were used and 73% (95% CI: 60–83%) when secondary diagnoses were used [10]. The primary reason for misclassification of first-time HF cases was attributed to other cardiac diseases (e.g., atrial fibrillation, atrioventricular block, or valvular heart disease) or related

Table 1: Positive predictive value of first-time heart failure in the Danish National Patient Registry, compared with medical record review, 2017–2022

Type of contact	Type of diagnosis	First-time heart failure		Positive predictive value (95% CI), %
		Confirmed, n	*Reviewed, n*	
In or outpatient	Primary or secondary	161	200	81 (74–86)
Inpatient	Primary	40	50	80 (66–90)
Inpatient	Secondary	38	50	76 (62–87)
Outpatient	Primary	40	50	80 (66–90)
Outpatient	Secondary	43	50	86 (73–94)

Abbreviation: CI, confidence interval.

Table 2: Positive predictive value of advanced heart failure treatments in the Danish National Patient Registry, compared with medical record review, 2017–2022

Treatment	First-time heart failure		Positive predictive value (95% CI), %
	Confirmed, n	*Reviewed, n*	
Implantable cardioverter-defibrillator (ICD)	97	199	97 (91–99)
Cardiac resynchronisation therapy pacemaker (ICD-P)	48	50	96 (86–100)
Cardiac resynchronisation therapy defibrillator (ICD-D)	44	50	88 (76–95)
Left ventricular assist device (LVAD)	20	20	100 (83–100)
Intra-aortic balloon pump (IABP)	6	14	43 (18–71)
Impella	19	50	38 (25–53)
Cardiopulmonary support (CPS)	50	50	100 (93–100)
Heart transplantation (HTx)	56	56	100 (94–100)

Abbreviation: CI, confidence interval.

Table 3: Positive predictive value of heart failure admission after implantable cardioverter-defibrillator (ICD) or cardiac resynchronisation therapy (CRT) in the Danish National Patient Registry, compared with medical record review, 2017–2022

Heart failure admission	First-time heart failure		Positive predictive value (95% CI), %
	Confirmed, n	*Reviewed, n*	
After implantable cardioverter-defibrillator (ICD)			
In or outpatient	18	71	25 (16–37)
Inpatient	8	21	38 (18–62)
Outpatient	10	50	20 (10–34)
After cardiac resynchronization therapy (CRT)			
In or outpatient	11	62	18 (9.2–30)
Inpatient	5	13	38 (14–68)
Outpatient	6	49	33 (20–48)

Abbreviation: CI, confidence interval.

procedures (e.g., implantation of or elective follow-up after ICD or pacemaker).

We found perfect validity of HTx within the DNPR, which is consistent with previous findings [18]. For the other examined advanced HF treatments, our study represents the first validation of their registration. The high validity observed for these treatments, except for IABP and impella, aligns with that reported for other cardiac procedures [18]. The primary reason for the low validity of IABP and impella was misclassification of other advanced HF treatments

We are the first to validate HF registration during admissions after ICD or CRT procedures. The observed low validity in these cases was attributed to the elective management of patients with ICD or CRT. This misclassification may stem from discharging physicians assigning HF as a discharge code, based on the patients' existing advanced HF condition, even when HF exacerbation was not the primary reason for the current admission.

Comparison with other heart failure registries

Denmark holds numerous clinical quality databases covering various disease specialties [7]. Among these databases is the Danish Heart Failure Registry [8, 9]. Patients are actively enrolled in this registry by cardiologists according to the European Society of Cardiology's definition of HF [1, 9]. The registry's content is registered during routine clinical care [9] and includes clinical procedures (e.g., echocardiography),

medical treatments (e.g., use of angiotensin-converting enzyme inhibitors and beta blockers), and modifiable risk factors (e.g., hypertension status, smoking history, and alcohol intake) [8, 9]. The data in the Danish Heart Failure Registry is considered valid but may have lower completeness than the DNPR and also solely registers first-time HF, limiting its utility for studying HF readmissions [9].

