

Heterogeneity in the impact of the COVID-19 pandemic on neonatal vitality indicators across urban and rural municipalities in Espírito Santo, Brazil

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Abstract

The COVID-19 pandemic posed major challenges to maternal and neonatal care, with potential repercussions for neonatal vitality indicators. This study aimed to analyze the associations between prenatal care adequacy, maternal age, and neonatal outcomes, birth weight and 5-minute Apgar score, in the state of Espírito Santo, Brazil, considering different epidemiological periods of the COVID-19 pandemic and the degree of urbanization of the municipalities. All live births recorded in the state between 2017 and 2024 in the Brazilian Live Birth Information System (SINASC) were included, totaling 427,605 cases. The variables analyzed were birth weight, 5-minute Apgar score, number of prenatal visits, and gestational duration, which were compared across the following periods: pre-pandemic (2017–2019), pandemic (2020–2021), and post-pandemic (2022–2024). Municipalities of birth were classified as urban, rural, or adjacent intermediate according to the Brazilian Institute of Geography and Statistics (IBGE). The results showed that the effects of the pandemic differed according to the degree of urbanization. In rural municipalities, reductions in gestational age, gestational duration, and birth weight were observed during the pandemic period, whereas in urban municipalities, 5-minute Apgar scores improved in the post-pandemic period. The number of prenatal visits showed a progressive increasing trend throughout the study period, regardless of the degree of urbanization. In the multivariate analysis, gestational duration was the main determinant of birth weight and 5-minute Apgar score, followed by the number of prenatal visits, whereas maternal age had a significant but smaller effect. These findings suggest that the quality of prena-

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tal care and the organization of healthcare networks may be more relevant to neonatal outcomes than the number of prenatal visits alone, reinforcing the need to strengthen maternal and neonatal care and reduce territorial inequalities in preparedness for future public health emergencies.

KEYWORDS: COVID-19; Maternal and Child Health; Newborn; Prenatal Care; Health Inequalities.

Introduction

Newborn health conditions at birth may reflect maternal health, gestational development, and the care received during pregnancy and childbirth. Early indicators, such as the 1- and 5-minute Apgar scores (Apgar5) and birth weight, provide information on different aspects of neonatal health and contribute to identifying newborns at increased risk of neonatal complications (MACHADO, 2006; MACHADO; HILL, 2003). These outcomes may be associated with maternal, gestational, fetal, and healthcare-related factors, including the quality of prenatal and intrapartum care, and have therefore become central indicators in neonatal health monitoring (SILVEIRA; SANTOS, 2004; FONSECA *et al.*, 2014; PILEGGI-CASTRO *et al.*, 2014).

Although often analyzed together, the 5-minute Apgar score and birth weight represent distinct and complementary dimensions of neonatal health. Low Apgar scores may indicate difficulties in the immediate transition to extrauterine life (MACHADO; HILL, 2003; CHRISMAN *et al.*, 2016), whereas low birth weight primarily reflects impaired fetal growth related to prematurity and/or intrauterine growth restriction, conditions associated with a higher risk of adverse outcomes during the neonatal period and later development (SILVEIRA; SANTOS, 2004; FONSECA *et al.*, 2014). Multicenter studies have shown that both a 5-minute Apgar score below seven and very low birth weight categories are useful markers of neonatal

tal severity (PILEGGI-CASTRO *et al.*, 2014), reinforcing the importance of considering them complementary indicators when assessing risks during the early stages of life.

Adequate prenatal care enables the early identification of maternal, fetal, and obstetric risk factors and the timely implementation of preventive and therapeutic interventions. These interventions include iron and folic acid supplementation, which has been associated with reductions in low birth weight and other adverse outcomes, as well as continuous clinical monitoring throughout pregnancy, which may facilitate the timely detection and management of obstetric and perinatal complications (SRI-VASTAVA *et al.*, 2024). In addition to biological factors, psychosocial and contextual factors may also be associated with neonatal health. Evidence suggests that mental health support and reduced maternal stress during pregnancy may be associated with lower rates of preterm birth and fetal growth restriction. One possible underlying pathway involves changes in fetal exposure to maternal cortisol (ALBARQI, 2025). However, the expected effects of these measures may vary according to socioeconomic conditions, access to healthcare services, adherence to prenatal care, and the quality of healthcare infrastructure, highlighting the importance of social determinants of perinatal health (ALBARQI, 2025).

