BMJ Open

Effect of maternal height on the risk of caesarean section in singleton births: evidence from a large-scale survey in India

Strong P Marbaniang,[1] Hemkhothang Lhungdim,[1] Himanshu Chaurasia[2]

To cite: Marbaniang SP, Lhungdim H, Chaurasia H. Effect of maternal height on the risk of caesarean section in singleton births: evidence from a large-scale survey in India. *BMJ Open* 2022;**12**:e054285. doi:10.1136/bmjopen-2021-054285

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2021-054285).

Received 07 June 2021
Accepted 17 December 2021

Check for updates

[1]Department of Public Health & Mortality Studies, International Institute for Population Sciences, Mumbai, Maharashtra, India
[2]Regional Resource Hub for Health Technology Assessment in India, National Institute for Research in Reproductive Health, Mumbai, Maharashtra, India

Correspondence to
Strong P Marbaniang;
strongmarbaniang@yahoo.com

ABSTRACT

Objective This study examines the association of maternal height with caesarean section (CS) in India. It is hypothesised that maternal height has no significant effect on the risk of undergoing caesarean section.

Design A cross-sectional study based on a nationally representative large-scale survey data (National Family Health Survey-4), conducted in 2015–2016.

Setting and participants Analysis is based on 125 936 women age 15–49 years, having singleton live births. Logistic regression has been performed to determine the contribution of maternal height to the ORs of CS birth, adjusting for other exposures. Restricted cubic spline was used as a smooth function to model the non-linear relationship between height and CS. Height data were decomposed using the restricted cubic spline with five knots located at the 5th, 27.5th, 50th, 72.5th and 95th, percentiles.

Primary and secondary outcome measures The main outcome variable of interest in the study is CS. Maternal height is the key explanatory variable. Other explanatory variables are age, parity, sex of child, birth weight, wealth index, place of residence, place of child delivery and household health insurance status.

Results The results reveal that the odds of undergoing CS significantly decrease with increase in maternal heights. Mothers with a height of 120 cm (adjusted OR (AOR): 5.08; 95% CI 3.83 to 6.74) were five times more likely, while mothers with height of 180 cm were 23% less likely (AOR: 0.77; 95% CI 0.62 to 0.95) to undergo CS as compared with mothers with height of 150 cm.

Conclusions Shorter maternal height is linked to a higher risk of CS. Our findings could be used to argue for policies that target stunting in infant girls and avoid unnecessary CS, as there is potential effect on growth during adolescence and early adulthood, with the goal to increase their adult heights, thereby lowering their risk of CS and adverse delivery outcomes.

Strengths and limitations of this study

- ► The sample for the study is relatively large as it is based on a nationally representative large-scale survey data.
- ► Maternal height has been measured by following the standard procedure and instrument.
- ► The cross-sectional design of the study renders appreciation for a potential causal effect dubious.
- ► In the absence of pregnancy complications, the role of clinician decision to perform caesarean section on short mothers cannot be captured.

INTRODUCTION

Caesarean section (CS) is a surgical procedure used to minimise maternal and fetal complications associated with childbirth.[1] While CS can be a life-saving for both the mother and the unborn child, CS itself is not out of risk and it should be performed only when the mother and the unborn child are at a greater risk of complications.[1 2] As CS may have a short-term and long-term health consequences on both the mother and the child, hence reducing unnecessary CS is generally viewed to be an important act.[1] Both the developed and low-income and middle-income countries reported an increase in the prevalence of CS, and while medical complications may be the reasons for this increase, non-medical complications may be partly responsible.[1] Evidence has shown that the short-term and long-term effects of CS for the mothers include increased risk of hysterectomy, abnormal placentation, uterine rupture, stillbirth and preterm birth in the subsequent pregnancy.[3] Also, the short-term and long-term effects of CS on children includes altered immune development, allergy, atopy, asthma, increased blood pressure, type 1 diabetes and reduced intestinal gut microbiome diversity.[3] CS on request has become a growing topical issue to emerge in recent decades, and it has been argued that maternal fear as the legitimate indication for CS on request.[4]

Short adult height, which is a sign of growth retardation, is a particular indication of childhood undernutrition in low-income and middle-income countries.[5] Evidence suggests that adult height is a good indicator of development and population health,[5] and that shorter height is associated with adverse consequences for mortality and morbidity, even after adjusting for education occupation and income.[5] The correlation between female height and the pelvic size[6] shows that mean pelvic area of tall females is greater than those of medium and short statures.[7] Short-statured women with narrow pelvic area are related to obstructed labour, through which the head or shoulder of the baby is hindered.[8] However, wider pelvises among the tall women, allow them to have easier childbirths with heavier birthweight babies, both factors reduce infant and maternal mortality.[9] The relation between maternal height and child mortality have also been highlighted in studies using Demographic Health Survey (DHS) data from 109 countries.[10] The influence of maternal height on obstetric, neonatal and fetal outcomes have been documented in the earlier studies.[11 12] A systematic and meta-analysis based on 56 studies on the effect of maternal height on preterm birth and low birth weight showed that the risk of preterm birth and low birth weight was significantly higher among short-statured women,[13] and such association has also been reported in other studies.[14 15] Also, maternal height has been found to be inversely related to the risk of pre-eclampsia,[16] placental abruption,[17] small for gestational age,[17] intrauterine growth restriction[18] and stillbirth.[6]

Maternal body mass index (BMI) in relation to the risk of CS has been an ongoing debate, which is of great importance for clinical management, and pregnancy and neonatal outcomes.[19] The impact of maternal height on pregnancy and childbirth outcomes warrants increased clinical attention. By having more evidence about maternal height and risk of CS, it would be more likely to benefit the health professionals in their counselling of pregnant women and in clinical management. Hence, in view of the issues discussed above, the objective of this study is to examine the association of maternal height with CS. Only a few studies in Europe, Latin America and Africa have analysed the association between maternal height and the risk of CS.[20–22] However, to our knowledge, no previous study in India has investigated the association between maternal height and CS using a large-scale data that represents a larger population. Although past studies in India have assess the association of socioeconomic factors,[23] maternal malnutrition,[24] place of childbirth[25] and healthcare accessibility[26] with the risk of CS, the likely effect of maternal height on the risk of CS is still poorly understood.

