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Association between child marriage and high blood glucose level in women: A birth cohort analysis

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ABSTRACT

Objectives: Child marriage prematurely forces girls (<18 years of age) to perform adult roles prior to physical and psychological maturity. Such precocious transitions to young adulthood can have consequences on their long-term health, however, limited work has examined such relationships to date. As such, this study examines whether child marriage is associated with the risk of having hyperglycemia, or high blood glucose, in adulthood.
Study design: Observational study using repeated cross-sectional data.
Methods: Using data from the 2015-16 and 2019-21 waves of the India National Family Health Survey, we matched 432,080 and 418,409 women, aged 20–49 years, by birth year and month to create birth cohorts. Fitting multivariable binomial and multinomial logistic models, we compared the odds of having hyperglycemia across groups by marriage age (i.e., before or after age 18 years) within respective birth cohorts.
Results: We found that the adjusted odds of having high blood glucose among women married as children were 1.12 (95 % CI: 1.07–1.16) times that of their peers married as adults in the full-sample. The adjusted relative risks of having blood glucose levels higher than normal but lower than diabetic and diabetic ranges were 1.09 (95 % CI: 1.04–1.14) and 1.23 (95 % CI: 1.15–1.31), respectively, in comparison to blood glucose within normal range. These results were persistent across sub-groups of different birth cohorts.
Conclusion: Our findings suggest that child marriage was associated with higher risk of having high blood glucose in women, later in life.

1. Introduction

Child marriage, defined as marriage before age 18 years, is a violation of human rights, with an estimated 650 million women currently alive to date married as children [1]. Extant literature documents that precocious transitions during developmental stages are associated with elevated risk of cardiometabolic disease and other health problems [2,3]. Child marriage similarly represents a stressful transition from girlhood to womanhood [4], contributing to adverse health outcomes, along with dire implications for fertility, health and nutrition, economic opportunities, and decision making ability in adulthood [5].

The practice of child marriage is more prevalent in the developing world and is rooted in gender inequality, poverty, insecurity, and social norms [6,7]. As such, women in low-and-middle income countries (LMICs), from disadvantaged households and lower socioeconomic status, are at greater risk of getting married at an early age [8]. Furthermore, onset of chronic conditions such as hypertension and diabetes, and the behavioral risk factors associated with these conditions have close links to the social determinants of health in both developed and developing countries [9,10]. As such, women married as children may have a relatively higher risk of noncommunicable diseases (NCDs), compared to their counterparts married as adults.

Beyond the scope of reproductive health outcomes, research on NCDs among women married as children, however, is limited [11]. Few recent studies have explored the relationship between child marriage and risk of hypertension among young adult women [12–15]. Another study assessed the risk of self-reported chronic conditions at midlife among women who were married as children [16]. Given the established association between psychosocial adversities in childhood and later life incidence of type 2 diabetes [17], it is plausible to extend this

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relationship to contextual adversities, such as child marriage and its impact on the risk of hyperglycemia.

Two cross-sectional studies, have some evidence on the relationship between early marriage and the risk of having high blood glucose among women in India using data from the India National Family Health Survey (NFHS) [18,19]. One study found that child marriage was associated with high blood pressure and high blood glucose comorbidity among young adult women (aged 18–34 years) [18]. Another study reported that compared to women married during age 20–24 years, women married during early (age 10–14 years) and middle (age 15–17 years) adolescence had a higher risk of having high blood glucose [19]. These cross-sectional studies had a key limitation. Neither study accounted for the role of aging (i.e., growing older) in developing risk of hyperglycemia. Further, women of different age in the cross-sectional setting had differential likelihood of getting married in their childhood. The joint influence of these two aspects impeded obtaining a better estimate of the relationship between child marriage and hyperglycemia in the extant studies.

Successive waves of the NFHS allow for the creation of birth cohorts to examine high blood glucose outcomes over time within a cohort. This essentially means that we were able to observe women who were of similar age at two points of time and thereby facilitates offering a more compelling estimate of the relationship between child marriage and hyperglycemia. Data from India are of relevance, with 223 million women in the country married before reaching adulthood [20], and approximately 107 million diabetic and 255 million prediabetic adults [21]. As such, investigating the association between child marriage and high blood glucose among women has important public health implications in the Indian context. The primary aim of this observational study was to assess whether child marriage was associated with differential risk of high blood glucose level in women within birth cohorts. The secondary aim was to examine whether the association within birth cohorts changed over time.