Territorial inequalities also significantly influence perinatal health indicators, particularly differences between urban and rural settings. Studies have shown that pregnant women living in rural areas are less likely to receive adequate prenatal care than those living in urban areas, even after adjustment for demographic and socioeconomic characteristics and maternal clinical conditions (POLAVARAPU *et al.*, 2024). During the COVID-19 pandemic, these disparities became even more apparent, with an overall decline in prenatal care adequacy associated with overwhelmed healthcare systems, mobility restrictions, and barriers to accessing obstetric and perinatal

services (CARVALHO-SAUER *et al.*, 2024; POLAVARAPU *et al.*, 2024). Studies have reported fewer prenatal visits, delayed initiation of prenatal care, and deterioration in the quality of available care during the pandemic period (CHMIELEWSKA *et al.*, 2021). Furthermore, worsening social vulnerabilities, including unemployment, food insecurity, and household impoverishment, may have contributed to adverse maternal and neonatal outcomes, including preterm birth and poorer conditions at birth (CARVALHO-SAUER *et al.*, 2024). In this context, reorganization of healthcare networks and, in some settings, the use of telemedicine were proposed as strategies to maintain prenatal follow-up. However, limitations in internet access, availability of electronic devices, and privacy during consultations highlighted important structural inequalities, particularly among rural and socially vulnerable populations (POLAVARAPU *et al.*, 2024).

Although national and international studies have investigated the effects of the pandemic on prenatal care and perinatal outcomes (CHMIELEWSKA *et al.*, 2021; GOMEZ *et al.*, 2022), evidence simultaneously assessing the number of prenatal visits, maternal age, pandemic-related periods, and degree of municipal urbanization remains limited, particularly within the sociodemographic context of Espírito Santo, Brazil. Moreover, the joint assessment of neonatal indicators such as gestational age, birth weight, and Apgar score across different degrees of urbanization may improve understanding of territorial inequalities among municipalities in Espírito Santo (MENDONÇA *et al.*, 2025). In this context, the present study aimed to analyze the associations between prenatal care adequacy, maternal age, and neonatal outcomes in Espírito Santo, considering differences across epidemiological periods related to the COVID-19 pandemic and across different degrees of urbanization of the municipality of maternal residence. We hypothesized that inadequate prenatal care was more frequent during the pandemic period and in less urbanized municipalities

and was associated with poorer neonatal outcomes, particularly among pregnancies at the extremes of maternal age.

Methods

A retrospective longitudinal, analytical, population-based study was conducted using publicly available secondary data from the Brazilian Live Birth Information System (SINASC), provided by the Ministry of Health. All records of live births to mothers residing in the state of Espírito Santo between 2017 and 2024 available in the official SINASC microdata were included, totaling 427,605 records. Analyses were performed at the individual level while also considering contextual factors related to the degree of urbanization of the municipality of residence and the epidemiological period.

Data were obtained from SINASC through the Department of Informatics of the Brazilian Unified Health System (DATASUS). Records of live births to mothers residing in Espírito Santo were selected based on official municipality-of-residence codes. Official SINASC data dictionaries were consulted for variable identification, organization, and standardization. Maternal variables included maternal age and place of birth; the health-care-related variable was the number of prenatal visits; and neonatal variables included gestational age, birth weight, and 5-minute Apgar score (Apgar5). Gestational age was categorized ordinally as follows: <22 weeks, 22–27 weeks, 28–31 weeks, 32–36 weeks, 37–41 weeks, and ≥42 weeks. Municipalities were classified according to their degree of urbanization based on the Classification of Rural and Urban Areas developed by the Brazilian Institute of Geography and Statistics (IBGE) as urban, corresponding to predominantly urban municipalities; rural, encompassing predominantly rural municipalities; and adjacent intermediate, characterized by interme-

diate levels of urbanization and strong functional integration with nearby urban centers.