The specific objective of this study is to examine the association of maternal height in relation to the risk of CS with adjustment for other risk factors known to be associated with CS, including birth weight. We hypothesised that maternal height has no significant effect on the risk of undergoing caesarean section. We also anticipate that our findings will help health professionals with comprehensive information on the relationship between maternal height and CS, which can be useful to counsel expecting mothers.

MATERIAL AND METHODS

Study location

The study is exclusively focused on India, which comprises of 28 states and 8 union territories (UTs), with a population of over 139 billion (48% females and 22.2% in age 15–44 years).[27]

Design

This is a cross-sectional study based on secondary data from the fourth round of the Indian equivalent of the DHS, known as the National Family Health Survey (NFHS-4) conducted during the year 2015–2016.[28]

Setting

NFHS-4 was conducted under the aegis of the Ministry of Health and Family Welfare, Government of India and coordinated by the International Institute for Population Sciences, Mumbai. The survey is a stratified two-stage sampling design. In the first stage, primary sampling units (PSUs) were selected with probability proportional to population size. Rural PSUs were villages and urban PSUs were census enumeration blocks. Lastly, in the second stage, systematic random sampling was used in each PSUs to select the households. In each selected household, basic information of all residents (household questionnaire) as well specific information of women (woman's questionnaire) and men (man's questionnaires) between the age of 15–49 years were collected during the survey. A survey procedure was followed to select the respondents from each household.[29] The study also provides data on anthropometry such as height, and weight measured by the trained field staff, weight and height is measured using the standard equipment: SECA 874 U digital scale and SECA 213 Stadiometer. Weight is measured in light clothing after removing of shoes/sandals and any heavy clothing. Height is measured by letting the person to stand on the Stadiometer without wearing shoes.

Patient and public involvement

No patient involved

Study sample

In our analysis, we include only singleton birth (ie, excludes all multiple births; n=4300), and the final sample comprised of 255 327 women. Exclusion of women with height less than 120 cm and above 180 cm, and missing cases resulted to 125 936 women who are considered in the analysis.

Outcome variables

The main outcome variable of interest in the study is the CS cases. The specific question asked during the survey was: 'Was (NAME) delivered by CS, that is, did they cut your belly open to take the baby out?'. The outcome variable is binary and is coded as '1'=Yes (ie, 'delivered by CS') and '0'=No (ie, 'not delivered by CS').

Explanatory variables

The explanatory variables chosen for this study were guided by the existing literature. The key explanatory

Table 1 Background characteristics of women with singleton birth (n=125 936) by type of delivery, India, 2015–2016

Variables	Caesarean section		P value
	No (%)	Yes (%)	
Maternal height (cm)			
Mean (SD)	153.0 (6.0)	152.2 (5.6)	<0.01*
Min-max	120.4–179.3	120.1–178.9	
Maternal age (years)			
15–19	84.5	15.5	<0.01†
20–24	82.1	17.9	
25–29	79.4	20.6	
30–34	76.1	23.9	
35–39	76.2	23.8	
40–44	77.0	23.0	
45–49	85.7	14.3	
Maternal parity			
First	73.7	26.3	<0.01†
Second	78.6	21.5	
Third	87.2	12.8	
Fourth	92.7	7.3	
Fifth	94.2	5.8	
Sixth+	95.2	4.9	
BMI			
Underweight	87.7	12.3	<0.01†
Normal	83.5	16.5	
Overweight	71.7	28.3	
Obese	56.8	43.2	
Maternal caste			
Other backward classes	79.2	20.8	<0.01†
Schedule caste	82.1	17.9	
Schedule tribe	88.2	11.8	
Others	72.9	27.2	
Child birth weight			
<4500 g	79.7	20.3	<0.01†
≥4500 g	70.5	29.5	
Residence			
Urban	70.8	29.2	<0.01†
Rural	83.3	16.7	
Place of delivery			<0.01†
Public	86.7	13.3	<0.01†
Private	57.8	42.2	
Pregnancy complication			
No	78.6	21.4	<0.01†
Yes	81.5	18.5	
Family insurance			
No	79.8	20.2	<0.01†
Yes	78.4	21.6	
Total	**79.6**	**20.4**	

*Test of difference for continuous variables with t-test.
†Test of difference for categorical variables with Pearson's χ^2 test.
BMI, body mass index.

variable is the height of mothers (in cm). Maternal height has been used as a continuous variable which ranges from 120 cm to 180 cm. Other explanatory variables were maternal age (years), parity, sex of child, birth weight (gram), household wealth index, place of residence, place of birth/delivery and possession of a health insurance by one member of the household. BMI is categorised into four classes according to the WHO classification for the Asian population; Underweight (BMI <18.5 kg/m^2), normal weight (BMI of 18.5–23 kg/m^2), overweight (BMI of 23–27.5 kg/m^2) and obese (BMI >27.5 kg/m^2).[30] Since the maternal height varies significantly across the population, and there is no specific cut-off point for short height in adults, we adopt a threshold of 150 cm, which is approximately the 25th percentile value of the population as the reference height. Based on the evidence on the risk of CS due to increased fetal weight[31 32] we dichotomised childbirth weight into two classes: (1) <4500 g and (2) ≥4500 g.

