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Determinants and patterns of utilization of primary percutaneous coronary intervention across 12 European countries: 2003–2008 ☆

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ABSTRACT

Background: Important differences exist between European countries in the degree of implementation of primary percutaneous coronary intervention (PPCI) for patients with ST-elevation myocardial infarction (STEMI). To investigate whether health care-associated economic and demographic country-level characteristics were associated with differences in utilization of PPCI, we aimed to examine 5-year trends in the implementation of PPCI for STEMI across 12 EU countries.

Methods: An ecological study of aggregated data from national and international registries. Main outcome was the number of PPCI per 1,000,000 population, collected annually for the years 2003 to 2008. Impact of year on PPCI implementation was modeled using linear regression and mixed effects models used to quantify associations between PPCI use and country-level parameters.

Results: The annual growth in utilization of PPCI was 1.11 (1.03,1.20) per million. Country-level utilization rates varied from 0.82 (95% CI 0.52, 1.30) to 1.38 (95% CI 1.15, 1.64) per million per year. Number of physicians per 100,000 population, number of nurses and midwifes per 100,000 population, number of acute care beds per 100,000 population, population density per km^2, and proportion of population under 50 years old were associated with PPCI utilization.

Conclusions: All 12 EU countries demonstrated evidence of PPCI implementation from 2003 to 2008. However, there was substantial variation in the use and rate of uptake of PPCI between countries. Differences in utilization rates of PPCI are associated with supply factors, such as numbers of beds and physicians, rather than healthcare economic characteristics. Further studies are needed to explore the influence of patient-level factors.

1. Introduction

International guidelines support the implementation of evidence-based clinical practice — to reduce variation in access to and quality of healthcare [1–3]. Primary percutaneous coronary intervention (PPCI) is recommended for patients with ST-elevation myocardial infarction (STEMI) [4]. Despite substantial evidence to support its effectiveness, international and national studies report large variation in access to PPCI both within and across countries [5–8]. A study including data from 2007 or 2008 based partly on expert estimation suggested that only 40% to 60% of patients with STEMI in Europe received PPCI [7]. The factual level of variation in PPCI across countries is still unknown [7], and knowledge of the underlying causes of variation is sparse. Successful implementation likely calls for a multilevel action, with e.g. public campaigns in order to educate the population to recognize STEMI symptoms; and urge the society to establish PPCI service 24 h a day seven days a week with the formation of regional networks between hospitals, including emergency medical system, in order to minimize time delays [9,10].

Studies on factors affecting PPCI implementation has so far mainly been based on surveys or expert opinions [9,11,12]. Modern health care systems are complex and factors affecting PPCI implementation may vary across countries. Studies based on aggregated health care data with countries as the unit of observation, will allow identification of determinants of variation in the economic, demographic and institutional context [11–17]. To our knowledge no such study exists

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within the field of PPCI diffusion across a large number of European countries.

Using aggregated data concerning patients hospitalized with a diagnosis of STEMI from national registries from 12 EU countries, we aimed to: 1) describe the temporal implementation of PPCI, 2) quantify variation in use of PPCI, and 3) investigate whether patient-level factors and country-level financial and healthcare system characteristics were associated with observed differences in the use of PPCI.

2. Methods

"The authors of this manuscript have certified that they comply with the Principles of Ethical Publishing in the International Journal of Cardiology".

3. Design and source population

We conducted an ecological study using aggregated data from the following European countries; Austria, Belgium, Denmark, England, Germany, Italy, Portugal, Spain, Sweden, Scotland, Northern Ireland and Wales.

4. Dependent variable

The primary outcome was utilization of PPCI per 1,000,000 population, which was defined as the annual number of patients (2003 to 2008) with a diagnosis of STEMI who underwent *acute* percutaneous coronary intervention (PCI). Data on the dependent variable were collected from national registries. Table 1 shows the data sources and time periods used for each country. Using the national population estimates on January 1st 2006 published by Eurostat we calculated the annual number of PPCI per 1,000,000 population.

To be eligible for PPCI, patients should meet the following criteria: symptom duration of ≤ 12 h and ST-segment elevation ≥ 0.1 mV in at least 2 continuous leads (≥ 0.2 mV in V_1–V_3) or presumed new-onset left bundle branch block [18,19]. The coding system of PPCI varied between the countries. In the Nordic countries the Nordic Medico-Statistical Committee (NOMESCO) classification of surgical procedures (FNG05A, FNG02A) was used [20]. In all other countries STEMI was based on the *International Classification of Diseases 10th Revision* (*ICD-10*) with the following codes I21.0, I21.1, I21.2, I21.3 and I21.9 [18,19]. In countries where no national PCI registry existed (such as Germany), we received information on ICD-10 STEMI codes combined with the specific procedure codes for PCI (Table 1). As noted in Table 1, a substantial number of the countries were not able to provide PPCI frequencies according to specified symptom duration (and therefore included patients undergoing PCI with a symptom-duration of >12 h).