The study period was divided into three temporal categories: pre-pandemic (2017–2019), pandemic (2020–2021), and post-pandemic (2022–2024), following the temporal classification widely adopted in studies assessing the impacts of the COVID-19 pandemic (MEIRELES *et al.*, 2025). This stratification allowed the assessment of potential changes in prenatal care and neonatal outcomes across different epidemiological periods.

The quantitative variables: number of prenatal visits, gestational age, birth weight, and Apgar5, were compared across temporal categories and degrees of urbanization of the municipality of maternal residence using two-way analysis of variance (two-way ANOVA) to identify differences among the study groups. Tukey's post hoc test was subsequently applied for pairwise comparisons among the categories, adopting a significance level of 5%.

Subsequently, linear regression models were fitted to investigate the associations of the quantitative covariates gestational age, number of prenatal visits, and maternal age with the quantitative neonatal outcomes birth weight and Apgar5. A forest plot was generated with the assistance of an artificial intelligence tool for visualization of the linear regression results. Statistical analyses, definition of the values presented, and verification of the data were performed by the authors based on the analytical results. All statistical analyses were conducted using Jamovi statistical software.

Results

Regarding the 5-minute Apgar score (Apgar5), no statistically significant differences were observed among the pre-pandemic, pandemic, and post-pandemic periods in rural ($p = 0.288$) or adjacent intermediate muni-

cipalities ($p = 0.554$). In urban municipalities, however, statistically significant differences were observed among the periods analyzed ($p = 0.005$). Pairwise comparisons showed that newborns in the post-pandemic period had higher Apgar5 scores than those in the pre-pandemic period ($p = 0.006$), with a mean difference of 0.057 points, and those in the pandemic period, with a mean difference of 0.049 points ($p = 0.052$). No statistically significant difference was observed between the pre-pandemic and pandemic periods ($p = 0.926$) (**Table 1**).

Regarding birth weight, the overall analysis showed that newborns delivered during the pandemic had a lower mean birth weight than those born during the pre-pandemic and post-pandemic periods, with mean differences of 41 and 45 g, respectively ($p < 0.05$). When stratified by degree of urbanization, rural municipalities showed a significantly lower mean birth weight during the pandemic, whereas urban municipalities showed significantly higher mean birth weight values in the post-pandemic period ($p < 0.001$). No statistically significant differences among the study periods were observed in adjacent intermediate municipalities ($p > 0.05$) (**Table 2**).

Table 1. Multiple comparisons using Tukey's test for the 5-minute Apgar score (Apgar5) according to the degree of municipal urbanization and the study periods: pre-pandemic, pandemic, and post-pandemic. (MD) = Mean Difference; (SE) = Standard Error.

Rural				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	-0,0736	0,0481	0,277
	Post-pandemic	-0,0588	0,0472	0,426
Pre-pandemic	Post-pandemic	0,0147	0,0418	0,934
Urban				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	0,00789	0,0211	0,926
	Post-pandemic	-0,04891	0,021	0,052
Pre-pandemic	Post-pandemic	-0,0568	0,0185	0,006

Adjacent Intermediate				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	0,0566	0,0575	0,587
	Post-pandemic	0,0127	0,0566	0,973
Pre-pandemic	Post-pandemic	-0,0439	0,051	0,665

Regarding the number of prenatal visits, statistically significant differences were observed among the three study periods in rural municipalities ($p < 0.05$). In this category, the mean number of visits was higher during the pandemic than in the pre-pandemic period and reached the highest values in the post-pandemic period. A similar trend was observed in adjacent intermediate municipalities, with a progressive increase in the mean number of prenatal visits across the study periods. In urban municipalities, although the difference in the number of visits between the pre-pandemic and pandemic periods was not statistically significant, values recorded in the post-pandemic period were significantly higher than in both previous periods (**Table 3**).

