**Association between cesarean delivery and early childhood diseases in Bangladesh**

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**Abstract**

Introduction: The rate of cesarean delivery (C-section) has increased worldwide, including Bangladesh. Because the C-section is major surgery, it has a negative impact on the mother and child's health. However, research on this area in ​​Bangladesh is scarce. Our aim was to examine the association between C-section (vs normal delivery) and childhood diseases in Bangladesh.

Methods: We used the latest available nationally representative data from a multiple indicator cluster survey (MICS, 2012 and 2019) and Bangladesh Demographic and Health Survey (BDHS, 2014). In total, 7921, 9183, and 4557 children were eligible for final analysis for MICS 2012, MICS 2019, and BDHS, respectively. We created the outcome variable using childhood diseases such as fever, short, rapid breaths, cough, blood in stools, and diarrhea. We considered several important confounding factors such as the age and sex of the child, child ever been breastfed, size of child at birth and weight at birth during the survey, geographical location, mother's age, and education, body mass index, the religion of household head, and wealth index quintile. We estimated crude and adjusted risk ratio (RR) using different count data analysis models (e.g., negative binomial).

Results: We found 19.1%, 36.0% and 23.3% of children were born in the C-section in MICS 2012, MICS 2019 and BDHS surveys, respectively. The crude RR for the C-section was 1.05 (95% confidence interval (CI): 1.02-1.08), 1.16 (CI: 1.14-1.18) and 1.08 (CI: 0.97-1.19) for MICS 2012, MICS 2019 and BDHS, respectively. The adjusted RR was 1.01 (95% CI: 0.97-1.04), 1.14 (CI: 1.11-1.17) for MICS 2012 and MICS 2019, respectively. For BDHS, the adjusted RR was 1.15 (CI:1.05-1.27). In the adjusted PS model, the RR was slightly increased in MICS 2012, 1.02 (CI: 0.90-1.14) and BDHS 1.17 (CI: 1.05-1.29), decreased in MICS 2019, 1.01 (CI: 0.98-1.03).

Conclusion: In both surveys, we observed an elevated risk of developing childhood diseases. The results from the BDHS data showed a significant association between C-section (vs normal delivery) and childhood diseases in Bangladesh. We recommend raising public awareness of the negative impact of unnecessary delivery of cesarean delivery in Bangladesh.

**Keywords:** Caesarean section; normal delivery; childhood disease; survey, MICS, BDHS

**1. Introduction**

Cesarean delivery (C-section) is a surgical procedure that is often performed or recommended when the life of the mother or child is at risk(Zakerihamidi et al., 2015). Recently, it has become a preferred choice as a mode of delivery among women because they believed that it is painless, comfortable, safer, and healthier than normal delivery (Lori & Boyle, 2011). This choice may increase unnecessary C-section and harm the mother and child health (Haider et al., 2018).

The C-section is rapidly increasing in many developed and developing countries (Farmer et al., 2003; Gomes et al., 1999). During the last decades, unnecessary C-section has increased rapidly (Magne et al., 2017). It is increasing significantly as evident more than half of the women voluntarily undergo C-section (Danforth & Gibbs, 2008). This choice is influenced by several factors, including ways to prevent labor pain, it is safer, healthier than normal delivery (Tatar et al., 2000), fear of normal delivery (Latifnejad-Roudsari et al., 2014), incorrect cultural assumptions (Aziken et al., 2007), and closure of the uterine tubes (Kasai et al., 2010). In contrast, most women prefer natural birth due to personal beliefs, cultural customs, and values (Latifnejad-Roudsari et al., 2014), faster recovery after delivery (Kasai et al., 2010), financial shortage (Zakerihamidi et al., 2014).

A trend analysis based on data from 121 countries reported that, from 1990 to 2014, the average C-section rates increased by 12.4% and it annually increased by 4.4% (Betrán et al., 2016). Moreover, a 2004-2008 world health organization (WHO) survey recorded an average global rate of C-section was 25.7% in which 27.3% in Asia, 29.2% in Latin America, and 19.0% in Europe (Lumbiganon et al., 2010; Villar et al., 2006). As stated by WHO, there is no justification for any region to have a cesarean rate higher than 10 -15%, which weighs a serious reason for worry in most of the countries worldwide (Rahman et al., 2015). In Bangladesh, the C-section rate increased from 3.5% in 2004 to 23% in 2014 (Khan et al., 2017).

