Socio-geographical factors associated with cardiac rehabilitation participation after percutaneous coronary intervention: A registry-based cohort study from France

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Abstract

Aims: Cardiac rehabilitation (CR) after percutaneous coronary intervention (PCI) for acute (ACS) or chronic (CCS) coronary syndrome is underutilised worldwide. The determinants of underuse are not fully understood. Using real-world data, this study explored the effect of socio-geographical factors on CR participation.

Methods: Patients from the Aquitaine region (France) who underwent PCI between 2017 and 2019 were selected from a regional PCI register. Their 1-year CR participation was tracked using the French hospital database. Associations between CR participation and socio-geographical factors, (social deprivation, general practitioner accessibility, and distance to the nearest CR centre) were assessed through logistic regression mixed models at 1 and 3 months in ACS, and at 3 and 6 months in CCS.

Results: Among the 19,002 patients, 5,073 (26.7%) participated in CR (ACS: 4,071, 33.0%; CCS: 1,002, 15.0%). A CR centre distance >25 km reduced participation at 3 months in ACS patients (OR = 0.83, 95% CI: 0.70–0.99, p = 0,023), but not at 1 month after PCI. CCS patients from most advantaged areas were more likely to participate in CR at 3 (OR = 0.62, 95% CI: 0.44–0.88, p = 0.002) and 6 months (OR = 0.59, 95% CI: 0.42–0.82, p < 0.001). General practitioner accessibility did not affect participation.

Conclusion: Post-PCI CR participation was low. Proximity to CR centres promoted participation for ACS patients, while CR usage correlated with higher socio-economic status for CCS patients. These findings highlight socio-geographical inequalities in CR access, providing a basis for targeted interventions, such as telerehabilitation or expanded coverage.

Keywords

Coronary heart disease, Percutaneous coronary intervention, Health inequalities, Geographic variation, Cardiac rehabilitation, primary care

Lay Summary

This study examined socio-geographical factors associated with participation in recommended cardiac rehabilitation programs following percutaneous coronary intervention in patients with coronary heart disease in France.

• Only one-third of patients with acute coronary syndrome and 15% of those with chronic coronary syndrome participated in these beneficial programs.

• Patients with acute coronary syndrome living far from cardiac rehabilitation centres and patients with chronic coronary syndrome living in most deprived areas had reduced access to cardiac rehabilitation programs. General practitioner availability did not seem to influence participation in these programs.

Health policies should consider place of residence and socio-economic status as factors influencing participation in cardiac rehabilitation programs and develop standardized post-PCI rehabilitation pathways. These pathways should integrate targeted interventions, such as telemedicine, automatic referrals and increased access to rehabilitation services, to address disparities and improve patient outcomes.

Introduction

Coronary heart disease (CHD), resulting from an acute (acute coronary syndrome, ACS) or chronic (chronic coronary syndrome, CCS) reduction in blood flow to the heart muscle, is the second leading cause of death and a major cause of years of life lost in most developed countries, including France [1,2]. Revascularization, achieved through percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG), is the preferred treatment for ACS, including myocardial infarction (MI), and is also recommended for selected CCS patients who exhibit cardiovascular symptoms despite optimal medical therapy [3].

Cardiac rehabilitation (CR) is a comprehensive multidisciplinary intervention that includes exercise training, physical activity counselling, education, risk factor modification, diet/nutritional counselling, and vocational and psychosocial support [4]. The European Society of Cardiology strongly recommends participation in CR programs for post-revascularization patients [4,5], emphasizing its role in the clinical management and secondary prevention of both ACS and CCS [6,7]. CR programs offer significant benefits, including reduced MI risk, potential decrease in all-cause mortality, substantial reductions in all-cause hospitalization and healthcare costs, and improved quality of life for up to 12 months [8]. Late referral to CR—over 1 month after revascularization for ACS and CCS—is related to reduced life expectancy and increased healthcare costs, indicating the importance of timely CR as a key public health initiative [4,9].

Despite the clinical benefits and cost-effectiveness of CR, its global uptake remains low. CR programs are available in only half of countries, with less than 30% of eligible patients participating [10,11]. Participation rates vary widely: in the United States, CR participation after PCI ranges from 7% to 53% across states, with a national average of just 14% for acute MI patients. In Canada, 34% of patients attend CR after cardiac hospitalisation, with about half referred after PCI. A European survey reported that less than half of patients are advised to attend CR programs after revascularisation or coronary events [11]. Despite standardized CR core goals and components, this variance arises due to differences in the organization of services and referral modalities, influenced by national guidelines, standards, legislation, and payment factors [4]. In France, since 2008, CR has been provided by specific rehabilitation services (*Soins de Suites et Réadaptation*, SSR) for both outpatients and inpatients. CR centres must obtain authorization and adhere to specific technical standards. However, a national retrospective study revealed that only 36.9% of ACS patients accessed rehabilitation units within 6 months after ACS between 2010 and 2014, with just 28.5% enrolling in specific CR programs [1]. A similar rate was found in 2019, with 22% of people suffering from ACS receiving CR one year after PCI [2].

Several individual-level factors and interventions have been identified as potential ways to increase CR participation rates [10]. A systematic review examining factors negatively associated with CR uptake identified intrapersonal, clinical, and health system factors, such as comorbidities, sex, MI severity, lack of referral, and low clinician endorsement, as significant barriers to CR access, alongside logistical challenges including travel distance to CR centres [1,12]. This highlights the importance of socio-geographical determinants of CR uptake. For most cardiovascular disease patients, proximity to care is a priority [13]. Therefore, it is essential to analyse health inequalities not only based on social characteristics but also considering spatial dimensions [14]. Three dimensions of spatial inequality have been described: physical environments, social characteristics of the population, and spatial accessibility of healthcare [14,15]. Although some socio-geographical factors affecting CR use have been individually investigated [16,17], a comprehensive assessment of all residence-related influencing factors is lacking. Socio-geographical factors have also been shown to influence outcomes in ACS and CCS [18,19]. In France, higher mortality rates for ACS have been correlated with lower socio-economic status at the place of residence [20]. Interestingly, CR participation has been shown to mitigate the adverse effects of socio-geographical factors on MI, including rehospitalisation and mortality [21].