Regarding gestational age, statistically significant differences among the study periods were observed only in rural municipalities. In these municipalities, mean gestational age was lower during the pandemic than in the pre-pandemic period, with a mean difference of 0.075 weeks. A mean difference of 0.051 weeks was observed between the post-pandemic and pre-pandemic periods; however, this difference did not reach statistical significance. In urban and adjacent intermediate municipalities, no statistically significant differences were identified among the study periods (**Table 4**).

Table 2. Multiple comparisons using Tukey's test for birth weight (in grams) according to the degree of municipal urbanization and the study periods: pre-pandemic, pandemic, and post-pandemic. (MD) = Mean Difference; (SE) = Standard Error.

Rural				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	-40,93	17,2	0,045
	Post-pandemic	-44,78	16,9	0,022
Pre-pandemic	Post-pandemic	-3,85	14,9	0,964
Urban				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	-8,57	8,35	0,56
	Post-pandemic	-30,74	8,31	<,001
Pre-pandemic	Post-pandemic	-22,17	7,31	0,007
Adjacent Intermediate				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	10,22	20,1	0,867
	Post-pandemic	1,11	19,8	0,998
Pre-pandemic	Post-pandemic	-9,11	17,8	0,866

Finally, linear regression models were fitted to identify factors associated with the quantitative neonatal outcomes: Apgar5 score and birth weight. In both models, gestational age showed the strongest estimated association with the outcomes after adjustment for the other variables included in the models ($p < 0.001$). Longer gestational age was positively associated with both outcomes, with each additional week of gestation corresponding to an estimated increase of 0.382 points in the Apgar5 score and 703.76 g in birth weight. The number of prenatal visits and maternal age were also significantly associated with Apgar5. The former showed a positive association, whereas the latter showed a negative association, indicating that a greater number of prenatal visits and younger maternal age were associated with higher Apgar5 scores, although maternal age had a smaller estimated effect size (**Figures 1 and 2**).

For birth weight, both the number of prenatal visits and maternal age showed significant positive associations, indicating that newborns of mothers who attended more prenatal visits and were older tended to have higher birth weight after adjustment for the other variables included in the model. Again, maternal age showed a smaller estimated effect size (**Figures 1 and 2**).

Table 3. Multiple comparisons using Tukey's test for the number of prenatal visits according to the degree of municipal urbanization and the study periods: pre-pandemic, pandemic, and post-pandemic. (MD) = Mean Difference; (SE) = Standard Error.

Rural				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	0,0616	0,0243	0,030
	Post-pandemic	-0,0562	0,0239	0,049
Pre-pandemic	Post-pandemic	-0,1178	0,0212	<,001
Urban				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	-0,0194	0,0141	0,356
	Post-pandemic	-0,0561	0,0141	<,001
Pre-pandemic	Post-pandemic	-0,0367	0,0124	0,008
Adjacent Intermediate				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	0,0698	0,0295	0,047
	Post-pandemic	-0,0628	0,0291	0,078
Pre-pandemic	Post-pandemic	-0,1326	0,0261	<,001

Table 4. Multiple comparisons using Tukey's test for gestational age (in weeks) according to the degree of municipal urbanization and the study periods: pre-pandemic, pandemic, and post-pandemic. (MD) = Mean Difference; (SE) = Standard Error.

Rural				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	-0,0752	0,0277	0,018
	Post-pandemic	-0,0243	0,0271	0,643
Pre-pandemic	Post-pandemic	0,0509	0,0241	0,088
Urban				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	-0,00533	0,0136	0,919
	Post-pandemic	-0,01822	0,0136	0,371
Pre-pandemic	Post-pandemic	-0,01288	0,0119	0,527
Adjacent Intermediate				
Period	Period	DM	EP	ptukey
Pandemic	Pre-pandemic	-0,01593	0,0335	0,883
	Post-pandemic	-0,01416	0,0331	0,904
Pre-pandemic	Post-pandemic	0,00177	0,0297	0,998

Figure 1. Estimated mean effect sizes (estimates) and 95% confidence intervals (95% CIs) for the explanatory variables gestational age, number of prenatal visits, and maternal age in relation to the 5-minute Apgar score (Apgar5).

