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SPATIAL DISTRIBUTION OF CORONARY REPERFUSION SERVICES AND ITS IMPACT ON ACUTE MYOCARDIAL INFARCTION MORTALITY IN PARANA STATE, BRAZIL

DISTRIBUIÇÃO ESPACIAL DOS SERVIÇOS DE REPERFUSÃO CORONARIANA E SEU IMPACTO NA MORTALIDADE POR INFARTO AGUDO DO MIOCÁRDIO NO ESTADO DO PARANÁ, BRASIL

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ABSTRACT

Objective: To analyze the impact of geographic location of coronary reperfusion (CR) services on acute myocardial infarction (AMI) mortality in Parana State, Brazil. Methods: This is a cross-sectional, ecologic study based on AMI mortality, between 2015 and 2019, among individuals aged 30–79 years. An spatial access index to CR services within 60 minutes of ground transportation was calculated using the enhanced two-step floating catchment area technique. AMI mortality rates were compared between municipalities with and without CR services coverage and between municipalities with low and high spatial access to CR services, both using the Wilcoxon test. Results: It was observed that 8.02% (32/399) of municipalities had access to two methods of reperfusion therapy, 24.56% (98/399) had access only to primary percutaneous coronary intervention, and 12.03% (48/399) had access only to chemical reperfusion. Municipalities with access to CR services had lower mortality rate (median = 74.67) than municipalities not covered by this service (median = 102.83) (p < 0.001). There was a significant difference between municipalities with low (median = 68.30) and high spatial access to CR services (median = 80.02) (p = 0.007). Conclusion: Increased spatial access to CR services is crucial for the survival of patients with AMI.

Keywords: Acute myocardial infarction. Coronary reperfusion. Percutaneous coronary intervention. Thrombolytic therapy. Spatial analysis.

RESUMO

Objetivo: Analisar o impacto da localização geográfica dos serviços de reperfusão coronariana (RC) na mortalidade por infarto agudo do miocárdio (IAM) no estado do Paraná, Brasil. Métodos: É um estudo ecológico transversal baseado na mortalidade por IAM, entre 2015 e 2019, em indivíduos de 30 a 79 anos. O índice de acesso espacial ao serviços de RC em até 60 minutos de transporte terrestre foi calculado usando a técnica aprimorada da área de captura flutuante de dois passos. As taxas de mortalidade por IAM foram comparadas entre municípios com e sem cobertura de serviços de RC e entre baixo e alto acesso espacial a estes serviços, ambos utilizando o teste de Wilcoxon. Resultados: Observou-se que 8,02% (32/399) dos municípios tinham acesso a ambos os tipos de reperfusão, 24,56% (98/399) acesso apenas à intervenção coronariana percutânea primária, e 12,03% (48/399) acesso apenas à reperfusão química. Municípios com acesso aos serviços de RC apresentaram menor taxa de mortalidade (mediana=74,67) comparado com aqueles sem cobertura deste serviço (mediana=102,83) (p<0,001). Houve diferença significativa entre municípios com baixo (mediana=68,30) e alto acesso espacial aos serviços de RC (mediana=80,02) (p=0,007). Conclusão: O aumento do acesso espacial aos serviços de RC é crucial para a sobrevivência dos pacientes infartados.

Palavras-chave: Infarto agudo do miocárdio. Reperfusão coronariana. Intervenção coronariana percutânea. Terapia trombolítica. Análise espacial.

INTRODUCTION

The clinical evolution of acute myocardial infarction (AMI) is time-dependent. Delayed therapeutic intervention represents a significant factor influencing AMI mortality, which has experienced a marked increase in developing countries (ZUROWSKA-WOLAK et al., 2019; OLIVEIRA et al., 2022; OMS, 2023a). In Brazil, a developing country, AMI affects 300,000 to 400,000 people every year, leading to death in 15% to 20% of cases, constituting the main cause of mortality in the country (BRASIL, 2023).

