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Real-world evaluation of Chinese National Maternal and Newborn Safety Action Plan for reducing neonatal mortality among pregnant women with conditions: a retrospective, matched, population-based cohort study

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ABSTRACT

Introduction In China, the increase in high-risk pregnancies along with rising maternal age and complications has underscored the need for the development of maternal and newborn risk management programmes. The Chinese National Maternal and Newborn Safety Action Plan (CNMNSAP) was initiated in 2017. Given that neonatal mortality is a key indicator of healthcare quality, we evaluate the real-world effects of CNMNSAP against neonatal mortality among pregnant women with high-risk conditions.

Methods In this retrospective, matched, population-based cohort study, we collected information on all pregnant women with clinically diagnosed conditions from electronic medical records in Chengdu, China, between July 2014 and December 2019. Individual-level data, covering all healthcare services and testing records in public hospitals, were obtained and categorised into two groups based on the timing of CNMNSAP implementation (pre-CNMNSAP vs post-CNMNSAP). After 1:1 propensity score matching, we calculated the annual percentage change (APC) of neonatal mortality within 7 days post-delivery and compared outcomes between two groups of pregnant women with conditions. We then employed multivariate log-binomial regression models to examine the association between the CNMNSAP implementation and temporal changes in neonatal mortality.

Results During the 5-year study period, a total of 241 343 women with high-risk conditions delivered prior to CNMNSAP and 163 367 after its implementation. After 1:1 propensity score matching, 299 190 mothers were included for analysis. We estimated that the APC changed from 10.0% (95% CI –0.4% to 21.5%) prior to the maternal risk management programme to –28.5% (95% CI –44.2% to –8.4%) after its implementation, with an attributed risk reduction of 1.29 neonatal deaths per 1000 deliveries annually. In subgroup analysis, we found a significant reduction in neonatal mortality after policy implementation among mothers aged 18–34 years, those with a normal body mass index and those having a history of abortion.

Conclusions The CNMNSAP was found to be associated with a significant annual reduction in early neonatal mortality risk among pregnant women with high-risk conditions in Chengdu, China. The maternal risk management programme effectively improved outcomes for high-risk pregnancies, highlighting the importance of maternal risk classification and management throughout pregnancy.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The Chinese National Maternal and Newborn Safety Action Plan (CNMNSAP) was initiated to address the increasing incidence of various conditions among pregnant women.
⇒ Current analyses have not focused on high-risk groups or neonatal outcomes within CNMNSAP.

WHAT THIS STUDY ADDS

⇒ Our research shows a significant reduction in early neonatal mortality following the implementation of CNMNSAP among pregnant women with the condition.
⇒ The effectiveness of CNMNSAP was observed among mothers aged 18–34 years, those with a normal body mass index and those having a history of abortion.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The maternal risk management programme has effectively improved outcomes for high-risk pregnancy.
⇒ The findings underscore the importance of maternal risk screening, classification and management during pregnancy.

INTRODUCTION

The neonatal mortality rate is a crucial indicator for assessing healthcare quality and the effectiveness of public health policies. Reducing this rate is essential for protecting infant lives, enhancing population health, fostering socioeconomic development and contributing to the Sustainable Development Goals.[1] Early neonates refer to newborns within the first week of life, who are also classified as perinatal.[2] Due to the transition from the intrauterine to the extrauterine environment, their internal organs are usually not fully mature, making them particularly vulnerable to mortality. Factors such as prenatal complications, congenital anomalies and infections can elevate neonatal mortality risk,[3 4] especially for high-risk deliveries.[5] Although the United Nations Millennium Development Goals set a broad target to reduce the under-five child mortality rate by two-thirds,[6] this goal did not include a specific indicator for neonatal mortality, which accounts for a large and increasing proportion of under-five deaths. In 2023, an estimated 2.3 million neonatal deaths within the first month of life occurred globally, representing approximately 48% of all deaths among children under 5 years of age that year.[7] This highlights the global challenge of neonatal health issues.

To address neonatal health-related issues, various international organisations and governments have implemented healthcare programmes to protect and improve maternal and neonatal health. The American Academy of Pediatrics and the American College of Obstetrics and Gynecologists recommend prenatal care for all patients, particularly emphasising the quality and frequency of care as vital for assessing adverse risk factors for both mother and fetus.[8] Other initiatives include the Saving Babies' Lives project in the UK[9] and the RMNCH+A strategy in India.[10] It has been estimated that, in the 75 high-burden countdown countries, which together account for more than 95% of maternal, neonatal and child deaths, increasing the coverage and quality of several interventions, including preconception care, could avert 71% of neonatal deaths (1.9 million, ranging from 1.6 to 2.1 million).[11]

In China, the introduction of the universal two-child policy in October 2015 led to increased fertility rates among multiparous and older mothers,[12] resulting in additional risk factors for adverse pregnancy outcomes,[13] such as advanced maternal age, excessive gestational weight gain and various pregnancy complications.[14 15] In response, the National Health Commission of China released the Chinese National Maternal and Newborn Safety Action Plan (CNMNSAP) in 2017.[16] This policy aims to enhance clinical management of pregnancies and prevent serious outcomes by implementing a tiered management system for pregnant women.[17] Key components include pregnancy risk screening and assessment, case management for high-risk pregnancies, referral and treatment of critically ill pregnant women and newborns, maternal death reporting and accountability measures.[18] Through these strategies, China has standardised the criteria for screening high-risk pregnant women and strengthened the maternal risk management and referral systems, enhancing the identification and handling of high-risk pregnancies, ultimately contributing to reducing maternal mortality risk.[19]

The impact of CNMNSAP on neonatal mortality among high-risk pregnancies has yet to be thoroughly investigated. This study, therefore, adopted a retrospective cohort design using population-based records to assess the real-world effectiveness of the CNMNSAP in reducing neonatal death within 7 days in China. We aimed to quantify the change in the trend of this specific outcome among pregnant women with the condition before and after the implementation of CNMNSAP.

METHODS

Data source and study participants

This study employed a population-based, retrospective, matched cohort study design, following the Strengthening the Reporting of Observational Studies in Epidemiology reporting guideline. Electronic health records were retrieved from the database of Chengdu Women's and Children's Central Hospital, a tertiary hospital specialising in children and women's healthcare services for the entire population of Chengdu. The dataset contained information on all hospital services, medical records, test results and medication prescriptions during pregnancy, covering all pregnant women under the CNMNSAP who used healthcare services or delivered at public hospitals in Chengdu.

Eligible subjects were pregnant women who delivered between July 2014 and December 2019 with at least one clinically diagnosed condition (categorised as general risk, high risk or extremely high risk groups by the CNMNSAP) (see online supplemental text S1). Data collection concluded in 2019 to avoid potential confounding effects from the COVID-19 pandemic. The detailed list of clinical diagnoses was provided in online supplemental text S2 for different classifications of maternal risks.

