7-13-2022

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Recommended Citation

Sedhom R, Elbadawi A, Megaly M, Jaber WA, Cameron SJ, Weinberg I, Mamas MA, and Elgendy IY. Hospital procedural volume and outcomes with catheter-directed intervention for pulmonary embolism: a nationwide analysis. Eur Heart J Acute Cardiovasc Care 2022.

ESC European Society of Cardiology

European Heart Journal: Acute Cardiovascular Care (2022) **00**, 1–10
https://doi.org/10.1093/ehjacc/zuac082

ORIGINAL SCIENTIFIC PAPER

Hospital procedural volume and outcomes with catheter-directed intervention for pulmonary embolism: a nationwide analysis

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Received 30 April 2022; revised 20 June 2022; accepted 22 June 2022

Aims There is limited data on the association between hospital catheter-directed intervention (CDI) volume and outcomes among patients with acute pulmonary embolism (PE).

Methods and results The Nationwide Readmissions Database years 2016–2019 was utilized to identify hospitalizations undergoing CDI for acute PE. Hospitals were divided into tertiles based on annual CDI volume; low-volume (1–3 procedures), moderate-volume (4–12 procedures) and high-volume (>12 procedures). The primary outcome was all-cause in-hospital mortality. Among 1 436 382 PE admissions, 2.6% underwent CDI; 5.6% were in low-volume, 17.3% in moderate-volume and 77.1% in high-volume hospitals. There was an inverse relationship between hospital CDI volume and in-hospital mortality (coefficient −0.344, $P < 0.001$). On multivariable regression analysis, hospitals with high CDI volume were associated with lower in-hospital mortality compared with hospitals with low CDI volume (adjusted odds ratio [OR] 0.71; 95% confidence interval [CI] 0.53, 0.95). Additionally, there was an inverse association between CDI volume and length of stay (LOS) (regression coefficient −0.023, 95% CI −0.027, −0.019) and cost (regression coefficient −74.6, 95% CI −98.8, −50.3). There were no differences in major bleeding and 30-day unplanned readmission rates between the three groups.

Conclusion In this contemporary observational analysis of PE admissions undergoing CDI, there was an inverse association between hospital CDI volume and in-hospital mortality, LOS, and cost. Major bleeding and 30-day unplanned readmission rates were similar between the three groups.

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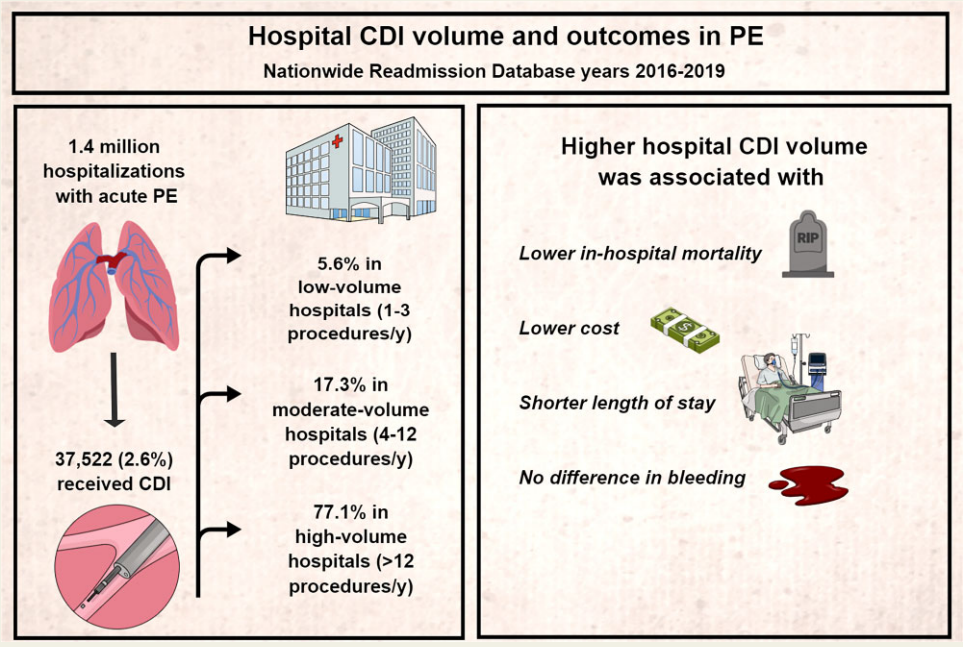
Graphical Abstract



CDI, catheter-directed intervention; PE, pulmonary embolism.