Upon confirmation of AMI diagnosis, the recommended treatment is primary percutaneous coronary intervention (PCI). The time from the first medical contact at the primary hospital to the passage of the guidewire through the obstructed artery at the interventional cardiology reference hospital should not exceed 120 min. This time is subdivided into door-in-door-out, transfer, and guidewire crossing times (WANG et al., 2011; ANDRADE et al., 2014; IBANEZ et al., 2017).

PCI, the gold standard recommended in the first hours after the onset of AMI symptoms (IBANEZ et al., 2017), is a complex procedure that strongly depends on access to health centers specialized in interventional cardiology. Patients residing in nearby areas are the actual beneficiaries of the service (BERGAMINI et al., 2020). It is known that there is an uneven distribution of coronary reperfusion hospitals and advanced life support ambulances in Brazil (PIEGAS et al., 2015), which may result in delays well above the time limits set by European and American guidelines (≤120 minutes for PCI and ≤ 30 minutes for chemical reperfusion) (CHANDRASHEKHAR et al., 2020).

For patients residing in geographic areas outside the reach of PCI therapy (access time >120 minutes), the recommendation is to perform fibrinolytic therapy (chemical reperfusion), ideally within 30 min of first medical contact (door-to-needle time), followed by rapid transfer (THIEMANN et al., 1999; KEELEY et al., 2003; ANDERSEN et al., 2003; WANG et al., 2011). Chemical reperfusion can be performed either at the primary hospital or in the prehospital setting of advanced life support ambulances, so long as they meet the basic requirements for the procedure (WAINSTEIN et al., 2008; PIEGAS et al., 2015).

Furthermore, in developing countries, precarious logistics, combined with economic issues and the poor infrastructure of health services, can cause delays in the care of AMI patients, which directly translates into higher mortality, as also increased length of stay, higher need for resources, and long-term sequelae that may lead to work disability and low quality of life (OMS, 2023a; OLIVEIRA et al, 2022; BARRETO et al., 2021; FOX et al., 2002).

Studies assessing the spatial access of these procedures within the optimal time frame are still scarce, especially in developing countries such as Brazil (CHAMBERS et al., 2020; NOZARI et al., 2020). Therefore, it is necessary to assess the impact of the location of coronary reperfusion services (CRS) and the actual spatial access of thrombolysis therapy, as these factors are closely linked to the survival of patients suffering from AMI. In view of these observations, this study aimed to analyze the impact of geographic location of coronary reperfusion services on acute myocardial infarction mortality in Parana state, Brazil.

METHODS

Study design and location

This is a cross-sectional, ecological study using geospatial techniques and secondary data on AMI deaths from 2015 to 2019 in Parana State, Brazil. The research protocol followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational studies (CUSCHIERI, 2019).

Parana state is located in the southern region of Brazil, between geographic coordinates 22°30′58″ and 26°43′00″S and 48°05′37″ and 54°37′08″W, covering an area of 199,298.979 km^2, equivalent to 2.34% of the national territory (IBGE, 2021). It is the sixth most populous state in the country, with 11,433,957 people (about 5.65% of the Brazilian population). Parana comprises 399 municipalities divided into 22 healthcare regions. Most municipalities (355/399, 88.9%) have less than 40,000 inhabitants (IBGE, 2019).

Data sources

Data on deaths from AMI among individuals aged 30 to 79 years residing in Parana municipalities were obtained from the Mortality Information System of the Brazilian Ministry of Health (SIM/DATASUS)..The selection of people aged 30 or older was motivated by the fact that less than 1% of AMI hospitalizations occurs in individual below this age group (GOTSMAN; LOTAN; MOSSERI, 2003; PETKOW et al., 2020, KHAN et al, 2022; OMS, 2023b).