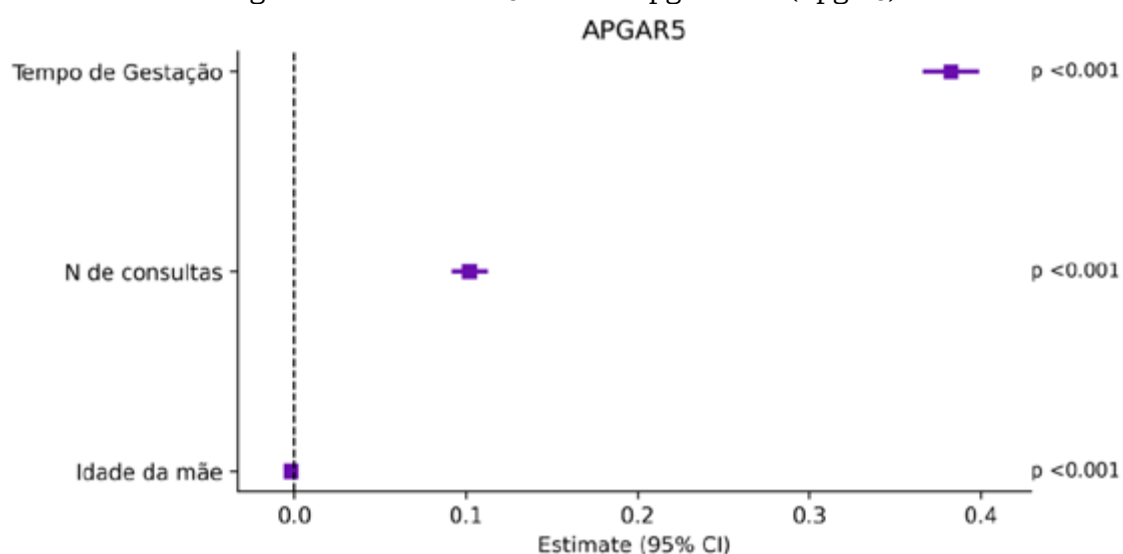
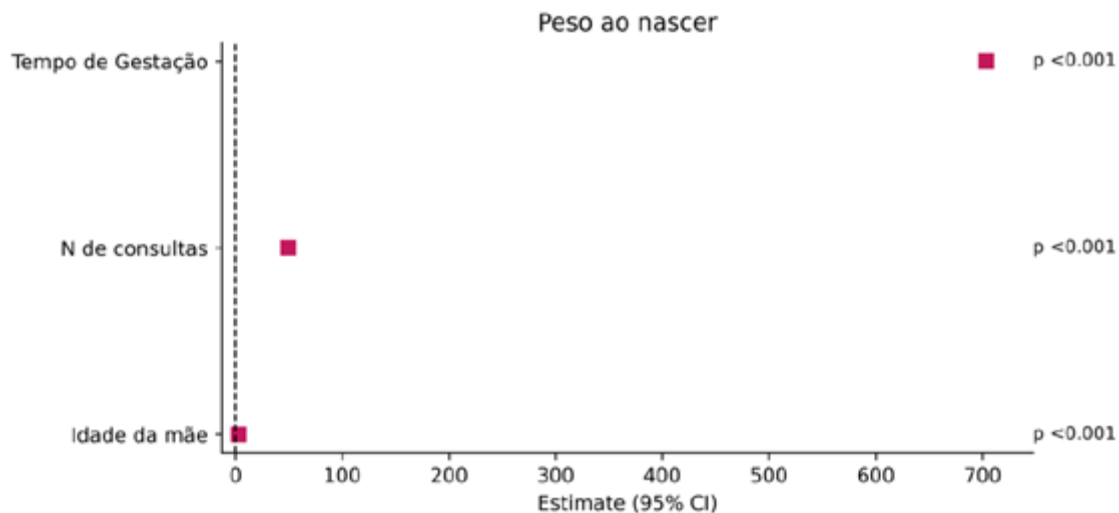