Participants who delivered during the initiation period of the CNMNSAP (from September 2017 to September 2018), and those with miscarriage, abortion or missing baseline covariate information, were excluded. The pregnant women with infectious diseases were also excluded, as their risk management focused on the control of infectious diseases.

Risk management programme and study settings

Since the first half of 2018, after the nationwide implementation of CNMNSAP, all pregnant women using public healthcare services have undergone risk assessment to identify and control risk factors related to pregnancy. The CNMNSAP involved a tiered clinical diagnosis, risk management and treatment procedures primarily conducted in hospitals (online supplemental text S1). These procedures can be summarised as follows[18]:

- Step 1: Initial risk screening and classification were performed for each pregnant woman at the first obstetric examination visit at primary care settings. Pregnant women identified with maternal risks were referred to secondary or tertiary hospitals within 2 weeks. For women without maternal risk, continuous risk monitoring and follow-up were conducted at primary care settings throughout pregnancy.
- Step 2: Further risk assessment and classification would be conducted in secondary or tertiary hospitals based on the clinical guideline of CNMNSAP (online supplemental text S2). Maternal risk levels were categorised into five groups: low risk (ie, no condition diagnosed), general risk, high risk, extremely high risk groups and those with infectious diseases. Pregnant women with identified maternal risks were managed on a case-by-case basis at secondary or tertiary hospital settings.
- Step 3: For each pregnant woman with maternal risks, follow-up risk assessment and continuous risk management would be conducted at each hospital visit during pregnancy.

As CNMNSAP comprises two components, including screening and risk management, this study focused on the risk management arm of the policy, which specifically targeted pregnancies with conditions. Pregnant women without any condition were cared for under identical risk management protocols before and after CNMNSAP implementation. Therefore, pregnant women without any condition (ie, low-risk group) were excluded from this study. In addition, pregnant women diagnosed with infectious diseases were excluded as they would be managed by the local Centers for Disease Control and Prevention according to the routine risk control strategies of infectious diseases in China (see online supplemental figure S1).

Due to socioeconomic disparities and population heterogeneity in China, the implementation process of CNMNSAP might vary across regions.[20] Thus, this observational study was conducted in Chengdu, the capital city of Sichuan province, which had a population of 20.9 million in 2020 (approximately 25% of the total provincial population).[21] As one of the most densely populated metropolitan areas in China, the government of Chengdu has made great efforts to improve healthcare services coverage and quality, leading to a comprehensive maternal and child health service package. Following the CNMNSAP, the Chengdu Health Commission launched the city-level maternal risk screening and management programme by the end of 2018, with the primary goal of reducing neonatal mortality risks given the growing trend of maternal age.

Exposure and outcomes

The cohort of pregnant women in Chengdu was divided into two groups according to the implementation timeline of CNMNSAP at the national and city levels.

- The exposure group included women who delivered *after* the CNMNSAP implementation, that is, from October 2018 to December 2019.
  The control group included women who delivered *before* the CNMNSAP implementation, that is, from July 2014 to August 2017.

The primary outcome was the early neonatal death rate within 7 days, calculated as the number of deaths per 1000 deliveries.

Covariates

The baseline covariates and risk factors before pregnancy included maternal age, maternal ethnicity, paternal age, paternal ethnicity, education level, height, weight, body mass index (BMI), baseline body development status, history of parity and history of gravidity. The characteristics during pregnancy included the consumption of folate supplementation, diagnosis of pre-eclampsia or eclampsia, gestational hypertension or severe anaemia, calendar month of the last menstruation, gestational week of the first obstetric examination, calendar month of delivery, weekday of delivery, delivery mode and the risk classification before prenatal care and delivery.

These covariates were chosen based on the existing knowledge of the pregnancy risk factors in the literature and the Chinese 'pregnancy risk assessment and management guideline', issued by the National Health Commission of China.[18] Furthermore, the selected variables for adjustment in regression models (including maternal risk classification, maternal age and calendar time) were identified as potential confounders that could influence both maternal risk management under CNMNSAP and the risk of neonatal mortality (online supplemental text S3). These statistical associations could be illustrated using a directed acyclic graph, see online supplemental figure S2.

Propensity score matching

Propensity score matching (PSM) was expected to eliminate the influence of measured demographic factors and key risk factors, indicating that the observed change is highly likely to be attributed to the implementation of the policy. We applied the nearest-neighbour method for 1:1 PSM without replacement, with a calliper set at 0.1-fold of the SD. The participants were matched for baseline covariates, risk factors before pregnancy, the characteristics and risk factors during pregnancy, and the risk classification before prenatal care and delivery. The absolute standardised mean difference (ASMD) was used as a measurement of the difference between the two groups, and we considered an ASMD less than 0.1 as a sign of a statistically sufficient balance between the two groups. In online supplemental text S4, the common support assumption was assessed and confirmed, with substantial overlap in propensity score distributions between the two groups (see online supplemental figure S3).

Statistical analysis

Descriptive statistics were computed for baseline characteristics. The primary analysis used a multivariable log-binomial model on the propensity score-matched cohort to estimate the annual percentage change (APC) in the neonatal death rate and assess policy effectiveness. This model, employing a linear spline for calendar time, was chosen to directly test our pre-specified hypothesis of a quantifiable change in the trend slope associated with the policy. Long-term temporal trends were modelled using a continuous time variable with a linear spline (knot at 2018), aiming to capture the temporal change in trend following policy implementation. Statistical adjustments were made for seasonal variation (using a periodic B-spline), day of the week and maternal age (modelled with natural splines). A sensitivity analysis was conducted using mixed-effects log-binomial regression models that incorporated a random-effect intercept accounting for a potential clustering effect of various delivery locations (see online supplemental table S1). The APC was derived as $(\exp(\beta)-1)\times100\%$, where β is the model coefficient for calendar time, with 95% CIs and p values derived from two-sided Wald's tests.

Subgroup analyses were conducted by stratifying the matched cohorts based on maternal age groups (<18 years, 18–34 years, 35–39 years and ≥40 years), BMI before pregnancy (underweight, normal range, overweight and obesity), history of abortions or miscarriage (<2 times and ≥2 times) and risk classification (general, high and extremely high risk).

All statistical tests were two-sided, with a statistical significance level set at p value <0.05. All analyses were conducted using R statistical software, V.4.2.2.

