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The impact of the COVID-19 pandemic on maternal healthcare costs: a time series analysis of pregnancies of multi-ethnic mothers in South London, United Kingdom

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Abstract

Background Due to the COVID-19 pandemic, maternity care reconfigurations disrupted in-person care, which shifted towards virtual care and self-monitoring. We assessed the impact of these changes on maternity service provision costs.

Methods Data from October 2018 to April 2023 were used from the population-based early-LIfe data cross-LInkage in Research, Born in South London (eLIXIR-BiSL) platform linking maternity, neonatal, and mental healthcare data from three National Health Service (NHS) hospitals in South London, United Kingdom. Maternity costs were generated from the NHS perspective, using national unit costs and individual-level use of maternity, mental health, and primary care services. Interrupted time series analysis estimated the pandemic impact on monthly mother-newborn costs over time. Cross-sectional pre-pregnancy cost models isolated the impact of virtual care and gestational diabetes (GDM) self-monitoring using the GDm-Health app. Ethnic inequalities in the impact of the pandemic on maternity costs were assessed via interaction terms.

Results Among 36,895 pregnancies, the monthly cost time series level dropped by 4% (£ − 38, 95% confidence interval: [£ − 65 to − 10]), during the first pandemic lockdown, and by 7.6% (£ − 72 [£ − 108 to − 36]), when lockdowns were lifted compared with the pre-pandemic period. However, the pre-pandemic slightly upward timeseries slope of costs (£4 per month, [£0.30 to £6.83]) was unchanged during the pandemic (£0.46 [£ − 2.93 to 3.84]). Monthly costs increased with first lockdown for Black (£103 [£26 to 181]) and Asian women (£128 [£38 to 218]) and increased more slowly during post-lockdown (£ − 12 [£ − 23 to − 2]), for Asian women, remaining higher throughout the pandemic for Black and Asian women compared with White women. A 1% increase in virtual care was associated with a £7 (£3 to 10) increase in maternity costs. GDM self-monitoring via GDm-Health was cost-neutral (£140 [£ − 68 to 348]).

Conclusions The pandemic was associated with temporary reductions in maternity costs due to lower healthcare utilisation. Ongoing, rising maternity costs were unchanged. The pandemic had differential effects on Black and Asian

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women compared with White women. Further research is needed into clinical outcomes of virtual care (associated with higher costs) and use of GDm-Health (cost-neutral).

Keywords Maternity care, COVID-19 pandemic, Interrupted time series analysis, Mother-newborn costs

Background

The COVID-19 pandemic had profound consequences for healthcare services, including maternity care [1, 2]. Some midwifery units closed or merged, and staffing shortages affected the available skill mix [3]. Perceived risk of infection led to hesitation in seeking healthcare [4], and there were reductions in routine [5] and unscheduled [6] antenatal care visits, prolonged maternal length of stay, and more maternal readmissions to hospital [7]. However, most data is from the first pandemic year (to February 2021), during lockdowns, and unadjusted for pre-existing trends; thus, the impact of the pandemic overall on maternity costs over time remains largely unexplored.

During the pandemic in the United Kingdom (UK), the Royal College of Obstetricians & Gynaecologists advised expansion of 'virtual care' (also known as 'remote consultation', 'telehealth', or 'eHealth') while ensuring at least six face-to-face antenatal visits [8]. By July 2020, most UK maternity units had adopted virtual care in varying intensities [3]. No impact of virtual care on outcomes was reported in an interrupted time series analysis from Australia [9], but extensive international qualitative data indicate that most women were less satisfied and less reassured by virtual (vs. face-to-face) care, resulting in further health care utilisation and potentially increased healthcare costs [10, 11]. Also, there were concerns that the pandemic exacerbated inequalities when virtual care is offered to digitally disadvantaged groups [12].

Existing studies of virtual care impact on UK maternity healthcare costs are scarce and inconclusive, highlighted by a systematic review of telemedicine among pregnant women with diabetes [13]. While subsequent studies of general [14] and diabetes-specific [15] pre/peripartum populations reported lower healthcare use with virtual care, results were based on small sample sizes (75 and 63 patients, respectively) and healthcare costs for mothers and newborns were not assessed.

The pandemic also saw rapid adoption of the GDm-Health app for gestational diabetes mellitus (GDM) care in the UK [16]. The app records remotely measured blood glucose levels with real-time review by healthcare-providers, facilitating rapid provider-patient communication [17]. This contrasts with the traditional written 'sugar diary' record discussed retrospectively at face-to-face appointments. Studies of the GDm-Health app show positive impacts on pregnancy outcomes when GDM self-monitoring is part of a care package [18], without incurring greater costs [17], acknowledging the small size of studies to date.

We assessed (i) the overall impact of the COVID-19 pandemic on monthly trajectory costs for maternity and newborn care, from October 2018 to April 2023; (ii) the impact of virtual care and GDm-Health app use on pregnancy costs; and (iii) whether costs differed across sociodemographic groups.

We hypothesise that maternity costs declined during the pandemic compared with the pre-pandemic period due to hesitancy to use healthcare services, reflecting fears of COVID-19 infection or of further overwhelming the NHS. Yet this effect may have been offset by increased health service use driven by COVID-19-related complications, poorer mental health, and dissatisfaction with the quality of virtual maternity care.