There are several risks associated with the C-section for mother and those risk of health conditions including cardiac arrest, hysterectomy, puerperal infection, thromboembolism, wound hematoma, anesthetics complications. (Yuan et al., 2016). In addition, babies born in C-section are at risk of developing asthma, type 1 diabetes, allergic diseases (Ajslev et al., 2011; Darmasseelane et al., 2014), Crohn's disease (Yuan et al., 2016), immune deficiencies, and leukemia. A study was conducted to examine the distribution of C-section and its correlates in the northern part of Bangladesh (Rahman et al., 2015). Rahman and colleagues showed that previous C-section, prolonged labor, higher maternal education level, mother age of 25 years or more, the lower order of birth, baby length greater than 45 cm, and unbalanced diet were some factors that were significantly associated with C-section. Another study found that higher the age of mother, lower birth order, higher education of parents, higher socioeconomic status, poor maternal history, and three or more antenatal cares was significantly associated with C-section delivery (Begum et al., 2017).

In Bangladesh, young children are generally suffering from several common diseases such as fever, the difficulty of breathing, blood in stools and diarrhea (Ferdous et al., 2018). However, to the best of our knowledge, there is no published record that any research has been conducted to determine the association between C-section and such early childhood diseases in Bangladesh. Therefore, it is important to study the consequence of C-section delivery on child health particularly on early childhood diseases applying an appropriate statistical method. To fill this gap in knowledge, we aimed to investigate the association between C-section delivery and childhood diseases. We also explore key factors associated with childhood diseases.

**2. Methods**

***Data source and study design***

We used the latest available dataset from the Bangladesh Demographic and Health Survey (BDHS, 2014) for our study. To compare and strengthen the association between C-section delivery and childhood diseases, we also used another parallel survey data, the multiple indicator cluster survey (MICS, 2012) and (MICS, 2019) in Bangladesh (MICS, 2015). The BDHS is a large household survey produced by the Demographic and Health Surveys Program and the MICS is also a large, multi-dimensional household survey conducted by UNICEF. Both surveys highlighted on identical measures of fertility and child health, mortality, and indicators of access to maternal and child health interventions, illness, treatment, and nutritional status. Both surveys represent the seven administrative divisions (Dhaka, Chittagong, Sylhet, Rajshahi, Rangpur, Barisal, and Khulna) of Bangladesh. These administrative divisions are taken as the main sampling strata for the sample (MICS, 2015; Yun et al., 2013). Both data-sets are fully open-access (Corsi et al., 2017).

In BDHS 2014, information on 7886 mother-child pairs was collected. Out of the mother-child pairs, 1236 children were excluded because they were not living with their mother. Moreover, as the BDHS data did not contain C-section information of greater than 3 years, 2093 children were omitted from the analysis. Hence, 4557 children were selected as a final sample for analysis (Figure 1).

Similarly, in MICS 2012, information on 59599 women was collected. Out of this number, 36197 women have not had a child and 15481 babies greater than 24 months were excluded from the analysis. Therefore, the sample included 7921 mother-child pairs for analysis (Figure 2).

In MICS 2019, information on 24453 mother-child pairs was collected. Out of the mother-child pairs, 13819 children were excluded because they were not living with their mother and some child were death after birth. Moreover, as the MICS 2019 data did not contain C-section information of greater than 3 years, 1451 children were omitted from the analysis. Hence, 9183 children were selected as a final sample for analysis (Figure 3).

**Outcome variable**

For creating the outcome variables, childhood disease, we used several variables such as develops a fever, short, rapid breaths, cough, blood in stools and diarrhea in the two weeks before or during the survey. Two types of outcome variables were considered. First, a count variable that means the frequency of the diseases of the children (figure 5); second, a binary outcome in which 0 means children were suffered from <3 diseases (as 3 was the median of the count of diseases) and 1 means greater than ≥3 diseases in MICS 2012 data, 0 means children were suffered from <2 diseases (as 2 was the median of the count of diseases) and 1 means greater than ≥2 diseases in MICS 2019 data and 0 means children were suffered from 0 (no) diseases (as 0 was the median of the count of diseases) and 1 means greater than >0 diseases in BDHS data, respectively.