RESULTS

Between July 2014 and August 2019, a total of 545 343 pregnant women were identified. Of them, 404 710 women (241 343 prior to the policy's initiation and 163 367 after it) met the inclusion criteria and were not subject to the exclusion criteria (figure 1). After 1:1 PSM, the exposure group included 149 595 delivered pregnant women, and the control group included 149 595 pregnant women, resulting in a total of 299 190 participants. The mean (SD) maternal age was 28.9 (4.9) years, and the mean (SD) BMI was 21.8 (3.4) kg/m^2. The baseline characteristics and risk factors of the study cohorts are shown in table 1. In the control group, the mean (SD) maternal age of mothers who delivered before August 2017 was 28.9 (5.1) years, which was similar to the exposure group,

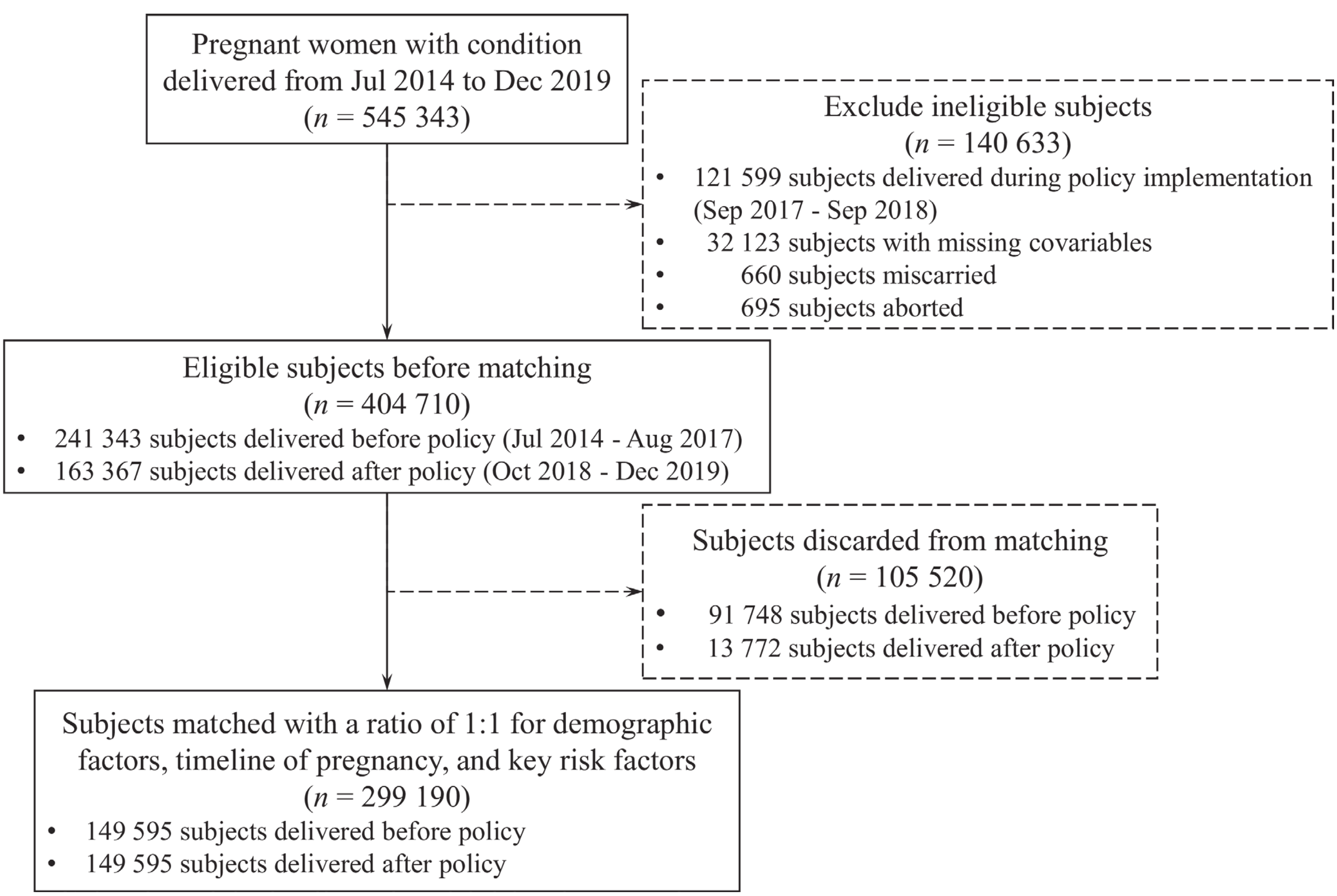

Figure 1 Sample selection procedures for pregnant women with conditions.

Table 1 Summary of baseline characteristics and risk factors for before-match cohorts and after-match cohorts

	Before-match cohorts, mean (SD) or *n* (column %)			After-match cohorts, mean (SD) or *n* (column %)		
	Women delivered in or before August 2017	Women delivered in or after October 2018	ASMD	Women delivered in or before August 2017	Women delivered in or after October 2018	ASMD
Total	241 343 (100%)	163 367 (100%)	NA	149 595 (100%)	149 595 (100%)	NA
Baseline characteristics and risk factors before pregnancy						
Maternal age, years	28.6 (5.1)	28.8 (4.6)	0.042	28.9 (5.1)	28.9 (4.6)	0.010
Maternal ethnicity						
Han ethnicity	235 200 (97.5%)	158 286 (96.9%)		145 197 (97.1%)	145 166 (97.0%)	
Other ethnicity	6143 (2.5%)	5081 (3.1%)	0.033	4398 (2.9%)	4429 (3.0%)	<0.001
Paternal age, years	31.1 (5.9)	31.0 (5.3)	0.035	31.1 (5.8)	31.0 (5.4)	0.013
Paternal ethnicity						
Han ethnicity	235 759 (97.7%)	158 822 (97.2%)		145 674 (97.4%)	145 609 (97.3%)	
Other ethnicity	5584 (2.3%)	4545 (2.8%)	0.028	3921 (2.6%)	3986 (2.7%)	<0.001
Highest level of education						
Primary school or below	6999 (2.9%)	3062 (1.9%)	0.076	3202 (2.1%)	3029 (2.0%)	0.009
Junior high school	58 338 (24.2%)	28 720 (17.6%)	0.173	29 046 (19.4%)	28 293 (18.9%)	0.013
Technical secondary school	18 311 (7.6%)	13 331 (8.2%)	0.021	12 401 (8.3%)	12 423 (8.3%)	0.001
Senior high school	90 830 (37.6%)	50 832 (31.1%)	0.141	49 595 (33.2%)	49 337 (33.0%)	<0.001
Associate degree	38 525 (16.0%)	37 520 (23.0%)	0.167	31 321 (20.9%)	31 842 (21.3%)	0.008
Undergraduate or above	28 340 (11.7%)	29 902 (18.3%)	0.170	24 030 (16.1%)	24 671 (16.5%)	0.011
Height, cm	158.5 (4.9)	158.8 (4.9)	0.063	158.7 (4.8)	158.7 (4.9)	0.009
Weight, kg	55.6 (9.0)	54.8 (9.2)	0.089	55.1 (8.7)	55.0 (9.3)	0.010
BMI, kg/m^2	22.1 (3.4)	21.7 (3.4)	0.120	21.9 (3.2)	21.8 (3.5)	0.014
Body development status						
Normal	231 245 (95.8%)	157 439 (96.4%)	0.030	143 927 (96.2%)	143 953 (96.2%)	0.001
Abnormal	420 (0.2%)	244 (0.1%)	0.006	239 (0.2%)	232 (0.2%)	0.001
Unknown	9678 (4.0%)	5684 (3.5%)	0.029	5429 (3.6%)	5410 (3.6%)	0.001
History of parity						
0	98 954 (41.0%)	73 700 (45.1%)	0.083	63 328 (42.3%)	64 537 (43.1%)	0.016
1	132 044 (54.7%)	81 071 (49.6%)	0.102	78 627 (52.6%)	77 457 (51.8%)	0.016
>1	6380 (2.6%)	5621 (3.4%)	0.044	4971 (3.3%)	4915 (3.3%)	0.002
Unknown	3965 (1.6%)	2975 (1.8%)	0.013	2669 (1.8%)	2686 (1.8%)	0.001
History of gravidity						