Methods

Study design and setting

In a longitudinal study design, monthly electronic health record data from the early-LIfe data cross-LInkage in Research, Born in South London (eLIXIR-BiSL) data linkage cohort were assessed. The dataset comprises routine maternity and neonatal health records of pregnant women accessing care via Guy's and St Thomas' Hospital National Health Service (NHS) Foundation Trust and King's College Hospital NHS Foundation Trust, linked to mental health (South London and Maudsley NHS Foundation Trust) and primary care data (Lambeth DataNet). These hospitals in inner-city boroughs in South London, UK, serve an urban, largely deprived, multi-ethnic population. Details of eLIXIR-BiSL have been published previously [19].

The study sample includes women registering for maternity care between October 2018 (eLIXIR-BiSL cohort initiation) and April 2023, with antenatal registration and birth information. Study epochs are defined as 'pre-pandemic' (October 2018 to February 2020), 'pandemic lockdowns' (March 2020 to June 2021), and 'post-lockdown' (July 2021 to April 2023). March 2020 was when the UK healthcare system's response began and the first national lockdown was implemented.

Data variables and measurement

Pregnancy costs were generated from the NHS perspective, based on individual-level health service use and

2021–2022 national unit costs (Additional file 1: Box S1 [20–22]), with the NHS Cost Inflation Index used to adjust for inflation [23]. Maternity services, mental healthcare, and primary care utilisation were included, from antenatal registration appointment to 6 weeks postpartum. Maternity services captured routine antenatal appointments, maternity assessment unit visits, birth and other inpatient stays, and postnatal reviews. Mental health services included 'Talking therapies' (for depression or anxiety), secondary mental health services 'community contacts', and inpatient stays. Primary care costs reflect primary care consultations and were available for 32% of individuals in our sample (limited to general practice in Lambeth borough). Neonatal costs were included across relevant services (inpatient stays, postnatal reviews, and primary care). Total pregnancy costs are aggregated for analyses at the monthly mother-newborn level. The data sources and definitions of all variables used in analyses are described in Additional file 1: Tables S3 and S4.

Statistical methods

Maternal characteristics and healthcare utilisation and costs were compared via descriptive statistics across pre-pandemic, pandemic lockdowns, and post-lockdown periods, with differences assessed using *t*-tests or Mann–Whitney *U* tests for continuous variables and Pearson chi-squared tests for categorical variables.

Model 1: effect of the COVID-19 pandemic on monthly pregnancy costs

Interrupted time series (ITS) analysis was used to predict the effect of the pandemic on monthly pregnancy costs, comparing with pre-pandemic costs and differentiating between lockdown and post-lockdown periods. Pregnancy-month is the unit of analysis, so each data point includes individuals who were pregnant that specific month. Interaction terms considered both a change in level (immediate effect) and slope (gradual effect) of the cost time series, from lockdown impositions (March 2020) to lifting (July 2021). Models adjusted for seasonality and autocorrelation, as well as ethnicity and the percentage of deliveries, each of which changed over time (Additional file 1: Box S2). Estimated counterfactual costs for what would have been anticipated had the pandemic not occurred were also calculated (Additional file 1: Box S2). Model 1 was re-run for each service component to explore utilisation and cost components driving the results.

Model 2: impact of virtual antenatal care on maternity costs

In this cross-sectional model, the dependent variable was total cost per pregnancy, summing all monthly costs from antenatal registration until 6 weeks postpartum. The independent variable was 'Virtual care percentage', capturing the percentage of antenatal care delivered virtually, by telephone or video. To avoid the virtual care estimate capturing the effect of pandemic lockdowns, a control was included for the percentage of the pregnancy duration overlapping with the pandemic (March 2020 to June 2021). Other control variables were maternal age (years), ethnicity (Black/Asian/Mixed/Other/Missing), difficulty speaking English (yes/no), socioeconomic deprivation (Index of Multiple Deprivation [IMD] in quintiles), multiple birth (yes/no), gestational age at booking (weeks), smoking status (yes/no), and antenatal care plan type (i.e. 'Midwife only', 'Shared midwife and obstetrician' (75/25 split), or 'Obstetrician only', as granular information on the type of provider who delivered care at each antenatal appointment was not available), GDM, one/more other health conditions (i.e. GDM, other physical or mental health conditions) recorded at antenatal registration (by organ system, see Additional file 1: Box S3), and the hospital providing care. The choice of independent variables was guided by Andersen's revised conceptual framework of healthcare utilisation, by which use of health services is determined by predisposing factors, enabling factors, and need [24]. Separate models predicting each utilisation type and delivery costs were also estimated to further explore the relationship between virtual care and total costs.

Model 3: effect of GDm-Health app self-monitoring on maternity costs

This analysis was restricted to women with GDM. The dependent variable was total cost per pregnancy. The independent variable was 'App-User' (dichotomised by app registration status [1 = yes, 0 = no]). As women may have initially been registered, but stopped using it, a sensitivity analysis was run with the definition of 'App-User' to those who recorded sufficient blood glucose readings to be clinically meaningful (Additional file 1: Box S4). An app cost of £8 per pregnancy was added to total cost per pregnancy for app users, based on payment made by each hospital for app access, and the number of individuals in our sample. The same control variables are used as in model 2 (above). Separate models predicting each utilisation type and delivery costs were also estimated to further explore the relationship between total costs and GDM app use.