Comparing the coding quality of HF between countries is challenged by differences in healthcare systems and coding standards. Such differences may be smaller among Nordic countries owing to somewhat similar healthcare systems. The PPV for *definite* HF has been reported as 62% in the Swedish Patient Registry [19, 20], 64% in the Norwegian Patient Registry [21, 22], and 85% in the Finnish Cardiovascular Disease Registry [23, 24]. In Norway, the PPV was higher for primary versus secondary diagnoses (76% versus 57%) and for inpatient versus outpatient diagnoses (66% versus 44%) [21]. The PPV for *probable* HF has been reported as 32% in the Swedish [19, 20] and 12% in the Norwegian patient registries [21, 22]. In Sweden, 64% of cases classified as probable lacked echocardiographic examination, which prevented them from being classified as definite [19]. Thus, our study's higher PPV compared with Sweden [19] and Norway [21] could be due to some probable cases actually having HF but missing necessary information for being classified as definite. Unlike the Norwegian study [21], we found no differences in PPV between primary and secondary diagnoses or between inpatient and outpatient diagnoses. To our knowledge, HF readmission after ICD or CRT and the examined HF treatments have not been validated in other Nordic healthcare systems.

Limitations

Caution should be exercised when applying our findings to healthcare systems that differ from the Danish or earlier study periods, as registration practices may vary across settings and over time. Additionally, our study was restricted to a single university hospital, potentially limiting generalisability to regional hospitals. However, the advanced HF treatments investigated are exclusively conducted at university hospitals, and Denmark is relatively homogenous in terms of demographics, socioeconomic factors, healthcare utilisation, and medication use [25]. Thus, our findings on the validity of advanced HF treatments likely generalise to other Danish regions. Concerning HF diagnoses, registration practices may differ between university and regional hospitals. However, given the consistency of our findings with previous validation studies that sampled patients from various hospitals across Denmark [10, 14, 15, 16, 17, 26], this limitation is likely of minor concern. Also, the results of the validations applied to the chosen codes and cannot be extrapolated to other codes or diseases. Furthermore, the limited sample size prevented us from estimating the validity of HF admissions after LVAD, IABP, impella, CPS, and HTx. Lastly, the negative predictive value could not be estimated as we sampled patients *with* and not *without* the specific diagnoses and procedure codes, and estimating sensitivity and specificity within the DNPR is unfeasible as this would require complete information on whether the specific diagnoses (or treatments) are present (or have been performed) for all Danish citizens (≈6,000,000 people) [27].

Conclusion

Routine registrations in the DNPR showed moderate validity for first-time HF, high validity for most advanced HF treatments, and low validity for HF admissions after ICD or CRT. The DNPR, therefore, represents a valuable data source for population-based research on first-time HF and many advanced HF treatments.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Conflict of interests

The authors declare that they have no competing interests.

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Authors' contributions

KB and MS conceptualised and designed the study. KB, HE, and MS acquired the data. KB and CTW performed the validation. KB performed the analyses. KB and MS drafted the manuscript. All authors interpreted the data and critically revised the manuscript. All authors agree on the submitted version of the manuscript and take responsibility and accountability for its content.

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Supplementary Table 1: International Classification of Diseases 10th edition and advanced heart failure treatment codes used in the validation

Diagnosis	*International Classification of Diseases 10th edition codes*
Heart failure	DI130, DI132, DI420, DI426, DI427, DI428, DI429, DI500, DI501, DI502, DI508, DI509, DI510
Advanced heart failure treatment	*Procedure codes*
Implantable cardioverter-defibrillator (ICD)	BFCB00, BFCB01, BFCB20
Cardiac resynchronisation therapy pacemaker (CRT-P)	BFCB05, BFCB06, BFCA21, BFCA63
Cardiac resynchronisation therapy defibrillator (CRT-D)	BFCB03, BFCB21
Left ventricular assist device (LVAD)	KFXL10, KZFX70
Intra-aortic balloon pump (IABP)	KFXG00
Impella	KFXL00
Cardiopulmonary support (CPS)	KFXD00, KFXE00
Heart transplantation (HTx)	KFQA00, KFQA10

Supplementary Table 2: The positive predictive value of first-time heart failure in the Danish National Patient Registry, 2017–2022, by sex

Type of contact	**Type of diagnosis**	**Male sex**		**Female sex**	
		Confirmed, n / reviewed, n	***PPV, % (95% CI)***	***Confirmed, n / reviewed, n***	*PPV, % (95% CI)*
In or outpatient	Primary or secondary	110/131	84 (77–90)	51/69	74 (62–84)
Inpatient	Primary	23/28	82 (63–93)	17/22	77 (55–92)
Inpatient	Secondary	29/35	83 (66–93)	9/15	60 (32–84)
Outpatient	Primary	32/38	84 (69–94)	8/12	67 (35–90)
Outpatient	Secondary	26/30	87 (69–96)	17/20	85 (62–97)

Abbreviations: CI, confidence interval; PPV, positive predictive value.
*Statistically significant different from males (significance level = 0.05).