Of the invited EU15 member countries, nine provided data on utilization of PPCI, for which reason we excluded the following countries: Finland, France, Greece, Ireland, Luxembourg and the Netherlands. Scotland, Northern Ireland and Wales were considered individual countries in the final analysis. We selected 2003 as baseline because this was the year in which the European guideline recommending PPCI as the first choice treatment for patients with STEMI was originally introduced [21]. The guideline was revised in 2008, when we therefore censored our analyses [4,22].

5. Explanatory variables

Eurostat was used as the main data source for the explanatory variables (http://epp.eurostat.ec.europa.eu/portal). Identification of factors potentially affecting the diffusion of PPCI was based upon a literature review and availability of data. Table 2 provides a list of potential explanatory variables by data source and their hypothesized influence on the implementation of PPCI. Computerized and validated information on the explanatory variables from Eurostat were available for 2006, with a few exceptions where the most current available year was used.

The first group of variables, considered 'demand variables,' includes age (categorized into 4 groups), gender, and average life expectancy of men and women.

The second group of variables, labeled 'supply variables,' includes human capital and financial capital. We hypothesized that availability of resources in a country would affect the level of implementation. Human capital was expressed as the number of physicians (medical group only) per 100,000 population, total number of nurses and midwifes working per 100,000 population and percentage of the population with the highest educational level according to the *International Standard Classification of Education* (*ISCED*) *system* groups 5 and 6 [23]. Because few countries had data concerning the numbers of cardiologists, we used the total number of medical physicians as a surrogate. As a measure of financial capital, we used the Gross Domestic Product (GDP) per capita (expressed in Euros purchasing power parity (PPP)), and the number of acute care hospital beds per 100,000 population, which was also considered an indicator of the efficiency of the health care sector. The number of acute care beds and educational level were only available for the combination of Scotland, Wales and Northern Ireland, therefore this single value was used for all of them.

The last group of variables, called 'framework conditions,' included characteristics of each country's health care system in 2006 based on classifications made by *The Organization for Economic Co-operation and Development* (*OECD*) [24] and *The Health Care System in Transition* reports (HiTs) from the European Observatory on Health Systems and Politics (www.euro.who.int/observatory/Hits). We classified health care systems according to the degree to which health care financing and delivery systems are publicly controlled or administered: 1) the public integrated model, 2) the public contract model and 3) the private insurance/public provider model (mixed model). Countries with organizational model 1 were Denmark, Italy, Spain, Sweden and UK. Countries with organization model 2 were Germany and Belgium. Countries classified with organization model 3 were Austria and Portugal. Hospital remuneration schemes were either fee-for-service remuneration systems, per case remuneration schemes (diagnosis-related group based (DRG)), or fixed remuneration schemes (global budget) [24]. Two types of remuneration schemes describe physician payments. Finally, we registered population density per km^2.

6. Data sources and comparability

6.1. Eurostat

The statistical office of the European Union (Eurostat) was established in 1953. Eurostat collects and verifies national- and regional-level statistics from the statistical authorities of the member countries. Eurostat ensures comparable data across countries and regions over time. The European Statistical System undertakes quality reporting, which can be consulted at the Eurostat homepage (http://epp.eurostat.ec.europa.eu/portal/page/portal/about_eurostat/introduction).

6.2. The European Observatory

The European Observatory on Health System and Policies is a partnership among several European Health Institutions and local governments that supports and promotes evidence-based health policy-making through comprehensive and rigorous analysis of health care systems in Europe. In order to maximize comparability across countries, a standard template and questionnaire are used when producing country reports (HiTs) (www.euro.who.int/observatory/Hits). Using the information from these reports provided the most comparable analyses of the health care systems for the countries.

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Table 1
Data sources for the dependent variable — primary percutaneous coronary intervention (PPCI), by European country.