Across all models, to assess inequalities in the impact of the pandemic on maternity care costs across minority groups and individuals with medical complexity, subgroup analyses are presented, examining ethnicity, IMD, difficulty speaking English, GDM, and mental

health problems. Interactions are added between each subgroup variable and the key terms of interest (i.e. change in time series level, change in time series slope, and independent variables of virtual care and GDm-Health app use).

Missing data were kept as missing except for primary care utilisation, for which multiple imputation via chained equations (MICE) [25] was performed (Additional file 1: Box S5). Sensitivity analyses explore the impact of multiple imputation of primary care costs (by excluding primary care costs from total costs), considering July 2021 in the pandemic lockdowns period (rather than in post-lockdown), and changing the definition of 'Shared midwife and obstetrician' antenatal care from a 75/25 to 90/10 split. Goodness of fit measures are used to identify the most appropriate estimation method for each of models 1 to 3: an ordinary least squares model (OLS) or a generalised linear model (GLM) with a gamma distribution and log link.

All analyses were conducted using R version 4.3.0.

Results

The sample size was 36,985 pregnancies, across pre-pandemic (N= 13,284), pandemic lockdowns (N= 11,470), and post-lockdown pandemic (N= 12,231) periods.

Pre-pandemic, women were on average aged 33 years, half were of White ethnicity, relatively deprived (60% in the two most deprived IMD quintiles), and with English as primary language in 70% (Table 1). Ten percent developed GDM, and many had a record at the booking appointment of at least one physical (41%) or mental (22%) health condition. Maternal characteristics remained stable during pandemic lockdowns and post-lockdown, albeit with slight, statistically significant, increases in age, the percentage of individuals of non-White ethnicity, those with missing IMD, GDM, and physical or mental health conditions.

Costs per pregnancy

Pre-pandemic, the distribution of total cost per pregnancy was right-skewed, with a mean of £7625 (standard deviation [SD] =2668) and median of £7118

Table 1 Maternal characteristics in the pre-pandemic, pandemic (with lockdowns), and post-pandemic (without lockdowns) periods

	Pre-pandemic	Pandemic with lockdowns	*p* value[a]	Pandemic without lockdowns	*p* value[b]
	***N*= 13,284**	***N*= 11,470**		***N*= 12,231**	
Age (years)	32.63	32.80	0.048	32.82	0.024
Ethnicity (%)			< 0.001		< 0.001
White	50.12	52.03		48.43	
Black	19.72	20.63		21.37	
Asian	8.36	9.85		10.91	
Mixed	4.43	5.24		5.96	
Other	6.50	7.99		6.36	
Missing	10.87	4.26		6.96	
IMD			0.2		< 0.001
Quintile 1 (most deprived)	19.11	19.22		20.01	
Quintile 2	41.41	41.15		40.32	
Quintile 3	25.38	24.83		23.52	
Quintile 4	9.21	9.26		9.55	
Quintile 5 (least deprived)	3.62	3.92		4.16	
Missing	1.28	1.62		2.44	
% of English speakers	69.56	70.28	0.2	69.59	> 0.9
% difficulty speaking English	6.94	6.82	0.7	7.28	0.30
% with GDM	10.19	13.49	< 0.001	13.05	< 0.001
% with a physical health condition	40.95	45.25	< 0.001	47.96	< 0.001
% with a mental health condition	21.67	24.90	< 0.001	27.08	< 0.001

The pre-pandemic period spans from October 2018 to February 2020, pandemic with lockdowns from March 2020 to June 2021, and pandemic without lockdowns from July 2021 to April 2023

IMD Index of Multiple Deprivation, GDM gestational diabetes mellitus

[a] *Chi-square tests for categorical variables and t-tests for continuous variables were used to compare maternal characteristics across study periods. This first p value column reflects the comparison between pandemic with lockdowns to pre-pandemic*

[b] *The second p value column reflects the comparison between pandemic without lockdowns to pre-pandemic*

(interquartile range [IQR] =£5625 to £9085) (Table 2). Total costs were driven primarily by delivery costs (~ 60%, £4734, SD =1781), followed by routine antenatal costs (~ 20%, £1344, SD =775), with much smaller contributions from primary care (mean of £154 per pregnancy, SD =128) and mental healthcare (mean of £28, SD =593). The composition of total costs remained stable across the pandemic, with or without lockdowns (Additional file 1: Fig. S1).

Over the pandemic, mean total cost per pregnancy grew, to £7932 (SD =2833) during pandemic lockdowns and £8096 (SD =2799) post-lockdown (Table 2). All cost components increased, except for progressive declines in routine postnatal review costs (from £775 pre-pandemic, to £667 during pandemic lockdowns, and £586 post-lockdown). Mean mental health costs showed the largest relative pandemic increase, from £28 pre-pandemic, to £56 during pandemic lockdowns and £35 post-lockdown. Similar fluctuations in healthcare utilisation were observed across the study period (Additional file 1: Table S5).

There was a sharp increase in use of virtual care during pandemic lockdowns compared with pre-pandemic use (Additional file 1: Fig. S3). While in February 2020 only 2% of routine antenatal care was virtual, this peaked at 18% in June 2020. Thereafter, virtual antenatal care declined progressively through pandemic lockdowns to 7% by June 2021 (resulting in an average monthly proportion of virtual care during the lockdowns of 12.3%), and reaching 5% by the end of post-lockdown (April 2023).