Coronary registries systematically collect real-world data on patient care pathways post-revascularization, offering invaluable insights into the impact of socio-geographical factors on healthcare service utilization, including CR [22]. In the context of the former Aquitaine region of South-western France, with a population of approximately 3.3 million, the Cardio Neurovascular (CNV) registries have been evaluating the care pathways for CHD and stroke patients since 2012. The comprehensive and prospective cohort of PCI and invasive coronary angiography (ICA) within the CNV registries presents a unique opportunity to investigate care management and its evolution across the region's 11 catheterization laboratories (Cath labs) and other health services involved in ACS and CCS care [22].

This study leveraged cohort data to address knowledge gaps regarding the effect of socio-geographical factors on CR participation in a country with universal health coverage. Specifically, it examined the interplay among socio-geographical factors, including area of residence, social deprivation, accessibility of general practitioners (GPs), and distance from the nearest CR centre. By providing a comprehensive analysis of these factors in France over 2 different time frames, this research fills critical gaps in understanding how spatial and social determinants influence CR uptake for both CCS and ACS patients. The findings will offer insights into targeted interventions to enhance equitable access to CR and mitigate the adverse effects of socio-geographical disparities and could be applied in other contexts with a universal healthcare system. Separate analyses were conducted for ACS and CCS to determine whether the same socio-geographical factors influenced access to CR across these patient groups, providing insight into whether targeted interventions could benefit both ACS and CCS patients. Finally, it explored whether socio-geographical factors had the same effects on early and late referral to CR.

Methods

Study design and population

We conducted a multicentre retrospective cohort study of patients who underwent PCI for ACS or CCS, using data from the exhaustive PCI/ICA cohort of the CNV Registries in the Aquitaine region, France, linked with the exhaustive French hospital medical information system database (Programme de médicalisation des systèmes d'information [PMSI]). Through data linkage with the PMSI, patients' hospitalizations could be tracked for up to 5 years, including access to CR services [22].

Patient selection

The study population included patients from the PCI/ICA cohort of the CNV registries who underwent PCI for ACS (ST segment elevation MI [STEMI] or non-ST segment elevation MI [NSTEMI]) or CCS (stable angina, silent ischemia, or other cardiac ischemic conditions) between 1 January 2017 and 31 December 2019 in the eleven Aquitaine Cath labs. Enrolled patients were residents of the Aquitaine region and older than 18 years. Patients who refused to participate in the CNV registries, who died during hospitalization when PCI was performed, were hospitalized for CABG or PCI procedures the month before the index PCI, or were not matched with any PMSI identifier were excluded from the study.

Data collected and linkage

The PCI/ICA cohort of the CNV registries contains information on sociodemographic characteristics (age, gender, place of birth, place of residence), patient clinical characteristics (cardiovascular risk factors: diabetes, dyslipidaemia, active smoking in the last 3 years, hypertension, obesity [BMI > 30]; previous neuro-cardiovascular events: MI, PCI, CABG, stroke or transient ischemic attack [TIA], renal insufficiency, peripheral arterial disease, heart failure with ejection fraction < 40%, therapy with anticoagulants), characteristics of the Cath lab (type of hospital, presence of a CR service in the Cath lab centre), and characteristics of the care pathway (cardiovascular events during PCI hospitalization, medical rehospitalisation within 30 days of PCI, participation in CR in outpatient or inpatient settings for ≤ 1 year). The data, primarily extracted from the hospital information system, are integrated into a single data warehouse, enabling the reconstruction of each patient's management pathway. At the municipality level, the place of residence is associated with its socio-geographical features (urban residence, social deprivation, accessibility of GPs, and distance to the nearest CR centre). Place of residence was classified as urban or rural according to the Institut National de la Statistique et des Études Économiques definition.

A deterministic data-matching algorithm was used to merge the PCI/ICA cohort and the 2017–2020 PMSI database to obtain 1-year follow-up data for all hospitalizations in medical and rehabilitation units [23]. The PMSI is an ongoing and exhaustive collection of anonymized and standardized hospital information providing detailed information on hospital healthcare pathways, hospital activity, and expenditure, including length of stay, in-hospital mortality, and all diagnoses and procedures coded in public or private hospitals, including CR services. Data linkage was performed for 12 hospital variables in the anonymized PMSI database and the PCI/ICA cohort [22]. As described elsewhere [23], the matching level between the two databases was 97.2% and no significant difference was observed between matched and unmatched patients.

The CNV registries and data linkage for this study were approved by the French authority on data protection and met the regulatory requirements for handling patient information (approval no. 2216283).

Outcomes

The study endpoints were participation in CR after reperfusion for ACS and CCS. CR participation was identified by the presence in the PMSI records of ICD-10 code Z50.0 (“cardiac rehabilitation”) as the main purpose of care, or the presence of “diseases of the circulatory system” and a stay in an establishment with CR authorization (ICD-10 codes 53A and 54A, respectively) in the French Hospitals Annual Statistical Record (Statistique annuelle des établissements de santé), and the presence of acts of CR according to the French classifications of medical and rehabilitative acts (CCAM and CSARR, respectively) performed all over France.

Due to the different clinical referrals for these two populations, four different endpoints after PCI were considered: 1 and 3 months for ACS patients and 3 and 6 months for CCS patients. Although 1 month after PCI is the optimal time for initiating CR [9], we considered a longer delay for CCS patients due to evidence of delays in accessing CR after PCI and actual practice reports from CR experts. We considered only CR activities within 6 months of PCI to maximize the probability of a link with the initial procedure. The time interval between the discharge day of the PCI index stay and the first day of participation in CR (admission) was calculated.

Exposure

We considered indicators across the spatial inequalities described in the literature [14]. Specifically, we used social deprivation, associated with the place of residence, social characteristics of the population, and accessibility of a GP, as an indicator of spatial accessibility of primary care, and the distance between the place of residence and the nearest CR centre as an indicator of spatial accessibility of CR. Socio-geographical factors at the place of residence were determined using validated indexes available in France.