Data were retrieved by entering the code I21 of the International Statistical Classification of Diseases and Related Health Problems (ICD) (BRASIL, 2023) . The geolocation of hospitals with the capacity to perform PCI and chemical reperfusion and information on advanced life support ambulances with the capacity to perform chemical reperfusion were obtained from the National Register of Health Establishments (CNES/DATASUS) available on the Brazilian Ministry of Health and Parana State Health Department websites (IBGE, 2019; SESA, 2020; BRASIL, 2023) (Table 1).

Table 1 – Data sources

Source	Variable*	Period
SIM/DATASUS	Deaths from acute myocardial infarction in individuals aged 30 to 79 years	2015–2019
CNES/DATASUS/ SESA 2020	Health centers with the capacity to perform primary percutaneous coronary intervention (mechanical reperfusion) Health centers with the capacity to perform fibrinolytic therapy (chemical reperfusion) Advanced life support ambulances belonging to the Mobile Emergency Medical Services (SAMU)	2015–2019
OpenStreetMap	Cartographic base and road network	2019
IBGE	Estimates of resident population in the 30 to 79 years age group	2015–2020

* All variables were calculated based on data for municipalities in Paraná State, Brazil.
Source: The authors.

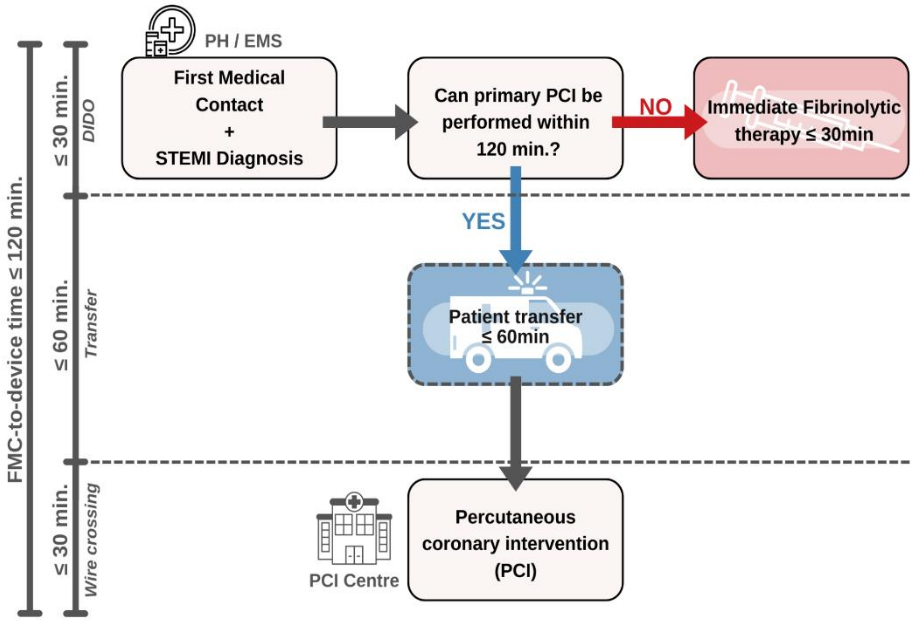
A cartographic base of Parana municipalities with streets, highways, and roads was obtained from the free website OpenStreetMap (https://www.openstreetmap.org/). Population data on the 30 to 79 years age group by municipality were obtained from the Brazilian Institute of Geography and Statistics (IBGE, 2021) (Table 1) and used to calculate age-adjusted AMI mortality rates for each municipality, determined as the ratio of the number of AMI death per inhabitants in the target age group multiplied by 100,000.

Spatial analysis

In order to better analyze the spatial access to CRS considering a maximum time to reperfusion of 120 min, we divided this time interval into three parameters. The first-time section, known as door-in-door-out time (DID) (WANG et al., 2011; STEG et al., 2012; O'GARA et al., 2013; ANDRADE et al., 2014), should not take longer than 30 min. This parameter refers to the time between patient admission (door in) into the primary hospital, which will provide the initial care and diagnostic identification of AMI, and transfer of the patient (door out) to an interventional cardiology center. The second time section, hereafter referred to as transfer time, refers to a maximum of 60 min for the transfer of patients to the CRS. Here, the mode of transport was standardized as land-based ambulance transport.