Continued

Table 1 Continued

	Before-match cohorts, mean (SD) or *n* (column %)			After-match cohorts, mean (SD) or *n* (column %)		
	Women delivered in or before August 2017	**Women delivered in or after October 2018**	**ASMD**	**Women delivered in or before August 2017**	**Women delivered in or after October 2018**	**ASMD**
0	111 (<0.1%)	165 (0.1%)	0.017	104 (0.1%)	115 (0.1%)	0.002
1	44 484 (18.4%)	45 985 (28.1%)	0.216	35 700 (23.9%)	37 375 (2.5%)	0.025
>1	193 281 (80.1%)	114 919 (70.3%)	0.213	111 559 (74.6%)	109 918 (73.5%)	0.024
Unknown	3467 (1.4%)	2298 (1.4%)	0.003	2232 (1.5%)	2187 (1.5%)	0.003
Characteristics and risk factors during pregnancy						
Folate supplementation intake						
Before pregnancy	59 948 (24.8%)	43 539 (26.7%)	0.041	39 009 (26.1%)	39 134 (26.2%)	0.002
During pregnancy	162 109 (67.2%)	112 202 (68.7%)	0.033	102 893 (68.8%)	102 940 (68.8%)	0.001
No intake	18 382 (7.6%)	7431 (4.5%)	0.147	7473 (5.0%)	7325 (4.9%)	0.005
Unknown	904 (0.4%)	196 (0.1%)	0.074	220 (0.1%)	196 (0.1%)	0.005
Pre-eclampsia or eclampsia	326 (0.1%)	457 (0.3%)	0.027	298 (0.2%)	331 (0.2%)	0.004
Pregnancy-induced hypertension	1418 (0.6%)	1374 (0.8%)	0.028	1092 (0.7%)	1142 (0.8%)	0.004
Severe anaemia	99 (<0.1%)	32 (<0.1%)	0.015	30 (<0.1%)	32 (<0.1%)	0.001
Calendar month of the last menstruation						
January	20 848 (8.6%)	21 811 (13.4%)	0.139	17 668 (11.8%)	18 050 (12.1%)	0.008
February	20 456 (8.5%)	22 576 (13.8%)	0.155	17 960 (12.0%)	18 545 (12.4%)	0.011
March	20 186 (8.4%)	20 801 (12.7%)	0.131	16 828 (11.2%)	17 317 (11.6%)	0.010
April	19 133 (7.9%)	11 440 (7.0%)	0.036	10 918 (7.3%)	10 872 (7.3%)	0.001
May	18 918 (7.8%)	10 659 (6.5%)	0.053	10 611 (7.1%)	10 405 (7.0%)	0.006
June	18 422 (7.6%)	10 413 (6.4%)	0.052	10 396 (6.9%)	10 172 (6.8%)	0.006
July	18 655 (7.7%)	10 436 (6.4%)	0.055	10 429 (7.0%)	10 201 (6.8%)	0.006
August	18 486 (7.7%)	10 172 (6.2%)	0.059	10 195 (6.8%)	9981 (6.7%)	0.006
September	19 016 (7.9%)	10 650 (6.5%)	0.055	10 669 (7.1%)	10 410 (7.0%)	0.007
October	22 351 (9.3%)	11 058 (6.8%)	0.099	11 021 (7.4%)	10 923 (7.3%)	0.003
November	24 552 (10.2%)	11 214 (6.9%)	0.131	11 224 (7.5%)	11 100 (7.4%)	0.003
December	20 320 (8.4%)	12 137 (7.4%)	0.038	11 676 (7.8%)	11 619 (7.8%)	0.001
Gestational week of first obstetric examination	12.6 (5.1)	12.1 (4.6)	0.112	12.2 (4.5)	12.2 (4.7)	0.007
Calendar month of delivery						