2. Methods

2.1. Data

This was an observational study using repeated cross-sectional data from the 2015-16 and 2019-21 waves of the India National Family Health Survey (NFHS-4 & 5). The Demographic and Health Surveys (DHS) Program, funded by the USAID, provided technical assistance in implementation of the NFHS [22,23]. The DHS program uses standard model questionnaires that are generally comparable across countries and the DHS datasets have been widely used to conduct public health research in the developing countries [24]. The NFHS-4 & 5 are nationally representative surveys that entail a two-stage stratified sampling framework; and covers rural and urban regions of all 36 states and union territories of India. The survey reports on various sociodemographic and anthropometric characteristics as well as several measures on reproductive-aged (i.e., age 15–49 years) women's health including random blood glucose level [22,23]. Our sample comprised of 850,489 married adult women, who were aged 20–47 years and 22–49 years during the 2015-16 and 2019-21 waves of the survey, respectively. Respondents were excluded if information was not available on age at marriage and valid blood glucose measure, including timing of the test. A flow diagram of the study population is provided in Supplementary Material Fig. S1. We matched birth year and month of women in the two survey waves to create five birth cohorts by year of birth as follows: i) 1969–1974 (oldest cohort), ii) 1975–1979, iii) 1980–1984, iv) 1985–1989, and v) 1990–1996 (youngest cohort). Each birth cohort spanned over five years except for the oldest and youngest cohorts, which had one or two additional years to include women who were otherwise not part of any other cohort.

Of note, we used publicly available anonymized secondary data for analysis. The datasets for this study meet the definition of National Institutes of Health (NIH) Exempt Human Subjects Research under the following exemption criteria – "Exemption 4: involves the collection/study of data or specimens if publicly available, or recorded such that subjects can not be identified" [25]. The original survey protocol was reviewed and approved by the International Institute for Population Sciences (IIPS) and ICF institutional review boards [22,23]. During both waves of the survey, written informed consents were obtained prior interview in the following manner. The interviewer read the informed consent statement that explained the purpose of the survey to the respondent. Participation in the survey was completely voluntary. If the respondent agreed to participate, the interviewer signed in the designated space in the paper questionnaire affirming that the informed consent statement had been read out to the respondent and that the respondent provided her consent to participate in the survey [26,27].

2.2. Measures

Respondents' random blood glucose was measured using the FreeStyle Optium H (in NFHS-4) and Accu-Chek Performa (in NFHS-5) glucometer. Blood samples were collected by trained health investigators, who were part of the survey team [26,27]. A respondent was determined to have high blood glucose if random blood glucose levels were ≥141 mg/dl [22,23]. Our primary outcome variable thus, was a dichotomous variable, HBG_i, indicating whether a respondent had high blood glucose. In addition, we analyzed a secondary categorical outcome indicating multiple ranges of blood glucose measures, denoted by a polychotomous variable $RBG_{j,i}$, as follows: i) normal range (≤140 mg/dl), iii) higher than normal but lower than diabetic range (141–199 mg/dl), and iii) diabetic range (≥200 mg/dl) [22,23,28].

We identified women who were married as children (i.e., before 18 years) or as adults (≥18 years) based on respondents' reported age at first marriage. Our key explanatory variable thus, is a dichotomous variable, CM_i, indicating whether a respondent was married as a child or as an adult.

2.3. Statistical analysis

We first estimated a set of multivariable logistic regressions to assess the relationship between child marriage and the risk of having high blood glucose for the full-sample (i.e., all birth cohorts together) as follows:

$$logit(HBG_i) = \alpha_0 + \alpha_1 CM_i + \boldsymbol{X_i\alpha_2} + Cohort + TLA + TLD + State \tag{1}$$

$$logit(HBG_i) = \beta_0 + \beta_1 CM_i + \boldsymbol{X_i\beta_2} + \beta_3 Year_i + Cohort + TLA + TLD + State \tag{2}$$

$$logit(HBG_i) = \gamma_0 + \gamma_1 CM_i + \boldsymbol{X_i\gamma_2} + \gamma_3 Year_i + \gamma_4 (CM_i \times Year_i) + Cohort + TLA + TLD + State \tag{3}$$

Equation (1) was estimated separately for the two survey waves. The exponentiated value of α_1 shows the odds of high blood glucose for child marriage in respective survey waves. *Cohort* and *State* are birth cohort fixed effects and state of residence fixed effects respectively. *TLA* and