Keywords Pulmonary embolism • Catheter-directed intervention • Procedure volume

Introduction

Pulmonary embolism (PE) remains a leading cause of cardiovascular morbidity and mortality, with an estimated annual mortality rate of 4.1–4.5 deaths per 100 000 population in the United States (US) in 2017.[1] Traditionally, patients with low-risk [normotensive, no right ventricular (RV) strain] PE are treated with anticoagulation alone.[2] While, for those with high-risk PE (i.e. cardiac arrest or cardiogenic shock), reperfusion therapy, with systemic thrombolysis or surgical embolectomy, might be considered.[2–4] Patients with intermediate-risk (RV strain, normotensive) are more challenging to treat, with care driven more by nuanced regional patterns, with anticoagulation, often with a catheter-directed intervention (CDI).[5]

In recent years, the utilization of CDI for the treatment of acute PE has increased reaching 2.5% of all PE cases.[6] CDI is an alternative option in select patients with intermediate-high risk PE and may involve thrombus aspiration, thrombus maceration, targeted thrombolysis, or a combination of each. Two common types of CDI are catheter-directed thrombolysis (CDT) and catheter-directed embolectomy (CDE). CDT involves the administration of lower doses (around 1/20th of the systemic dose) of thrombolytic agents directly into the pulmonary arteries while CDE involves mechanical disruption or aspiration of the emboli. CDT can be combined with ultrasound (i.e. US-CDT) which disrupts fibrin strands allowing effective thrombolysis at lower doses.[7–10] Studies have shown that CDT is associated with a lower risk of major and intracranial haemorrhage (ICH) compared with systemic thrombolysis.[11–14] CDE has the advantage of rapid mechanical extraction of the thrombus alongside avoidance of the use of thrombolytics[15] and is most useful for proximal PE (i.e. main or lobar pulmonary arteries).[16,17]

Prior studies have suggested that admission to high-volume hospitals was associated with lower 30-day and 1-year mortality, less readmission, lower cost, and shorter length of stay (LOS) among patients with acute PE.[18,19] However, the data on the association between hospital CDI volume and outcomes in patients with acute PE are scarce. To better address these knowledge gaps, we aimed to examine the association between hospital CDI volume and short-term outcomes from a contemporary nationally representative dataset.

Study design and methods

Data source

We used the Nationwide Readmissions Database (NRD) years 2016–2019. The NRD is sponsored by the Agency for Healthcare Research and Quality as a part of the Healthcare Cost and Utilization Project (HCUP).[20] The NRD contains discharge data from 30 geographically dispersed States, accounting for ~62% of the total US resident population and ~60% of all US hospitalizations. The NRD contains data from approximately 35 million weighted discharges. The NRD includes discharge records of patients treated at US community hospitals, excluding rehabilitation and long-term acute-care facilities. Patients with 1 or more inpatient

hospitalizations have verified patient linkage numbers that can be used to track individual patients across hospitals within a state. However, patient linkage numbers do not track hospitalizations across the calendar years.[20] We identified the cohort, procedures, and outcomes using the International Classification of Diseases, Tenth Revision, Clinical Modification (ICD 10-CM) and procedure (ICD 10-PCS) codes along. The codes used are summarized in Supplementary material online, *Table S1*.

Study population and exposure

The study cohort included hospitalized patients with acute PE who were ≥18 years and underwent CDI defined as CDT or CDE. First, we identified hospitalizations with any diagnosis of acute PE using ICD 10-CM codes. Then, we identified those undergoing any form of CDI (i.e. CDT, CDE, or US-CDT) using the corresponding ICD 10-PCS codes (see Supplementary material online, *Table S1*). We excluded hospitalizations with acute limb ischaemia and acute ischaemic stroke, since these conditions might be treated with CDI as well as those with missing data on mortality. To examine 30-day readmission rates, we excluded those admitted in December of each calendar year (30-day readmissions for hospitalizations in December could not be obtained since the NRD does not cross the calendar year) and those who died during the index admission. We identified the proportion of urgent 30-readmissions due to PE recurrence using the ICD-10 codes of the first 3 recorded readmission diagnoses.

The main exposure was the annual hospital procedural volume for any CDI. Hospitals were divided into tertiles; low-volume (1–3 procedures/year), moderate-volume (4–12 procedures/year), and high-volume (>12 procedures/year).

Patient and hospital-level variables provided by HCUP NRD were used to identify demographics and baseline characteristics. The Elixhauser method was used to assess comorbidities.[21] The other comorbidities were identified using appropriate ICD 10 CM codes (see Supplementary material online, *Table S1*). PE with critical illness was defined as PE with cardiogenic shock, mechanical ventilation, mechanical circulatory support [MCS], or vasopressors.[22,23] The NRD is a publicly available database with de-identified hospitalization records; thus this study was exempt from institutional review board approval.

Outcomes

The primary outcome was the rate of all-cause in-hospital mortality. The secondary outcomes included (i) intracranial haemorrhage (ICH), (ii) non-ICH bleeding (i.e. respiratory tract haemorrhage, haemothorax, gastrointestinal haemorrhage, retroperitoneal bleeding, hematuria, hemarthrosis, hemopericardium, intraocular haemorrhage and unspecified post-procedural bleeding), (iii) 30-day unplanned readmissions, (iv) length of stay (LOS), and (v) cost.