Country	Year	Data source and content
Austria	2003–2008	Austrian Health Information System ÖGIS at Ministry of Health statistics Population based registry — includes all hospitalized patients — information on hospital admissions since 1992. Registration is regarded representative PPCI defined as PPCI in patients with diagnosed STEMI (ICD10) •Registration includes rescue and facilitated procedure •No national PCI registry exists
Belgium	2006–2008	Belgian registry of PCI — Belgian STEMI registry Registration of all STEMI patients admitted in Belgian hospitals — includes 32 cardiac centers in Belgium Registry is regarded representative PCCI defined as PPCI in patients with diagnosed STEMI (ICD10) •Registration includes rescue and facilitated procedures •No national PCI registry exists
England	2003–2008	MINAP registry — Myocardial Ischaemia National Audit Project Population based registry on STEMI treatment and management Includes patients hospitalized with an acute coronary syndrome in England and Wales since 1999. No mandatory registration, registry regarded representative PPCI defined as PPCI in patients with diagnosed STEMI (ICD10) •Registration does not include rescue and facilitated procedures
Denmark	2003–2008	Danish Heart registry Population based registry — includes all coronary angiographics and revascularizations by PCI and CABG at Danish hospitals since the year 2000. Registry is regarded representative PPCI defined as PPCI (procedure codes KNFG05A, KNFG02A) in patients with diagnosed STEMI (ICD10) •Registration includes rescue and facilitated procedures
Germany	2005–2008	National statistics Germany "Statistisches Bundesamt" Population based registry on hospitalized patients. Registration is regarded representative PPCI defined as PPCI (procedure code OPS-8-837 (OPS version 2009)) in patients with diagnosed STEMI (ICD10) •Registration includes rescue and facilitated procedures
Italy	2003–2008	GISE registry, Italian Society of Interventional Cardiology. Registration of coronary angiographics and Revascularizations by PCI and CABG at all Italian hospitals. Registry is regarded representative PPCI defined as PPCI in patients with diagnosed STEMI (ICD10) •Registration includes rescue and facilitated procedures
Portugal	2003–2008	Population based registration of cardiovascular disease and treatment since 2007. Registry is regarded representative PPCI defined as PPCI in patients with diagnosed STEMI (ICD10) •Registration includes rescue and facilitated procedures
Spain	2004–2008	Spanish Cardiac Catheterization and Coronary Intervention Registry Registry comprises all cardiac catherization laboratories in Spain. Registration began in 1990. Registry is regarded representative PPCI defined as PCI in patient with diagnosed STEMI (ICD10) •Until 2007 the registration includes rescue and facilitated procedures
Sweden	2004–2008	Swedeheart Population based registry — includes all coronary angiographics and revascularizations by PCI and CABG at all Swedish hospitals Registry is regarded representative PPCI defined as PPCI in patients with diagnosed STEMI (ICD10) •Registration does not include rescue and facilitated procedures
Scotland	2003–2006	Population based registry — registration of all coronary angiographics and revascularizations by PCI and CABG at all Scottish NHS hospitals since 1996, PCI since 1997. Registry is regarded representative PPCI defined as PPCI in patients with diagnosed STEMI (ICD10) •Registration includes rescue and facilitated procedures
Northern Ireland	2003–2008	Northern Ireland Statistics and Research Agency (NISRA) Population based registry — Includes all hospitalized patients — information on hospital admissions since 2000 PPCI defined as PPCI in patients with diagnosed STEMI (ICD10) •Registration includes rescue and facilitated procedures
Wales	2003–2008	MINAP registry — Myocardial Ischaemia National Audit Project Population based registry on STEMI treatment and management Includes patients hospitalized with an acute coronary syndrome in England and Wales since 1999 PPCI defined as PPCI in patients with diagnosed STEMI (ICD10) •Registration does not include rescue and facilitated procedures

7. Analysis

Individual countries' implementation curves were plotted. The annual change in implementation per country was modeled using linear regression. A multilevel random slope model of the rate and level of PPCI procedures within countries over years was built to study the relationship between growth in PPCI use per million population and country-level covariates (where covariates were included as grouped variables). A natural log (ln) transformation was used to correct for right skewness of PPCI per million population and the model was fitted via maximum likelihood.

A forward inclusion of statistically significant covariates and their interaction with year of performed acute percutaneous reperfusion was performed. Table 3 shows all the included variables adjusted for the covariates found to be statistically significant. All regression estimates are presented as antilogarithms along with their corresponding 95% confidence intervals (CI) and p-values, so represent the geometric mean growth in PPCI use. All tests were two-sided, and a p-value less than 0.05 was used as a cut-off for statistical significance. All analyses were conducted using Stata 10.1 (Stata Corporation).