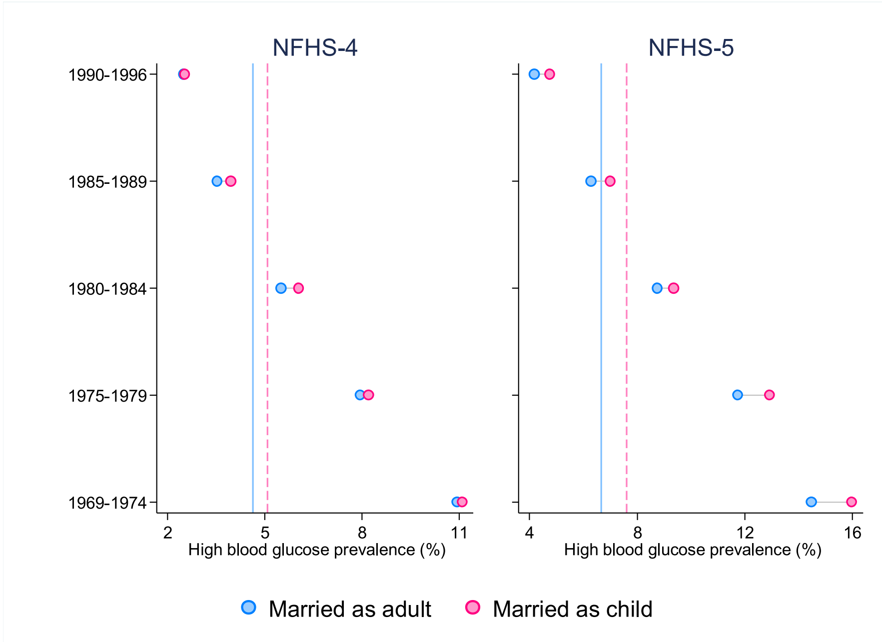

Fig. 1. Differences in prevalence of high blood glucose by child marriage, birth cohort, and survey year
Note: The solid blue vertical line shows the prevalence for all women married as adults in respective survey waves. The dashed pink vertical line shows the prevalence for all women married in childhood in respective survey waves. Differences (between women married as children and as adults) were statistically significant for all birth cohorts in the NFHS-5. Differences were statistically significant for the 1975–1979 and 1980–1984 birth cohorts in the NFHS-4. Overall difference (i.e., the gap between the solid and dashed line) was statistically significant in both survey waves. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

TLD are sets of dummy variables indicating time last ate and time last drank (other than water), respectively, before blood glucose test. Categories of *TLA* and *TLD* are provided in supplementary file 2.

$\boldsymbol{X_i}$ is a vector of potential confounders including sociodemographic characteristics and risk factors for type-2 diabetes. The sociodemographic correlates included educational attainment, household wealth index quintiles, religion, caste, and urban/rural residence. The risk factors included body mass index (BMI) categories, tobacco smoking, parity (number of children born), pregnancy status, and lactating mother status [29]. These are the common set of correlates used in extant literature on determinants of diabetes among women in India [30]. Observations, for which data on sociodemographic correlates and risk factors were missing (n = 1710), were excluded from the adjusted analysis. Of note, our intention was not to assess these sociodemographic correlates as predictors of high blood glucose outcomes in women, but to include these correlates in the model to control for any confounding relationship and thereby to obtain an unbiased estimate of the relationship between child marriage and high blood glucose levels. However, we estimated separate logistic regression models for each of the sociodemographic characteristics and risk factors for sub-groups of women married as adults and as children to see if the associations were similar (or different) across the two groups. These results are presented in supplementary file 3.

Equations (2) and (3) were estimated for the pooled sample (i.e., both survey waves together). $Year_i$ is a binary variable indicating survey wave 2019-21. The coefficient β_3 in equation (2) and γ_3 in equation (3) refers to the odds of having high blood glucose during 2019-21 compared to that during 2015-16. The coefficient γ_1 in equation (3) refers the odds of having high blood glucose for women in the 2015-16 wave, who were married as children. The coefficient γ_4 indicates whether the odds of high blood glucose for child marriage among women in the 2019-21 wave were different from that among women in the 2015-16 wave.

To achieve the power of 0.90 for an effect size (odds ratio) of 1.10, probability of married as children being 0.40, and probability of high blood glucose among women married as adults being 0.07, the required sample size was estimated to be 70,562 [31]. For the model with interactions between child marriage and survey wave, the required sample size was estimated to be 272,827 [32]. As such, our sample size of 850, 489 (432,080 in the 2015-16 wave and 418,409 in the 2019-21 wave) was adequate to assess the differences between the two groups.

Next we estimated multinomial logistic regression models, similar to equation (3), where the outcome variable was $RBG_{j,i}$ with three categories (j∈{1,2,3}) of blood glucose ranges. Replacing the binary outcome with a categorical outcome served as a sensitivity analysis. The normal range was considered as the base outcome. Relative to the base outcome, we assessed the risk of having blood glucose levels in the "higher than normal but lower than diabetic" and "diabetic" ranges for women married as children. Regressions were estimated for the full sample as well as for sub-samples of each of the five birth cohorts.

Next, to assess a possible causal relationship between child marriage and risk of elevated blood glucose level later in life, we employed an instrumental variable regression approach. We instrumented the binary child marriage indicator with respondent's mother-in-law's years of education to estimate two-stage least squares (2SLS) regression. We estimated 2SLS linear probability models (LPM) that corresponded to equations (1)–(3) for women who had their mother-in-law living with them in the same household. The rationale behind mother-in-law's years of education being a valid instrument for child marriage was that the lower the years of education of a mother-in-law the higher is the probability of her choosing an underaged (i.e., age <18 years) girl as daughter-in-law. The exclusion restriction was satisfied under the assumption that after controlling for household environment, mother-in-law's years of education impacted daughter-in-law's risk of elevated blood glucose level only through the event of daughter-in-law's marriage in childhood. In other words, accounting for household environment blocked any potential backdoor paths through which mother-in-law's education might influence daughter-in-law's elevated blood

Table 1
Descriptive statistics.