Statistical analysis

All analyses were conducted using multilevel complex analysis, to account for hospital clustering, weights, and stratification following the HCUP regulations. The hospital cost of an individual admission episode was calculated using total charge and cost-to-charge ratio data provided by the HCUP.[20,24,] Continuous variables were summarized as medians and interquartile range (IQR) (25th and 75th percentiles) and compared with the Mann–Whitney U test. Categorical variables were displayed as frequencies and percentages and compared with Pearson's chi-square or Fisher's exact tests. All *P*-values are 2-sided with a significance threshold of <0.05. Statistical analyses were performed using STATA software for Windows (version 16.0. College Station, TX: StataCorp LLC) and IBM SPSS Statistics for Windows (version 27.0. Armonk, NY: IBM Corp).

Hospital CDI volume was analyzed both as a categorical and continuous variable. Curvilinear (quadratic) regression analysis was conducted to examine the association between hospital CDI volume as a continuous variable and the primary study outcome. Multivariable logistic regression analysis was conducted to account for the differences in patient- and hospital-related characteristics, PE severity and treatment modalities. We included the following variables in the regression model; age, sex, pregnancy, smoking history, morbid obesity, hypertension, diabetes mellitus, anemia, coagulopathy, pulmonary hypertension, chronic lung diseases, atrial fibrillation, heart failure, valvular heart disease, connective tissue disease, malignancy, chronic kidney disease, chronic liver disease, coronary artery disease, peripheral arterial disease, history of stroke, deep venous thrombosis (DVT), hospital size, hospital teaching status, hospital total PE volume, saddle PE, cor pulmonale, cardiogenic shock, vasopressors, MCS, mechanical ventilation, systemic thrombolysis, surgical embolectomy and CDE. We performed a sensitivity analysis for the primary outcome by excluding admissions who were transferred from another hospital. Additionally, multivariable linear regression analysis was conducted to examine the association between hospital CDI volume as a continuous variable and both LOS and cost. A falsification endpoint analysis was conducted to assess for residual confounders after the multivariable-adjusted analysis. For this analysis, we evaluated other outcomes that are not pathophysiologically related to acute PE or CDI, including sepsis, pressures ulcer and acute hepatitis.

Results

The total number of admissions with acute PE during the years 2016–2019 was 1 436 382 with 37 522 admissions (2.6%) who underwent CDI. Low-volume hospitals performed 1–3 (median 2, IQR 1–2), moderate-volume hospitals performed 4–12 (median 7, IQR 5–9) and high-volume hospitals performed 13–200 (median 23, IQR 17–37) procedures/year. Among all PE admissions, 209 523admissions (14.6%) were in low-volume, 267 688(18.6%) in moderate-volume and 487 605 (33.9%) in high-volume hospitals while the remainder of PE admissions were in hospitals which did not perform CDI. Among acute PE admissions in low-volume hospitals, 2094(1%) underwent CDI compared with 6505 (2.4%) in moderate-volume and 28 923 (5.9%) in high-volume hospitals. (*Figure 1*)

The baseline characteristics of the study cohort according to the CDI volume are shown in *Table 1*. Less than 1% of PE was associated with pregnancy. Admissions at low-volume hospitals had higher rates of anemia, coagulopathy, chronic pulmonary disease, atrial fibrillation, valvular heart disease, malignancy, and cardiogenic shock. Additionally, the utilization of systemic thrombolysis, CDE, inferior vena cava (IVC) filter, vasopressors and mechanical ventilation was