Supplementary Table 3: The positive predictive value of first-time heart failure in the Danish National Patient Registry, 2017–2022, by age

Type of contact	**Type of diagnosis**	**Age ≤59 years**		**Age 60–79 years**		**Age ≥80 years**	
		Confirmed, n / reviewed, n	***PPV, % (95% CI)***	***Confirmed, n / reviewed, n***	***PPV, % (95% CI)***	***Confirmed, n / reviewed, n***	***PPV, % (95% CI)***
In or outpatient	Primary or secondary	39/43	91 (78–97)	88/100	80 (71–87)	34/47	72 (57–84)*†
Inpatient	Primary	10/10	100 (69–100)	22/30	73 (58–88)	8/10	80 (44–97)
Inpatient	Secondary	6/9	67 (30–93)	21/24	88 (68–97)	11/17	65 (38–86)
Outpatient	Primary	11/12	92 (62–100)	22/27	81 (62–94)	7/11	64 (31–89)
Outpatient	Secondary	12/12	100 (74–100)	23/29	79 (60–92)	8/9	89 (52–100)

Abbreviations: CI, confidence interval; PPV, positive predictive value.
*Statistically significant different from age ≤59 years (significance level = 0.05).
†Statistically significant different from age 60–79 years (significance level = 0.05).

Supplementary Table 4: The positive predictive value of first-time heart failure in the Danish National Patient Registry, 2017–2022, by sex

Advanced heart failure treatment	Male sex		Female sex	
	Confirmed, n / reviewed, n	*PPV, % (95% CI)*	*Confirmed, n / reviewed, n*	*PPV, % (95% CI)*
Implantable cardioverter-defibrillator (ICD)	80/82	98 (91–100)	17/18	94 (73–100)
Cardiac resynchronisation therapy pacemaker (CRT-P)	41/43	95 (84–99)	7/7	100 (59–100)
Cardiac resynchronisation therapy defibrillator (CRT-D)	40/46	87 (74–95)	NA	NA
Left ventricular assist device (LVAD)	19/19	100 (82–100)	NA	NA
Intra-aortic balloon pump (IABP)	6/12	50 (22–79)	NA	NA
Impella	13/36	36 (21–54)	6/14	43 (18–71)
Cardiopulmonary support (CPS)	34/34	100 (90–100)	16/16	100 (79–100)
Heart transplantation (HTx)	38/38	100 (91–100)	18/18	100 (81–100)

Abbreviations: CI, confidence interval; PPV, positive predictive value.
*Statistically significant different from males (significance level = 0.05).

Supplementary Table 5: The positive predictive value of first-time heart failure in the Danish National Patient Registry, 2017–2022, by age

Advanced heart failure treatment	Age ≤59 years		Age 60–79 years		Age ≥80 years	
	Confirmed, n / reviewed, n	*PPV, % (95% CI)*	*Confirmed, n / reviewed, n*	*PPV, % (95% CI)*	*Confirmed, n / reviewed, n*	*PPV, % (95% CI)*
Implantable cardioverter-defibrillator (ICD)	33/35	94 (81–99)	48/49	98 (89–100)	6/6	100 (54–100)
Cardiac resynchronisation therapy pacemaker (CRT-P)	6/6	100 (54–100)	18/19	95 (74–100)	24/25	96 (80–100)
Cardiac resynchronisation therapy defibrillator (CRT-D)	11/13	85 (55–98)	32/34	94 (80–99)	NA	NA
Left ventricular assist device (LVAD)	10/10	100 (69–100)	12/12	100 (74–100)	NA	NA
Intra-aortic balloon pump (IABP)	NA	NA	6/13	46 (19–75)	NA	NA
Impella	NA	NA	12/20	60 (36–81)	NA	NA
Cardiopulmonary support (CPS)	27/27	100 (87–100)	22/22	100 (85–100)	NA	NA
Heart transplantation (HTx)	32/32	100 (89–100)	24/24	100 (86–100)	NA	NA

Abbreviations: CI, confidence interval; PPV, positive predictive value.
*Statistically significant different from age ≤59 years (significance level = 0.05).
†Statistically significant different from age 60–79 years (significance level = 0.05).