The third time section, which should not take longer than 30 min, encompasses the time from the entry of the patient into the interventional cardiology center to the passage of the guidewire through the obstructed artery, being therefore referred to as guidewire crossing time (Figure 1). For patients residing in an area more than 120 min away from a PCI center, the indication is to perform immediate chemical reperfusion, within 30 min of admission to the primary facility (door-to-needle time) (PIEGAS et al., 2015; O'GARA et al., 2013, IBANEZ et al., 2017) (Figure 1).

Figure 1 – Time from first medical contact to ST-elevation myocardial infarction (STEMI) diagnosis in a primary hospital (door-in-door-out time [DIDO]), secondary transfer time, and time to coronary reperfusion in an interventional cardiology center for patients undergoing primary percutaneous coronary intervention or chemical reperfusion



Source: The authors.

Travel time

Road routes with the maximum travel times to CRS were traced by using the HQGis plugin of QGIS software (QGIS DEVELOPMENT TEAM, 2019). These data were used to create isochrone maps and identify municipalities located within a specific distance from a given starting point, that is, with a maximum travel time of 60 min to a PCI center by land or a maximum travel time of 30 min to a CRS.

Spatial access: enhanced two-step floating catchment area method

The enhanced two-step floating catchment area (E2SFCA) spatial access model was developed to circumvent the limitations of the two-step floating catchment area (2SFCA) method proposed by Radke and Mu (2000) and later modified by Luo and QI (LUO; QI, 2009). Two-step floating catchment area considers that the entire population within the catchment area has the same access to health services, being a dichotomous measure, which means that all regions outside the catchment area do not have spatial access (NAGY, 2023).

In clinical practice, the farther individuals reside from the analyzed point, the longer the time to reach the destination and, consequently, the lower the spatial access. The E2SFCA model, in turn, assigns multiple weights to distance decay, replacing the dichotomous 0 and 1 of the 2SFCA model. This method allows for a more intuitive interpretation that is consistent with reality, as the population seeks health services closer to their municipality (place) of residence. As the name suggests, E2SFCA also consists of two steps, which are penalized by distance using Gaussian functions. Smaller weights are assigned to larger distances within a buffer area and vice versa (LUO; QI, 2009).

In the current study, spatial access to reperfusion treatment was evaluated in a maximum interval of 60 min, assigning a weight of 100 for each PCI center and of 25 for chemical reperfusion services, using the USWFCA package of ArcGIS Pro software (ERSI, 2022). For better visualization of the results, choropleth maps were plotted using ArcGIS Pro 3.0, illustrating the area and population covered by the respective service (MIYASHITA; OKANO, 1995).

Analysis of AMI mortality

The crude AMI mortality rate was calculated by dividing the number of deaths by the adjusted population multiplied by 100,000 (OMS, 2023c). For assessment of the impact of spatial access to CRS, we calculated the median and first and third quartiles of the AMI mortality rates of municipalities with and without access to the service using RStudio version 4.1.0 (BATES et al., 2013). Given that the data showed non-normal distributions by the Kolmogorov–Smirnov test (PIRES et al., 2018), the non-parametric Wilcoxon test was applied for statistical comparisons between groups (municipalities with and without access to CRS) at a significance level of 5%. Boxplots were constructed to better visualize the results (PAULINO et al., 2011).

In the next step, municipalities with access to CRS were subdivided into two groups according to the mean E2SFCA value: municipalities with low spatial access to CRS (median<0.303) and municipalities with high spatial access to CRS (median ≥0.303). Next, we calculated the medians, as well as the first and third quartiles of the mean AMI mortality rates of municipalities with low and spatial access to the services. The data showed non-normal distributions and thus were subjected to the non-parametric test for comparison between groups.