Statistical analysis

All frequency distribution were weighted by applying the appropriate sampling weight. Descriptive statistics present the mean and proportion values. The t-test was applied to test the difference between two independent samples mean value. Pearson's χ^2 was used to test the association between two categorical variables. Multivariable logistic regression was used to determine the effects of the socioeconomic demographic categorical variables and the non-linear effects of height as a continuous variable on the risk of CS. Restricted cubic spline was used as a smooth function to model the non-linear relationship between height and CS. In this study, height data points were decomposed using the restricted cubic spline with five knots located at the 5th, 27.5th, 50th, 72.5th and 95th, percentiles. Restricted cubic spline uses linear function before the first and after the last knot, and cubic function between the first and last knot.[33] The statistical significance level was set at 5% (ie, p<0.05). Statistical analysis was performed using STATA software V.13. The survey command (svy) in STATA was used to take into account the sampling design of the survey.

RESULTS

Participants

In our analysis, we include only women having only singleton birth (ie, excluding multiple births), and women with heights between the range of 120 cm and 180 cm.

Descriptive statistics

The mean maternal height and age for all women were 152.67 cm and 26.9 years, respectively. The mean childbirth weight is 2837.3 grams (online supplemental table S1). The analysis reveals that the marginal difference between the mean maternal height of the mother who had CS (152.2 cm) and mother who did not have CS

(153.0 cm) was statistically significant at 1 percent level of significance (p<0.01) (table 1). It is found that the risk of CS increases with age of the mother. The prevalence of CS across maternal parity ranges from 26.3% to 4.9%, with the highest prevalence observed among the first parity and lowest among the sixth parity and above. In the case of maternal BMI status, our study indicates that the prevalence of CS is highest among obese mothers, followed by overweight and lowest among the underweight mothers. The size of the child at birth is statistically significantly associated with the risk of CS (p<0.01). The results show that the prevalence of CS among those mothers whose child birth weight is greater than or equal to 4500 g is higher (29.5%) than those mothers whose child birth weight is less than 4500 g (20.3%). The prevalence of CS among mothers who gave birth at the private health facility (42.2%) is three times more than mothers who gave birth at the public health facility (13.3%). Interestingly, we found that the prevalence of CS among mothers with pregnancy complications has been much lower than those with no pregnancy complications.

Odds of CS and maternal height: results of multivariate logistic regression

Maternal height has been modelled by a restricted cubic spline with five knots points (142.9, 148.9, 152.2, 155.5 and 161.6) at percentiles 5%, 27.5%, 50%, 72.5% and 95% in a logistic regression model (table 2). The ORs of CS by maternal heights have been derived by applying *xbrcspline* STATA command,[34] and illustrated in figure 1. It is evident form the graph that the risk of CS is high among shorter mothers, as compared with the taller mothers. Similarly, mothers with height of 120 cm (adjusted OR (AOR): 5.08; 95% CI 3.83 to 6.74) were five times more likely, and mothers with height of 147 cm were 1.2 times more likely (AOR 1.18; 95% CI 1.15 to 1.21) to undergo CS, as compared with mothers with height of 150 cm. However, mothers with height of 153 cm were 10% less likely (AOR 0.89; 95% CI 0.87 to 0.91) and mothers with height of 180 cm were 33% less likely (AOR 0.77; 95% CI 0.62 to 0.95) to undergo CS, as compared with mothers with height of 150 cm (online supplemental table S2). However, we did not interpret the effect of estimates for variables other than the primary exposure as evidence has suggested caution in drawing causal inference based on estimates from multivariate regression model.[35]

Figures 2–5 represent the non-linear effects of height on CS by BMI, birth weight, place of delivery, and status of pregnancy complications. The probability of CS is higher among the shorter mothers, and low among the taller mothers. Irrespective of birth weight, the probability of CS decreases with increasing heights of the mothers. Further, among the mothers who gave birth at the public or private health facility, the probability of CS decreases with increasing mothers' height.

Table 2 Results of multivariate logistic regression with OR (with 95% CI) for CS in relation to specified explanatory variables, India, 2015–2016

	Caesarean section (n=125 936)	
Background characteristics	**OR**	**95% CI**
Maternal age (years)		
15–19 Ref	1.00	
20–24	1.11**	1.01 to 1.23
25–29	1.35***	1.23 to 1.49
30–34	1.79***	1.62 to 1.99
35–39	2.26***	2.01 to 2.53
40–44	2.87***	2.44 to 3.38
45–49	2.69***	1.92 to 3.76
Maternal parity		
First Ref	1.00	
Second	0.68***	0.66 to 0.71
Third	0.36***	0.34 to 0.38
Fourth	0.21***	0.19 to 0.23
Fifth	0.16***	0.13 to 0.18
Sixth and above	0.13***	0.11 to 0.16
Sex of child		
Female Ref	1.00	
Male	1.00	0.98 to 1.04
Caste		
Other backward caste Ref	1.00	
Schedule caste	1.12***	1.07 to 1.17
Schedule tribes	0.82***	0.78 to 0.86
Others	1.13***	1.09 to 1.18
Wealth index		
Poorest Ref	1.00	
Poorer	1.37***	1.27 to 1.47
Middle	1.85***	1.73 to 1.98
Richer	1.98***	1.85 to 2.13
Richest	1.79***	1.65 to 1.92
Birth weight		
<4500 g Ref	1.00	
≥4500 g	1.81***	1.58 to 2.06
Place of delivery		
Public Ref	1.00	
Private	3.79***	3.66 to 3.92
Residence		
Urban Ref	1.00	
Rural	0.89***	0.85 to 0.92
Family insurance		
No Ref	1.00	
Yes	1.28***	1.23 to 1.33
Pregnancy complication		
Yes Ref	1.00	

Continued

Marbaniang SP, *et al. BMJ Open* 2022;**12**:e054285. doi:10.1136/bmjopen-2021-054285

Table 2 Continued

Background characteristics	Caesarean section (n=125 936) OR	95% CI
No	0.92***	0.88 to 0.95
BMI		
Underweight Ref	1.00	
Normal	1.16***	1.11 to 1.22
Overweight	1.78***	1.69 to 1.87
Obese	2.86***	2.69 to 3.05

**P<0.01, ***p<0.001
BMI, body mass index; Ref, reference.

DISCUSSION

The frequency of CS and its relationship with maternal height were investigated based on data of a nationally representative sample survey, which comprised live newborn singleton births delivered by mothers in the reproductive age (15–49 years). The study portrays that the size of the newborn, and the mother's height predict well the risk of CS.