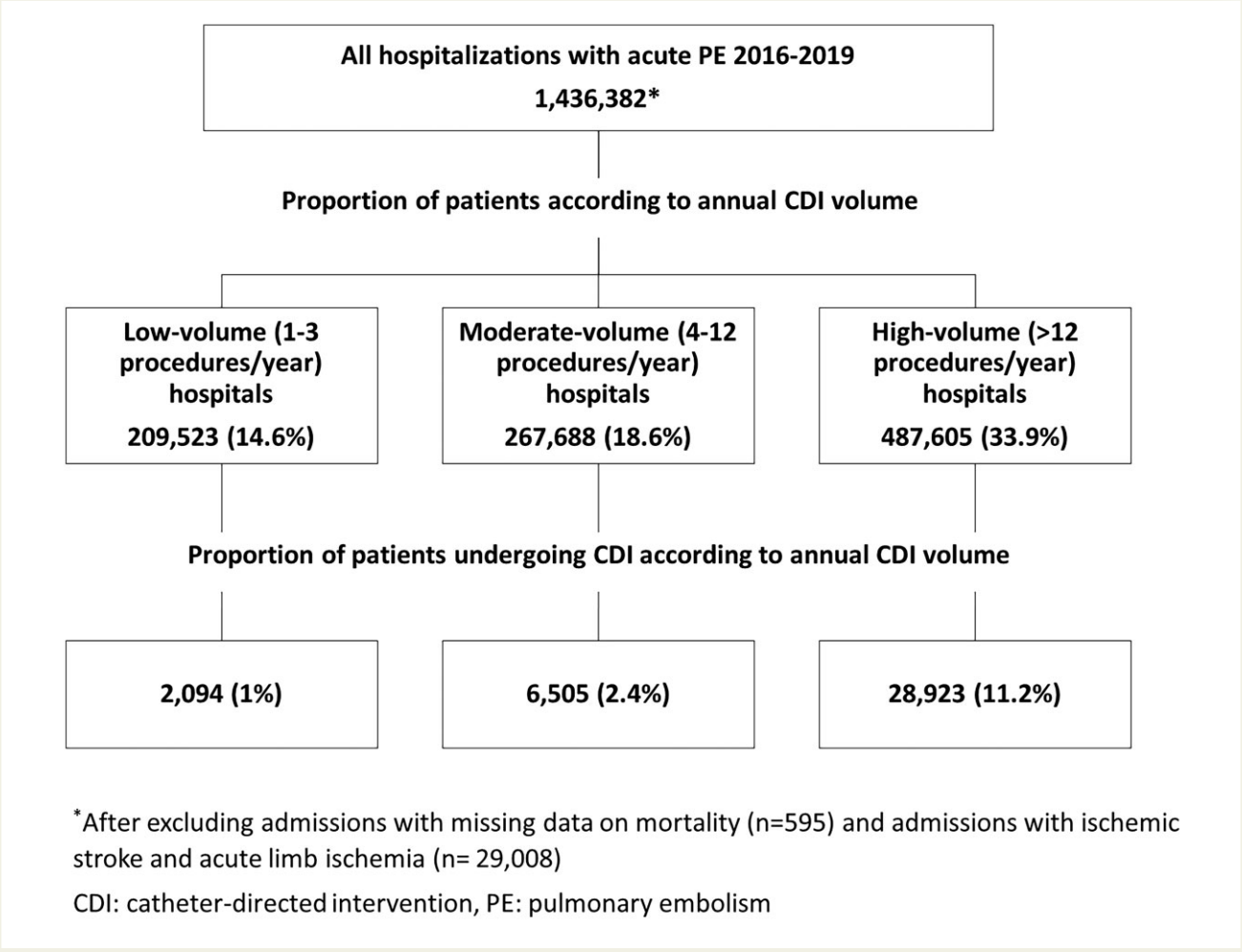


Figure 1 Study flowchart. CDI, catheter-directed intervention; PE, pulmonary embolism.

more common among admissions at low-volume hospitals. On the other hand, admissions at high-volume hospitals had higher rates of morbid obesity, hypertension, diabetes mellitus, pulmonary hypertension and acute cor pulmonale. The utilization of US-CDT was more common in high-volume hospitals.

Primary outcome

Among admissions receiving CDI, the unadjusted in-hospital mortality differed across the 3 groups. In-hospital mortality was 11% in low-volume, 6.8% in moderate-volume and 5.1% in high-volume hospitals ($P < 0.001$) (*Table 2*). Among admissions who did not receive CDI, the unadjusted in-hospital mortality was 6.9% in low-volume, 7% in moderate- and 7.2% in high-volume centers ($P = 0.13$) (see Supplementary material online, *Table S2*).

Among admissions receiving CDI, curvilinear regression analysis revealed an inverse relationship between hospital CDI volume and in-hospital mortality (coefficient −0.344, $P < 0.001$). On multivariable regression analysis, in-hospital mortality was lower among high- vs. low-volume hospitals (adjusted odds ratio [OR] 0.71; 95% confidence interval [CI] 0.53, 0.95, $P = 0.021$) but no significant difference was observed among moderate- vs. low-volume hospitals (adjusted OR 0.76; 95% CI: 0.58, 1.002, $P = 0.051$). (*Table 3*, *Figure 2*). Sensitivity analysis excluding admissions who were transferred from other hospitals showed that in-hospital mortality was lower among moderate- vs. low-volume hospitals (adjusted OR 0.72; 95% CI 0.54, 0.96, $P = 0.02$) and among high- vs. low-volume hospitals (adjusted OR 0.63; 95% CI 0.47, 0.85, $P = 0.002$).

When analyzing the hospital volume as a continuous variable, there was a significant reduction in in-hospital mortality with higher hospital CDI volume (for every increase in 10 procedures per year: adjusted OR 0.971; 95% CI 0.944, 0.999, $P = 0.04$) even after excluding admissions who were transferred from other hospitals (for every increase in 10 procedures per year: adjusted OR 0.969; 95% CI 0.942, 0.998, $P = 0.04$). (*Table 3*).