Finally, a bivariate map was constructed for a better understanding and analysis of the relationship between mortality and spatial access variables using RStudio (PRENER, 2022) and ArcGIS Pro 3.0 (ESRI, 2022) software.

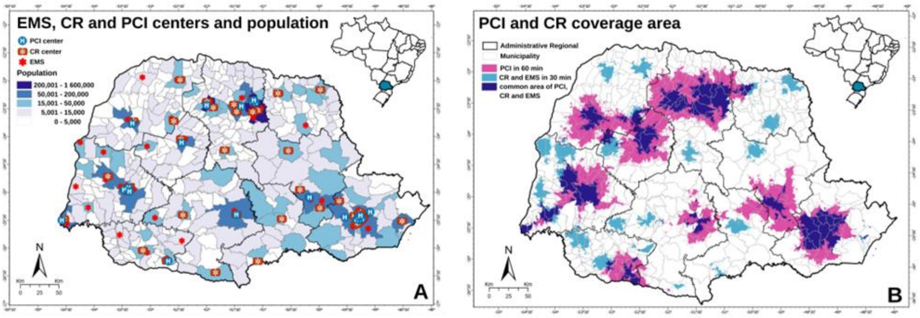
Ethical aspects

Since this study used secondary data available in the public domain, in accordance with Resolution No. 510/16 of the Brazilian National Health Council, it was exempted from ethical analysis by the Human Research Ethics Committee of the State University of Maringa (Protocol No. 07/2021).

RESULTS

Between 2015 and 2019, 18,202 deaths from AMI were recorded among residents of Parana state aged 30 to 79 years, with an average annual rate of 83.39 ± 36.62 deaths per 100,000 inhabitants. These deaths occurred mainly in men (65.76%), individuals who were married (50.54%), and people with 1–7 years of formal education (56.74%). Figure 2A shows the CRS locations and the quantity of age-adjusted population of each municipality of Parana. It can be seen that the North-Central, Southeast, and Western regions have a higher number of CRS and greater population size.

Figure 2 – Isochrone maps of distribution of emergency medical services (EMS), primary percutaneous coronary intervention (PCI) centers, chemical reperfusion (CR) centers, and age-adjusted population (30–79 years) (figure A) and coverage areas of PCI centers (60 min of ground travel time) and CR centers (30 min of ground travel time) in Parana State, Brazil (figure B

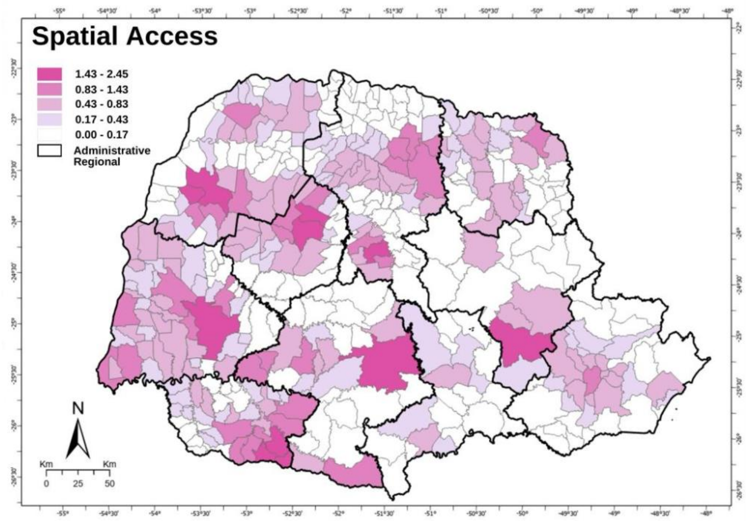


Source: The authors.

The travel time map revealed that 32.58% (130/399) of the municipalities in the state had access to PCI (60 min travel time); of these, 8.02% (32/399) had access to both forms of reperfusion (PCI and CR, dark blue, Figure 2B) and 24.56% (98/399) had access to PCI only (pink, Figure 2B). In considering ambulance and chemical reperfusion services (30 min travel time), it was found that 12.03% (48/399) of the municipalities had access to chemical reperfusion only (light blue, Figure 2B).