The Fdep15 index, a validated measure at the municipality level (the smallest administrative unit in France) was used to measure the social deprivation [24]. This ecological index was constructed using four variables: median household income, percentage of high school graduates aged ≥ 15 years, percentage of blue-collar workers in the active population, and unemployment rate. These four variables were combined through a principal component analysis to reflect levels of socioeconomic disadvantage. The Fdep was positively associated with mortality rates throughout France [24]. For analysis, the Fdep15 was categorized into five national quintiles, where the first quintile (Q1) represents the least deprived areas and the fifth quintile (Q5), the most deprived.

Accessibility of GPs was estimated using the 2018 GP Localized Potential Accessibility indicator (GP LPA 2018). GP LPA 2018 is based on the "two-step floating catchment area" method, which estimates access to healthcare by considering both the geographic distribution of GPs and patients.GP LPA calculates the ratio of GP supply (based on consultations and adjusted activity levels) to population demand (weighted by age structure and average healthcare consumption by age group). It accounts for cross-border movement between administrative boundaries and adjusts for distance decay, with closer services having a heavier weighting [25]. GP LPA is officially used in France to define areas with a shortage of GPs and other healthcare professionals [15]. GP LPA has been categorized into four national quartiles.

The distance between the place of residence and CR centres was calculated using the software Metric (MEsure des TRajets Inter-Communes/Carreaux). Consistent with other studies on this subject, the distance was categorized into four groups: nearest (0–9 km), near (10–24 km), far (25–49 km), and farthest (≥ 50 km) [16,26].

Statistical analysis

Analyses were performed separately for each patient outcome: participation in CR after PCI for ACS patients at 1 and 3 months and CCS patients at 3 and 6 months. Continuous variables are expressed as mean ± SD and median (interquartile range). Categorical data are expressed as numbers and percentages.

Logistic regression, with the Cath lab that performed the initial PCI as a random effect, was performed to assess the associations of the three independent variables (Fdep15, GP LPA, and the distance between the place of residence and the nearest CR centre) with participation in CR. Patients with missing data for socio-geographical variables were excluded from the models. A directed acyclic graph (DAG) was drawn to correctly identify potential confounding factors using the online tool DAGitty (Figure S1). Following causal inference principles, we included confounders, variables associated with both the exposures and the outcome. The models were adjusted for the confounder's variables identified by the DAG: age, sex, and urban residence (Figure S1). Scenarios were checked to ensure a sufficient number of admissions for CR to build a statistical model. The best-performing models according to the Akaike information criterion, area under the curve, receiver operating characteristic curve, and Hosmer–Lemeshow test were selected for the four outcomes of interest, and possible interactions among the independent variables were analysed. Odds ratios (ORs) associated with independent variables were calculated along with their confidence intervals (CIs) and global *p*-values. *P*-values < 0.05 were considered significant. Finally, the homoscedasticity of model residuals was tested, along with the influence of observations (Cook's distance). The variance inflation factor indicated no collinearity between model variables.

All statistical analyses were performed using SAS® 9.4 Software (SAS Institute Inc., Cary, NC, USA). Maps were created using QGIS Zanzibar (ver. 3.8), and isochrones were calculated using the ORS Tools plugin.

Results

Study population

During the study period, 19,002 patients in Aquitaine received PCI, including 12,336 for ACS and 6,666 for CCS. In the ACS group, 73.4% of patients were male, with a mean age of 68 ± 13 years. Among them, 38.4% had a history of CHD and/or stroke or TIA, 41.9% underwent PCI in private hospitals, and 14.5% experienced cardiovascular events during hospitalisation. The overall average hospital stay after PCI was 4.1 days, 5.1 days for ACS patients and 2.4 days for CCS patients. In the CCS group, 79.7% of patients were male, with a mean age of 69 ± 11 years, and 54.1% had neurocardiovascular events in their past medical history. In this group, 50.7% of patients underwent PCI procedures in private hospitals, and 7.4% experienced cardiovascular events during their hospital stay (Table 1).

Regarding socio-geographical characteristics, 37.9% of the study population lived in an area classified as advantaged (Q2) or most advantaged (Q1), 67.3% had high or very high local access to a GP, and 54.1% resided < 24 km from an authorized CR centre (Table 1).

CR participation

During the 1-year follow-up, 5,073 patients (26.7%) participated in CR at one centre in France, with 93.8% (n = 4,757) of these patients attending a CR centre in the Aquitaine region. Specifically, 4,071 ACS patients (33.0% of the ACS population) participated in CR, with 88.2% (n = 3,590) starting within 3 months after PCI. Notably, 50.9% of patients began CR in the first month following PCI. The median delay from PCI to CR participation for ACS patients was 28 days. For the CCS cohort, 1,002 patients (15.0% of the CCS population) participated in CR. Within this group, 42.3% enrolled in a CR program within the first month following PCI, and 77.2% initiated CR within 3 months after PCI. The median time to start CR for CCS patients was 39 days (Table 1). A direct transfer from PCI to CR occurred in 3.6% (n = 683) of patients, with 4.4% in the ACS group and 2.1% in the CCS group.

Most CR activities for ACS and CCS patients were carried out in a day hospital setting (60% at 6 months). The spatial distribution of CR in Aquitaine highlights an uneven distribution of CR centres (Figure 1), alongside a complex referral network (Figure S2). CR services are primarily concentrated in the region's main administrative centre (Bordeaux) and two coastal areas with a history of tourism and health retreats (Bay of Arcachon and French Pays Basque).

Association between socio-geographical factors and participation in CR

At 3 months after PCI, distance was associated with lower participation in CR for ACS patients ($p = 0.023$). Specifically, ACS patients residing 25–49 km (n = 12,202, OR = 0.83, 95% CI: 0.72–0.95) or > 50 km (n = 12,202, OR = 0.83, 95% CI: 0.70–0.99) from the nearest CR centre had a decreased likelihood of participating in CR (Figure 2). This distance effect was not observed among patients who engaged in CR within the first month after their PCI ($p = 0.154$). There were no notable correlations among social deprivation, local access to a GP, and CR participation at 1- or 3-months post-PCI for ACS patients.

CCS patients living in the most socially advantaged municipalities were more likely to access CR at both 3 months ($p = 0.002$) and 6 months ($p < 0.001$) after PCI. Factors such as GP accessibility and distance from the nearest CR centre did not significantly affect CR participation for CCS patients across the evaluated time intervals (Figure 3).