In line with previous studies,[8 36 37] our findings also indicate that shorter women have a higher risk of CS, and that risk declines as height increases. Mothers with a height of less than 148 cm have twice the probability of CS compared with mothers with a height of 148 cm or more. This finding is consistent with that of a study done in sub-Saharan African settings, which analysed all live births and the first births. That study also concluded that mothers with a height of less than 145 cm have twice the probability of CS compared with mothers with a height of 145 cm or more.[20] Maternal height has been associated with an obstetric risk during birth, according to a study. For example, mothers with a small stature (less than 145–150 cm) have a higher risk of prolonged or labour blockage

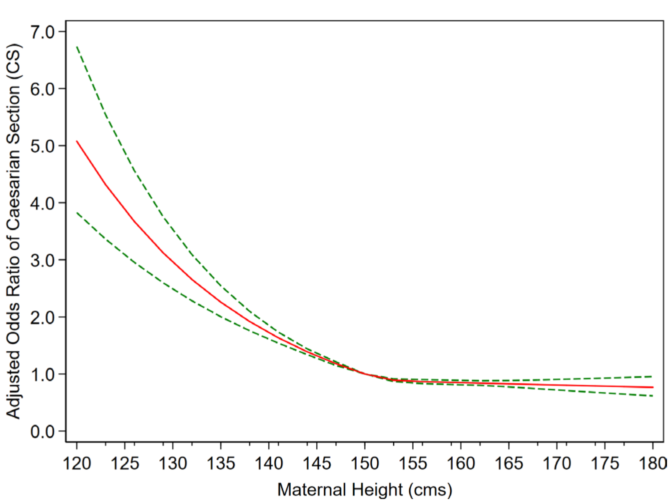

Figure 1 Illustrates the adjusted ORs (red line) with 95% CI (green dash) for the relationship of maternal height with the risk of CS. The reference height is 150 cm. CS, caesarean section.

due to cephalopelvic disproportion.[36 38] The mother's BMI is a well-known risk factor for CS, with rising risks as the BMI rises.[39] There was a consistent trend exhibiting increased risk of CS with rising BMI class for each maternal height category.

Another important factor that contributes to the association between short maternal height and CS is nutritional status. Shorter women were more likely to be overweight or obese than taller women,[21 40] and obesity has been linked to increase in CS.[21 41] Furthermore, our study found that higher odds of CS among mothers who were overweight/obese before pregnancy and had a higher risk related to height and pregnancy related complications than those among mothers' with normal weight.[21] Therefore, obesity prior to or during pregnancy in short or very short mothers may cause labour to be prolonged, and triggers a need for CS.[42]

A combination of maternal height and birth weight, with shorter women has been more vulnerable to the effect of neonatal weight on CS risk (contrary to previous research[43–45]). The increasing size of the baby has minimal effect on the risk of CS for taller women, who have the lowest overall risk of CS, and a low-birthweight newborns seem to be more predictive of an adverse pregnancy outcome for similar reasons, as found by a previous study.[8]

In India, CS births are more common in private health facilities, despite the fact that more women deliver in public health facilities. Institutional deliveries in India have increased dramatically over the years. This high increase has been due to the implementation of some flagship maternal and child health programmes by the government such as the Janani Suraksha Yojana and Janani Shishu Suraksha Karyakram schemes to boost institutional births and hence reduce home deliveries.[46]

Other studies have shown that mother age is a significant factor in caesarean deliveries because medical-related disorders such as hypertension and diabetes are more common in the older age group.[47 48] In comparison to women who lived in rural areas, metropolitan women had more CS deliveries. Additional access to medical intervention in metropolitan regions, as well as the existence of more health facilities and insurances could be contributing factors.[49]

Wealthier women and those belonging to a higher social hierarchy (caste) are more likely to give birth by CS. CS appears to be a preferred option of birth for women who can afford it rather than a medically necessary surgery.[50 51] Women from lower socioeconomic backgrounds may be unable to pay or gain access to healthcare institutions that are prepared to do caesarean deliveries, as indicated by other studies in impoverished nations.[52] Furthermore, to our knowledge, this is the first study that documented the effect of maternal height on the risk of CS in singleton births and using restricted cubic spline method in an Indian setting. Our finding clearly indicates that shorter women have higher risk for pregnancy related complications, as concluded by previous studies. Shorter women