Continued

Table 1 Continued

	Before-match cohorts, mean (SD) or *n* (column %)			After-match cohorts, mean (SD) or *n* (column %)		
	Women delivered in or before August 2017	**Women delivered in or after October 2018**	**ASMD**	**Women delivered in or before August 2017**	**Women delivered in or after October 2018**	**ASMD**
January	19321 (8.0%)	10392 (6.4%)	0.067	10341 (6.9%)	10208 (6.8%)	0.004
February	17294 (7.2%)	9483 (5.8%)	0.058	9456 (6.3%)	9284 (6.2%)	0.005
March	19245 (8.0%)	10721 (6.6%)	0.057	10752 (7.2%)	10492 (7.0%)	0.007
April	18213 (7.5%)	10254 (6.3%)	0.052	10239 (6.8%)	10005 (6.7%)	0.006
May	18299 (7.6%)	10090 (6.2%)	0.058	10063 (6.7%)	9906 (6.6%)	0.004
June	18999 (7.9%)	10398 (6.4%)	0.062	10493 (7.0%)	10185 (6.8%)	0.008
July	22779 (9.4%)	11263 (6.9%)	0.100	11199 (7.5%)	11110 (7.4%)	0.002
August	26684 (11.1%)	11877 (7.3%)	0.146	12011 (8.0%)	11803 (7.9%)	0.005
September	18125 (7.5%)	11475 (7.0%)	0.019	10924 (7.3%)	10994 (7.3%)	0.002
October	20934 (8.7%)	21441 (13.1%)	0.132	17662 (11.8%)	17949 (12.0%)	0.006
November	21087 (8.7%)	23969 (14.7%)	0.168	18807 (12.6%)	19468 (13.0%)	0.012
December	20363 (8.4%)	22004 (13.5%)	0.147	17648 (11.8%)	18191 (12.2%)	0.011
Weekday of delivery						
Sunday	27709 (11.5%)	18536 (11.3%)	<0.001	17041 (11.4%)	17012 (11.4%)	0.001
Monday	37351 (15.5%)	25558 (15.6%)	0.005	23276 (15.6%)	23330 (15.6%)	0.001
Tuesday	37455 (15.5%)	26105 (16.0%)	0.013	23760 (15.9%)	23760 (15.9%)	<0.001
Wednesday	37090 (15.4%)	24247 (14.8%)	0.015	22395 (15.0%)	22328 (14.9%)	0.001
Thursday	36334 (15.1%)	24611 (15.1%)	<0.001	22567 (15.1%)	22619 (15.1%)	0.001
Friday	36832 (15.3%)	25137 (15.4%)	0.003	22953 (15.3%)	22991 (15.4%)	0.001
Saturday	28572 (11.8%)	19173 (11.7%)	0.003	17603 (11.8%)	17555 (11.7%)	0.001
Delivery mode						
Spontaneous vaginal delivery	89210 (37.0%)	68792 (42.1%)	0.104	59941 (40.1%)	60882 (40.7%)	0.013
Caesarean section	145724 (60.4%)	91851 (56.2%)	0.084	87093 (58.2%)	86087 (57.5%)	0.014
Other mode of vaginal delivery	6409 (2.7%)	2724 (1.7%)	0.077	2561 (1.7%)	2626 (1.8%)	0.003
Risk classification before prenatal care and delivery						
General risk	212531 (88.1%)	144613 (88.5%)	0.014	131728 (88.1%)	131728 (88.1%)	<0.001
High risk	20397 (8.5%)	15952 (9.8%)	0.044	15065 (10.1%)	15065 (10.1%)	<0.001
Extremely high risk	8415 (3.5%)	2802 (1.7%)	0.136	2802 (1.9%)	2802 (1.9%)	<0.001

ASMD, absolute standardised mean difference; BMI, body mass index.

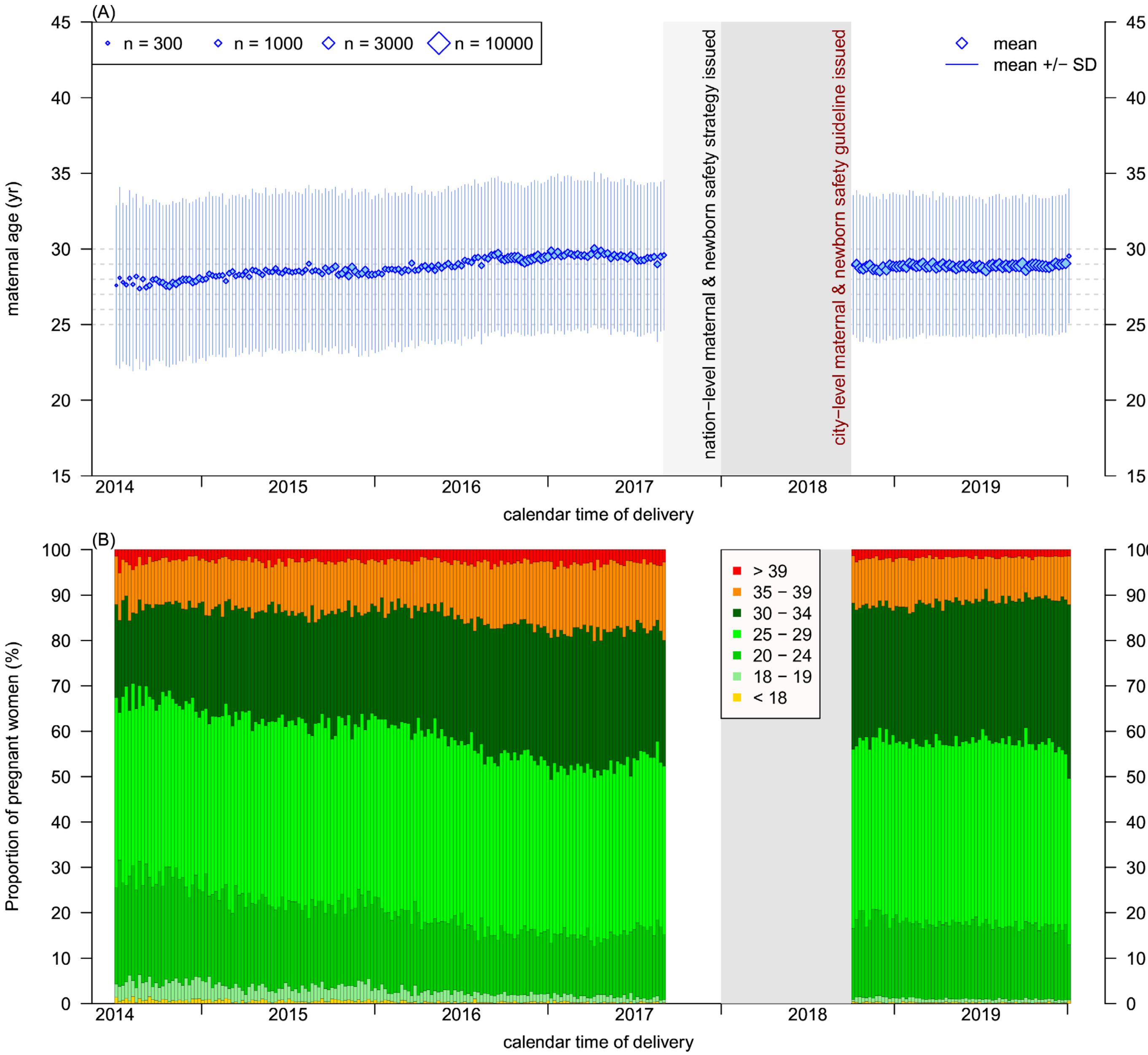

Figure 2 Maternal ages for after-match cohorts of pregnant women with a condition in Chengdu from July 2014 to December 2019. Panel (A) shows the temporal change in maternal age of pregnant women with the condition on a weekly basis. Panel (B) shows the distribution of maternal age of pregnant women with the condition.

where the mean (SD) age was 28.9 (4.6) years. Most participants had a history of one parity (51.8% for exposure group vs 52.6% for control group) and more than one gravidity history (73.5% for exposure group vs 74.6% for control group). Most of the participants were classified as the general risk category in both the exposure group (88.1%) and the control group (88.1%).