8. Results

8.1. Trends in PPCI implementation

Fig. 1 depicts the implementation of PPCI from 2003 to 2008 for each country. The three countries with the highest utilization levels were Germany, Austria and Denmark, while utilization was lowest in Wales — which like England and Sweden did not include PPCI over 12 h, rescue or facilitated PCI. By 2008, Germany and Austria performed

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Table 2
Variables, description, data sources and hypothesized influence used for this study.

Topic	Variable	Description	Data source	Year	Hypothesized influence
Demand factors					
Social and demographic variables	Prevalence of STEMI	(ICD10 DI21.0, 21.1, 21.2, 21.3, 21.9) Defined as the annual in hospital discharges of STEMI	National statistics	2003–2008	
(population structure)	Population	Total population January 1st	EUROSTAT	2006	
	Age	Age <30 Proportion of population aged 30 years or less	EUROSTAT		÷
		Age 30–<50 Proportion of population aged 30–49 years	EUROSTAT	2006	+
		Age 50–<70 Proportion of population aged 50–69 years	EUROSTAT	2006	+
		Age 70+ Proportion of population aged 70 years or more	EUROSTAT	2006	÷
	Gender	Proportion of males in the country	EUROSTAT	2006	+
	Life expectancy	Estimated life expectancy, males and females	EUROSTAT	2006	+
Supply factors					
Supply of health care services	Numbers of PPCI	(Emergency procedure within 12 h, national procedure coding. NOMESCO coding (FNG05A, FNG02A) in the Nordic countries. If not able to provide procedures time specified, then procedures are defined as PPCI in patients with STEMI. Where not specified this include both urgent and rescue procedures. Most countries do not register the time factor.	National statistics	2003–2008	
	Number of physicians per 100,000 population	Medical group of specialties includes e.g. cardiology, internal medicine and Gastroenterology. Full-time equivalent, working in hospital	EUROSTAT	2006	+
	Number of nurses and midwives per 100,000 population	Nurses and midwifes working in hospital. Full-time equivalent	EUROSTAT	2006	+
Supply of health care services	Number of acute care hospital beds per 100,000 population	Curative care beds in hospitals or hospital department with average length of stay 18 days or less	EUROSTAT	2006	−
	Educational level	Percentage of people between 25 and 64 years old who have completed the highest levels of schooling according to the International Standard Classification of Education (ISCED) system Group 5 & 6	EUROSTAT	2006	+
	GDP per capita	Gross Domestic Product per capita in Purchasing power parity (PPP) Euro	EUROSTAT	2006	+
Framework conditions	Population density	Average population density per square km	EUROSTAT	2006	+
	Hospital remuneration scheme	1) Global budget	National statistics bureaus	2006	−
		2) Fee-for-service	European Observatory HIT		÷
		3) Per discharge (DRG)	country reports		+
	Physician remuneration scheme	1) Fee-for-service	National statistics bureaus	2006	+
		2) Fixed salary	European Observatory HIT country reports		−

about 700 PPCI per million inhabitants. These two countries performed roughly 4 times the number of PPCI as did, for instance, Wales. We found a year on year increase in the use of PPCI for every country except Germany and Denmark, where the curves peaked in 2006 and 2007, respectively. Overall, an increase in utilization was evident over the 5 years studied. The total growth was greatest in Italy, Sweden and Austria, where utilization almost doubled over the years. The annual country specific changes in utilization were estimated to range from 0.82 per million (Wales, 95% CI 0.52, 1.30) to 1.38 per million (Scotland, 95% CI 1.15, 1.64).

8.2. Predictors of utilization of PPCI

Table 3 presents both the unadjusted and adjusted impact of the covariates on the growth in utilization of PPCI over time. The analyses revealed a significant correlation between physicians per 100,000 population; nurses and midwifes per 100,000 population, acute care beds per 100,000 population, proportion of people under the age of 50, population density per km^2, and the utilization of PPCI. Between 2003 and 2008, countries with 200–<300 physicians per 100,000 population had an increase in PPCI utilization of 5.39 (95% CI 2.74, 10.61) procedures per 1,000,000 population compared with countries with 200–<300 physicians per 100,000 population. The growth was less in countries with a higher underlying basis of physicians (Table 3).

Countries with more acute care beds per 100,000 population experienced a larger yearly growth in PPCI utilization of, on average, 3.16 (95% CI 1.78, 5.61) (300–<350 compared to <300) and 5.63 (95% CI 3.22, 9.85) (350+ compared to <300) compared with countries with fewer acute care beds per 100,000 population.