Overall, 4399/35,985 (12%) of pregnancies were complicated by GDM, of which 3215 (75%) were registered on the GDm-Health app (Additional file 1: Table S5).

Main results

Model 1: effect of the COVID-19 pandemic on monthly pregnancy costs

According to the ITS model, there was an increasing trend in maternity costs prior to the pandemic, with costs increasing £4 (95% CI 0.3–6.8) per month per pregnancy (Table 3). In the initial months of pandemic lockdowns, monthly pregnancy costs (blue line, Fig. 1) were lower than they would have been if the pandemic had not occurred (dotted red line, Fig. 1). Compared with pre-pandemic, the level of the monthly cost time series dropped by £− 38 (£ −65 to −10) with the onset of pandemic lockdowns (equivalent to 4% of monthly pregnancy costs) and by £− 72 (£ −108 to −36) with the onset of post-lockdown (equivalent to 8% of monthly pregnancy costs) (Table 3). However, there were no statistically significant changes to the cost time series slopes. In March 2020, monthly pregnancy costs were

Table 2 Mean cost per pregnancy (SD) in the pre-pandemic, pandemic (with lockdowns), and post-pandemic (without lockdowns) periods

	Pre-pandemic *N*= 13,284	Pandemic with lockdowns[a] *N*= 11,470	Pandemic without lockdowns[b] *N*= 10,233
Total pregnancy costs	£7624.54 (2668.05)	£7932.20 (2833.68)***	£8095.86 (2799.60)***
Total maternity services costs	£7442.85 (2577.67)	£7704.72 (2548.21)***	£7860.91 (2657.19)***
Routine antenatal	£1344.45 (775.10)	£1571.02 (710.41)***	£1557.70 (743.36)***
Maternity assessment unit	£341.03 (321.70)	£373.94 (349.37)***	£427.37 (411.22)***
Inpatient stay	£248.21 (634.64)	£282.59 (674.05)***	£313.75 (775.25)***
Delivery	£4734.06 (1781.55)	£4810.31 (1791.18)***	£4976.29 (1855.58)***
Post-natal review	£775.10 (573.65)	£666.87 (590.31)***	£585.80 (553.61)***
Total primary care costs	£153.91 (128.06)	£171.50 (156.12)***	£199.86 (172.69)***
Total mental health services costs	£27.79 (593.21)	£55.98 (1156.36)**	£35.10 (789.80)***
Talking therapy	£7.58 (59.07)	£11.07 (77.23)***	£9.15 (64.54)***
Community contacts	£9.33 (87.94)	£14.50 (139.36)	£13.41 (115.95)***
Inpatient stay costs	£10.87 (572.28)	£30.41 (1093.15)	£12.55 (751.45)

Total pregnancy costs include costs relevant to the mother and newborn(s). Given a pregnancy can span more than one period, each pregnancy was assigned to a period based on the date of their booking appointment. The pre-pandemic period spans from October 2018 to February 2020, pandemic with lockdowns from March 2020 to June 2021, and pandemic without lockdowns from July 2021 to April 2023

[a] The stars indicate statistical significance corresponding to the *t*-tests (Mann–Whitney *U*) comparing mean costs during the pandemic with lockdowns to pre-pandemic

[b] The stars indicate statistical significance corresponding to the *t*-tests (Mann–Whitney *U*) comparing mean costs during the pandemic without lockdowns to pre-pandemic

* < 0.05

** < 0.01

*** < 0.001

Table 3 Parameter estimates from the ITS model assessing the impact of the pandemic on total monthly pregnancy costs

Control	Parameter estimate	95% CI
Constant	147.64***	(124.35, 170.93)
Time	3.56*	(0.30, 6.83)
Pandemic lockdowns—change in level	− 37.66**	(− 65.07, − 10.25)
Pandemic lockdowns—change in slope	0.46	(− 2.93, 3.84)
Post lockdown—change in level	− 72.05***	(− 107.95, − 36.16)
Post lockdown—change in slope	0.87	(− 2.42, 4.17)
Delivery	5659.46***	(5636.88, 5682.04)
Ethnicity		
Black	52.11***	(42.36, 61.85)
Asian	33.71***	(22.38, 45.04)
Mixed	2.64	(− 11.57, 16.84)
Other	16.43*	(2.19, 30.68)
Missing	− 40.80***	(− 55.22, − 26.38)

Model also controls for month, hospital, and lagged residuals. Reference group for ethnicity is 'White' and changes in level and slope are compared to the pre-pandemic period. The 'time' estimate represents the monthly pre-pandemic slope. The unit of measurement of parameter estimates is monthly pregnancy costs. For example, the parameter estimate of 'Pandemic lockdowns—change in level' = − 37.66 indicates that, compared with pre-pandemic, the level of the monthly cost trendline dropped by £38 with the onset of pandemic lockdowns (equivalent to 4% of monthly pregnancy costs)