**Exposure variable**

The exposure variable was the type of delivery (C-section versus normal delivery), which is a binary variable.

**Potential confounding variables**

We considered important confounding variables and/or covariates including, religion, breastfeeding status, child’s sex, age of mother and child, size of child at birth, weight of child at birth, mother’s education, mother’s education, body mass index, wealth index quintile, place of residence and geographical location (division).

**Statistical analyses**

**Descriptive statistics:** Descriptive statistics of each of the selected confounding variables and distribution of type of delivery were shown by adjusting the sampling weight of the survey. Similarly, weighted percentages were calculated to compare demographic and socioeconomic characteristics among the type of delivery. Pearson's chi-squared test was used to determine whether differences in demographic and socioeconomic characteristics between C-section and normal delivery were statistically significant.

**Poisson regression models:**As our main outcome is a count variable, frequency of diseases,Poisson regression models were applied. However, this model often displays overdispersion, for that reason, negative binomial (NB) regression models are perhaps the most convenient too with and have been used by various authors (Lawless, 1987). Hence, we also applied the NB regression method with a log link. In the analyses, we reported crude (only exposure and outcome in the model) and adjusted (exposure and other confounding variables in the model) exposure effects.

**Model assessment:** We used the AIC and BIC values to compare the models (Poisson regression versus NB regression); the lowest value of AIC and BIC indicates a better fit of the data after accounting for model complexity (i.e. the number of model parameters). Using the best model, we reviewed the variability of the results from the models.

**Propensity score models:** As a sensitivity, we also applied a propensity score (PS) method for the second outcome (binary) variable. The propensity score method is the probability of exposure (C-section versus normal delivery) assignment conditional on possible confounding variables. This approach helps us to design and analyze our observational survey data so that it mimics some of the characteristics (covariates) of a randomized controlled trial (Austin, 2011). The detailed practical explanations of the PS method can be found elsewhere (Ali et al., 2016; Austin, 2011).

All statistical analyses were performed by SAS and SPSS (IBM SPSS 25). In SAS, the survey analysis procedures command (e.g. PROC SURVEYFREQ, SURVEYLOGISTIC) were used to allow for the adjustments of the complex sampling design.

***Ethics approval***

Our study was wholly based on an analysis of existing public domain health survey datasets obtained from the BDHS 2014 and MICS 2012, 2019 which is freely available online with all personal identifying information removed. The BDHS 2014 data were reviewed and approved by the ICF Macro Institutional Review Board and the National Research Ethics Committee of the Bangladesh Medical Research Council. The MICS procedures were reviewed and approved by the Bangladesh Bureau of Statistics (BBS) and UNICEF. Informed consent was obtained from participants while interviewing them. Because this study involved the analysis with secondary data thus, it did not require the ethical approval of the respective institution.

**3. Results**

Our analyses showed that the proportions of cesarean deliveries were 19.1%, 36.0% and 23.3% for MICS (2012), MICS (2019) and BDHS (2014) data, respectively (Figure 4). Moreover, for both MICS surveys, most of the children suffering from 2-3 diseases (about 72% for 2012 and 82% for 2019) in the two weeks before or during the survey and which is more noticeable in the C-section group. However, in BDHS, this percentage was only 29% and almost equal between two delivery groups (Table 1). These findings indicate that there was a different trend for disease counts in MICS and BDHS surveys (Figure 5).

Table 1 outlines the maternal and child characteristics between C-section and normal delivery for three databases. The mean age of mothers was about 25 years and for all age groups, the distribution of the mothers between C-section and normal delivery was approximately similar. Mothers living in urban areas or belong to the richest family being delivered by C-section were significantly higher in all databases. Moreover, education of mother was significantly related to the C-section and the percentage was higher for the mothers with secondary or higher education. For example, for MICS 2019, about 84% (vs 60% normal delivery) mother gave birth in C-section. Although large size of the child at birth is one of the reasons for C-section, the highest percentage was observed for the average size of the child at birth in all databases (59.4% for MICS 2012, 66.8% for MICS 2019 and BDHS).