Discussion

Our research in the Aquitaine Region demonstrated a low CR participation rate following PCI for both ACS and CCS patients in Aquitaine (26.7%). Access to CR was lower for CCS patients (15%) than for ACS patients (33%). Half of the CR utilization occurred within the first month for ACS patients, while the percentage was slightly lower for CCS patients (approximately 40%). After investigating the socio-geographical factors that could affect CR participation, we found that residence > 25 kilometres from a CR centre significantly decreased CR participation for ACS patients at 3 months following PCI. This proximity effect was not observed for ACS patients who began CR within 1 month of reperfusion or for CCS patients at any time point analysed. Socio-economic status also appeared to influence CR access: CCS patients from wealthier areas had higher CR uptake than those from other areas, whereas access for ACS patient was unaffected by socio-economic status. Accessibility of GPs showed no significant association with CR participation for ACS or CCS patients.

CR participation

The CR participation rate in our study was in agreement with the most recently published French national data [1,2,27], as well as with international research [10,28] reporting persistently low CR utilization following PCI. A recent scoping review of 23 studies reporting the CR participation rate after PCI noted a participation rate of < 50% in 12 of the studies [28]. Similarly, the low CR participation rates observed in our study align also with findings from a recent pan-European survey, which reported that uptake rates for CR after MI were also below 50% in the majority of European Society of Cardiology (ESC) member countries. Specifically, 17 countries reported uptake rates of only 0–25%, while 14 countries, including France, Belgium, the Netherlands, and Italy, had rates between 25–50%. Seven countries, generally from Northern Europe, achieved rates of 50–75%, while only four countries—Iceland, Belarus, Lithuania, and

Luxembourg—declared uptake rates of 75–100% [30]. Barriers to CR participation across different countries were identified at patient, staff, and healthcare levels, including socioeconomic disparities, lack of automatic referral systems, and geographical challenges. [29]. CR registries have also described lower CR participation among CCS patients than ACS patients [30]. While there is little evidence regarding specific determinants of low participation in CCS patients, it could be explained by a higher incidence of cardiovascular risk factors and neurovascular history, which are well-documented barriers to CR participation [7,31]. This contrasts with the accumulating evidence that CR improves frailty levels, particularly in individuals who are frailer at the time of admission [32]. Moreover, patients with CCS may be less informed about the benefits of CR and less motivated to participate in CR programs as they do not experience the urgency and stress associated with ACS [33]. There may also be a trend towards lower clinician referral rates for CR within this group due to a historical lack of evidence of the necessity of CR in CCS patients [34]. However, recent European guidelines have reported benefits of CR in all diagnostic categories [7,31]. Moreover, the limited number of CR centres may lead cardiologists to prioritise prescriptions for ACS patients.

Influence of socio-geographical factors

To our knowledge, our study is the first to address socio-geographical factors for both ACS and CCS, spanning both early post-PCI and later stages. A key finding of this study was that the distance from the patient's residence to the nearest CR centre significantly influenced CR participation for ACS patients. This aligned with the results of a previous systematic review, which found that longer travel times were associated with lower CR participation rates after MI with high variability between studies from the USA, Europe, Canada and Oceania (OR range for non-participation [1,2-10]) [12], highlighting the role of geographical accessibility in healthcare outcomes, even in countries with universal healthcare systems. The optimal distance for ACS patients in the present study was < 25 km, consistent with European studies exploring CR accessibility, while North American and Australian studies have reported longer acceptable travel distances [16,26,35,36]. However, distance did not impact CR participation rates within the first month after PCI, indicating that early referral to CR after an acute event can counteract distance problems. This original finding has not been explored before, as previous studies focused on longer follow-up periods (six months or more after PCI) to assess CR participation [16,26,36]. For ACS patients, the recent experience of a cardiac event could prompt immediate actions aimed at health management [28], further facilitated by arrangement of CR support by hospital personnel. This finding aligned with the fact that face-to-face interactions are the most effective in promoting CR participation [10]. Conversely, delayed referral, i.e. after patients have returned to their normal activities and environments, can make the inconvenience of distance a more prominent barrier. For CCS patients, however, distance did not affect CR participation at the 3- or 6-month interval, indicating a role for other factors.

Our study demonstrated a relationship between living in socio-economically disadvantaged areas and reduced access to CR for CCS patients. A similar relationship was identified in an American study, which found that the lowest neighbourhood socio-economic status reduced the likelihood of initiating CR after MI, PCI and CABG by more than half (OR=0.42, 95% CI, [0.27–0.66]) [17]. Additionally, a systematic review found that both high and middle levels of deprivation also affect CR participation after MI, PCI and CABG, with data from countries with universal health coverage, such as the UK and New Zealand

[12]. In our cohort, interestingly this effect was present only in CCS patients, for whom socio-economic inequities regarding CR access were greater compared to ACS patients. The difference in outcomes among CCS patients based on socio-economic status requires further investigation. The difference could not be attributed to inequities in PCI access, as this was similar to that in ACS patients. It could, however, be related to the care path after PCI. An initial barrier could be the low referral rate due to scepticism about CCS benefits among healthcare professionals and the notion that patients from disadvantaged areas would be less likely to participate [37]. The higher utilisation of private hospitals by CCS patients could have skewed CR participation towards wealthier CCS patients. Moreover, follow-up consultations with cardiologists in public or private settings could have influenced the rehabilitation options. Although our dataset did not include ambulatory consultations, future research could retrieve them from the French National Health Data System.

Interestingly, there was no significant correlation between access to GPs and CR participation in ACS or CCS patients. To our knowledge, no other studies have evaluated the association between GP access and CR participation. However, the literature suggests that primary care represents an untapped opportunity for improving health equity and CR uptake [38]. Strengthening the referral capabilities of GPs, particularly in underserved areas, can help address healthcare access inequities and avoid care fragmentation, a known barrier to CR participation [39]. Interventions to achieve this could include increasing exposure to CR during medical training, targeted GP training to enhance their understanding of and advocacy for CR, improved communication tools to facilitate coordination with cardiologists, and focused patient education to overcome obstacles to CR participation [40,41].