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

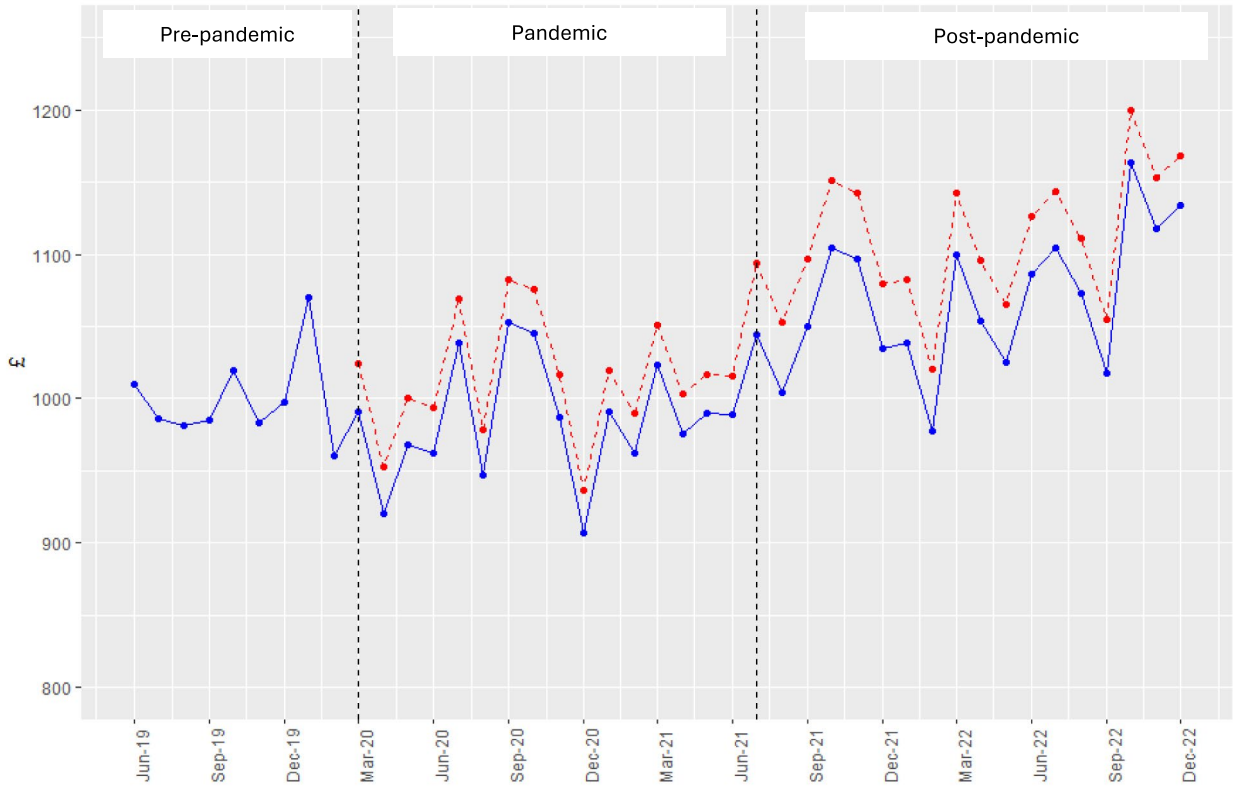

Fig. 1 Results of ITS analysis—average monthly pregnancy costs and counterfactual scenario. Legend: This figure presents average monthly pregnancy costs (blue line) and counterfactual scenario (dashed red line). Average monthly pregnancy costs capture the average cost in a specific month among women who were pregnant that month

3% lower (£991) than the counterfactual if the pandemic had not occurred (£1024) (Additional file 1: Table S7). The separate utilisation and cost components models suggest that the drop in monthly pregnancy costs at the beginning of the pandemic was driven by a reduction in medical assessment unit (MAU), postnatal, and primary care use and costs, as well as lower Improving Access to Psychological Therapies (IAPT) and community mental health contacts (Additional file 1: Box S6). Similarly, the drop in monthly pregnancy costs at the end of the lockdowns may have resulted from lower MAU, postnatal, and primary care utilisation and costs, as well as delivery costs. On the other hand, the antenatal appointments trend increased in level at the start of the pandemic, yet costs remained stable, which may reflect a higher use of cheaper virtual care appointments (Additional file 1: Fig. S3).

Subgroup analyses found a differential effect of monthly pregnancy costs over time, by ethnicity (Additional file 1: Tables S8, S9 and Fig. S4). While mean costs among White ethnicity women dropped in level by £ − 74 (95% CI: £ − 38 to £ − 109) at the start of pandemic lockdowns, costs for Black ethnicity women increased in level by £30 (for a difference vs. White ethnicity women of £ + 103, CI: 26–181) and costs for Asian ethnicity women grew by £54 (for a difference of £ + 128, CI: 38–218). Thereafter, costs for Black and Asian (vs. White) ethnicity women grew more slowly during the pandemic (by £ − 10 and £ − 16 per month, respectively, vs. £ + 4 for White ethnicity women), but those costs for Black and Asian (vs. White) ethnicity women remained higher throughout the pandemic (Additional file 1: Fig. S4). There was less variation in costs post-lockdown, with the only difference being for women of Asian ethnicity, who had a £12 slower monthly trend.

Model 2: impact of virtual antenatal care on maternity costs

In this cross-sectional model, women with a higher proportion of virtual antenatal care had higher pregnancy costs, with a 1% point increase in virtual care associated with a £7 (95% CI: 3–10) increase in costs (Table 4). As the average monthly proportion of virtual care during pandemic lockdowns was 12.3%, compared with 1.9% pre-pandemic (a 10.4% difference), this represents a £73 increase in cost per pregnancy during pandemic lockdowns. Assuming that all of the 11,470 pregnancies during pandemic lockdowns received 12.3% of their antenatal care virtually, the NHS incurred £837,310 (£73 × 11,470) additional costs compared with pre-pandemic use of virtual care. The cost increasing effect of virtual care seemed to stem from a higher use of antenatal and MAU visits and higher delivery costs (Additional file 1: Table S10).