Table 2 demonstrates the goodness of fit of two models, Poisson and NB regression. The NB model has the smallest AIC and BIC in all data sets and therefore it was chosen as a final model.

Table 3 shows the results from crude and adjusted estimates obtained from the NB regression model. The analyses showed that the risk ratio (RR) for the C-section (vs normal delivery) was 1.05 (95% confidence interval (CI): 1.02-1.08) for MICS 2012, 1.16 (CI: 1.14-1.18) for MICS 2019 and 1.08 (CI: 0.97-1.19) for BDHS, respectively, which indicates that children were born in C-section compared with the normal delivery were at increased risk for developing childhood disease. The association was statistically significant for both MICS data (p-value=0.001) but for BDHS, this was not significant (p-value=0.159) in the crude model. Moreover, after adjusting for possible confounding factors in the adjusted NB model, the RR was 1.01 (95% CI: 0.97-1.04) for MICS 2012, 1.14 (CI: 1.11-1.17) for MICS 2019 and 1.15 (CI: 1.05-1.27) for BDHS, respectively. Here, the association between C-section and childhood disease was statistically significant only for MICS 2019 (P<0.001) and BDHS data (P=0.004) (Table 3).

Similarly, for the binary outcome, the crude estimates from the PS method were 1.12 (95% CI: 0.94-1.31), 1.02 (CI:0.87-1.20) and 1.11 (95% CI: 1.01-1.23) for MICS 2012, 2019 and BDHS, respectively. The RR from adjusted (type of delivery and propensity scores) model was 1.02 (CI: 0.90-1.14) for MICS 2012, 1.01 (CI: 98-1.03) for MICS 2019 and 1.17 (1.05-1.29) for BDHS, respectively. Like NB binomial model, the association between C-section and childhood disease was statistically significant only for BDHS data in both models (Table 4).

**Risk factors for childhood diseases**

Apart from the type of delivery, we observed that age of mother, geographical location, BMI and were significantly associated to childhood diseases in MICS 2012 and 2019 data. Moreover, BMI, sex of child and child age were the contributing factors to childhood diseases according to BDHS data (Table S1 and S2).

Table S3 shows the association between early childhood diseases and other confounding factors. Children from young mothers, aged between 15-19 years, were more affected by diseases, 1.04 (CI: 0.97-1.12) for MICS 2012 and 1.05 [0.95-1.15] for BDHS, than those of other categories of ages. However, this association was not statistically significant. Moreover, children who were born to underweight and overweight mothers were more likely to have the disease, 1.11 (CI: 1.04-1.19) and 1.12 (95 % CI: 1.03-1.21) in MICS and 1.13 (CI: 1.01-1.26) and 1.17 (CI: 1.03-1.32) in BDHS. We found age of the children was one of the important factors for childhood diseases in BDHS but not in MICS, and the results showed that children with age between 0-11 months and 12-23 months were more at risk of suffering from diseases than 24–35 months, 1.15 (CI: 1.04-1.27) and 1.14 (CI: 1.04-1.26).

**4. Discussion**

Using multiple nationally representative databases, in this study, we examined the association between C-section (versus normal delivery) and early childhood diseases in Bangladesh. We found the percentage of cesarean deliveries were 19.1%, 36.0% and 23.3% for MICS (2012), MICS (2019) and BDHS (2014) data, respectively. As compared to the previous surveys, the rate of cesarean delivery continued to increase gradually. Although the trend of cesarean delivery is increasing in all databases, there is a big discrepancy between databases. Moreover, our analyses showed that the risk of having childhood diseases were significantly higher for the C-section child as compared to the normal delivery child. We observed that this finding is consistent across the databases. Apart from the C-section, we also found that mother’s body mass index was a significant risk factor for the childhood diseases in all databases. Furthermore, geographical location and weight at birth of the child were identified other important risk factors for diseases in both MICS databases. In addition, sex of the child and child age were significantly associated with the common childhood diseases only for BDHS database.