Supplementary Table 6: The positive predictive value of heart failure admissions after implantable cardioverter-defibrillator (ICD) or cardiac resynchronisation therapy (CRT) in the Danish National Patient Registry, 2017–2022, by sex

Heart failure admission	Male sex		Female sex	
	Confirmed, n / reviewed, n	***PPV, % (95% CI)***	***Confirmed, n / reviewed, n***	***PPV, % (95% CI)***
After implantable cardioverter-defibrillator (ICD)				
In or outpatient	16/65	25 (15–37)	NA	NA
Inpatient	8/19	42 (20–67)	NA	NA
Outpatient	8/46	17 (7.8–31)	NA	NA
After cardiac resynchronization therapy (CRT)				
In or outpatient	15/47	32 (19–47)	6/15	40 (16–68)
Inpatient	5/11	45 (17–77)	NA	NA
Outpatient	10/36	28 (14–45)	6/13	46 (19–75)

Abbreviations: CI, confidence interval; PPV, positive predictive value.
*Statistically significant different from males (significance level = 0.05).

Supplementary Table 7: The positive predictive value of heart failure admissions after implantable cardioverter-defibrillator (ICD) or cardiac resynchronisation therapy (CRT) in the Danish National Patient Registry, 2017–2022, by age

Heart failure admission	Age ≤59 years		Age 60–79 years		Age ≥80 years	
	Confirmed, n / reviewed, n	***PPV, % (95% CI)***	***Confirmed, n / reviewed, n***	***PPV, % (95% CI)***	***Confirmed, n / reviewed, n***	***PPV, % (95% CI)***
After implantable cardioverter-defibrillator (ICD)	6/22	27 (11–50)	12/47	26 (14–40)	NA	NA
In or outpatient	NA	NA	NA	NA	NA	NA
Inpatient	NA	NA	8/35	23 (10–40)	NA	NA
Outpatient						
After cardiac resynchronisation therapy (CRT)	8/22	36 (17–59)	10/30	33 (17–53)	NA	NA
In or outpatient	NA	NA	NA	NA	NA	NA
Inpatient	7/19	37 (16–62)	6/20	30 (12–54)	NA	NA
Outpatient						

Abbreviations: CI, confidence interval; PPV, positive predictive value.
*Statistically significant different from age ≤59 years (significance level = 0.05).
†Statistically significant different from age 60–79 years (significance level = 0.05).

Supplementary Table 8: Agreement between medical records adjudicators

Diagnosis or procedure	Type of contact	Type of diagnosis	Agreement	Kappa
First-time heart failure	In or outpatient	Primary or secondary	90%	0.72
	Inpatient	Primary	90%	0.70
	Inpatient	Secondary	96%	0.90
	Outpatient	Primary	94%	0.82
	Outpatient	Secondary	82%	0.34
Advanced heart failure treatment				
Implantable cardioverter-defibrillator (CRT)	NA	NA	98%	0.49
Cardiac resynchronisation therapy pacemaker (CRT-P)	NA	NA	96%	NA
Cardiac resynchronisation therapy defibrillator (CRT-D)	NA	NA	94%	0.64
Left ventricular assist device (LVAD)	NA	NA	100%	NA
Intra-aortic balloon pump (IABP)	NA	NA	100%	1.00
Impella	NA	NA	98%	0.96
Cardiopulmonary support (CPS)	NA	NA	100%	NA
Heart transplantation (HTx)	NA	NA	100%	NA
Heart failure admission				
After implantable cardioverter-defibrillator (ICD)	In or outpatient	Primary	94%	0.85
	Inpatient	Primary	95%	0.90
	Outpatient	Primary	94%	0.81
After chronic resynchronization therapy (CRT)	In or outpatient	Primary	98%	0.96
	Inpatient	Primary	100%	1.00
	Outpatient	Primary	98%	0.95