Countries with a large proportion of people under the age of 30 experienced a slower growth in utilization of PPCI 0.9 (95% CI 0.9, 1.0) per 100,000 population, whereas countries with a large proportion of inhabitants between the age of 30–< 50 experienced a faster growth in PPCI utilization 1.20 (95% CI 1.03, 1.41) per 100,000 population.

After adjustment, both nurses and midwifes per 100,000 population and population density per km^2 became significantly associated with growth in PPCI over time (Table 3). Countries with fewer nurses and midwifes experienced a faster growth in PPCI, 2.22 (95% CI 1.40, 3.52) for countries with 300–<600 nurses and midwifes per 100,000 population and 1.03 (95% CI 0.56, 1.89) for countries with 600–<800 nurses and midwifes per 100,000 population compared with countries with >800 nurses and midwifes per 100,000 population.

Countries with both a low population density per km^2 (<100 per km^2, 0.86 (95% CI 0.55, 1.35) as well as a high population density per km^2 (200+ per km^2, 0.49 (95% cI 0.32, 0.77) experienced a slower yearly growth in PPCI utilization compared with countries with a population density per km^2 of 100–<200. There were no associations between growth in utilization and other 'demand factors', except young age or

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Table 3
Characteristics of possible factors associated with the variation in utilization of primary percutaneous coronary intervention (PPCI) per 1,000,000 population in selected European countries.

Covariate	Unadjusted regression coefficient (95% CI)[a]	Adjusted regression coefficient (95% CI)[b]	P-value
Age			
<30	0.76 (0.66, 0.87)	0.91 (0.85, 0.99)	0.04
30–<50	1.79 (1.32, 2.44)	1.20 (1.03, 1.41)	0.02
50–<70	1.44 (1.00, 2.07)	1.26 (0.85, 1.87)	0.25
70+	1.54 (1.04, 2.28)	0.79 (0.53, 1.18)	0.25
Male gender	2.14 (0.84, 5.45)	1.27 (0.96, 1.70)	0.10
Life expectancy males	0.93 (0.66, 1.33)	1.07 (0.94, 1.20)	0.31
Population density per km^2			
<100	1.74 (0.48, 6.38)	0.86 (0.55, 1.35)	<0.001
100–<200	Reference	Reference	
200+	2.35 (0.58, 9.57)	0.49 (0.32, 0.77)	
Covariate	**Unadjusted regression coefficient (95% CI)[a]**	**Adjusted regression coefficient (95% CI)[b]**	**P-value group level**
GDP per capita in PPP EURO			
20,000–<25,000	1.48 (0.13, 3.38)	1.87 (1.08, 3.24)	0.5
25,000–<30,000	Reference	Reference	
30,000+	2.26 (0.66, 7.71)	0.57 (0.36, 0.90)	
Physicians per 100,000 population			
200–<300	Reference	Reference	<0.0001
300–<360	8.04 (3.99, 17.71)	5.39 (2.74, 10.61)	
360+	13.78 (5.82, 32.67)	2.33 (1.12, 4.87)	
Number of nurses/midwifes per 100,000 population			
300–<600	2.20 (0.49, 9.91)	2.22 (1.40, 3.52)	<0.0001
600–<800	2.62 (0.79, 8.61)	1.03 (0.56, 1.89)	
800+	Reference	Reference	
Numbers of acute care beds per 100,000 population			
<300	Reference	Reference	<0.0001
300–<350	0.67 (0.24, 1.91)	3.16 (1.78, 5.61)	
350+	3.60 (1.10, 11.73)	5.63 (3.22, 9.85)	
Percent of population with highest educational level (ISCED index 5–6)			
<45		Reference	0.21
45+	0.76 (0.22, 2.62)	1.29 (0.87, 1.91)	
Organization of the health care system			
Public integrated	Reference	Reference	0.29
Public contract and mixed	2.84 (1.01, 8.01)	0.76 (0.46, 1.27)	
Reimbursement of hospitals			
Global budget	Reference	Reference	0.41
Public integrated	2.81 (0.47, 16.67)	0.65 (0.27, 1.60)	
Mixed	3.52 (1.30, 9.55)	10.73 (0.45, 1.19)	

[a] Based on random coefficient model.
[b] Based on random coefficient model adjusted for number of physicians per 100,000, numbers of acute care beds per. 100,000 and proportion of the countries' population <30 and 30–<50 years old.

'framework conditions' such as gender, GDP per capita and educational level. Moreover, we found no interaction between time and the explanatory variables.