Other factors such as center capacity and age-adjusted population may influence CRS spatial access; therefore, we applied the E2SFCA method. The results showed greater spatial access mainly in the Southwest, Northwest, and East regions. The peripheral regions of the Southeast, Northeast, and North had poorer access to the service (Figure 3).

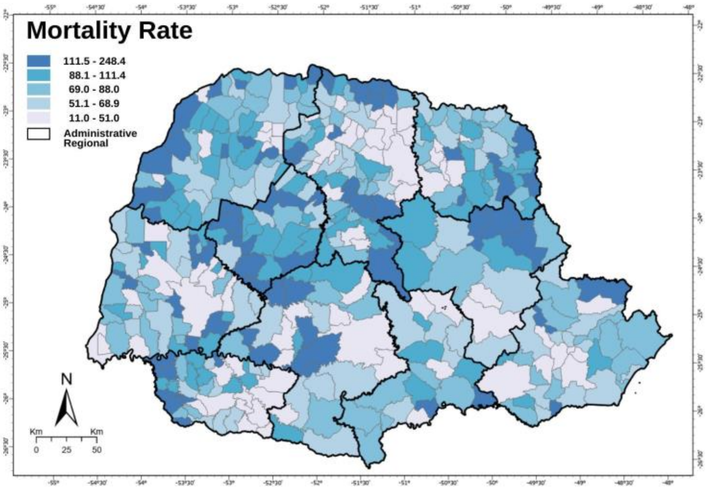
Figure 3 – Enhanced two-step floating catchment area of spatial access to primary percutaneous coronary intervention (PCI) (60 min of ground travel time) and chemical reperfusion (30 min of ground travel time)



Source: The authors.

The highest AMI mortality rates were observed in municipalities without access to coronary reperfusion services, located mainly in the middle to north, northwest and northeast of the state (in dark blue), where these rates reached up to 284.4 deaths per 100,000 inhabitants. On the other hand, the southeast region showed lower mortality rates (Figure 4).

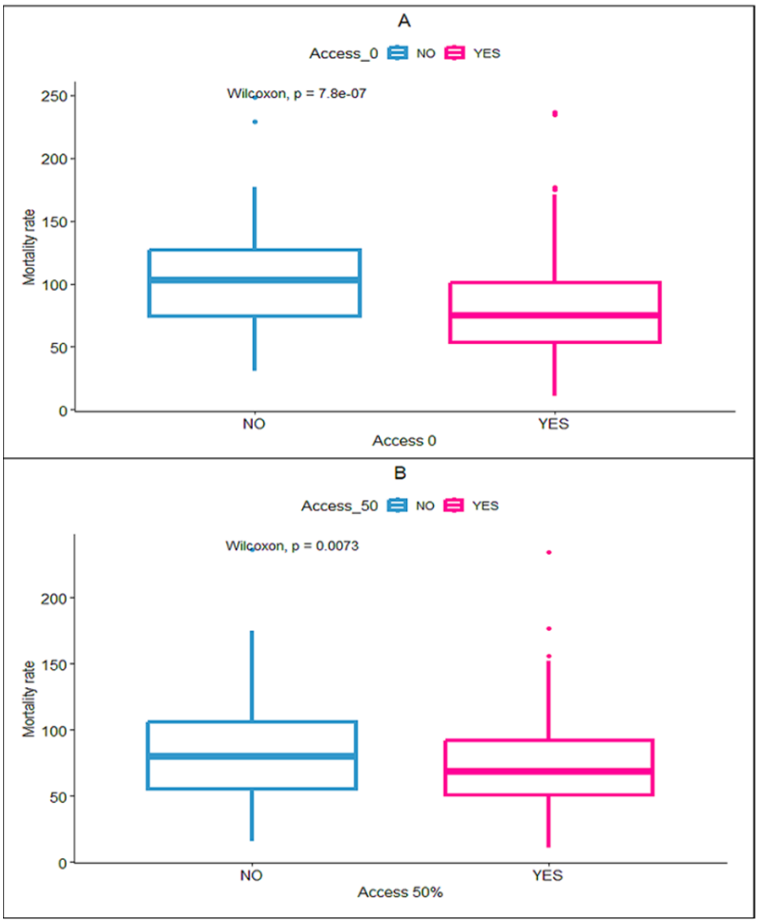
Figure 4 – Mortality rate of acute myocardial infarction per 100,000 population in Parana State, Brazil