Secondary outcomes

In the unadjusted analysis, the rates of ICH were different while the rates of non-ICH bleeding events were similar among the 3 groups. The rates of ICH were 1.7% in low-volume, 1.3% in moderate-volume and 1% in high-volume hospitals ($P = 0.04$). Non-ICH was 12.8% in low-volume, 11.2% in moderate-volume and 10.8% in high-volume hospitals ($P = 0.10$) (*Table 2*). On multivariable logistic

Table 1 Baseline patients' and hospitals' characteristics among admissions with acute PE undergoing CDI according to the annual hospital CDI volume

	Low CDI volume ($n = 2094$)	Moderate CDI volume ($n = 6505$)	High CDI volume ($n = 28\,923$)	*P* value
Percentage from all PE admissions	1% (2094/209 523)	2.4% (6505/267 688)	5.9% (28 923/487 605)	<0.001
Number of hospitals[a]				<0.001
Year 2016	168	200	193	
Year 2017	180	215	272	
Year 2018	146	227	341	
Year 2019	179	233	363	
Age, median (IQR)	63 (50–71)	63 (52–72)	62 (50–72)	0.02
Female	48.2%	47%	47.1%	0.75
Pregnancy	0.9%	0.2%	0.2%	<0.001
Smoking	22.5%	21%	23.2%	0.02
Comorbidities				
Morbid obesity	19.1%	19%	21.6%	0.001
Hypertension	61.9%	61.1%	63.3%	0.04
Diabetes mellitus	25.2%	25.3%	27.5%	0.01
Anemia	23.8%	18.6%	17.9%	<0.001
Coagulopathy	19.2%	17%	14.6%	<0.001
Pulmonary hypertension	15.1%	14.7%	17.4%	0.004
Chronic pulmonary disease	20.6%	18.5%	18.9%	0.31
Atrial fibrillation/flutter	14.6%	12%	11.8%	0.02
Heart failure	19.2%	18.3%	18.4%	0.78
Valvular heart disease	10.6%	7%	7.9%	0.002
Chronic kidney diease (stage 3 and above)	10.3%	8.9%	10.7%	0.007
Chronic liver disease	4.8%	4.8%	4.2%	0.18
Connective tissue diseases	2.9%	2.6%	3.1%	0.21
Malignancy	11.5%	9%	8.9%	0.01
CAD	13.2%	12.8%	14.4%	0.03
Prior MI	*3.4%*	*2.7%*	*3.8%*	*0.002*
Prior PCI	*NR*	*0.3%*	*0.3%*	*0.80*
Prior CABG	*2.2%*	*1.9%*	*2.4%*	*0.28*
Prior stroke	4.3%	4%	4.1%	0.88
PAD	3.3%	2.3%	2.4%	0.13
Presentation and severity				
Transfered from another hospital	9.9%	5.1%	6.2%	<0.001
Saddle PE	37.6%	38%	36.7%	0.39
Acute cor pulmonale	26.8%	31.4%	41.1%	<0.001
Cardiogenic shock	8.5%	6.4%	5.1%	<0.001
Concomitant DVT	57.1%	55.2%	57.5%	0.07
PE with critical illness	22.9%	14.3%	11.3%	<0.001
Hospital characteristics				
Large hospital[b]	41.5%	48.6%	69.1%	<0.001
Teaching hospital	59.3%	68.1%	79.2%	<0.001
Treatment modalities				
Systemic thrombolysis	6.1%	4.8%	3.9%	0.001
Surgical embolectomy	NR	0.3%	0.3%	0.51
CDE	30.2% (633/2094)	26.7% (1734/6505)	20.1% (5810/28 923)	<0.001
CDT	76.5% (1602/2094)	78.9% (5133/6505)	82.9% (23 970/28 923)	<0.001

Continued

Table 1 *Continued*

	Low CDI volume (*n* = 2094)	Moderate CDI volume (*n* = 6505)	High CDI volume (*n* = 28 923)	*P* value
US-facilitated CDT	12.5% (261/2094)	15.8% (1027/6505)	23.5% (6801/28 923)	<0.001
IVC filter	29%	23.1%	19.7%	<0.001
Circulatory and ventilatory support				
Vasopressors	2.8%	1.6%	1.3%	0.001
Mechanical ventillation	18.9%	11.2%	8.6%	<0.001
Mechanical circulatory support	1.7%	1.1%	1.2%	0.40
Impella	NR	0.2%	0.3%	0.65
ECMO	1.1%	0.8%	0.9%	0.67
IABP	NR	NR	0.1%	0.001