	Count			Share (%)			Difference: married as children & as adults (%-points)
	All	Married as Adults	Married as Children	All	Married as Adults	Married as Children	
	N = 850,489	N = 513,664	N = 340,628	N = 850,489	N = 513,664	N = 340,628	
Birth cohorts							
1969–1974	132,414	75,857	56,557	15.57	14.77	16.79	2.02***
1975–1979	146,682	83,054	63,628	17.25	16.17	18.89	2.72***
1980–1984	172,334	100,506	71,828	20.26	19.57	21.33	1.76***
1985–1989	187,095	116,107	70,988	22.00	22.60	21.08	−1.53***
1990–1996	211,964	138,140	73,824	24.92	26.89	21.92	−4.98***
Covariates							
Education							
No education	274,832	123,285	151,547	32.31	24.00	44.99	20.99***
Primary	125,228	62,086	63,142	14.72	12.09	18.75	6.66***
Secondary	364,506	248,415	116,091	42.86	48.36	34.47	−13.90***
Higher	85,923	79,878	6045	10.10	15.55	1.79	−13.76***
Wealth Index Quintiles							
1st (Poorest)	170,310	84,753	85,557	20.02	16.50	25.40	8.90***
2nd (Poorer)	183,595	98,143	85,452	21.59	19.11	25.37	6.26***
3rd (Middle)	177,106	103,729	73,377	20.82	20.19	21.78	1.59***
4th (Richer)	166,530	109,295	57,235	19.58	21.28	16.99	−4.29***
5th (Richest)	152,948	117,744	35,204	17.98	22.92	10.45	−12.47***
Religion							
Hindu	647,011	377,278	269,733	76.08	73.45	80.08	6.63***
Muslim	104,501	63,063	41,438	12.29	12.28	12.30	0.03
Christian	57,730	42,821	14,909	6.79	8.34	4.43	−3.91***
Other	41,247	30,502	10,745	4.85	5.94	3.19	−2.75***
Caste							
None	208,900	139,692	69,208	24.56	27.20	20.55	−6.65***
Scheduled caste	157,702	86,855	70,847	18.54	16.91	21.03	4.12***
Scheduled tribe	151,672	94,925	56,747	17.83	18.48	16.85	−1.63***
Other backward class	332,215	192,192	140,023	39.06	37.42	41.57	4.16***
Residence							
Rural	627,316	360,826	266,490	73.76	70.25	79.12	8.87***
Urban	223,173	152,838	70,335	26.24	29.75	20.88	−8.87***
Body Mass Index							
Normal (18.5–24.9)	507,312	305,962	201,350	59.77	59.68	59.90	0.22*
Underweight (<18.5)	126,256	69,904	56,352	14.88	13.64	16.77	3.13***
Overweight (25.0–29.9)	163,514	103,944	59,570	19.26	20.28	17.72	−2.55***
Obese (≥30.0)	51,697	32,852	18,845	6.09	6.41	5.61	−0.80***
Parity							
0	55,456	48,060	7396	6.52	9.36	2.20	−7.16***
1–2	429,135	299,641	129,494	50.46	58.33	38.45	−19.89***
3–4	283,077	135,096	147,981	33.28	26.30	43.93	17.63***
5+	82,821	30,867	51,954	9.74	6.01	15.42	9.42***
Smoking	12,504	6200	6304	1.47	1.21	1.87	0.66***
Pregnant	42,611	32,674	9937	5.01	6.36	2.95	−3.41***
Lactating	174,487	123,281	51,206	20.52	24.00	15.20	−8.80***

Note: Shares add to 100 across rows for respective characteristics. The shares between women married as adults and as children were statistically different for all characteristics. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

glucose outcome. As a proxy for household environment, we accounted for respondent's relationship to household head, household head's sex, household size, adult (age 18+ years) male to female ratio, and husband's presence in the household. These variables, along with other individual- and household-level covariates in the original model ensured that the exclusion restriction was met and thereby our proposed instrument was valid.

Since we pooled two survey waves together, we could not apply the complex survey weights that were wave specific. As such, robust standard errors were obtained by clustering at the state level. The level of significance was set at 0.05. Statistical analyses were conducted using Stata 17.0 software (StataCorp, College Station, TX, USA).

3. Results

3.1. Descriptive results

Around 40 % of the women in our sample (336,825 of 850,489) were married before the age of 18 years. A higher prevalence of women in the older cohorts were married as children compared to women in the younger cohorts. In 2015–2016, the prevalence of high blood glucose was 5.8 %. The prevalence of high blood glucose specifically among women married as children was 6.2 %, which was 0.6 %-points (11.3 %) higher than that of women married as adults.

The prevalence of high blood glucose increased in 2019-21 to 8.6 %. Within this period, the prevalence of high blood glucose among women married as children increased to 9.5 %, which was 1.3 %-points (15.9 %) higher than that of women married as adults. In both survey waves, a greater proportion of women married as children had blood glucose higher than normal but lower than diabetic (i.e., 141–199 mg/dl), as

Table 2
Unadjusted and adjusted odds ratios from binomial logistic regression.