Our findings and previous literature highlight the importance of defining clear referral pathways for post-PCI CR, starting from hospitalisation to ensure early referrals. Automatic referral at discharge has been shown to improve CR participation after PCI in experimental and real-world contexts[29,36]. The effect of social deprivation suggests the need for targeting more socially disadvantaged patients to increase their participation in CR. Interventions targeting healthcare professionals to promote a more systematic and automatic referral to CR, as well as raising awareness about advocating for CR among disadvantaged populations, could play a crucial role in this effort. Our findings also suggest the need for more equitable CR availability across the Aquitaine region, where services are currently concentrated in coastal and urban areas. Increasing the number of CR centres in underserved areas and improving referral pathways after PCI could help address this disparity. In this context, telemedicine may offer a promising solution, as it can mitigate socio-geographical barriers and ensure more equitable access. Increasing evidence suggests that telerehabilitation interventions are as effective as centre-based CR [42]. Expanding coverage for CR services to reduce financial barriers for patients, such as by offering travel reimbursements and financial incentives for program completion, could also help achieve equitable CR access [41]. A study conducted in the United States found that combining financial incentives with case management was the most effective approach to improving CR completion rates among patients with low socioeconomic status [43].

Strengths and weaknesses

Our study analysed a large, high-quality cohort dataset comprising almost 20,000 patients who underwent revascularisation in a large number of care institutes throughout the Aquitaine region over 3 years and explored their access to CR over 1 year after revascularisation. Our analysis had several original elements, simultaneously assessing the role of different dimensions of spatial inequality on early and late CR participation in ACS and CCS patients. This allowed us to identify disease-specific socio-geographical factors and their influence after PCI. The study area was limited to the Aquitaine region, which has a population of 3.3 million inhabitants and encompasses sparsely populated rural and densely populated urban areas, as well as mountainous and coastal areas. However, the fundamental mechanisms by which socio-geographical factors influence CR participation are likely to extend beyond the specific context of Aquitaine. Our findings highlight the importance of considering these factors when designing and implementing interventions to improve CR participation.

This study used validated, readily available indicators to explore socio-geographical differences [15]. The use of socio-economic deprivation as an ecological indicator, due to the lack of individual-level socio-economic data in our cohort, may have introduced ecological bias in the interpretation of our findings. This may lead to potential misclassification of individuals' socio-economic position, resulting in less accurate estimates of its relationship with CR participation. Although, the most recent edition of the FDep dates back to 2015, preceding the data collection for this study, it remains relevant, as socio-economic changes at the local level are typically gradual. The high patient mobility in the region could also lead to underestimation of social inequalities relative to when using individual data; thus, in general caution is advised when applying group-level estimates to individuals [18]. The LPA GP index is also subject to ecological bias as it does not show the actual use of GPs but only their availability in an area. GP LPA was used at the municipality level according to the availability of information in our cohort, and can serve as a robust proxy of healthcare accessibility at population level. Patients with missing data for socio-geographical variables (n=134 [1.1%] for ACS, n=70 [1.05%] for CCS) were excluded from the analyses. Given the very low proportion of missing data, it is unlikely to have impacted the logistic models results, thus minimizing the risk of bias in our findings. All records were retained in the descriptive analysis to ensure an accurate representation of the sample.

Our study focused primarily on initial participation in CR programs, without assessing completion rates. Additionally, our analysis may not encompass the full spectrum of CR services, such as day hospital programs. Our research cohort was selected before the COVID-19 pandemic, which significantly affected access to PCI procedures [44]. As such, future research is needed to evaluate the impact of the pandemic on the utilisation of CR services. Care should be taken when generalising our findings, particularly to regions without universal health coverage, as our results may not fully capture health disparities in such contexts. Nonetheless, our causal analysis, conducted using a directed acyclic graph methodology, allowed us to consider a broad range of potential confounding factors, enhancing the robustness and reliability of our results.

Conclusions

As the global population is ageing, the demand for accessible CR is increasing. Despite France's comprehensive healthcare system and commitment to equality, our study found ongoing socio-geographic disparities in CR access. To address these disparities, it is essential to develop and assess standardised post-PCI rehabilitation pathways, and to use primary care and new technologies. High-quality data from cardiovascular registries can inform the planning and implementation of such interventions, promoting higher and more equitable CR participation.

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Conflict of interest

The authors declare no competing interests with this study

Data availability statement

Deidentified participant data will be available upon reasonable request. Proposals may be submitted to the corresponding author. Data requestors will need to sign a data access agreement.

Author Contribution Statement

FQ and EL conceived and coordinated the study. FQ conducted the literature review. EL had full access to all of the data and takes responsibility for their integrity and accuracy. JPL managed the data. SD and SMH performed the statistical analysis. FQ, EL, FSG, TC, PC, SMH, JPL and SD interpreted the data. FQ wrote the manuscript and drew the maps. FQ, EL, FSG, TC, PC, SMH, JPL and SD critically reviewed the manuscript. All gave final approval and agreed to be accountable for all aspects of work, ensuring integrity and accuracy.

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Figure legends

Figure 1 Spatial distribution of cardiac rehabilitation centres by number of admissions, main roads and cities - Aquitaine region - 2017-2019

Figure 2 Estimation of socio-geographical factors influencing cardiac rehabilitation participation at 3 months (A) / 1 month (B) after PCI for ACS (N = 12,202)

Global effects of socio-geographical factors (social deprivation, accessibility of general practitioners, and distance from the nearest CR centre) estimated as odds ratio with 95% confidence interval; results of multivariate logistic regression mixed model with PCI as a random effect; variable to be explained: Y = cardiac rehabilitation participation at 3 months (A) / 1 month (B) after PCI for ACS. Results adjusted on age, gender, and urbanicity of residence.

Figure 3 Estimation of socio-geographical factors influencing cardiac rehabilitation participation at 6 months (A) / 3 months (B) after PCI for CCS (N = 6,596)

Global effects of socio-geographical factors (social deprivation, accessibility of general practitioners, and distance from the nearest CR centre) estimated as odds ratio with 95% confidence interval; results of multivariate logistic regression mixed model with PCI as a random effect; variable to be explained: Y = cardiac rehabilitation participation at 6 months (A) / 3 months (B) after PCI for CCS. Results adjusted on age, gender, and urbanicity of residence.