[a]Individual hospital cannot be tracked across different years as the NRD assigns a different number for each hospital each year.
[b]Large hospitals were defined based on HCUP definition which is based on hospital beds and are specific to the hospital's location and teaching status (https://www.hcup-us.ahrq.gov/db/vars/hosp_bedsize/nisnote.jsp) as follows; Northeastern region: rural > 100, urban non-teaching > 200, urban teaching > 425 beds. Midwest region: rural > 50, urban non-teaching > 175, urban teaching > 375 beds. Southern region: rural > 75, urban non-teaching > 200, urban teaching > 450 beds. Western region: rural > 45, urban non-teaching > 175, urban teaching > 325 beds.
CAD, coronary artery disease; CDI, catheter-directed intervention; PE, pulmonary embolism; IQR, interquartile range; MI, myocardial infarction; PCI, percutaneous coronary intervention; CABG, Coronary artery bypass grafting; DVT, deep venous thrombosis; CDT, catheter-directed thrombolysis; CDE, catheter-directed embolectomy; US, ultrasound; IVC, inferior vena cava; ECMO, extracorporeal membrane oxygenation; IABP, intra-aortic balloon pump; PAD, peripheral arterial disease; NR: not reportable.

Table 2 Unadjusted outcomes with CDI for PE according to the hospital annual CDI volume

	Low CDI volume (*n* = 2094)	Moderate CDI volume (*n* = 6505)	High CDI volume (*n* = 28 923)	*P* value
In-hospital mortality	11%	6.8%	5.1%	<0.001
Intracranial haemorrhage (ICH)	1.7%	1.3%	1%	0.04
Non-ICH	12.8%	11.2%	10.8%	0.10
Length of stay (days) median (IQR)	6 (4–10)	5 (3–8)	4 (3–7)	<0.001
Cost of stay (US Dollars) median (IQR)	30 189(20 556–48 459)	25 953(18 576–38 014)	23 833(18 059–32 909)	<0.001
30-day unplanned readmissions	8.5% (143/1685)[a]	8% (437/5457)[a]	7.3% (1825/25 102)[a]	0.19
- *Due to PE recurrence*	21.9%	15.4%	18.9%	0.30
- *Due to DVT*	12.9%	10.3%	11.1%	0.77

[a]After excluding those who died during the index admissions and those who were admitted in December of each calendar year.
IQR, interquartile range; PE, pulmonary embolism; DVT, deep venous thrombosis; CDI, catheter-directed interventions

regression analysis, there was no difference in the rates of ICH and non-ICH bleeding events between high- vs. low-volume and moderate- vs. low-volume hospitals (*Table 3*, *Figure 2*).

The LOS and cost were lower among high- and moderate-volume hospitals compared with low-volume hospitals. Multivariable linear regression analysis revealed an inverse association between CDI volume and both LOS (regression coefficient −0.023, 95% CI −0.027, −0.019, $P < 0.001$) and cost (regression coefficient −74.6, 95% CI −98.8, −50.3, $P < 0.001$). There were no differences in the 30-day unplanned readmission rates between the three groups (*Table 2*).

Falsification endpoint analysis

There was no difference in the rate of sepsis among moderate-volume (adjusted OR 0.96; 95% CI 0.73, 1.26, $P = 0.77$) and high-volume (adjusted OR 0.88; 95% CI 0.67, 1.16, $P = 0.39$) hospitals compared with low-volume hospitals. There were no differences in the rates of pressure ulcers (moderate- vs. low-volume: adjusted OR 1.19; 95% CI 0.69, 2.04, $P = 0.53$; high- vs. low-volume: adjusted OR 1.03; 95% CI 0.62, 1.70, $P = 0.91$) and acute hepatitis (moderate- vs. low-volume: adjusted OR 2.13; 95% CI 0.52, 8.69, $P = 0.29$; high- vs. low-volume: adjusted OR 1.37; 95% CI 0.47, 4.05, $P = 0.56$) between moderate- and high-volume hospitals compared with low-volume hospitals.

Table 3 In-hospital mortality and bleeding events following CDI for PE according to the annual hospital volume of CDI

	Moderate- vs. low-volume hospitals	High- vs. low-volume hospitals	Volume as a continuous variable[a]
In-hospital mortality	0.76 (0.58–1.002)	0.71 (0.53–0.95)	0.971 (0.994–0.999)
Intracranial haemorrhage (ICH)	0.79 (0.42–1.49)	0.60 (0.33–1.02)	0.960 (0.900–1.023)
Non-ICH bleeding events	0.95 (0.78–1.16)	1.03 (0.85–1.24)	0.982 (0.964–1.001)

Values are adjusted odds ratio (95% confidence interval)
[a]For every increase in 10 procedures per year.
CDI, catheter-directed intervention; PE, pulmonary embolism