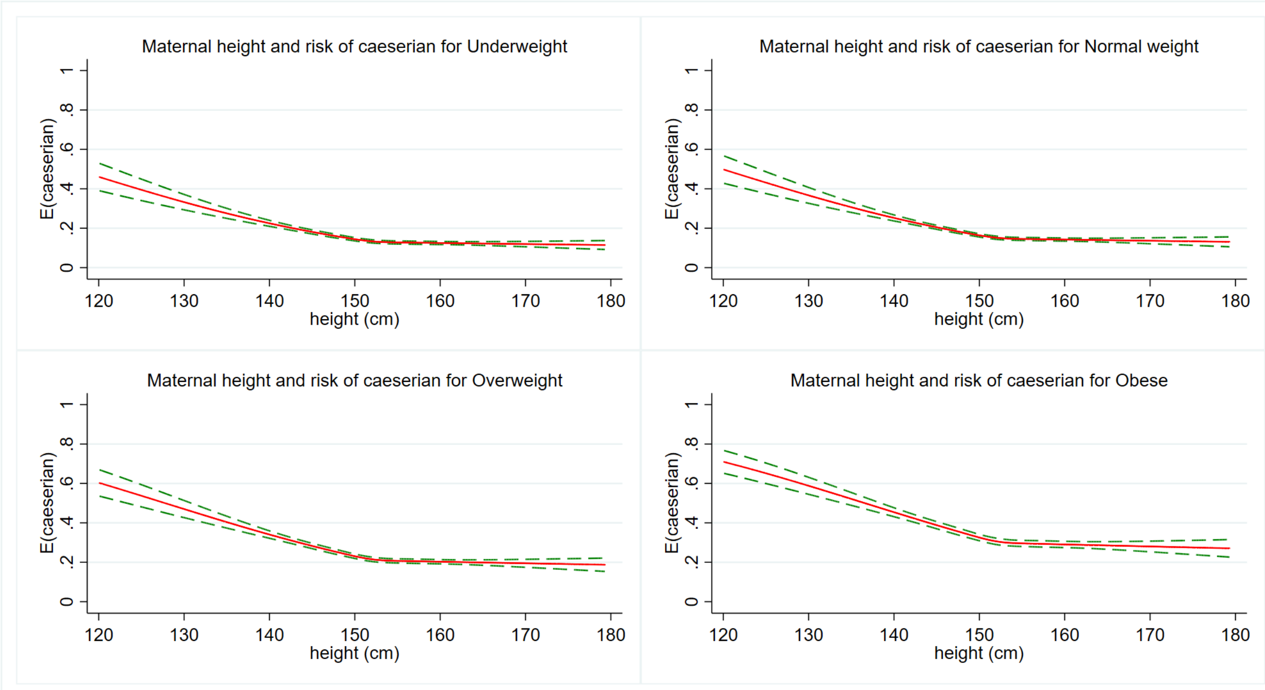

Figure 2 Non-linear effects of height on caesarean section by BMI of mothers, with 95% CI, India, 2015–2016. BMI, body mass index.

tend to have husbands or partners who are on average much taller. But among taller women, the height gap between spouses narrows.

Our study also found that CS is associated with older age, urban residence and higher wealth. These crude associations remained significant in our adjusted model. The findings are consistent with many other studies, and, in particular, in sub-Saharan Africa using 34 national datasets.[20]

Strength and limitation

This study has both strengths and limitations. This study has a large sample size, as well as, a very high household and individual levels response rates (over 95%), which

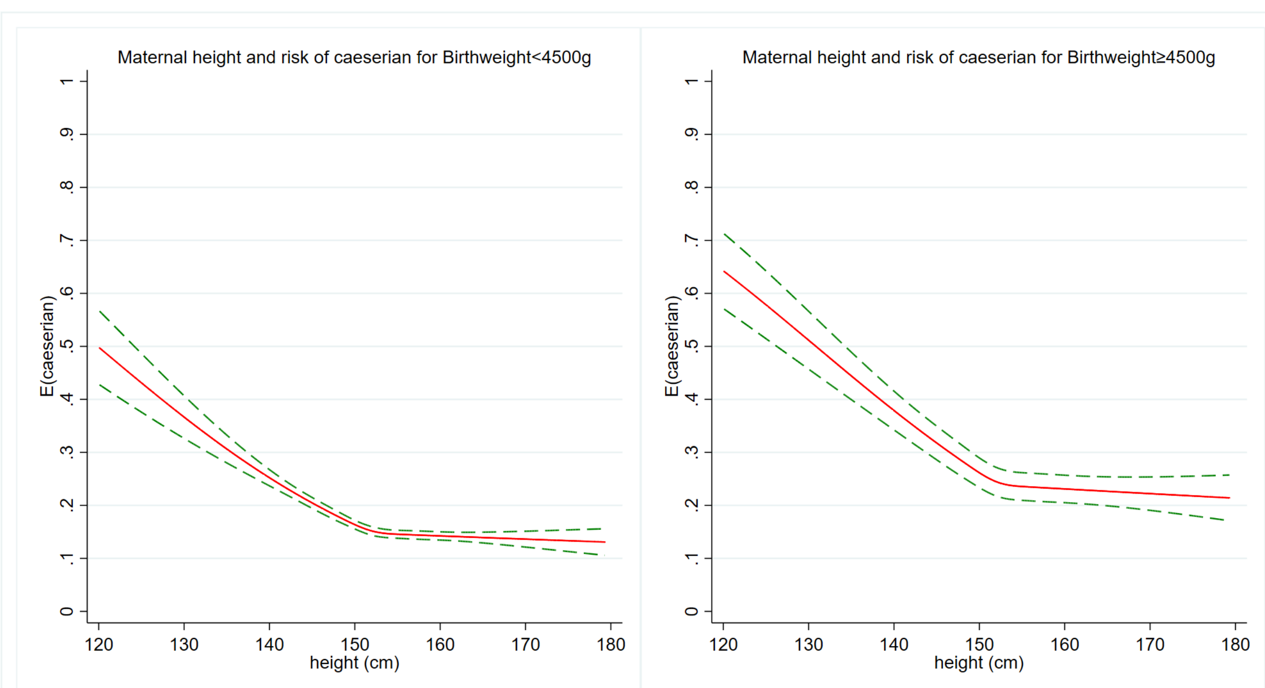

Figure 3 Non-linear effects of height on caesarean section by birth weight of mothers, with 95% CI, India, 2015–2016.