During normal delivery, the contact with the maternal vaginal and intestinal flora is an important source for the start of the infant's colonization. During cesarean delivery, this direct contact is absent, and non-maternally derived environmental bacteria play an important role for infants’ intestinal colonization (Biasucci et al., 2008). There is an increasing body of evidence that the intestinal microbiota plays an essential role in the postnatal development of the immune system, the mechanisms remain poorly understood. Hällström et al., (2004) found a link between cesarean delivery, disturbed intestinal colonization, and, possibly, occurrence of necrotizing enterocolitis (NEC) in preterm infants. In addition, during vaginal birth, babies swallow maternal vaginal bacteria, and those bacteria are early colonizers of the babies’ intestines. Cesarean-born babies miss this exposure (Houghteling & Walker, 2015). It is possible that the resulting early differences in resident gut bacteria result in differences in health, later on. Another theory focuses on the healthy, positive stress of labor and delivery, and the ways that stress “programs” a baby’s genes (Cha & W., 2013). According to this theory, the key programmers are levels of hormones such as oxytocin, cortisol and adrenalin. These give rise to so-called epigenetic changes that in turn determine the risk of disease later in life.

There is accumulating evidence that intestinal bacteria play an important role in the postnatal development of the immune system (Björkstén, 2004). Thus, if the intestinal flora develops differently depending on the mode of delivery, the postnatal development of the immune system might also be different. Available epidemiological data show that atopic diseases appear more often in infants after cesarean delivery than after vaginal delivery (Debley et al., 2005; Eggesbø et al., 2003; Laubereau et al., 2004; Negele et al., 2004). The epidemiological studies demonstrated that elective cesarean delivery provides an increased risk for allergic diseases in later childhood, confounding factors could also play intermediate roles. This increase was even more apparent when accounting for the factors surrounding the cesarean delivery. The risk of asthma was increased by 60% in females who underwent a repeat cesarean without ruptured membranes versus those babies with ruptured membranes and/or labor prior to cesarean delivery (Renz-Polster et al., 2005). Children born by cesarean delivery are also significantly more likely to suffer from celiac disease and to be hospitalized for gastroenteritis (Decker et al., 2010). Type I Diabetes Mellitus (DM) has been on the rise in recent decades, mirroring the rise in cesarean delivery (Onkamo et al., 1999). Meta-analysis found a 19% increase in Type I DM in cesarean children when controlling for confounders such as gestational age, maternal age, and birth weight (Cardwell et al., 2008). A recent retrospective study of children in Scotland failed to show such an association (Robertson & Harrild, 2010). Meta-analyses of cohort and case-control studies find a positive association with asthma (23 studies) (Thavagnanam et al., 2008), and obesity (9 studies) (Masukume et al., 2018). Blustein & Liu, (2015) did not find any meta-analyses that reported no association with these outcomes. The risk of serious respiratory morbidity was increased in babies delivered by elective caesarean section in each of the gestational weeks 37 to 39 compared with babies delivered during the same weeks after intended vaginal delivery. The relative risk increased with decreasing gestational age but the risk estimates were all higher than those for respiratory morbidity in general, with a fivefold increase for infants delivered at 37 weeks’ gestation, a fourfold increase for infants delivered at 38 weeks, and a more than twofold increase for infants delivered at 39 weeks, although the increased risk at 39 weeks was not statistically significant (Hansen et al., 2008).

Data available from several studies indicate a delayed onset of lactation with cesarean section (Dewey et al., 2003; Evans et al., 2003). Thus, many infants born by cesarean delivery also lacked the early support of breast milk as stimulator for a physiological intestinal flora. Both the nonphysiologically start of colonization and the missing early dietary support by delayed start of lactation might result in these long-lasting effects.

From our findings, we have seen that the rate of C-section delivery was higher particularly in the Dhaka division compared to other divisions in Bangladesh. A previous study demonstrated that women in Chittagong, Dhaka, Khulna, and Rajshahi division were more likely to avail of institutional delivery and C-section (Kamal, 2013).

For instance, the risk of disease was higher in Khulna in the MICS survey. It indicates that the availability of midwives and stuff in Barisal, Chittagong, and Sylhet divisions were low, and access to maternity care services is quite less. Dhaka, Khulna, and Rajshahi division have many more healthcare providers (Kamal, 2013). Lower number midwifery services might be the reason for the high occurrences of C-section as well as high occurrences of diseases on those divisions.