9. Discussion

9.1. PPCI patterns

This study describes substantial between-country variation in the numbers of patients with STEMI who received acute PCI per 1,000,000 population between 2003 and 2008. It agrees with the geographical variation reported by the OECD in 2003 [25] and Widimsky et al. in 2009 [7]. Moreover, these reports described high utilization rates in Germany and low utilization rates in the UK. In the OECD report, patterns of implementation were based on numbers of PCI. However, a study from the Technological Change in Health Care (TECH) Research Network published in 2009 emphasized international variation in use of PPCI, more so than coronary angiography, PCI, and coronary artery bypass grafting [15].

One explanation for the observed variations could be the underlying demand for PPCI, expressed as the level of disease (STEMI). Unfortunately, the incidence and mortality from STEMI are not continuously monitored by surveillance registries, and very few countries have sufficient national coverage and availability of reliable and valid healthcare data including activity data for PPCI [11,26]. Measuring the appropriate utilization rates is important to help manage treatment use, to assess and plan hospital performance, and to improve quality of care in the future [11,16,23]. However, we do not believe that potential differences in disease burden in western European countries fully explain our findings. Utilization rates for PCI, as an example, are considerably higher in Portugal than in the UK, despite the latter's higher level of ischemic heart disease (standardized discharge rates per 100,000 population 113.1 vs. 164.6 (2006)) (OECD health database).

Differences in utilization appear more related to geographical variation in clinical practice and hospital type, especially availability of suitable PCI facilities (number of catheterization laboratories and revascularization centers) rather than to patient type and risk or outcome [15,16,27]. An earlier study suggested that in relatively low income countries, the capacity constraints are associated more with capital than a qualified labor force [25].

10. Health care personnel

10.1. Number of physicians

We demonstrate an association between the availability of physicians and growth in PPCI utilization. Earlier studies of barriers to implementation of PPCI have reported heterogeneous results [12,14–16,23]. A sufficient cardiology workforce *is* necessary to ensure access to high quality cardiovascular care including PPCI. Our findings are particularly relevant for policy makers — they indicate that availability of physicians with the requisite skills is associated with the implementation of new innovations. Furthermore, concerns have been raised about potential gaps between the demand for, and the supply of, health care professionals, which may emerge in the future in light of demographic changes, increasing income, earlier retirement, growing specialization and increasing international mobility [28,29]. Shortage of physicians should, therefore, continue to be of focus in the health care policy arena.

10.2. Number of nurses and midwifes

We found that a reduced number of nurses and midwifes resulted in a steeper growth in PPCI utilization from 2003 to 2008. The ratio of nurses to physicians varies widely across Europe. Shortages of physicians have led to replacement of physicians with nurses as a way of maintaining productivity [29]. In our study, countries with a high number of nurses and midwifes had a tendency also to be the countries with the lowest number of physicians (Scotland, Northern Ireland and Wales). This association might reflect an overall lack of physicians, and thereby a necessary change in the skill-mix of the health care workforce. However, changing the skill-mix to achieve higher usage rates is not possible with this particular technology (PPCI), which at present is fully dependent on availability of specialized physicians [29]. The secondary data precluded separation between nurses and midwifes or area of specialty. This may have biased the estimated association between nurses and midwifes and PPCI utilization. However, we found no existing studies addressing this issue.

Whereas the number of physicians clearly contributes to utilization, it is the hospital that employs the healthcare personnel and purchases

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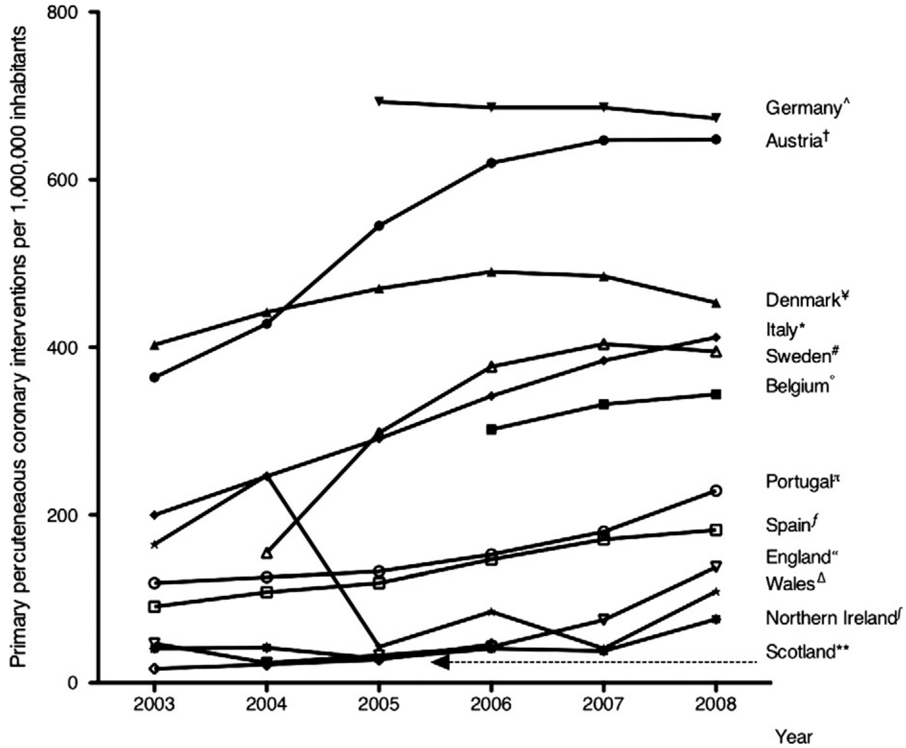