Source: The authors.

Analysis of mortality rates showed that the individuals living in municipalities with access to CRS presented a lower AMI mortality (74.67 (53.31-100.81)) than those living in regions without access to these services (102.83 (74.11-126.90)) ($p<0.001$) (Figure 5A). There was also a significant difference in mortality rates between patients living in areas with high spatial access (higher than median) (68.30 (50.82-91.79)) than those living in areas with low spatial access (lower than median) (80.02 (55.46-106.19)) ($p<0.007$). These findings indicate that a lack of and/or poor access to CRS may contribute to increasing the number of deaths from AMI in Parana State (Figure 5B).

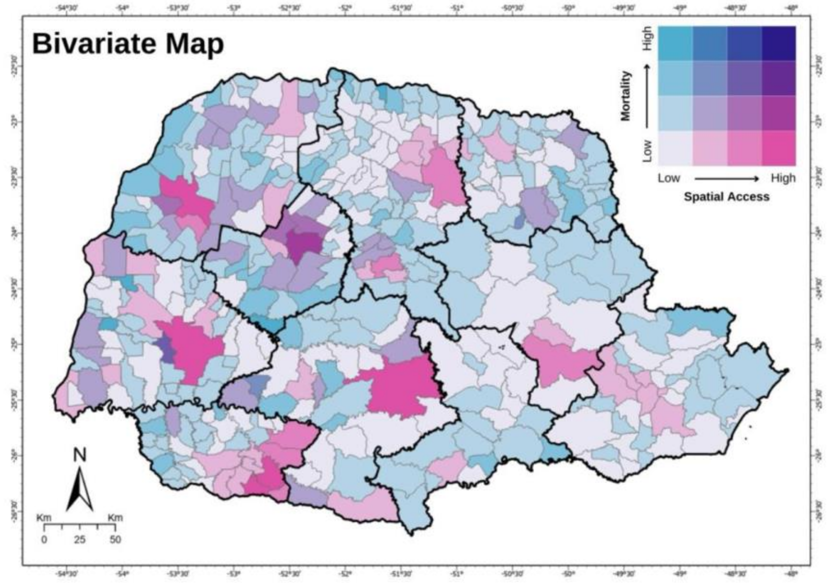
Figure 5 – Median, first quartile, and third quartile of acute myocardial infarction mortality rates as a function of spatial access (with or without) to coronary reperfusion centers (Figure 5A) and low and high spatial access to coronary reperfusion centers (Figure 5B)



* Access_0 = access to some form of coronary reperfusion.
** Access_50 = median access to coronary reperfusion centers; municipalities above the median were considered to have access to the service and those below the median were considered to not have access to the service.
Source: The authors.

The bivariate map of AMI mortality and CRS spatial access showed a predominance of low spatial access and intermediate-to-high mortality rates. Areas with high mortality and low spatial access (darker navy blue) were mainly concentrated in the peripheral regions of the state, whereas regions with high spatial access and low mortality (pink) were observed in the Northwest, West, Southwest, South, and South-Center. The region with the highest spatial access and mortality rate was located in the West region, more specifically the municipality of Santa Tereza do Oeste (dark blue) (Figure 6).

Figure 6 – Bivariate map of acute myocardial infarction mortality rate versus spatial access index, as calculated by the enhanced two-step floating catchment area method.