	Survey wave 2015-16	Survey wave 2019-21	Both waves without interaction	Both waves with interaction
A. Unadjusted				
Child marriage	1.219*** (1.172, 1.266)	1.216*** (1.162, 1.272)	1.219*** (1.175, 1.265)	1.194*** (1.135, 1.257)
$Year_{2019}$			1.460*** (1.314, 1.622)	1.438*** (1.286, 1.608)
Child marriage × $Year_{2019}$				1.036 (0.966, 1.111)
Observations	432,080	418,409	850,489	850,489
B. Adjusted				
Child marriage	1.130*** (1.093, 1.167)	1.133*** (1.096, 1.171)	1.132*** (1.104, 1.161)	1.116*** (1.074, 1.160)
$Year_{2019}$			1.456*** (1.317, 1.610)	1.441*** (1.291, 1.608)
Child marriage × $Year_{2019}$				1.025 (0.958, 1.097)
Observations	431,304	417,475	848,779	848,779

Note: All models accounted for timing of blood glucose test and state of residence fixed effects. Robust standard errors were obtained by clustering at the state level. ***p < 0.001, **p < 0.01, *p < 0.05. 95 % confidence intervals are in parenthesis. Multivariable specifications accounted for birth cohort fixed effects, education, household wealth index quintiles, religion, caste, urban/rural residence, BMI category, tobacco smoking, parity (i.e., number of children born), current pregnancy status, and lactating mother status.

well as within the diabetic (i.e., ≥200 mg/dl) range compared to women married as adults.

Fig. 1 presents the prevalence of high blood glucose by birth cohorts and child marriage. Prevalence was lowest for the youngest birth cohort and gradually increased with age. Within each birth cohort, in general, women who were married as children had a higher prevalence of high blood glucose compared to women who were married as adults. The differences between the two groups were more evident in 2019-21 than in 2015-16.

Table 1 presents the descriptive statistics of the study population by child marriage. While a greater proportion (45.0 %) of women married as children had no education, nearly two-third (63.9 %) of women married as adults had secondary or higher level of education. Half (50.8 %) of women married as children were from poor households (bottom two quintiles of household wealth index), whereas 44.2 % of women married as adults were from wealthier households (top two quintiles of household wealth index). Around 70.3 % of women married as adults live in rural areas, in comparison to 79.1 % for women married as children. The association between high blood glucose levels and these covariates were very similar across women married as children and as adults (Supplementary Material Fig. S2).

Results of the binomial logistic regressions for the full sample are presented in Table 2. In 2015-16, the adjusted odds of having high blood glucose for women married as children were 1.1 times that of their counterparts married as adults. Similar trends were seen in 2019-21. In addition, while women, both married as children and as adults, were more likely (AOR: 1.5) to have high blood glucose in the 2019-21 wave, the interaction term (between child marriage and survey year) was not found to be statistically significant.

Results of the binomial logistic regressions by birth cohorts are presented in Table 3. Except for the youngest birth cohort, women married as children within all birth cohorts had higher adjusted odds of having high blood glucose (AOR ranging from 1.1 to 1.2). While the odds were higher for the 2019-21 wave (AOR ranging from 1.3 to 1.8), the coefficients of the interaction terms were not statistically significant.

Table 4 presents the relative risk ratios of blood glucose levels at the "higher than normal but lower than diabetic" and "diabetic" ranges, relative to the base outcome of within normal range. Women married as children had higher relative risks of having blood glucose at the higher than normal but lower than diabetic (ARRR: 1.1) and diabetic (ARRR: 1.2) ranges. The relative risks of higher than normal but lower than diabetic and diabetic range outcomes were higher for women in 2019-21. Similar to the binary outcome (in Table 2), the estimates of the interaction terms were not statistically significant.

Similar results were seen in multinomial specifications across birth cohorts. The higher relative risk of having blood glucose at "higher than normal but lower than diabetic" range for women married as children were evident in the three older birth cohorts (i.e., 1969–1974, 1975–1979, and 1980–1984). The relative risk of having blood glucose in the diabetic range was higher for women married as children in all birth cohorts except for the youngest birth cohort (i.e., 1990–1996). Like the binomial results, the relative risks were higher for the 2019-21 wave, and the interaction terms were not statistically significant.

Results of the instrumental variable regressions, presented in Table 5, suggest a possible causal relationship between child marriage and elevated blood glucose level later in life. Data on mother-in-law's years in education that we used as an instrument for child marriage were available for 31.4 % of the sample. In this sub-population, we found that being married in childhood increased the likelihood of having high blood glucose by 6.6 %.

Table 3
Unadjusted and adjusted odds ratios from binomial logistic regression by birth cohort.