The findings of our study also confirmed that among the educated women, the highest rate of C-section has occurred among secondary completed or higher educated women. We also observed that lower risk of diseases occurred for C-section babies than children born by normal delivery in all other education levels of mother compared to this group. Since education is directly related to the autonomy of women, they are economically more solvent and mostly living in urban areas, may decide to give birth through a C-section. However, some studies reported no visible link between women's preference for C-section and their level of education (Angeja et al., 2006; Chu et al., 2010).

By wealth status, health care facilities were higher for the richest family than the middle and poorer family. Rates of C-section were also higher among the richest family compared to those belonging to the poorest or poorer families (Shahabuddin et al., 2016). This might be a reason for the high risk of diseases in the richest group in our study. However, economic anxiety is strongly associated with malnutrition of children, poor mental development and weakness of the immune system, so it can increase the vulnerability to infectious diseases. Children from financially well-off families may enjoy a healthier and safer lifestyle, with greater access to health-promoting conditions compared to poorer families in later life (Yaya & Bishwajit, 2019).

The analyses of this study confirmed that childhood disease is associated with maternal age according to MICS data. In earlier studies, children born to younger mothers (aged <20 years) were found to have a relatively high risk of diarrhea, cough, and fever in their young children (Kandala, 2006), probably because the relationship between maternal age is associated with some adverse pregnancy outcomes and a higher risk of medical conditions such as hypertension, diabetes or other causes. In the present study, there was no clear and consistent relationship between the ages of the mothers and the risk of short-term diseases in BDHS data.

**Conclusion**

In conclusion, this study demonstrated a positive association between C-section and childhood diseases in areas with different SES in Bangladesh and according to MICS and BDHS, this trend is growing rapidly. An increase in the rates of cesarean section delivery is a burden on the health system and childhood diseases. The results also showed that C-section is associated with an increased risk of childhood diseases than normal delivery child. The analysis of this study confirmed that childhood disease is associated with maternal age. The rate of C-section delivery was higher particularly in the Khulna division compared to other divisions of Bangladesh according to MICS data and is similar in the BDHS survey. Among the educated women, the highest rate of C-section has occurred among secondary completed or higher educated women. Rates of C-section were also higher among the richest family compared to those belonging to the poorest or poorer families. Improving maternal health requires regular monitoring and evaluation of the provision of emergency obstetric services to combat under-utilization of Caesarean section in poor and rural areas and excessive use in rich and urban areas. Unnecessary cesarean delivery can also be a stress on the family and can complicate maternal and child health. Thus, the decision to perform a C-section delivery must be carefully chosen and not aimed at profit.

**Recommendations**:

To reduce unnecessary C-sections and encourage normal birth, various strategies must be taken, such as the implementation of standardized protocols, requests of a second medical opinion prior to surgery, improving maternal empowerment during pregnancy and delivery, maternal and medical collaboration on birth plans. The use of partographs is important in emergency obstetric care, in addition, training of hospital staff, health officers, midwives, and health extension workers, as well as the decision to adopt a neonatal resuscitation skill and C-section, are critical. Prior to delivery, all available birthing procedures and its merit and demerit should be explained to the pregnant women during the antenatal care period. Further studies are needed to enrich our knowledge on the negative impact of C-section delivery and its association with the development of childhood disease, the incidence of the chronic immune system and metabolic disorders in developing countries including Bangladesh. However, we recommend increasing public awareness of the negative impact of unnecessary cesarean delivery in Bangladesh.

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**TABLES AND FIGURES**



**Figure 1: Flow Chart of BDHS data for the study population**



**Figure 2: Flow Chart of MICS 2012 data for the study population**

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**Figure 3: Flow Chart of MICS 2019 data for the study population**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | |  |  | |
| **Figure 4a: C-section delivery in MICS (2012)** | | **Figure 4b: C-section delivery in MICS (2019)** | **Figure 4c: C-section delivery in BDHS (2014)** | |
|  |  | | |  |
| **Figure 5a: Count (diseases) variable in MICS (2012)** | **Figure 5b: Count (diseases) variable in MICS (2019)** | | | **Figure 5c: Count (diseases) variable in BDHS (2014)** |