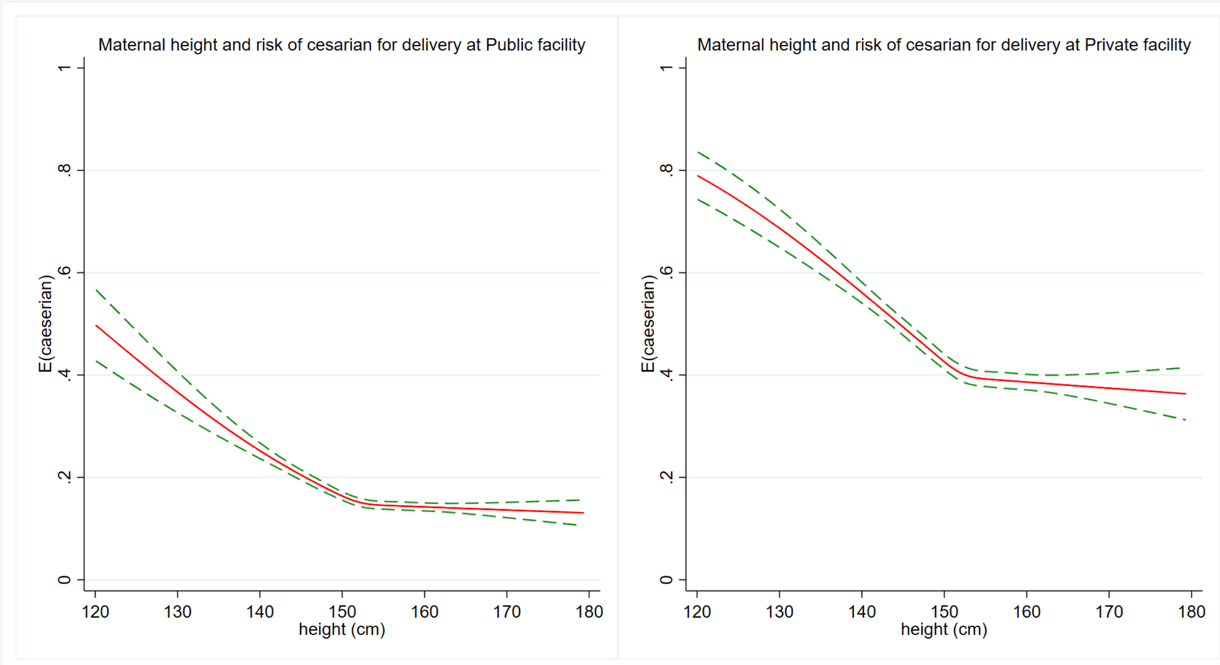

Figure 4 Non-linear effects of height on caesarean section by place of delivery of mothers, with 95% CI, 2015–2016.

eliminates the chance for selection bias. The sample size is nationally representative and comprised of 255 327 women, covering all the states/UTs in India.

The cross-sectional design of the study limits us to conclude any causal inference from this study. On the other hand, our other variables were based on women's self-report and could have been influenced by memory bias. Furthermore, data on CS was restricted to live births in the 5 years preceding the study. Hence, our analysis looked at the effect of a singleton birth rather than considering multiple births. In addition, if one twin was stillborn while the other was born alive, they may have been mistakenly recorded as twins, or the possibility of a live twin being misclassified as a singleton birth, which was not possible to identify in the dataset.

CONCLUSIONS

Our findings show that maternal height, coupled with obesity, is significantly associated with increased risk for

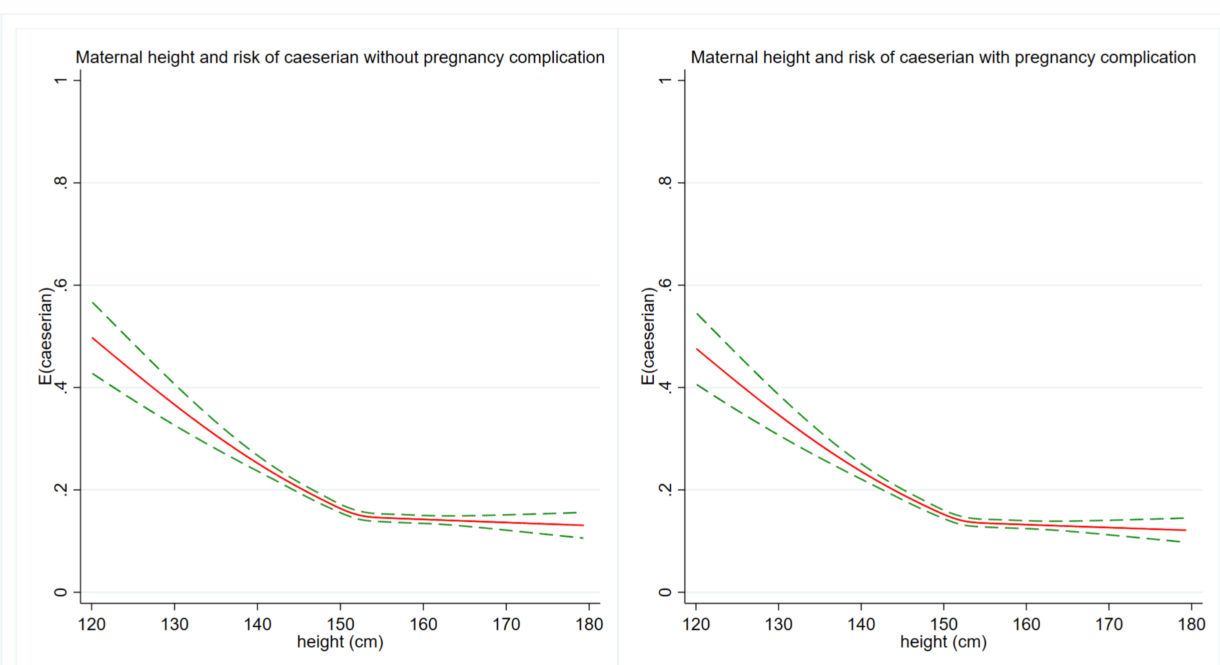

Figure 5 Non-linear effects of height on caesarean section by status of pregnancy complications of mothers, with 95% CI, India, 2015–2016.

birth, and with adverse pregnancy outcomes. Shorter women are more likely to undergo CS, as they have a higher rate of newborn loss than taller women. While caesarean procedures can save lives, they are expensive, and also linked to poorer health outcomes. One implication based on the findings is the need for healthcare system to investigate the reasons for this association as well as the mother's social circumstances. Furthermore, because short maternal height indicates the cumulative effect of social, health and nutrition deprivations across generations, our findings indirectly emphasise the significance of developing comprehensive and cost-effective health and nutrition intervention strategies.[5 21 53 54]

Acknowledgements The authors are thankful to the editor and the three reviewers for their insightful comments and valuable suggestions, which hugely improved the analysis and the overall quality of the paper.