Model 3: effect of GDm-Health app self-monitoring on maternity costs

Among women with GDM, there were no differences in total costs per pregnancy between those who registered on the GDm-Health app and those who did not (Table 4). App use was associated with increased antenatal care use, decreased (yet not statistically significant) primary care use and delivery costs, and a neutral effect on MAU and postnatal appointments, resulting in an overall null effect on total maternity costs (Additional file 1: Table S11).

Also, there was no difference in costs in the sensitivity analysis that compared costs for those who showed clinically relevant app use (vs. those who did not; analyses available upon request).

In both models 2 and 3, no differential impacts on cost per pregnancy were found for virtual care (Additional file 1: Table S12) or GDM app registration (Additional file 1: Table S13), across ethnic groups, IMD quintiles, difficulty speaking English, or mental health status.

All models were estimated using OLS, as it showed slightly better goodness of fit than a GLM model with the log link and the gamma distribution (Additional file 1: Table S14 [26–29]). The GLM log link and gamma distribution model yielded comparable parameter estimates to OLS across the three models (results available upon request).

Sensitivity analyses supported the stability of our results, with similar findings: after exclusion of primary care costs, with a change in the proportion of midwifery/obstetrician care in a shared care model, or after considering July 2021 as part of pandemic lockdowns (rather than post-lockdown) (Additional file 1: Tables S15 and S16).

Discussion

Summary

The COVID-19 pandemic led to a drop from pre-pandemic values in maternity costs at the onset of pandemic lockdowns, and again post-lockdown when all restrictions were lifted, but there was no change in the rate of rise of costs over time within either pandemic period (with or without lockdowns). Importantly, our findings suggest that the pandemic affected minority ethnic women differently; compared with White ethnicity women, those of Black or Asian ethnicity experienced an increase (not decrease) in costs at the start of pandemic lockdowns, and their costs rose more slowly during pandemic lockdowns, with that trend continuing for Asian ethnicity women during post-lockdown.

Descriptive analyses of costs per pregnancy (resulting from aggregating monthly pregnancy costs for each woman over the duration of their pregnancy) suggest

Table 4 Parameter estimates from the cross-sectional models assessing the impact of virtual care and self-monitoring via the GDm-Health app on costs per pregnancy

Control	Parameter estimate	95% CI	Parameter estimate	95% CI
Virtual care	6.92***	(3.49, 10.35)	–	
Self-monitoring			139.73	(– 68.49, 347.95)
Proportion of care during the pandemic	– 200.14	(– 569.15, 168.86)	– 746.06	(– 1948.91, 456.80)
Age (years)	12.24***	(7.27, 17.21)	23.14**	(8.61, 37.67)
Ethnicity				
Black	302.33***	(226.48, 378.18)	369.81***	(175.61, 564.02)
Asian	222.91***	(138.60, 307.21)	62.90	(– 135.95, 261.76)
Mixed	63.27	(– 46.46, 172.99)	17.57	(– 337.27, 372.40)
Other	144.99**	(40.72, 249.26)	53.59	(– 206.81, 314.00)
Missing	– 243.46***	(– 332.54, – 154.39)	– 196.11	(– 565.34, 173.13)
IMD				
Quintile 2	– 62.95	(– 135.58, 9.68)	– 84.08	(– 278.38, 110.23)
Quintile 3	– 101.66*	(– 179.69, – 23.62)	– 42.63	(– 265.66, 180.39)
Quintile 4	– 102.54*	(– 202.57, – 2.51)	– 121.56	(– 425.70, 182.57)
Quintile 5 (least deprived)	– 98.62	(– 229.47, 32.23)	– 290.64	(– 666.53, 85.25)
Missing	– 105.40	(– 333.46, 122.66)	174.64	(– 680.17, 1029.45)
Smoking status				
Smoker	– 7.16	(– 148.23, 133.91)	4.96	(– 479.15, 489.07)
Smoking status missing	67.08	(– 74.79, 208.94)	– 4.33	(– 383.82, 375.16)
Antenatal care type				
Shared	735.79***	(680.15, 791.42)	799.68***	(606.96, 992.41)
Obstetrician only	1470.96***	(1209.05, 1732.87)	2794.53***	(1889.53, 3699.52)
Missing	318.00	(– 39.87, 675.88)	1465.98	(– 317.37, 3249.33)
Multiple births	7655.76***	(7387.55, 7923.96)	7671.23***	(7096.10, 8246.36)
Difficulty speaking English	– 0.59	(– 57.00, 55.82)	25.63	(– 131.99, 183.25)
Physical condition	451.56***	(398.95, 504.16)	523.34***	(368.99, 677.70)
Mental health condition	393.68***	(328.55, 458.82)	560.81***	(364.92, 756.70)
GDM	726.84***	(648.03, 805.66)	–	
Gestation at booking (weeks)	– 57.89***	(– 61.49, – 54.29)	– 57.89***	(– 70.80, – 44.97)
Constant	6345.05***	(6117.46, 6572.63)	6172.56***	(5449.89, 6895.23)