Figure 2. Estimated mean effect sizes (estimates) and 95% confidence intervals (95% CIs) for the explanatory variables gestational age, number of prenatal visits, and maternal age in relation to birth weight (g).



Discussion

Our results are partially consistent with the hypothesis that prenatal care would have been less adequate during the pandemic and in less urbanized municipalities, resulting in poorer neonatal outcomes, particularly among pregnancies at the extremes of maternal age. The number of prenatal visits was higher in the post-pandemic period in both urban and rural municipalities. However, the impact associated with fewer prenatal visits was greater in rural municipalities, as hypothesized, where lower birth weight and shorter gestational age were observed during the pandemic.

Among the potential mechanisms underlying reduced neonatal vitality associated with SARS-CoV-2 infection are alterations in the renin-angiotensin-aldosterone system (RAAS), endothelial dysfunction, complement activation, and the procoagulant effects of COVID-19. These mechanisms resemble processes observed in pregnancies complicated by preeclampsia and may result in progressive vascular damage. Pregnancy and its complications may therefore represent a state of increased vul-

nerability to severe SARS-CoV-2 infection through several overlapping cellular mechanisms (NARANG, 2020). In addition to the direct cytotoxic effects of the virus, COVID-19-associated tissue injury may be mediated by an exacerbated inflammatory response, commonly referred to as a cytokine storm. Immune responses undergo substantial changes during pregnancy; the first and third trimesters, for example, are characterized by pro-inflammatory states that support implantation and labor, respectively. Pregnant women infected with SARS-CoV-2 during these periods may therefore be at greater risk of an exaggerated inflammatory response to the virus (NARANG, 2020).

However, if these mechanisms were directly responsible for the differences observed in neonatal vitality indicators, more pronounced effects would be expected in urban municipalities, which had the highest infection rates according to data from the Espírito Santo COVID-19 Dashboard. Previous studies have reported declining birth rates during the pandemic in urban municipalities of Espírito Santo, accompanied by more pronounced changes in mobility patterns and social isolation than in rural and intermediate municipalities (MEIRELES et al., 2025).

This pattern was observed for Apgar5, as significant variation occurred only in urban municipalities, where post-pandemic values were higher than those recorded during the pandemic, although pandemic values did not differ from those observed in the pre-pandemic period. A similar temporal pattern was observed for the number of prenatal visits, which increased significantly in the post-pandemic period compared with both the pandemic and pre-pandemic periods. Our findings suggest that a possible strengthening of healthcare capacity required during the pandemic in urban municipalities may have resulted in improved quality of care in the post-pandemic period, when the additional pressure on healthcare sys-

tems had subsided. Similar effects have been described in several regions worldwide (MOYNIHAN et al., 2021; OKYERE et al., 2024).

Birth weight and Apgar5 score were significantly associated with gestational age, number of prenatal visits, and maternal age, with gestational age showing the strongest association in both regression models. In rural municipalities, shorter gestational age was accompanied by lower birth weight during the COVID-19 pandemic. In this context, the indirect effects of the pandemic on the organization of healthcare services may have played a more important role in less urbanized municipalities, where healthcare infrastructure is generally more limited. Robertson and colleagues (2020) estimated that disruptions in the provision and quality of essential maternal and child health services could result in substantial increases in maternal and neonatal morbidity and mortality, particularly in low- and middle-income settings. Thus, key components of prenatal care, such as access to complementary examinations, timely referral to specialized services, monitoring of high-risk pregnancies, and continuity of care, may have been disproportionately compromised in rural municipalities during the pandemic, potentially explaining the effects observed on gestational age and birth weight in these areas (MARTINELLI et al., 2024; POLAVARA-PU et al., 2024). Moreover, pregnant women living in rural municipalities often need to travel to other municipalities for diagnostic examinations, medical appointments, and delivery. Transportation restrictions and the strain placed on healthcare systems during pandemic peaks may have further limited this access. Santos and colleagues (2016) highlighted persistent shortcomings in prenatal care associated with socioeconomic, educational, and territorial inequalities. These conditions may hinder access to healthcare services, delay the initiation of prenatal care, and contribute to discontinuation of prenatal follow-up.