Contributors Conceived and designed the research paper: SPM and HL. Analysed the data: SPM. Contributed agents/materials/analysis tools: SPM, HL and HC. Wrote the manuscript: SPM and HC. Refined the manuscript: SPM, HL and HC.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval As this study was based on secondary data analysis which is publicly available, deidentified survey data, the institutional review board (IRB) exempted this study requiring IRB approval.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. Data of all NFHS series are available to all and can be had at https://dhsprogram.com/data/dataset/India_Standard-DHS_2015.cfm?flag=1 on request.

ORCID iD

Strong P Marbaniang http://orcid.org/0000-0001-5347-1867

REFERENCES

1 Khunpradit S, Tavender E, Lumbiganon P. Non-clinical interventions for reducing unnecessary cesarean section. *Cochrane Database Syst Rev* 2018;2011.
2 World Health Organization (WHO). Cesarean sections should only be performed when medically necessary, 2015. Available: https://www.who.int/mediacentre/news/releases/2015/cesarean-sections/en/ [Accessed 27 Sep 2020].
3 Sandall J, Tribe RM, Avery L, *et al*. Short-term and long-term effects of caesarean section on the health of women and children. *Lancet* 2018;392:1349–57.
4 Lavender T, Hofmeyr GJ, Neilson JP, *et al*. Caesarean section for non-medical reasons at term. *Cochrane Database Syst Rev* 2012;9:34–5.
5 Perkins JM, Subramanian SV, Davey Smith G, *et al*. Adult height, nutrition, and population health. *Nutr Rev* 2016;74:149–65.
6 Bresler JB. Maternal height and the prevalence of stillbirths. *Am J Phys Anthropol* 1962;20:515–7.
7 Sharma K, Gupta P, Shandilya S. Age related changes in pelvis size among adolescent and adult females with reference to parturition from Naraingarh, Haryana (India). *Homo* 2016;67:273–93.
8 Stulp G, Verhulst S, Pollet TV, *et al*. Parental height differences predict the need for an emergency caesarean section. *PLoS One* 2011;6:e20497–8.
9 Sear R, Allal N, Height MR. *Marriage and reproductive success in Gambian women*. In: Research in Economic Anthropology, 2004: 203–24.
10 Özaltin E, Hill K, Subramanian SV. Association of maternal stature with offspring mortality, underweight, and stunting in low- to middle-income countries. *JAMA* 2010;303:1507–16.
11 Stulp G, Barrett L, Tropf FC, *et al*. Does natural selection favour taller stature among the tallest people on earth? *Proc Biol Sci* 2015;282:20150211.
12 Camilleri AP. The obstetric significance of short stature. *Eur J Obstet Gynecol Reprod Biol* 1981;12:347–56.
13 Han Z, Lutsiv O, Mulla S, *et al*. Maternal height and the risk of preterm birth and low birth weight: a systematic review and meta-analyses. *J Obstet Gynaecol Can* 2012;34:721–46.
14 Derraik JGB, Lundgren M, Cutfield WS, *et al*. Maternal height and preterm birth: a study on 192,432 Swedish women. *PLoS One* 2016;11:e0154304–7.
15 Dickey RP, Xiong X, Xie Y, *et al*. Effect of maternal height and weight on risk for preterm singleton and twin births resulting from IVF in the United States, 2008–2010. *Am J Obstet Gynecol* 2013;209:349.e1–349.e6.
16 Basso O, Wilcox AJ, Weinberg CR, *et al*. Height and risk of severe pre-eclampsia. A study within the Danish national birth cohort. *Int J Epidemiol* 2004;33:858–63.
17 Ogawa K, Morisaki N, Saito S, *et al*. Association of shorter height with increased risk of ischaemic placental disease. *Paediatr Perinat Epidemiol* 2017;31:198–205.
18 Chan BC-P, Lao TT-H. Maternal height and length of gestation: does this impact on preterm labour in Asian women? *Aust N Z J Obstet Gynaecol* 2009;49:388–92.
19 Cedergren MI. Optimal gestational weight gain for body mass index categories. *Obstet Gynecol* 2007;110:759–64.
20 Arendt E, Singh NS, Campbell OMR. Effect of maternal height on caesarean section and neonatal mortality rates in sub-Saharan Africa: an analysis of 34 national datasets. *PLoS One* 2018;13:e0192167.
21 Roldán E, Grajeda LM, Pérez W. Maternal height associated with cesarean section. A cross-sectional study using the 2014-2015 national maternal-child health survey in Guatemala. *Int J Equity Health* 2020;19:95.
22 Mogren I, Lindqvist M, Petersson K. Maternal height and risk of cesarean section in singleton births in Sweden—a population-based study using data from the Swedish pregnancy register 2011 to 2016. *PLoS One* 2018;13.
23 Sahoo H, Jeermison RK. Repeated cesarean section delivery in India. *Child Youth Serv Rev* 2020;116:105258.
24 Wells JCK, Wibaek R, Poullas M. The dual burden of malnutrition increases the risk of cesarean delivery: evidence from India. *Front Public Health* 2018;6:1–14.
25 Bhatia M, Banerjee K, Dixit P, *et al*. Assessment of variation in cesarean delivery rates between public and private health facilities in India from 2005 to 2016. *JAMA Netw Open* 2020;3:e2015022.
26 Panda BK, Mishra US, Mohanty SK. Rising extent of cesarean delivery and its differential access in regions of India 2005–2016. *J Public Heal* 2019.
27 United Nations,, Department of Economic and Social Affairs PD. World population prospects 2019, volume I: comprehensive tables (ST/ESA/SER.A/426).; 2019.
28 DHS. The DHS Program-India: standard DHS, 2015-16 dataset,. Demogr. heal. Surv., 2017. Available: https://dhsprogram.com/data/dataset/India_Standard-DHS_2015.cfm?flag=1
29 International Institute for Population Sciences (IIPS) and ICF. *National family health survey (NFHS-4), 2015-16: India*. Mumbai: IIPS, 2017. http://rchiips.org/nfhs/NFHS-4Reports/India.pdf
30 BarbaC, Cavalli-SforzaT, CutterJ, *et al*. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet* 2004;363:157–63.
31 Poma PA. Correlation of birth weights with cesarean rates. *Int J Gynaecol Obstet* 1999;65:117–23.