	Birth cohort: 1969–1974	Birth cohort: 1975–1979	Birth cohort: 1980–1984	Birth cohort: 1985–1989	Birth cohort: 1990–1996
A. Unadjusted					
Child marriage	1.089** (1.034, 1.148)	1.111*** (1.056, 1.168)	1.172*** (1.088, 1.263)	1.152** (1.042, 1.275)	1.001 (0.934, 1.073)
$Year_{2019}$	1.331*** (1.185, 1.495)	1.502*** (1.309, 1.722)	1.598*** (1.409, 1.812)	1.762*** (1.547, 2.006)	1.624*** (1.431, 1.843)
Child marriage × $Year_{2019}$	1.057 (0.992, 1.126)	1.048 (0.957, 1.149)	0.957 (0.858, 1.066)	0.995 (0.869, 1.139)	1.123* (1.020, 1.237)
Observations	132,414	146,682	172,334	187,095	211,964
B. Adjusted					
Child marriage	1.110*** (1.055, 1.169)	1.114*** (1.065, 1.164)	1.178*** (1.092, 1.270)	1.127* (1.006, 1.263)	1.029 (0.956, 1.108)
Year	1.356*** (1.215, 1.513)	1.439*** (1.264, 1.638)	1.517*** (1.342, 1.716)	1.609*** (1.417, 1.828)	1.563*** (1.379, 1.772)
Child marriage × $Year_{2019}$	1.045 (0.982, 1.113)	1.052 (0.963, 1.150)	0.959 (0.861, 1.068)	1.010 (0.881, 1.158)	1.072 (0.970, 1.185)
Observations	132,071	146,392	171,996	186,744	211,576

Note: Regressions were separately estimated for each birth cohort. All models accounted for timing of blood glucose test and state of residence fixed effects. Robust standard errors were obtained by clustering at the state level. ***p < 0.001, **p < 0.01, *p < 0.05. 95 % confidence intervals are in parenthesis. Multivariable specifications accounted for birth year fixed effects, education, household wealth index quintiles, religion, caste, urban/rural residence, BMI category, tobacco smoking, parity (i.e., number of children born), current pregnancy status, and lactating mother status.

Table 4
Unadjusted and adjusted relative risk ratios from multinomial logistic regression by birth cohort.

		Unadjusted		Adjusted	
	Base outcome: Normal range	Outcome I: > Normal but < diabetic range	Outcome II: Diabetic range	Outcome I: > Normal but < diabetic range	Outcome II: Diabetic range
	≤140 mg/dl	141–199 mg/dl	≥200 mg/dl	141–199 mg/dl	≥200 mg/dl
A. All					
Child marriage		1.164***	1.346***	1.090***	1.227***
		(1.100, 1.232)	(1.246, 1.454)	(1.042, 1.141)	(1.150, 1.310)
$Year_{2019}$		1.416***	1.545***	1.415***	1.573***
		(1.259, 1.592)	(1.361, 1.755)	(1.259, 1.591)	(1.395, 1.773)
Child marriage × $Year_{2019}$		1.036	1.032	1.026	1.015
		(0.961, 1.117)	(0.949, 1.123)	(0.955, 1.103)	(0.928, 1.110)
B. Birth cohort: 1969–1974					
Child marriage		1.061*	1.178**	1.075*	1.224***
		(1.008, 1.117)	(1.056, 1.314)	(1.015, 1.139)	(1.112, 1.348)
$Year_{2019}$		1.332***	1.327***	1.347***	1.384***
		(1.177, 1.507)	(1.163, 1.514)	(1.195, 1.517)	(1.232, 1.554)
Child marriage × $Year_{2019}$		1.083*	0.985	1.072*	0.971
		(1.011, 1.159)	(0.875, 1.109)	(1.002, 1.148)	(0.863, 1.092)
C. Birth cohort: 1975–1979					
Child marriage		1.101***	1.149	1.102***	1.156
		(1.048, 1.157)	(0.977, 1.351)	(1.050, 1.157)	(0.994, 1.345)
$Year_{2019}$		1.440***	1.761***	1.388***	1.645***
		(1.260, 1.646)	(1.434, 2.162)	(1.217, 1.583)	(1.371, 1.975)
Child marriage × $Year_{2019}$		1.037	1.086	1.040	1.101
		(0.948, 1.135)	(0.889, 1.327)	(0.953, 1.136)	(0.900, 1.347)
D. Birth cohort: 1980–1984					
Child marriage		1.155***	1.269**	1.149**	1.339***
		(1.062, 1.257)	(1.096, 1.470)	(1.054, 1.252)	(1.176, 1.524)
$Year_{2019}$		1.528***	2.036***	1.460***	1.871***
		(1.342, 1.739)	(1.675, 2.474)	(1.281, 1.664)	(1.571, 2.230)
Child marriage × $Year_{2019}$		0.939	1.033	0.942	1.044
		(0.828, 1.065)	(0.895, 1.191)	(0.830, 1.068)	(0.918, 1.187)
E. Birth cohort: 1985–1989					
Child marriage		1.131*	1.351**	1.099	1.384**
		(1.017, 1.257)	(1.087, 1.678)	(0.977, 1.237)	(1.090, 1.756)
$Year_{2019}$		1.671***	2.634***	1.545***	2.203***
		(1.459, 1.915)	(2.253, 3.079)	(1.344, 1.776)	(1.936, 2.506)
Child marriage × $Year_{2019}$		1.012	0.870	1.025	0.891
		(0.879, 1.165)	(0.679, 1.115)	(0.889, 1.183)	(0.694, 1.142)
F. Birth cohort: 1990–1996					
Child marriage		0.992	1.115	1.014	1.197
		(0.924, 1.066)	(0.798, 1.557)	(0.940, 1.094)	(0.850, 1.683)
$Year_{2019}$		1.604***	1.862***	1.553***	1.650**
		(1.414, 1.821)	(1.318, 2.630)	(1.369, 1.763)	(1.213, 2.243)
Child marriage × $Year_{2019}$		1.120*	1.146	1.076	1.034
		(1.027, 1.222)	(0.731, 1.796)	(0.981, 1.180)	(0.671, 1.593)