Table 1. Description of the study population

	Total N=19,002		1- ACS N=12,336		2- CCS N=6,666	
	N	(%)	n	(%)	n	(%)
Socio-demographic characteristics						
Sex, N	19,002		12,336		6,666	
Male	14,363	(75.6)	9,052	(73.4)	5,311	(79.7)
Female	4,639	(24.4)	3,284	(26.6)	1,355	(20.3)
Age (in class), N	19,002		12,336		6,666	
≤ 40 years	236	(1.2)	208	(1.7)	28	(0.4)
41 - 50 years	1,303	(6.9)	1,018	(8.3)	285	(4.3)
51 - 60 years	3,496	(18.4)	2,404	(19.5)	1,092	(16.4)
61 - 70 years	5,390	(28.4)	3,189	(25.9)	2,201	(33.0)
71 - 80 years	4,777	(25.1)	2,784	(22.6)	1,993	(29.9)
> 80 years	3,800	(20.0)	2,733	(22.2)	1,067	(16.0)
Place of birth, N	19,002		12,336		6,666	
France	16,335	(86.0)	10,670	(86.5)	5,665	(85.0)
Abroad	2,275	(12.0)	1,399	(11.3)	876	(13.1)
Undetermined	392	(2.1)	267	(2.2)	125	(1.9)
Urbanicity of place of residence, N	18,846		12,232		6,614	
Urban	14,094	(74.8)	9,124	(74.6)	4,970	(75.1)
Rural	4,752	(25.2)	3,108	(25.4)	1,644	(24.9)
missing data	*156*		*104*		*52*	
Social Deprivation of place of residence - Fdep15 (in class), N	18,846		12,232		6,614	
Most advantaged	2,438	(12.9)	1,553	(12.7)	885	(13.4)
Advantaged	4,711	(25.0)	3,128	(25.6)	1,583	(23.9)
Intermediate	4,536	(24.1)	2,983	(24.4)	1,553	(23.5)
Disadvantaged	3,917	(20.8)	2,478	(20.3)	1,439	(21.8)
Most disadvantaged	3,244	(17.2)	2,090	(17.1)	1,154	(17.4)
missing data	*156*		*104*		*52*	
Accessibility to the general practitioner of place of residence - GP LPA 2018 (in class), N	18,820		12,216		6,604	
Lowest accessibility	2,692	(14.3)	1,716	(14.0)	976	(14.8)
Low accessibility	3,462	(18.4)	2,206	(18.1)	1,256	(19.0)
High accessibility	5,743	(30.5)	3,711	(30.4)	2,032	(30.8)
Highest accessibility	6,923	(36.8)	4,583	(37.5)	2,340	(35.4)
missing data	*182*		*120*		*62*	
Distance between the place of residence and nearest CR centres (53A) - in kilometres (in class), N	18,978		12,321		6,657	
Nearest (0-9 km)	5,855	(30.9)	3,787	(30.7)	2,068	(31.1)
Near (10-24 km)	4,379	(23.1)	2,907	(23.6)	1,472	(22.1)
Far (25-49 km)	5,435	(28.6)	3,445	(28.0)	1,990	(29.9)
Farthest (≥50 km)	3,309	(17.4)	2,182	(17.7)	1,127	(16.9)
missing data	*24*		*15*		*9*	
Patient clinical characteristics						
Cardiovascular risk factors (1), N	19,002		12,336		6,666	
Yes	14,871	(78.3)	9,414	(76.3)	5,457	(81.9)
No	4,131	(21.7)	2,922	(23.7)	1,209	(18.1)
Previous neuro-cardiovascular events (2), N	19,002		12,336		6,666	

1

Yes	8,342	(43.9)	4,736	(38.4)	3,606	(54.1)
No	10,660	(56.1)	7,600	(61.6)	3,060	(45.9)
Structural characteristics of care						
Type of hospital, N	19,002		12,336		6,666	
Public hospital	7,857	(41.3)	5,032	(40.8)	2,825	(42.4)
Private hospital	8,551	(45.0)	5,174	(41.9)	3,377	(50.7)
University hospital	2,594	(13.7)	2,130	(17.3)	464	(7.0)
Presence of a CR centre (53A) in the PCI centre, N	19,002		12,336		6,666	
Yes	10,111	(53.2)	6,588	(53.4)	3,523	(52.9)
No	8,891	(46.8)	5,748	(46.6)	3,143	(47.1)
Characteristics of the care pathway						
Cardiovascular events during PCI hospitalisation (3), N	19,002		12,336		6,666	
Yes	2,285	(12.0)	1,791	(14.5)	494	(7.4)
No	16,717	(88.0)	10,545	(85.5)	6,172	(92.6)
Medical rehospitalisation within 30 days from PCI, N	19,002		12,336		6,666	
Yes	3,492	(18.4)	2,383	(19.3)	1,109	(16.6)
No	15,510	(81.6)	9,953	(80.7)	5,557	(83.4)
Participation in CR (in class), N	19,002		12,336		6,666	
≤ 1 month	2,580	(13.6)	2,156	(17.5)	424	(6.4)
]1 - 3 month]	1,783	(9.4)	1,434	(11.6)	349	(5.2)
]3 - 6 month]	471	(2.5)	342	(2.8)	129	(1.9)
> 6 months	239	(1.3)	139	(1.1)	100	(1.5)
Total (up to 1 year)	5,073	(26.7)	4,071	(33.0)	1,002	(15.0)
Type of CR setting (6 months), N	4,834		3,932		902	
Full Hospitalisation	1,644	(34.0)	1,329	(33.8)	315	(34.9)
Day Hospital	2,902	(60.0)	2,359	(60.0)	543	(60.2)
Outpatient	288	(6.0)	244	(6.2)	44	(4.9)

Abbreviations CR: Cardiac Rehabilitation; Fdep15: Social deprivation index 2015; GP LPA 2018: General practitioner local potential accessibility 2018; PCI: Percutaneous Coronary Intervention

Notes

1. Cardiovascular risk factors include diabetes, dyslipidaemia, active smoking in the last three years, hypertension, obesity (BMI> 30)