During the study period, the mean maternal age of participants increased from around 28 to 30 years old between 2014 and 2017, but remained steady at around 29 years old after the implementation of the CNMNSAP (figure 2A). The proportion of mothers under 30 years old was considerably lower for participants recruited before the policy than for those recruited after (figure 2B). As shown in figure 3, neonatal deaths within 7 days exhibited an increasing trend before CNMNSAP implementation and transitioned to a decreasing trend after CNMNSAP implementation. By the end of 2019, the neonatal mortality rate fell back to around 3 per 1000 live births among pregnancies with conditions. Before August 2017, the overall neonatal mortality rate was 3.55 per 1000 deliveries, with an annual increase of 10% (95% CI −0.4% to 21.5%) (table 2). After October 2018, the APC changed to −28.5% (95% CI −44.2% to −8.4%). The transition in the APC before and after the policy implementation was statistically significant (p value=0.001). Specifically, there was an annual reduction of 1.29 in neonatal deaths per 1000 deliveries in 2019. Among high-risk categorised pregnant women, the neonatal mortality

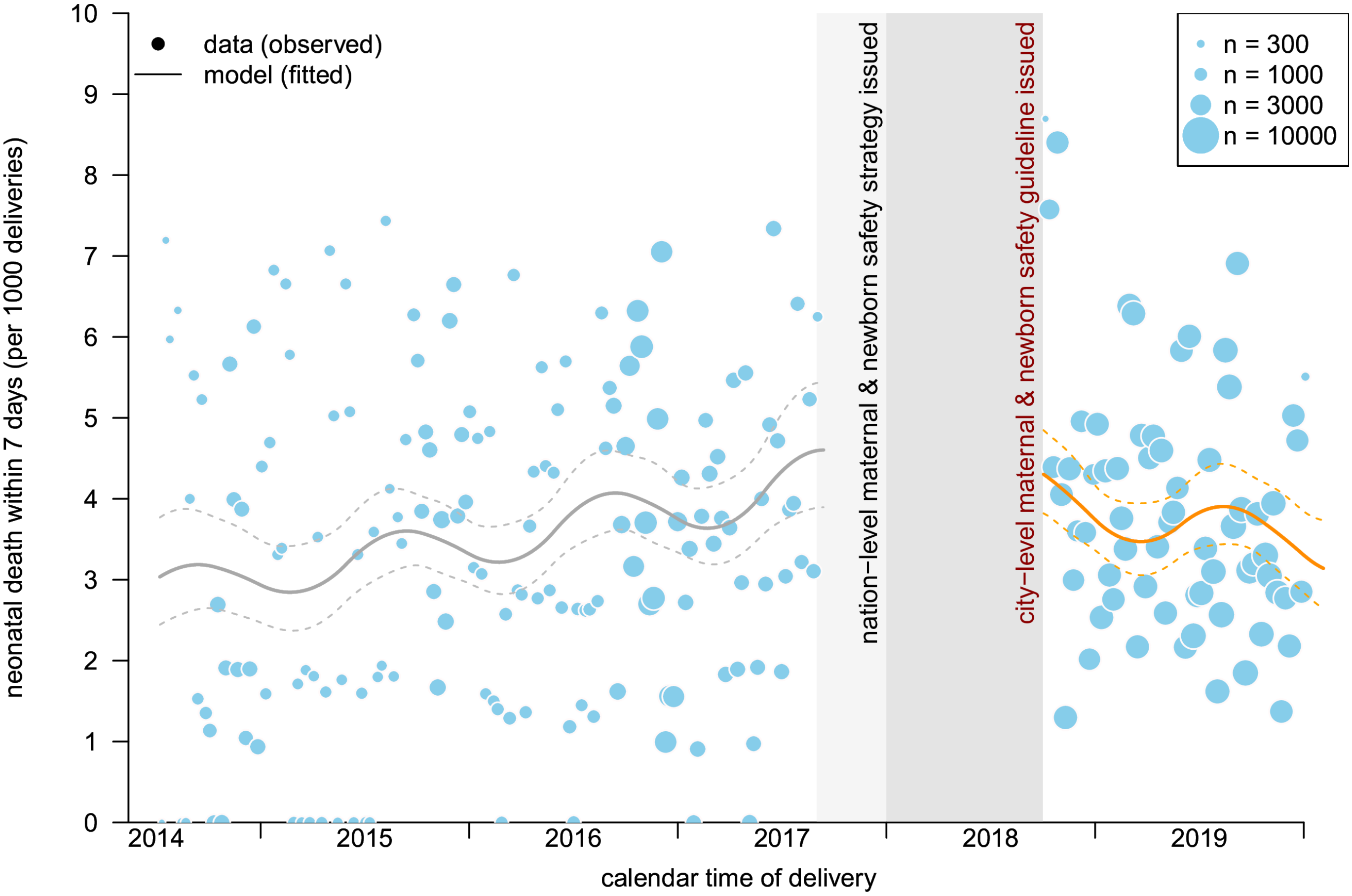

Figure 3 Temporal trend in the rate of neonatal death within 7 days per 1000 deliveries among the matched cohort of pregnant women with conditions, from July 2014 to December 2019. Fitted lines from the multivariable log-binomial regression model are shown for pre-policy (dark grey) and post-policy (dark orange) periods, with dashed lines showing the 95% CI. Light blue dots represent the observed rate of neonatal death on a weekly basis. The shaded area shows the period of maternal risk management programme implementation at the national level in late 2017, and city level in September 2018.

within 7 days has seen a reduction from 4.58 to 3.12 per 1000 live births.

Subgroup analyses (table 2) showed a significant association between the implementation of CNMNSAP and a reduction in APC of neonatal mortality within 7 days for mothers with conditions aged 18–34 years (from 5.1% to −32.8%, p value=0.002). Further, the significant reductions were observed in mothers with a BMI (before pregnancy) in the normal range (from 7.8% to −35.7%, p value=0.003) and those with a BMI in the overweight range (from 36.5% to −51.1%, p value=0.005). Women with a history of abortion or miscarriage also showed significant reductions (from 15.7% to −23.2%, p value=0.007 or from 0.5% to −43.9%, p value=0.041). Moreover, the policy implementation led to a pronounced decrease in the attributed incidence change in 2019 for delivering mothers at a maternal age ≥40 years (−3.96 neonatal deaths per 1000 deliveries), those with a BMI (before pregnancy) between 25.0 and 27.9 kg/m^2 (−2.49 neonatal deaths per 1000 deliveries), and those with a history of abortion or miscarriage ≥2 times (−2.41 neonatal deaths per 1000 deliveries).