Two separate cost models were estimated, one assessing the impact of virtual care and the other the impact of self-monitoring on costs per pregnancy. Model also controls for month of booking appointment and hospital. Reference group for ethnicity is 'White', and reference group for antenatal care type is 'Midwife only' care. Multiple births, difficulty speaking English, physical condition, mental health condition, and GDM are all yes/no variables, with 'no' as the reference category. The unit of measurement of parameter estimates is cost per pregnancy. For example, the parameter estimate of 'Virtual care' = 6.92 indicates that a 1% point increase in virtual care associated with a £7 increase in costs. As the average monthly proportion of virtual care during pandemic lockdowns was 12.3%, compared with 1.9% pre-pandemic (a 10.4% difference), this represents a £73 increase in cost per pregnancy during pandemic lockdowns. Assuming that all of the 11,470 pregnancies during pandemic lockdowns received 12.3% of their antenatal care virtually, the NHS incurred £837,310 (£73 × 11,470) additional costs compared with pre-pandemic use of virtual care

IMD Index of Multiple Deprivation, *GDM* gestational diabetes mellitus

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

that a pregnancy was more expensive for the NHS during the pandemic than before, with (by an average of £307), or without lockdowns (by £471). However, this pattern reflects a pre-pandemic trend of rising pregnancy costs that continued at the same rate during the pandemic, and so the higher costs cannot be attributed to the pandemic per se.

In additional analyses, use of virtual care was associated with an increase in pregnancy costs. However, for women with GDM, self-monitoring through the GDm-Health app had no significant impact on pregnancy costs. There was no evidence of a differential impact of the pandemic on these costs according to ethnicity.

Comparison with the literature

To our knowledge, this is the first study assessing the impact of the COVID-19 pandemic on maternity costs, covering the entire pandemic period and differentiating between overall trends in monthly pregnancy costs and costs per pregnancy.

Our ITS results predicting lower monthly pregnancy costs during the pandemic align with previous literature reporting decreased healthcare utilisation in maternity services during the pandemic [7, 30]. This has been attributed to women's hesitancy to seek care during the pandemic, due to fears of infection or staff shortages restricting access to care [3, 4, 31, 32]. The decrease in monthly pregnancy costs occurred with the onset of pandemic lockdowns and their withdrawal, without ongoing change in the previous rate of rise in monthly pregnancy costs. Whereas an increase might have been anticipated with release of lockdowns, we saw another decrease in monthly pregnancy costs. A potential explanation may be continued fear of infection from contacts with the healthcare system, particularly as maternity services were still cautious [33]. Also, the post-lockdown reduction in use of virtual care—which we had found to be more expensive than standard care—may have contributed. Thereafter, and in common with the pandemic with lockdowns, there was no ongoing change in the rate of rise in monthly pregnancy costs.

Importantly, we found some evidence that the pandemic affected minority ethnic groups differently to White ethnicity women. A previous population-based study of pregnancies during the pandemic using routinely collected data from England reported that individuals of ethnicities other than White (vs. White) were associated with slightly higher rates of preterm birth and caesarean births, and lower unassisted vaginal birth [7]. Our results suggest that women of Black and Asian (vs. White) ethnicities experienced an initial increase in maternity costs at the onset of pandemic lockdowns, and a slower rise thereafter, but that this still resulted in overall higher costs during pandemic lockdowns. Higher costs for women of Black and Asian (vs. White) ethnicities could have stemmed from these minority ethnic groups being at higher risk of severe COVID-19 illness and having disproportionally more hospital admissions during their pregnancy [34].

The cost component with the largest relative increase over the study period was from mental health services, although these made up a small fraction (0.5%) of overall pregnancy and postpartum costs. This finding aligns with previous literature reporting worsening of women's mental health during pandemic pregnancies; reasons cited have included disruption of service delivery, uncertainty about the effects of COVID-19 on pregnancy, and birth partners being excluded from some elements of pregnancy care and delivery [4, 35, 36]. Others have reported that postnatal reviews were the only cost component of maternity care to decrease over time, which aligns with surveys reporting that care after birth was particularly impacted by the pandemic, and women's reports that they received less postnatal support [37].

While virtual care is generally considered less expensive than face-to-face care, our findings are that virtual antenatal care is associated with higher pregnancy costs (vs. face-to-face). This may result from care being deferred. Virtual care was associated with an increase in the total number of antenatal appointments, which could reflect the use of virtual appointments as a triage mechanism to identify patients who need a face-to-face appointment. A higher use of antenatal care might also reflect the difficulty in ascertaining important clinical features when not seeing an individual face-to-face or patients perceiving worse quality of care [4], resulting in follow-up appointments. Virtual care was also associated with increased MAU and delivery costs, which further supports the argument that additional clinical care may be required among women receiving a high proportion of antenatal virtual visits. Existing comparable literature is limited. Our results contradict two previous studies which found virtual care in maternity care (non-pandemic) to be associated with lower healthcare use [14, 15]; each study had a small sample size (75 and 63 patients), and only one addressed virtual care in general; other reports have focused on virtual care for GDM. Given the importance of understanding the full impact of virtual care in maternity services, further quantitative studies of the healthcare costs of virtual care are warranted.