Note: Regressions were separately estimated for each birth cohort. All models accounted for timing of blood glucose test and state of residence fixed effects. Robust standard errors were obtained by clustering at the state level. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. 95 % confidence intervals are in parenthesis. Other covariates in the multivariable specifications include birth year fixed effects, education, household wealth index quintiles, religion, caste, urban/rural residence, BMI category, tobacco smoking, parity (i.e., number of children born), current pregnancy status, and lactating mother status.

4. Discussion

The objective of this study was to examine whether child marriage (i.e., marriage before age 18 years) was associated with the risk of having high blood glucose in women from same birth cohorts. We find that the risk of having high blood glucose was higher among women who were married as children compared to women who were married as adults in respective birth cohorts. Since women from different birth cohorts had differential odds of getting married in childhood as well as differential likelihood of having hyperglycemia due to aging, investigating the association within birth cohorts provided us with more compelling results compared to those in previous studies. Further, we employed an instrumental variable approach to provide evidence on the possible causal relationship between child marriage and hyperglycemia. Our results of the instrumental variable analyses implied a higher risk of hyperglycemia in women during later in life, attributable to getting married in childhood.

Our study adds to the burgeoning literature examining the long-term health consequences of child marriage beyond the widely studied reproductive health outcomes. Findings from the current study, however, are subject to some limitations. First, the blood glucose level measures were random, and not fasting levels. As such, hyperglycemia was not clinically diagnosed in our sample. However, the random blood glucose measure can be rendered as a proxy for the risk of high blood glucose at the population level. Second, the timing of the test was not uniform for all respondents, which might influence the blood glucose measures. However, to mitigate any bias emanating from the differential timing of the test, we controlled the time when a respondent last ate and last drank before taking the test. Third, the practice of child marriage in India encompasses many factors such as poverty, gender inequality, patriarchal cultural values, as well as local traditions and societal norms. The intersectionality of these psychosocial contributors and consequences of child marriage may influence differential risks of high blood glucose among women in India. As such, our results could be specific to Indian population, and may not be generalizable to other societal and cultural settings. Future qualitative research will improve our understanding of these aspects. Fourth, marital age in the survey was self-reported, which might be subject to some recall bias. However,

Table 5
Results from instrumental variable (2SLS-LPM) regression.

	Survey wave 2015-16	Survey wave 2019-21	Both waves without interaction	Both waves with interaction
A. OLS				
Child marriage	0.003* (0.000, 0.007)	0.006** (0.002, 0.010)	0.005** (0.002, 0.008)	0.002 (-0.001, 0.006)
$Year_{2019}$			0.017*** (0.010, 0.025)	0.015*** (0.008, 0.023)
Child marriage × $Year_{2019}$				0.006 (-0.000, 0.012)
Observations	143,606	123,516	267,122	267,122
B. IV				
Child marriage	0.081* (0.011, 0.150)	0.048 (-0.032, 0.129)	0.065* (0.001, 0.130)	0.066* (0.004, 0.129)
$Year_{2019}$			0.022*** (0.013, 0.031)	0.022*** (0.010, 0.034)
Child marriage × $Year_{2019}$				−0.001 (-0.027, 0.024)
Observations	143,606	123,516	267,122	267,122

Note: Child marriage was instrumented by mother-in-law's years of education. Respondent's relationship to household head, household head's sex, household size, adult (age 18+) male to female ratio, and husband's presence in the household were controlled as proxies for household environment. Robust standard errors were obtained by clustering at the state level. ***p < 0.001, **p < 0.01, *p < 0.05. 95 % confidence intervals are in parenthesis. All models accounted for timing of blood glucose test, state of residence fixed effects, birth cohort fixed effects, education, household wealth index quintiles, religion, caste, urban/rural residence, BMI category, tobacco smoking, parity (i.e., number of children born), current pregnancy status, and lactating mother status.

instead of continuous marital age, using a binary indicator (based on the cut-off value of age 18 years) helped mitigating the potential influence of such recall biases. Fifth, due to the cross-sectional nature of the data, we were unable to explore any causal pathways of the relationship between child marriage and the risk of hyperglycemia. However, our birth cohort analysis, previously unexplored in the literature, allowed assessing the risk within different cohorts. Additionally, our instrumental variable analysis indicated a possible causal relationship between child marriage and elevated blood glucose level later in life.