2. Previous neuro-cardiovascular events include myocardial infarction, PCI, Coronary Artery Bypass Graft surgery, stroke or TIA, renal insufficiency, peripheral arterial disease, heart failure with ejection fraction <40%, therapy with anticoagulants

3. Cardiovascular events include myocardial infarction, PCI, Coronary Artery Bypass Graft surgery, stroke, or TIA

1

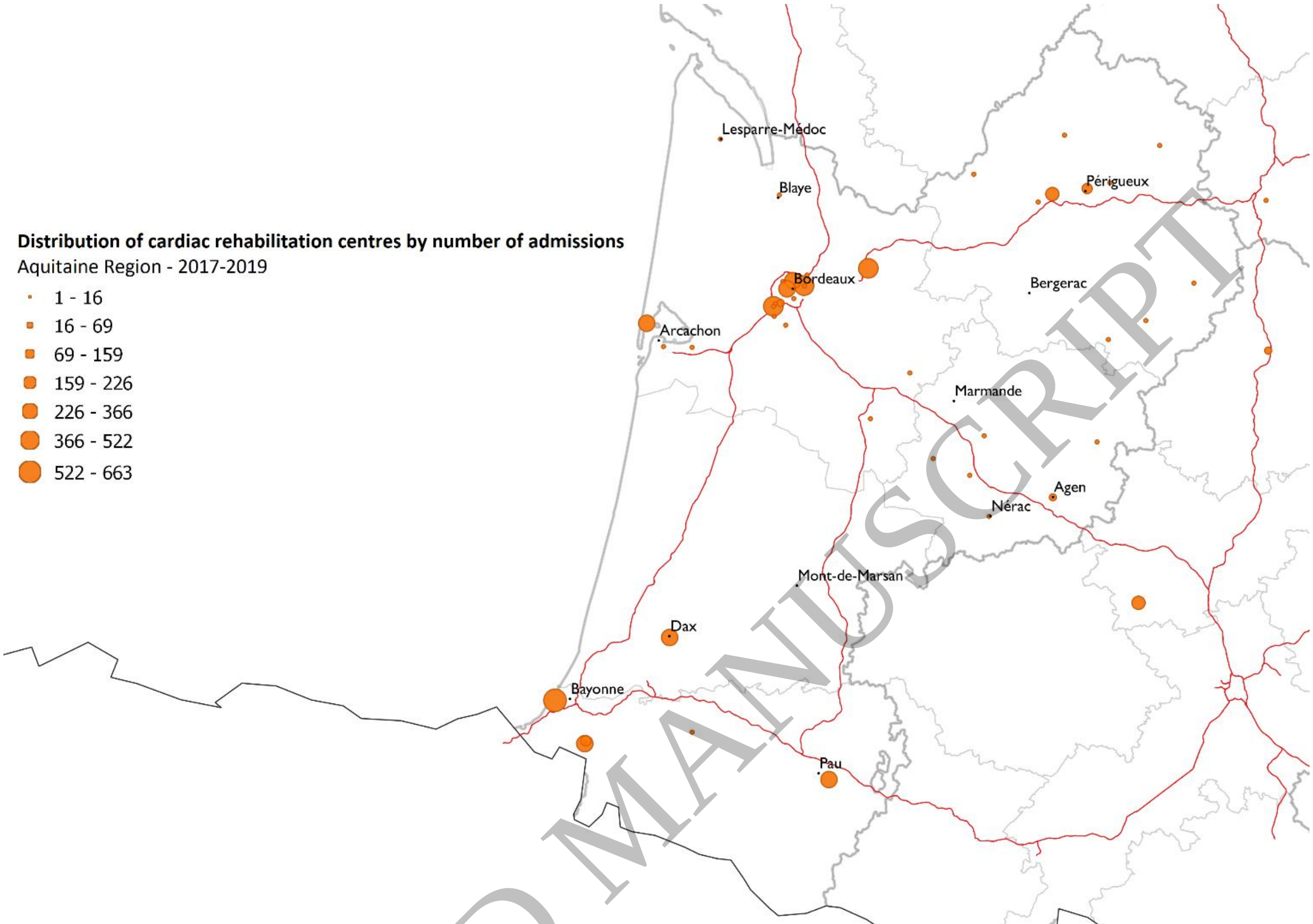

Figure 1

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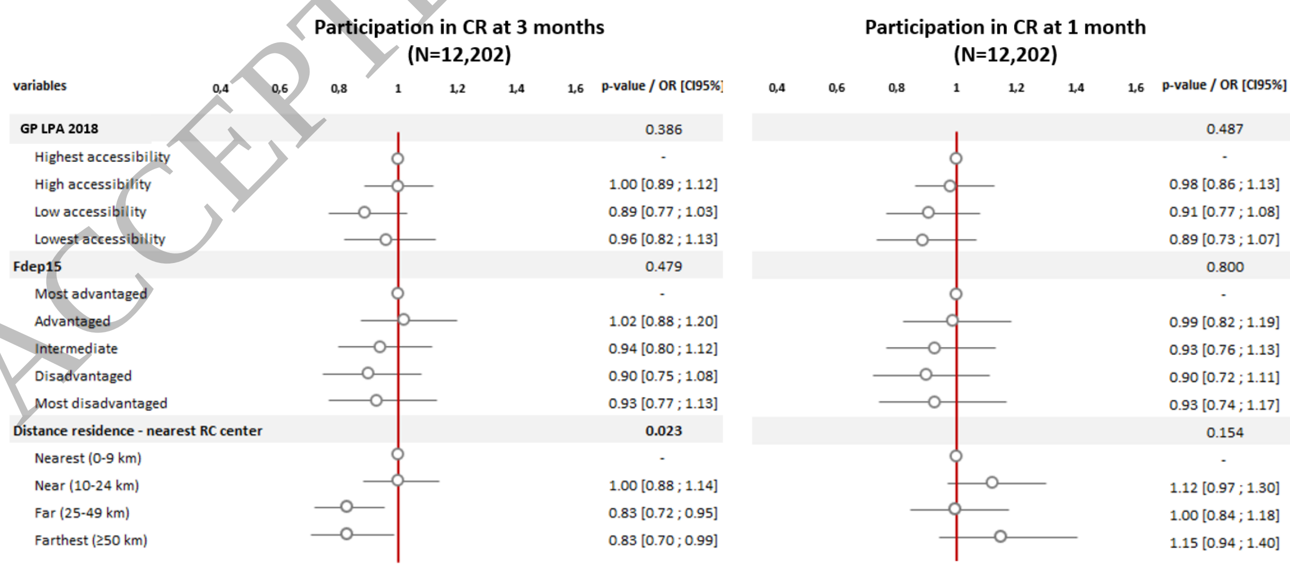