Finally, this study complements previous research on the positive impacts of GDM self-monitoring using GDm-Health in non-pandemic settings [17, 18], by finding it is cost-neutral compared with the traditional, non-digital health approach. Our findings add to the scarce cost evidence base in this area.

Strengths and limitations

Strengths of our work include the ethnically diverse and socioeconomically disadvantaged study population. Comprehensive ethnicity data allowed for assessment of ethnic inequalities when examining the impact of the pandemic on maternity care costs. Total costs captured healthcare use, for mothers, as well as newborns. Maternity services assessed included mental health and primary care, to provide a more holistic view of healthcare needs during pregnancy and postpartum.

Some limitations should be acknowledged. Total costs were computed from the NHS perspective and did not capture social care costs and patient out-of-pocket

expenses, which may have been substantial during pandemic lockdowns and the subsequent cost-of-living crisis. Primary care use was available for only 32% of women, who were registered to a GP practice in the borough of Lambeth; despite this, missing values were imputed, and sensitivity analyses removing primary care from total costs did not affect the main results. While granular information was not available on the type of provider who delivered care at each antenatal appointment, in sensitivity analyses, our results were robust to assumptions about the proportion of care provided by midwives and obstetricians. The dataset used in this study is limited to South London, an urban, largely deprived, multi-ethnic population. Results may not be generalisable to rural and less ethnically diverse populations. Finally, ITS is a quasi-experimental design with limited ability to assign causality to pandemic effects detected in this study; the possibility of residual confounding cannot be ruled out.

Conclusions

Maternity care costs declined in association with the COVID-19 pandemic, with onset of pandemic lockdowns and then with lifting of all restrictions; however, there was no effect on the trend of rising costs seen pre-pandemic, despite the most severe public health crisis in the last century. Of importance for planning future maternity services, is our findings that virtual antenatal care appears to be more expensive than face-to-face care, and the cost-neutral nature of digital technology to support GDM self-monitoring of glycaemic control. Further research on the effects of virtual care and GDm-Health use on clinical outcomes is needed to inform future guidelines on antenatal care delivery, especially during health system shocks.

Abbreviations

eLIXIR-BiSL	Early-LIfe data cross-LInkage in Research, Born in South London
NHS	National Health Service
GDM	Gestational diabetes mellitus
UK	United Kingdom
ITS	Interrupted time series analysis
IMD	Index of Multiple Deprivation
MICE	Multiple imputation via chained equations
OLS	Ordinary least squares model
GLM	Generalised linear model
IQR	Interquartile range
SD	Standard deviation
CI	Confidence interval

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-04165-0.

Additional file 1: Table S1 Members of the RESILIENT Study Group. Table S2 Members of the The Early Life Cross Linkage in Research, Born in South London (eLIXIR-BiSL) Partnership. Box S1 Details on pregnancy costing methods. Table S3 Sources of each utilisation component. Table S4 Sources of control variables and their definitions. Box S2 Details on the ITS model predicting the impact of the pandemic on monthly maternity costs—model specification. Box S3 Maternal organ system involved in medical conditions, as recorded at the registration visit. Box S4 Definition of GDm-Health app user. Box S5 Dealing with missing data in primary care. Fig. S1 Breakdown of total costs over the three pandemic periods. Table S5 Healthcare utilisation by care type and pandemic period. Fig. S3 Percentage of virtual routine antenatal care over time. Table S6 Comparison of characteristics between GDm-Health app users and non-users. Table S7 Predicted and counterfactual monthly pregnancy costs. Box S6 ITS model results for each healthcare services component. Table S8 Parameter estimates from the ITS model assessing the impact of the pandemic on monthly pregnancy costs—by ethnicity. Table S9 Predicted and counterfactual monthly pregnancy costs—by ethnicity. Fig. S4 Predicted monthly pregnancy costs and the impact of implementing and lifting the lockdowns—by ethnicity. Table S10 Parameter estimates from the cross-sectional models assessing the impact of virtual care on utilisation types and delivery costs. Table S11 Parameter estimates from the cross-sectional models assessing the impact of self-monitoring on utilisation types and delivery costs. Table S12 The impact of virtual care on pregnancy costs by subgroups. Table S13 The impact of GDM app registration on pregnancy costs by subgroups. Table S14 Goodness of fit measures comparing OLS to GLM with gamma distribution and log link. Table S15 Results of sensitivity analyses for ITS Model assessing the impact of the pandemic on monthly pregnancy costs—removing primary care from pregnancy costs. Table S16 Results of sensitivity analyses for ITS model assessing the impact of the pandemic on monthly pregnancy costs—changing routine antenatal costing assumption.

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Authors' contributions

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Data availability

The data accessed by eLIXIR remain within an NHS firewall and governance is provided by the eLIXIR Oversight Committee reporting to relevant information governance clinical leads. Subject to these conditions, data access is encouraged and those interested should contact the eLIXIR Chief Investigator (Professor Lucilla Poston; Lucilla.poston@kcl.ac.uk).

Declarations

Ethics approval and consent to participate

The Early Life Cross Linkage in Research, Born in South London (eLIXIR-BiSL) Partnership has received ethical approval from the Oxfordshire Research Ethics Committee C (23/SC/0116) as an anonymised dataset for medical research.

Consent for publication
All authors have participated in the work and approved the submission to *BMC Medicine*.

Competing interests
The authors declare no competing interests.

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