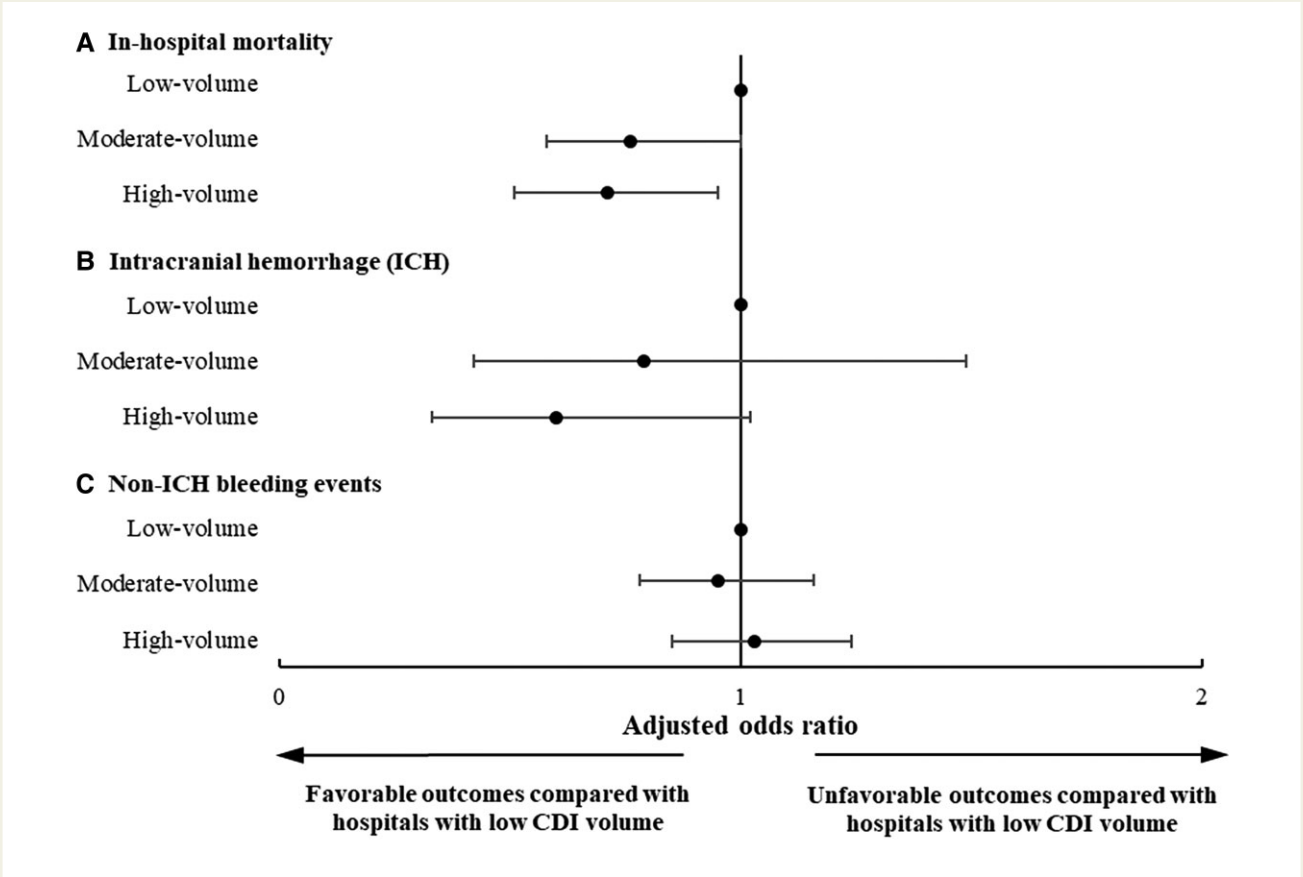


Figure 2 Forest plot showing the adjusted odds of in-hospital mortality, ICH and non-ICH bleeding events following CDI for PE according to the hospital annual volume of CDI. CDI, catheter-directed intervention; ICH, intracranial haemorrhage; PE, pulmonary embolism. Central Illustration. In-hospital mortality after CDI for acute PE according to the annual hospital CDI volume. (*A*) Forest plot for in-hospital mortality after CDI for acute PE according to the annual hospital CDI volume. (*B*) Scatter plot showing the relationship between annual hospital CDI volume and in-hospital mortality CDI, catheter-directed intervention; PE, pulmonary embolism.

Discussion

We investigated the association between hospital procedure volume and short-term outcomes among 37 522 hospitalizations with acute PE undergoing CDI. The main findings of this study were as follows: (1) there was an inverse association between in-hospital mortality following CDI for acute PE and annual hospital CDI volume. Compared with low-volume hospitals (1–3 procedures), high hospital CDI volume (>12 procedures) was independently associated with lower odds of in-hospital mortality. However, when the hospital volume was used as a continuous variable, the reduction in mortality was borderline significant; (2) hospitals with moderate or high CDI

volumes were not associated with lower odds of ICH or non-ICH bleeding events compared with low-volume hospitals; (3) higher volume hospitals were associated with shorter LOS and lower cost; (4) there was no difference in the 30-day unplanned readmission rate according to the annual hospital CDI volume. Importantly, the falsification endpoint analysis showed no significant difference in the incidence of other outcomes, which are not influenced by acute PE and CDI, suggesting that the main findings from this analysis are unlikely driven by unmeasured confounding.