DISCUSSION

In this study, we assessed the effectiveness of the CNMNSAP against neonatal death within 7 days, a critical indicator of adverse pregnancy outcomes. Our findings suggested that the policy's implementation was associated with a significant reduction in early neonatal mortality, particularly among subgroups of pregnant women with conditions, including those aged 18–34 years, with a normal BMI and a history of abortion. By the end of 2019, the city-wide early neonatal death rate had reached the national target, demonstrating the policy's positive impact on neonatal health outcomes.

Decrease in neonatal mortality risk

The neonatal mortality rate within 7 days for women who delivered in or before August 2017 increased at an estimated annual rate of 10.0%; however, this upward trend was not statistically significant (95% CI −0.4% to 21.5%). According to the CNMNSAP, high-risk pregnant women were required to receive prenatal care at maternal care centres at the county level or above through a referral system and were advised to deliver in tertiary medical institutions. Following the introduction of the policy,

Table 2 Summary of incidence and change in annual percentage change (APC) of neonatal death within 7 days before and after the implementation of maternal risk management programme

	Sample size (incidence/1000 deliveries)		Annual percentage change* (95% CI)			
	Women delivered in or before August 2017	Women delivered in or after October 2018	In or before August 2017	In or after October 2018	P value† for change in trends	Attributed incidence change in 2019/1000 deliveries
Overall	149 595 (3.55)	149 595 (3.79)	10.0% (–0.4% to 21.5%)	–28.5% (–44.2% to –8.4%)	0.001	–1.29
Stratified by *maternal age group*						
<18 years	667 (7.50)	351 (8.55)	(Not calculated)‡	(Not calculated)‡	(Not calculated)‡	(Not calculated)‡
18–34 years	126 284 (3.30)	131 970 (3.66)	5.1% (–5.9% to 17.4%)	–32.8% (–48.6% to –12%)	0.002	–1.27
35–39 years	18 668 (4.29)	14 638 (4.17)	28.7% (–2.7% to 70.1%)	7.7% (–49.6% to 130.1%)	0.665	–0.72
≥40 years	3976 (7.29)	2636 (7.59)	38.4% (–12.8% to 119.8%)	–34.4% (–80.9% to 125.6%)	0.263	–3.96
Stratified by *BMI before pregnancy*, kg/m²						
Underweight (<18.5)	19 420 (2.88)	23 715 (3.80)	2.7% (–23.9% to 38.6%)	7.4% (–39.9% to 91.9%)	0.894	0.16
Normal range (18.5–24.9)	106 907 (3.37)	101 412 (3.54)	7.8% (–4.4% to 21.5%)	–35.7% (–53.5% to –11.1%)	0.003	–1.43
Overweight (25.0–27.9)	16 324 (4.35)	16 530 (4.36)	36.5% (2.2% to 82.1%)	–51.1% (–75.1% to –4.2%)	0.005	–2.49
Obesity (≥28.0)	6944 (6.34)	7938 (5.79)	–0.1% (–29.4% to 41.3%)	16% (–46.9% to 153.4%)	0.731	0.94
Stratified by *history of abortion or miscarriage*						
<2	97 193 (3.33)	132 380 (3.53)	15.7% (2.3% to 30.8%)	–23.2% (–41.6% to –1.1%)	0.007	–1.17
≥2	52 402 (3.99)	17 215 (5.81)	0.5% (–15.6% to 19.6%)	–43.9% (–68.7% to –0.6%)	0.041	–2.41
Stratified by *risk classification*						
General risk	131 728 (3.43)	131 728 (3.83)	9.3% (–1.8% to 21.8%)	–28.9% (–45.4% to –7.3%)	0.003	–1.29
High risk	15 065 (4.58)	15 065 (3.12)	13.6% (–13.4% to 49.1%)	–14.0% (–22.7% to –3.6%)	0.093	–0.76
Extremely high risk	2802 (3.57)	2802 (6.07)	(Not calculated)‡	(Not calculated)‡	(Not calculated)‡	(Not calculated)‡

*Annual percentage change (APC) was estimated with the adjustment of seasonality, weekday, maternal age and risk classification.
†The p value was calculated from two-sided Wald's test for the difference in APC before and after risk management programme.
‡The statistics were not calculated due to small number of events (ie, <30), which led to unconverging estimating results.
BMI, body mass index.

the annual rate of change in early neonatal mortality was −28.5% (95% CI −44.2% to −8.4%), suggesting that 1.29‰ of neonatal deaths were prevented annually. These findings align with previous studies, such as an analysis using the National Health Statistics Yearbooks in China suggested that a series of comprehensive health-related risk management strategies implemented in China, including CNMNSAP, have effectively reduced the maternal mortality ratio from 23.2 to 18.3 per 100 000 live births from 2013 to 2018.[19] Screening and risk management for pregnant women can facilitate early identification of high-risk pregnancies, thereby improving maternal and newborn health.[22 23] A hybrid effectiveness-implementation trial further suggested the benefits of tiered care for improving perinatal anxiety.[24] Perinatal anxiety was not listed as a risk factor in the policy, but it may have an indirect impact on neonatal health.[25] Dynamic risk assessment of pregnant women's glucose, blood lipid levels and thrombotic risk can facilitate early pharmacological interventions or lifestyle modification.[26–28] Similar pregnancy risk scoring systems can help identify pregnant women with conditions to increase Apgar scores.[29]

Trend of maternal age from 2014 to 2019

The implementation of CNMNSAP was significantly associated with a decrease in early neonatal mortality among mothers with a maternal age between 18 and 34. Women over 35 years old were classified into the advanced maternal age (AMA) group, and pregnant women over 40 years old were classified into the very advanced maternal age (VAMA) group.[30] While point estimates indicated a modest decline in 7-day neonatal mortality for both AMA and VAMA groups, the reductions were not statistically significant. We found that by 2019, the policy was able to prevent 3.96‰ of neonatal deaths among VAMA mothers. In the AMA group, the early neonatal mortality rate decreased from 4.29 to 4.17 per 1000 live births, highlighting the positive impact of risk stratification management for high-risk pregnant women on the birth outcomes of their infants.

With the introduction of the two-child policy in 2015 in China, the proportion of women classified as AMA has continued to rise.[12] Older mothers are known to be at higher risk for adverse obstetric outcomes.[31] An investigation conducted in Japan indicated that AMA was associated with an increased likelihood of caesarean sections and heightened risks of pre-eclampsia, placenta previa and preterm birth.[32] In our pre-CNMNSAP cohort, the average age of pregnant women with conditions was on the rise and included a proportion of adolescent pregnancies (under 20 years). In contrast, in our post implementation cohort, we observed that the average maternal age at childbirth was below 30 years, and the proportion of pregnant women with AMA decreased. The CNMNSAP guidelines specifically emphasise addressing the healthcare needs of high-risk pregnant individuals, identifying pregnant women with AMA as a key target group for specialised interventions. This alignment suggests that the policy's focus corresponded with the demographic characteristics of the post implementation population in our sample. Through ongoing risk assessments and monitoring during pregnancy, coupled with the enhanced healthcare services, the risk of neonatal mortality associated with AMA may be mitigated, demonstrating the health benefits derived from the risk management programme. Besides, the policy facilitated early education and systematic fertility planning, positively adjusted the age structure of pregnant women.