^ 0.99 (CI 0.98-1.01)	Registration includes both PPCI ≤12 and >12 hours, see also Table 1
† 1.13 (CI 1.06-1.20)	Registration includes both PPCI ≤12 and >12 hours, see also Table 1
¥ 1.03 (CI 0.99-1.07)	Registration includes both PPCI ≤12 and >12 hours, see also Table 1
* 1.16 (CI 1.12-1.20)	Registration includes both PPCI ≤12 and >12 hours, see also Table 1
# 1.24 (CI 0.97-1.59)	Registration only includes PPCI ≤12 hours, see also Table 1
° 1.07 (CI 0.87-1.31)	Registration includes both PPCI ≤12 and >12 hours, see also Table 1
π 1.14 (CI 1.08-1.19)	Registration includes both PPCI ≤12 and >12 hours, see also Table 1
ƒ 1.16 (CI 1.13-1.19)	Registration includes both PPCI ≤12 and >12 hours, see also Table 1
“ 1.29 (CI 0.97-1.72)	Registration only includes PPCI ≤12 hours, see also Table 1
Δ 0.82 (CI 0.52-1.30)	Registration only includes PPCI ≤12 hours, see also Table 1
ʃ 1.09 (CI0.90-1.33)	Registration includes both PPCI ≤12 and >12 hours, see aso Table 1
** 1.38 (1.15-1.64)	Registration includes both PPCI ≤12 and >12 hours, see aso Table 1

Fig. 1. Number of primary percutaneous coronary interventions per 1,000,000 inhabitants including annual changes in implementation with 95% confidence intervals (CI) for 12 European countries, 2003–2008.

the equipment. For this reason, we hypothesized that financial incentives to hospitals would be a driver for PPCI implementation. Yet, we found no significant association between payment methods and utilization of PPCI, in contrast to earlier European findings [15]. Nor were we able to reveal an association between remuneration methods for physicians and utilization of PPCI, which has been reported by a number of studies especially for high-cost procedures, such as PPCI [15,16,25].

11. Number of acute care beds

Perhaps the most striking result was the positive effect on utilization rates associated with number of acute care beds. International perspectives on this finding, however, are unclear. A negative association between the number of available hospital beds and implementation of complex medical innovations has been reported, indicating that the availability of more sophisticated medical equipment (in more mature medical systems), may in the long run prevent unnecessary hospital admissions and, therefore, tends to lead to a progressive reduction in the number of beds. Alternatively, it could be evidence of what is known as Roemer's law — *s*, [30] thus a consequence of supplier induced demand. Moreover, it could mean forced cuts in spending, which is more in line with our findings [31,32]. Last, hospital size has been reported to play a predominant role in the implementation of various technologies in different countries — larger hospitals (>500 beds) adopt procedures earlier than small hospitals (<250 beds) [32].

12. Population density

We found that countries with both low and high population density per km^2 had a slower growth in PPCI utilization compared with countries with a medium population density. This result agrees with studies reporting that widespread adoption of PPCI is potentially limited by anticipated transport delays, and practicalities associated with transporting the patients to appropriate treatment facilities within the recommended timeframe [11,33–35]. Different complexity of infrastructure in the rural as well as the metropolitan areas, has prompted countries to build PPCI networks between hospitals and the emergency medical system leading to reductions in case fatality [36].

13. Age

We found a significant positive relationship between growth in PPCI utilization and age less than 50 years. Ischaemic heart disease is an age related disease, so an age dimension on treatment utilization would be expected [37].