The current study demonstrated an inverse volume-outcome relationship among patients with acute PE undergoing CDI and in-hospital all-cause mortality, cost, as well as LOS. Previous studies have shown that among all-comers with acute PE, admission to high-volume hospitals was associated with improved outcomes irrespective of the treatment modalities or severity of presentation.[18,19] Additionally, improved clinical outcomes with higher procedural volume have been established with various catheter-based cardiovascular interventions including percutaneous coronary intervention,[25,26] transcatheter aortic valve replacement,[27] transcatheter mitral valve repair,[28] CDT for acute DVT[29] and endovascular treatment for acute ischaemic stroke[30] and critical limb ischaemia.[31]

Several factors might explain the inverse association between in-hospital mortality and annual hospital CDI volume observed in the current study. These factors may be related to the patients, the procedure or other peri-procedural care factors. As with most interventional procedures, the learning curve and operator experience play an important role in procedural success and clinical outcomes. We found that higher CDI volume was not associated with lower odds of major bleeding thus, peri-procedural factors may play a larger role in the volume-outcome relationship. High-volume hospitals may have greater staff interventional experience, subspecialty support services, greater intensive care unit staffing and advanced infrastructure to ensure pre- and post-procedural care of patients undergoing CDI.[19] Also, the development of multidisciplinary pulmonary embolism response teams (PERT) may contribute to the volume-outcome relationship. PERT help in rapid risk stratification of patients as well as choosing the most appropriate management strategy. Studies have shown that with the introduction of PERTs, there has been an increase in the utilization of advanced therapies for PE with a possible decrease in in-hospital mortality.[32–35]

There was no difference in in-hospital mortality between low- and moderate-volume hospitals. However, when excluding admissions that were transferred from other hospitals, we found a significant reduction in mortality in moderate- vs. low-volume hospitals. This suggests that transferred patients may represent a cohort of patients who are 'sicker' and have worse outcomes. It has been previously shown that transferred PE patients had higher rates of right ventricular strain and oxygen requirements. They were more likely to have intermediate or high-risk PE and to receive advanced therapy. PE-related mortality was higher among transferred patients.[36,37]

The current analysis showed that only a small proportion of patients admitted with acute PE to low- or moderate-volume hospitals receive CDI for PE (1 and 2.4%, respectively), whereas 5.9% of those admitted to high-volume hospitals receive CDI. Interestingly, admissions at low-volume centres had greater comorbidities and higher risk PE features. It is plausible that patients admitted to low-volume centres were sicker, hence, they were not offered CDI. Our results highlight the importance of the centers' experience in achieving better outcomes with CDI for acute PE. It has been suggested that an experienced interventionalist requires three to five cases to optimize CDE with FlowTriever Aspiration System (Inari Medical, Irvine, CA, USA).[16] Additionally, the lower cost and shorter LOS seen with higher CDI volume suggest that adequate CDI volume can help in reducing healthcare costs, improving bed turnover, and preventing complications related to prolonged hospitalization (e.g. nosocomial infections).[38] Further analyses with longer follow-up periods are warranted to determine the CDI volume needed to achieve optimal outcomes.

Limitations

The findings of this study should be interpreted in the context of some limitations. First, this study is a retrospective observational study with the inherent limitation of selection bias. We attempted to mitigate that risk by performing multivariable regression analyses. Reassuringly, the falsification endpoint analysis suggested that the findings are unlikely driven by residual confounding. Second, given the administrative nature of the NRD, the study is subject to coding errors and data quality at the site of collection, without the ability to adjudicate accuracy. Additionally, the NRD uses discharge not admission diagnoses, so we could not ascertain if PE was present on admission or later during the course of hospitalization. Also, the NRD assigns a number for each hospital every year and an individual hospital cannot be followed across different years, so hospitals were classified based on their annual CDI procedural volume. Third, patients with multiple admissions could have been included more than once if they have received CDI for PE during each admission. Fourth, the temporal relationship of certain outcomes cannot be reliably established. Fifth, details about the CDI procedure including duration, thrombolytic dose, type of interventional device used as well as data on discharge medications are not available in the NRD. Sixth, long-term outcomes could not be assessed. Seventh, data regarding operators' volume and experience and the influence on the outcomes were also not available. Finally, the NRD also lacks data on imaging and cardiac biomarkers which could influence the outcomes.

Conclusions

In this nationwide contemporary analysis of patients admitted with PE and undergoing CDI, we found an inverse association between hospital CDI volume and in-hospital mortality, LOS, and cost. There were no differences in major bleeding and 30-day unplanned readmission rates among low-, moderate-, and high-volume hospitals. Future studies are needed to examine the effect of hospital CDI volume on long-term outcomes.

Supplementary material

Supplementary material is available at European Heart Journal: Acute Cardiovascular Care online.

Conflict of interest: None declared.

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