Decrease in neonatal mortality among overweight women

The CNMNSAP notably improved birth outcomes, particularly for pregnant women with obesity (pre-pregnancy BMI≥28.0 kg/m²), where early neonatal mortality rates have decreased from 6.34 to 5.79 per 1000 deliveries. This policy also led to significant declines in the APC of neonatal mortality rates for women with a normal BMI (18.5–24.9 kg/m²) and those classified as overweight (25.0–27.9 kg/m²). A prospective cohort study conducted in the USA found that pregnant women with a healthy weight (pre-pregnancy BMI: 18.5–24.9 kg/m²) have a lower risk of preterm birth,[33] while overweight or obese pregnant women are at a higher risk of developing complications, including gestational hypertension and gestational diabetes.[34 35] To address these risks, the CNMNSAP has established a referral system directing pregnant women to maternal critical care centres for risk management on a case-by-case basis, thereby reducing the risk of various pregnancy complications.[36] In our study, the neonatal mortality rate within 7 days for overweight pregnant women decreased significantly from 36.5% (95% CI 2.2% to 82.1%) to −51.1% (95% CI −75.1% to −4.2%), preventing 2.49‰ of early neonatal deaths, demonstrating the considerable health benefits of CNMNSAP on pregnancies with conditions.

It was suggested that prenatal underweight in pregnant women is associated with an increased risk of preterm birth and low birth weight,[37] with variations in these risks observed across different ethnic groups.[38] Furthermore, individuals with normal or low body weight may have a higher mortality risk from specific causes of death, a phenomenon frequently referred to as 'obesity paradox'. This paradox suggests that individuals with significant illnesses may experience weight loss due to their condition or intentionally lose weight as a result of their illness, with increased mortality risk being primarily attributed to the underlying disease itself.[39] Conversely, some studies have found that underweight pregnancies were not necessarily associated with an increased risk of neonatal mortality,[40] indicating that early weight management may provide potential health benefits for infants. Therefore, large-scale prospective studies are needed to validate these findings, and it is essential to develop personalised health management plans for pregnant individuals with extreme BMI to optimise outcomes for both mothers and their children.

Strengths and limitations

This study has several strengths. First, it is based on comprehensive, population-wide electronic health records from Chengdu covering all pregnant women who used public healthcare services, which ensures a representative sample. The generalisability of our findings is reinforced by the study setting. Chengdu is a major metropolitan centre with a large and socioeconomically diverse population, and its healthcare system operates under the same national guidelines that apply throughout China. Given that the CNMNSAP is a uniformly implemented national policy, the mechanisms of risk screening, management and referral observed in this study are likely to reflect how the policy is carried out in other urban areas across the country. Second, the analysis benefited from strong governmental commitment to the policy, which secured its rigorous enforcement and the allocation of substantial medical resources. This provided a real-world test of its effectiveness under conditions of high-level support. Third, the use of evidence-based PSM enabled a well-balanced comparison between pre- and post-policy cohorts, leading to a more accurate assessment of the intervention's effects. Consequently, our findings not only evaluate the policy's impact in a key urban setting but also offer a valuable framework for understanding its potential mechanisms in comparable contexts nationwide. These insights hold important implications for improving maternal and neonatal health policies, both within China and in similar settings globally. For other places considering maternal risk screening and management programmes, our findings highlighted the importance of implementing timely risk screening and risk classification during the course of pregnancy, and in addition to primary care, high-level healthcare would improve the clinical outcomes of pregnant women with maternal conditions.

This study has several limitations. First, due to the interference of the COVID-19 pandemic, the data from 2020 onward were unavailable, which restricted our ability to assess the long-term effects of CNMNSAP. Second, the analysis was based on cases without missing data. While the proportion of missing data for covariates was relatively small (<0.5%), our analysis relies on the assumption that data were missing completely at random. Third, while we matched the baseline characteristics of pregnant women with conditions to balance the maternal risks between the prior- and post-CNMNSAP subjects, we cannot fully account for all sources of potential bias. This might include not only unobservable confounding factors, such as maternal mental health[41] and environmental exposures,[42] but also broader secular trends (eg, unrelated health system improvements) that occurred concurrently with the policy and could influence neonatal outcomes. Furthermore, as the study was conducted within a metropolitan area, the findings might not be generalised across China or to other places, particularly those with different socioeconomic conditions or healthcare accessibility. Therefore, a causal relationship between CNMNSAP and the reduction in neonatal mortality cannot be conclusively established. Fourth, the control group included participants from the transition period between the one-child and universal two-child policy. To mitigate potential bias, we matched and adjusted the history of gravidity. However, some degree of insufficient comparability and representativeness of the control group might still exist. Fifth, women's views are crucial in any action plan, particularly when many are referred to higher-level facilities. This may entail additional transportation and transfer costs, potentially imposing extra financial burdens on women. It also involves greater use of healthcare resources, which could increase the economic strain on the healthcare system. However, such referrals are intended to provide higher-quality medical services, thereby improving maternal and infant health outcomes. Further detailed data and research are necessary to assess these impacts fully. Finally, this study did not examine the potential unintentional consequences of the CNMNSAP, such as the impact of over-screening and over-treatment on the rate of unnecessary induction of labour, caesarean section, iatrogenic preterm birth and admission to a neonatal intensive care unit.[43] Future research should consider these potential outcomes to provide a holistic picture of the policy's effects.

CONCLUSIONS

In this retrospective cohort study, we found that the implementation of CNMNSAP was significantly associated with a reduction in early neonatal deaths among pregnant women with maternal conditions. This significant improvements in neonatal health outcomes might be contributed by enhancing maternal risk assessment, stratification and management under CNMNSAP. These results highlighted the importance of targeted interventions for high-risk pregnancies. Further investigation is needed to evaluate the long-term health-related effects of CNMNSAP to fully understand its benefits on maternal and neonatal health.

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Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and this study was approved by the ethics committee of Tianjin Medical University (No.: TMUhMEC20240028). The studies were conducted in accordance with the local legislation and institutional requirements. The requirement for informed consent was waived by the ethics committee due to the retrospective nature of the research, and because all personal identifiers were removed from the dataset prior to analysis, ensuring participant anonymity.

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