Figure 2

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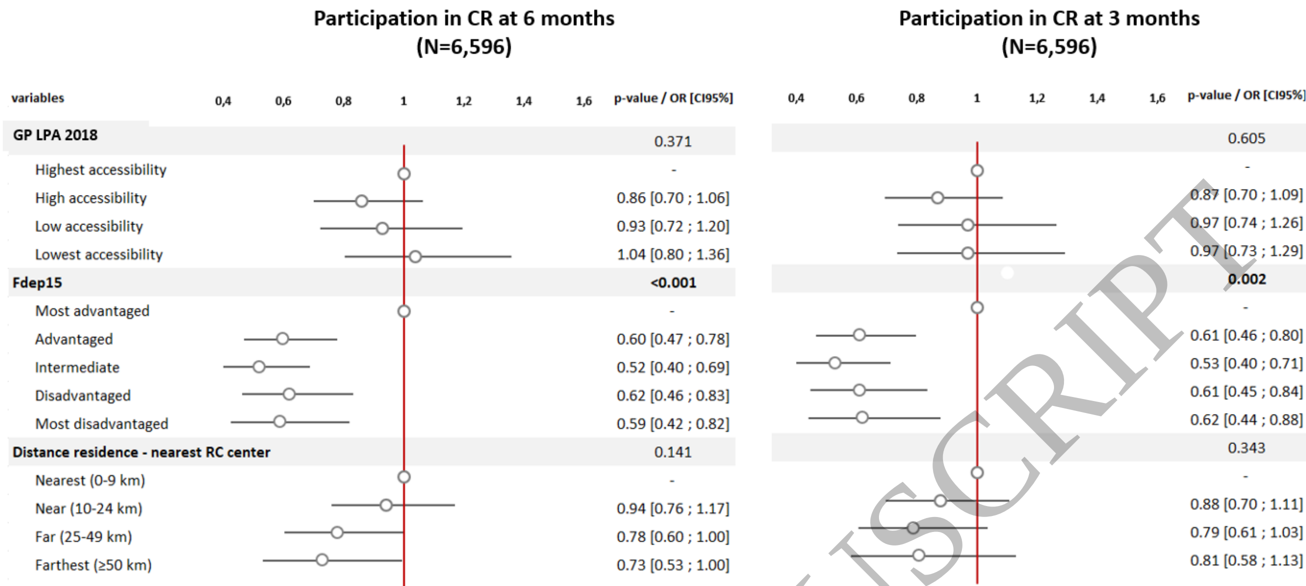

Figure 3
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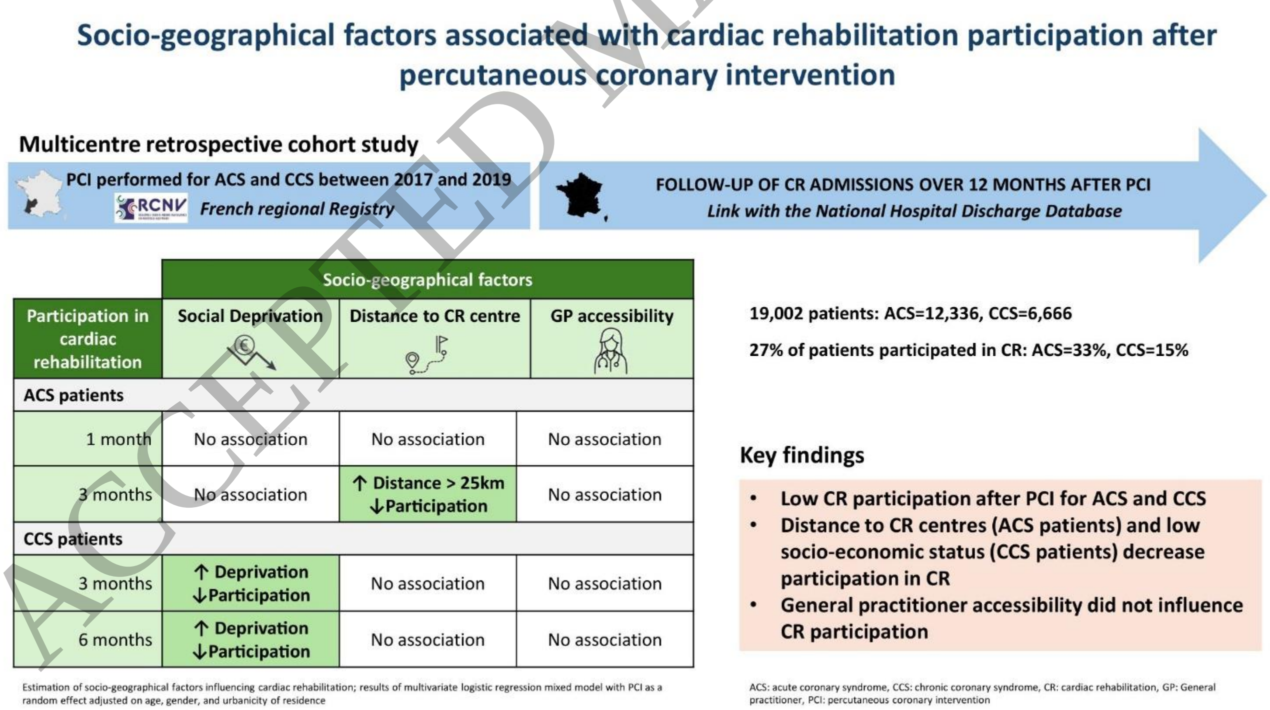

Graphical Abstract
297x210 mm (x DPI)