In different birth cohorts, the elevated risk of high blood glucose among women married as children was evident after accounting for various demographic and anthropometric risk factors notably associated with diabetes prevalence and/or child marriage, including state of residence and urban/rural locality, educational attainment, household wealth, and caste [33,34]. The results though should be cautiously interpreted, keeping in mind the interplay between the causes and consequences of child marriage. Interestingly, however, we found no differences in the risk of high blood glucose among women married as children and as adults in the youngest birth cohort. This cohort primarily included women aged 20–26 years in 2015-16 and women aged 22–30 years in 2019-21. The insignificant difference in odds in the youngest cohort may be due to the generally lower risk of type-2 diabetes among women in this age group, with evidence suggesting significantly lower risk of diabetes among women in their 20s, compared to those in their 30s and 40s [35].

Obesity is one of the major risk factors for elevated blood glucose levels. In our study population, we observed that women who had BMI at the obese level had a significantly higher odds of having high blood glucose. This was evident among women in both marital-age groups, i.e., married as adults and as children. The role of obesity on the risk of high blood glucose, therefore, deemed similar in both groups, and the relationship between child marriage and hyperglycemia persisted after accounting for obesity in the analyses.

Another interesting finding was that the estimates of the interaction term between child marriage and survey year indicators were not statistically significant either in the full-sample or in birth cohort subgroups. This suggests that the heightened risk of high blood glucose among women who were married as children, compared to their counterparts married as adults, did not change over time within the birth cohorts. In other words, differential risk may remain with the changes in population level risk of hyperglycemia in women.

Of note, the prevalence of child marriage in India has notably declined in recent years after the enactment of the "Prevention of Child Marriage Act" in 2006. However, considerable variations in the progress of preventing child marriage were observed across states [36]. The burden of diabetes in India, on the other hand, has been gradually increasing with varying rates being observed across states [37]. Our models included state fixed effects to account for state-level variations in trends of child marriage and elevated blood glucose levels.

There are potential mechanisms which may explain these results. Several studies have established the association between interpersonal violence (IPV) and diabetes [38,39], and child marriage was found associated with higher risk of experiencing IPV [11,40]. As such, IPV exposure may influence the risk of high blood glucose in women married as children. Another potential channel could be lack of dietary diversity, which is linked to the risk of type 2 diabetes [41]. Lack of knowledge and awareness about nutrition is one of the key barriers of dietary diversity among women in India [42]. This can further be linked to lower educational attainment associated with child marriage [5], influencing perceptions of the importance of dietary diversity [43]. Poor economic conditions, along with lack of agency and bargaining power associated with child marriage [44], could impact women's access to balanced diet [43], and thereby may influence the risk of high blood glucose.

The eco-biological framework of childhood adversity and long-term health risk, proposed by Shonkoff et al. (2009) [45], can be a potential pathophysiological mechanism behind the relationship between child marriage and risk of high blood glucose. This framework suggests that two processes can occur: i), cumulative exposures to stressful experiences, namely toxic stress, lead to poor health; or ii) repeated environmental insults during sensitive developmental periods lead to biologic injury. The prolonged activation of the body's stress response system, known as "allostatic load", may cause certain physiological changes [45,46], which could contribute to the risk of developing high blood glucose [47]. Future research using appropriate data is needed to explore and validate these potential pathways.

This paper, using nationally representative data from India, demonstrates an association between child marriage and later life risk of hyperglycemia in women. Given the chronic nature of diabetes, prompt diagnosis and treatment are essential to preventing long-term health adversity. Unfortunately, India and other LMICs have an alarmingly high proportion of adults with undiagnosed diabetes, estimated at 50 % or 210 million people worldwide, with 39 million in India alone [48]. The WHO Global Diabetes Compact has recommended 5 strategic global diabetes coverage targets for 2030, which include 80 % of people with diabetes being diagnosed [49]. Based on the current study, women married as children should become a prioritized subgroup for strategic public health initiatives for screening and diagnosis of diabetes. Targets for this vulnerable population should also include diabetes prevention, timely access to diabetes care, and modification of other risk factors which might contribute to developing diabetes in later life. At the same time, elimination of child marriage is critical for the primary prevention of such chronic health outcomes in the future.

The findings of this study thus encompass at least two targets of the United Nations Sustainable Development Goals (SDGs) – eliminating child marriage (Target 5.3) and reducing pre-mature mortality from non-communicable diseases (Target 5.4) [50]. This creates opportunities to potentially embed dual objectives in policy actions to simultaneously achieving progress on multiple SDG targets. All together, policymakers, researchers, and social advocates should consider concerted socioeconomic and public health efforts to end the harmful practice of child marriage and to improve the health and wellbeing of women who were married in childhood.

Ethics approval

Our study did not require an ethical board approval because we used publicly available anonymized secondary data for analyses. The dataset used in this study meet the definition of National Institutes of Health (NIH) Exempt Human Subjects Research under the following exemption criteria: "Exemption 4: involves the collection/study of data or specimens if publicly available, or recorded such that subjects cannot be identified". The original survey protocol was approved by the institutional review boards of International Institute for Population Sciences (IIPS) and ICF. The survey complied with the U.S. Department of Health and Human Services regulations for the protection of human subjects (45 CFR 46).

Declaration of interests

None.

Competing interests

None.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhip.2024.100556.

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