Source: The authors.

DISCUSSION

Currently, there are different treatment protocols for patients with AMI, based on national and international guidelines (BERNAL-DELGADO et al., 2015; MEEUS; HAELTERMAN; BELGIUM, 2014). There are still no studies on the impact of geographic location on access to CRS and AMI mortality and its influence on the outcome of patients with this disease in southern Brazil. Our results demonstrate that high spatial access to CRS is essential for the survival of patients affected by AMI. However, only 98 municipalities in Parana State have timely access to PCI (travel time shorter than 120 min), 48 municipalities have access to chemical reperfusion (travel time shorter than 30 min), and only 32 municipalities have access to both forms of reperfusion, as recommended by international and national protocols (PINTO et al., 2011; IBANEZ et al., 2017).

The low supply of these services in Parana is justified by the fact that PCI centers are mostly concentrated in large cities with good healthcare infrastructure, which cover nearby small municipalities (O'GARA et al., 2013; SESA, 2015). Municipalities without spatial access to this service in a timely manner, consequently, have higher average AMI mortality rates, as indicated in the present study. In addition to low spatial access (32.58%) to PCI centers, there was a poor and non-compensatory distribution of thrombolytics. The lack of technologies, emergency equipment, and qualified human resources and logistics are determining factors that hinder access to reperfusion services within the ideal time threshold, explaining the high mortality clusters in the Parana state (ANDRADE et al., 2014; MATHEW et al., 2017).

In developing countries such as Brazil, chemical reperfusion (fibrinolytic therapy) may serve as an alternative to reduce the severity of injuries and deaths from AMI, especially in regions that are geographically far from PCI referral centers (FAZEL et al., 2020). These results underscore the need to expand the number of hospitals with the capacity to perform chemical reperfusion (DUTRA et al., 2021). Another point that deserves to be taken into account is the feasibility of air transport, as this form of transport can improve the clinical outcome of patients with AMI, increasing survival and providing better coverage and support for small centers or regions with poor coverage (ISHIYAMA et al., 2021).

So, the information reported in this study can be used to understand the spatial access to PCI centers in Parana and other regions with the same condition and improve the healthcare services in low- and middle-income countries.

CONCLUSION

Research investigating spatial access has underscored the crucial significance of ensuring high spatial access to cardiac reperfusion services (CRS) for the survival of patients experiencing acute myocardial infarction (AMI). Consequently, the allocation of financial and material resources by state health departments’ managers to services such as emergency medical services (EMS), primary percutaneous coronary Intervention (PCI) centers and chemical reperfusion (CR) centers to areas with higher vulnerability is crucial.

The peripheral regions of Parana state with high AMI mortality rates and low spatial access to CRC demand specific attention from healthcare managers. Nevertheless, it's imperative to acknowledge that potential access doesn't invariably translate to actual access to healthcare centers for those who need it. Spatial access encompasses users' characteristics such as income, education, culture, and social barriers, which can significantly affect their ability to access these services, irrespective of their geographical location.

Therefore, understanding how inequalities in access to healthcare services can arise and how policies and interventions can be developed to improve equitable access to medical care is crucial. However, we should point out some limitations of this study, such as the use of freely available secondary data, which can lead to over- or under-reporting of AMI mortality. To minimize this, we used the big data from official databases of the Brazilian Ministry Health, whose quality of information has improved in recent decades.

Furthermore, we estimated the time to access the coronary reperfusion services in Parana state, so it was possible to measure the distance to EMS, primary PCI centers, CR centers and their locations. However, it was not possible to measure the actual travel time, the availability and quantification of specialized staff, and the supplies needed for the thrombolysis and angioplasty. We also cannot assess the safety conditions of secure transportation, whether due to vehicle conditions or road conditions. For this, a future study with primary data in collaboration with the service-providing teams would be necessary to conclude the real mapping and healthcare services coverage.

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