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14. Supply and demand

Our study demonstrates a link between health care system supply-side incentives and the level of implementation of PPCI. Evidence suggests that supply-side characteristics have a stronger influence on treatment patterns than do demand-side characteristics [16,23,31]. Supply-side constraints reflect a complex interaction between financial and human capital that determines utilization levels. Given the universal health care coverage afforded to citizens in European countries, it is not a surprise that supply factors are important [25]. We found, however, that universal coverage does not necessarily guarantee similar utilization rates for treatment across countries. Our study highlights some of the challenges in the evaluation of the relationship between the population-based rates of PPCI and capacity. While it is known that the clinical demand for PPCI has prompted European countries to establish regional cardiac networks [36], our study was not designed to capture the existence of such networks. Future studies should aim to quantify this and the impact of any variation in PPCI implementation on regional outcomes [38].

15. Strengths and limitations

The main strength of our study is that STEMI is a relatively common and well-defined clinical condition worldwide, allowing international comparison of diagnoses and treatment. Second, most STEMI patients are initially hospitalized providing reliable inpatient data across countries. Third, uniform definitions of the explanatory variables were available through Eurostat. Fourth, PPCI implementation has changed rapidly in recent years, allowing the investigation of implementation patterns. With this study we were able to link numerous European cardiovascular registries.

The main limitation of this study is the data quality, and several points should be highlighted. First, the data are on an aggregate level, preventing inclusion of patients' characteristics. Second, the reliability and comprehensiveness of the information of PPCI utilization in STEMI patients is dependent upon registry quality, and the completeness and design of the registries varied. Consequently, incomplete or inconsistent reporting from hospitals may lead to over- or underestimation of the factual use and thereby existing variation. Although, we tried to identify the magnitude of the problem by seeking as much information as possible about the registration methods, validity and completeness of the registries, there are errors that we cannot overcome, and that needs to be kept in mind when comparing across countries. This is especially true for the definition of PPCI. In countries like Germany and Austria, we received information from their national statistical bureaus on STEMI patients receiving PPCI. These registrations include the number of patients receiving PCI after 12 h of symptom debut and those who received rescue and facilitated PCI, which will overestimate PPCI use. According to the available registries, these procedures comprise over 20% of the total PPCI procedures per year (Italy and Berlin, Germany). Moreover, not all countries were able to provide data on all five years.

Third, explanatory variables were registered for the year 2006, yet we modeled PPCI use from 2003 to 2008. Interactions between time and the explanatory variables were reported by Bech et al. in 2009. Almost consistently, the interactions seemed to diminish over time or reverse the main effects [15]. This is consistent with the general implementation dynamics of technology where the spread of knowledge of use, experience, and updates to health care practice guidelines play a significant role on adoption, particularly as the technology matures [15]. Our study revealed no interaction between time and the explanatory variables, it should however be interpreted with caution taking the size of the data material into account.

Finally, given the complexities of such a large and diverse set of information, it was not possible to collect data for all the first intended indicators for all participating countries. Therefore, we were only able to address some of the key issues hypothesized to influence implementation of PPCI, while leaving some topics for further research.

16. Perspectives and conclusions

While making cross-country comparisons with these data is challenging, these results nevertheless are instructive in presenting a picture of the striking international variation in the use of and uptake of PPCI for STEMI across several European countries. Our study was designed to shed light on health care system level factors, whereas much remains to be answered about the influence of patient-level factors on variation. The results of our study should be seen as a preliminary step in exploring the large interplay of factors causing variation of implementation of life-saving treatment across Europe. The main obstacle limiting analyses of health care utilization and outcomes is the lack of a sound scientific European database on PPCI and STEMI. Good quality data at both the macro- and micro-level is a requisite for identifying barriers and to target initiatives, as well as for monitoring and evaluating treatment use, quality of care and effects.

In conclusion, this study demonstrates the uptake of PPCI across Europe. It highlights the significant between-country variation in the use of PPCI. Differences in utilization rates of PPCI can partly be explained by countries' supply factors such as the number of physicians and number of acute care beds, rather than financial factors. The impact of different constraining measures as well as patient-level factors will need to be further investigated to explore their relationship with PPCI implementation and outcomes for patients with STEMI.

Conflict of interests

Conflict of interests: none declared.

Contributorship

KGL, TLL and SDK conceived the study idea and designed the study. KGL collected the data. KGL and SDK reviewed the literature. KGL and TLL directed the analyses, which were carried out by KGL and TLL. CPG revised the analysis. All authors participated in the discussion and interpretation of the results. KGL organized the writing and wrote the initial draft. All authors critically revised the manuscript for intellectual content and approved the final version.

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