It is important to emphasize that the effects of the pandemic on maternal and child health were not homogeneous across different territorial contexts (CHMIELEWSKA et al., 2021). One possible explanation for the observed differences involves the psychosocial effects of the pandemic. Studies conducted in different countries reported significant increases in anxiety, stress, and depressive symptoms among pregnant women during the pandemic (KOTLAR et al., 2021; SHOREY; NG, 2021). In addition to their potential effects on maternal mental health, there is evidence that prenatal stress may influence fetal development through biological mechanisms. Changes in maternal cortisol levels and hypothalamic–pituitary–adrenal axis activity have been associated with alterations in the intrauterine environment, potentially affecting fetal growth, neurological maturation, and neonatal adaptation after birth (VRIJDERS et al., 2020; VAN DEN BERGH et al., 2020). Although these mechanisms were not directly investigated in the present study, they represent a biologically plausible hypothesis for interpreting differences in neonatal vitality during pandemic periods.

Conclusions

Our results indicate that gestational age, the variable with the strongest association with Apgar5 and birth weight, was affected by the pandemic only in rural municipalities, which may have contributed to the lower birth weight observed in these areas during the pandemic. These findings indicate that the effectiveness of prenatal care depends not only on expanding healthcare coverage but also on its capacity to prevent events related to preterm birth. Efforts to improve maternal and neonatal outcomes during public health crises, such as pandemics, should therefore focus particularly on strengthening healthcare infrastructure in rural municipa-

lities and providing psychosocial support in urban municipalities, where lower Apgar5 scores were observed during the pandemic.

Although the results should be interpreted considering the limitations inherent to the use of secondary data and the lack of information on clinical and socioeconomic factors and on the quality of healthcare services, this study contributes to the understanding of territorial inequalities in neonatal outcomes and prenatal care. It also reinforces the importance of strategies aimed at strengthening maternal and child healthcare and reducing regional disparities in health.

Further studies are needed to investigate the effects of stress associated with traumatic events on pregnancy outcomes within the Brazilian context, thereby supporting the implementation of strategies focused on maternal emotional health and contributing to safer and healthier pregnancies. In addition, further research should examine how regional differences in the organization of healthcare services influence the quality of prenatal care and neonatal outcomes across urban and rural municipalities in Brazil.

Author contributions

Conceptualization: MMC; JAN; KMK; VAC; ACAG; JVBC; JFPW; LLCL; LW; MCAP; NWS; FTC; AGS; LFSN; LBL

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Visualization: MMC; JAN; KMK; VAC; ACAG; JVBC; JFPW; LLCL; LW; MCAP; NWS; FTC; AGS; LFSN; LBL

Writing — original draft: MMC; JAN; KMK; VAC; ACAG; JVBC; JFPW; LLCL; LW; MCAP; NWS; FTC; AGS; LFSN; LBL

Writing — review & editing: MMC; JAN; KMK; VAC; ACAG; JVBC; JFPW; LLCL; LW; MCAP; NWS; FTC; AGS; LFSN; LBL

Conflict of Interest

The authors declare no conflicts of interest related to this study. This work was conducted independently, without influence from institutions, organizations, or sponsors that could affect the results or the interpretation of the data presented.

Data Availability

The authors declare that the data supporting the results of this study are available in the article. Derived data supporting the study's conclusions that are not found in the article may be requested from the corresponding author.

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