32 Mahmood TA. Maternal height, birthweight, obstetric conjugate and their influence on the management of parturients with a previous cesarean scar. *Acta Obstet Gynecol Scand* 1989;68:595–8.
33 Gauthier J, Wu QV, Gooley TA. Cubic splines to model relationships between continuous variables and outcomes: a guide for clinicians. *Bone Marrow Transplant* 2020;55:675–80.
34 Orsini N. XBRCSPLINE: Stata module to tabulate differences in predicted responses after restricted cubic spline models. *Stat Softw Components* 2009.
35 Westreich D, Greenland S. The table 2 fallacy: presenting and interpreting confounder and modifier coefficients. *Am J Epidemiol* 2013;177:292–8.
36 McGuinness BJ, Trivedi AN. Maternal height as a risk factor for caesarean section due to failure to progress in labour. *Aust N Z J Obstet Gynaecol* 1999;39:152–4 http://files/5328/j.1479-828X.1999.tb03360.html
37 Kirchengast S, Hartmann B. Short stature is associated with an increased risk of cesarean deliveries in low risk population. *Acta Medica Litu* 2007;14:1–6.
38 Kara F, Yesildaglar N, Uygur D. Maternal height as a risk factor for caesarean section. *Arch Gynecol Obstet* 2005;271:336–7.
39 Cedergren MI. Maternal morbid obesity and the risk of adverse pregnancy outcome. *Obstet Gynecol* 2004;103:219–24.
40 Randive B, Diwan V, De Costa A. India's conditional cash transfer programme (the JSY) to promote institutional birth: is there an association between institutional birth proportion and maternal mortality? *PLoS One* 2013;8:e67452.
41 Khan MN, Islam MM, Shariff AA, *et al*. Socio-demographic predictors and average annual rates of caesarean section in Bangladesh between 2004 and 2014. *PLoS One* 2017;12:e0177579.
42 Lin H-C, Sheen T-C, Tang C-H, *et al*. Association between maternal age and the likelihood of a cesarean section: a population-based multivariate logistic regression analysis. *Acta Obstet Gynecol Scand* 2004;83:1178–83.
43 Khanal V, Karkee R, Lee AH, *et al*. Adverse obstetric symptoms and rural-urban difference in cesarean delivery in Rupandehi district, western Nepal: a cohort study. *Reprod Health* 2016;13:17.
44 Cavallaro FL, Cresswell JA, França GV, *et al*. Trends in caesarean delivery by country and wealth quintile: cross-sectional surveys in southern Asia and sub-Saharan Africa. *Bull World Health Organ* 2013;91:914–22.
45 Ronsmans C, Holtz S, Stanton C. Socioeconomic differentials in caesarean rates in developing countries: a retrospective analysis. *Lancet* 2006;368:1516–23.
46 Boatin AA, Schlotheuber A, Betran AP, *et al*. Within country inequalities in caesarean section rates: observational study of 72 low and middle income countries. *BMJ* 2018;360:k55.
47 Castaño Luz Stella Álvarez, Restrepo AE, Rueda JDG, *et al*. The effects of socioeconomic status and short stature on overweight, obesity and the risk of metabolic complications in adults. *Colomb Med* 2013;44:146–45.
48 Poobalan AS, Aucott LS, Gurung T, *et al*. Obesity as an independent risk factor for elective and emergency caesarean delivery in nulliparous women--systematic review and meta-analysis of cohort studies. *Obes Rev* 2009;10:28–35.
49 Chu SY, Kim SY, Schmid CH, *et al*. Maternal obesity and risk of cesarean delivery: a meta-analysis. *Obes Rev* 2007;8:385–94.
50 Shy K, Kimpo C, Emanuel I, *et al*. Maternal birth weight and cesarean delivery in four race-ethnic groups. *Am J Obstet Gynecol* 2000;182:1363–70.
51 Merchant KM, Villar J, Kestler E. Maternal height and newborn size relative to risk of intrapartum caesarean delivery and perinatal distress. *BJOG* 2001;108:689–96.
52 Brabin L, Verhoeff F, Brabin BJ. Maternal height, birthweight and cephalo pelvic disproportion in urban Nigeria and rural Malawi. *Acta Obstet Gynecol Scand* 2002;81:502–7.
53 Stein AD, Barnhart HX, Wang M, *et al*. Comparison of linear growth patterns in the first three years of life across two generations in Guatemala. *Pediatrics* 2004;113:e270–5.
54 Imdad A, Sadiq K, Bhutta ZA. Evidence-based prevention of childhood malnutrition. *Curr Opin Clin Nutr Metab Care* 2011;14:276–85.