**Table 1: Distribution of maternal and child characteristics including diseases count with the type of delivery**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **MICS 2012** | | | **MICS 2019** | | | **BDHS 2014** | | |
|  | **Type of Delivery** | | | **Type of Delivery** | | | **Type of Delivery** | | |
| **Sources** | **Caesarean**  **(n=1513)**  **N (%)** | **Normal (n=6408)**  **N (%)** | **p-value** | **Caesarean**  **(n=3306)**  **N (%)** | **Normal**  **(n=5877)**  **N (%)** | **p-value** | **Caesarean**  **(n=1062)**  **N (%)** | **Normal**  **(n=3495)**  **N (%)** | **p-value** |
| **Disease Count** | | | | | | | | | |
| 0 (No) | 20 (1.5) | 80 (1.2) | <0.001 | 13 (0.4) | 39 (0.7) | <0.001 | 518 (48.8) | 1813 (51.9) | <0.001 |
| 1 | 135 (10.1) | 981 (15.1) |  | 333 (10.1) | 583 (10.1) |  | 245 (23.1) | 607 (17.4) |  |
| 2 | 505 (37.6) | 2434 (37.5) |  | 823 (25.0) | 3486 (60.2) |  | 162 (15.3) | 535 (15.3) |  |
| 3 | 497 (37.0) | 2241 (34.5) |  | 1884 (57.3) | 1259 (21.7) |  | 122 (11.5) | 493 (14.1) |  |
| 4 | 137 (10.2) | 559 (8.6) |  | 220 (6.7) | 378 (6.5) |  | 15 (1.4) | 47 (1.3) |  |
| 5 | 49 (3.6) | 195 (3.0) |  | 16 (0.5) | 44 (0.8) |  | - | - |  |
| **Mother’s age group in years at birth** | | | | | | | | | |
| Mean (SD) | 25.4 (5.2) | 25.9 (6.0) | <0.001 | 25.4 (5.3) | 25.7 (5.7) | <0.009 | 24.9 (5.5) | 24.5 (5.8) | 0.038 |
| 15-19 | 171 (11.4) | 740 (11.6) | <0.001 | 427 (13.0) | 812 (14.0) | <0.001 | 191 (18.0) | 745 (21.3) | 0.402 |
| 20-34 | 1241(82.5) | 4952 (77.5) |  | 2682 (81.5) | 4481 (77.4) |  | 802 (75.5) | 2550 (73.0) |  |
| 35+ | 93 (6.1) | 700 (10.9) |  | 180 (5.5) | 497 (8.6) |  | 69 (6.5) | 200 (5.7) |  |
| **Religion** | | | | | | | | | |
| Islam | 1343 (88.9) | 5894 (92.2) | <0.001 | 2955 (89.8) | 5373 (92.8) | <0.001 | 961 (90.5) | 3236 (92.6) | 0.705 |
| Other\* | 167 (11.1) | 497 (7.8) |  | 334 (10.2) | 416 (7.2) |  | 101 (9.5) | 259 (7.4) |  |
| **Place of residence** | | | | | | | | | |
| Urban | 548 (36.3) | 1110 (17.4) | <0.001 | 952 (28.9) | 1029 (17.8) | <0.001 | 532 (50.1) | 925 (26.5) | <0.001 |
| Rural | 962 (63.7) | 5282 (82.6) |  | 2337 (71.1) | 4760 (82.2) |  | 530 (49.9) | 2570 (73.5) |  |
| **Geographical location** | | | | | | | | | |
| Barishal | 50 (3.3) | 428 (6.7) | <0.001 | 374 (6.5) | 134 (4.1) | <0.001 | 105 (9.9) | 435 (12.4) | <0.001 |
| Chattogram | 267 (17.7) | 1577 (24.7) |  | 1391 (24.0) | 589 (17.9) |  | 169 (15.9) | 716 (20.5) |  |
| Dhaka | 604 (40.0) | 1872 (29.3) |  | 1157 (20.0) | 1027 (31.2) |  | 262 (24.7) | 548 (15.7) |  |
| Khulna | 230 (15.2) | 524 (8.2) |  | 429 (7.4) | 480 (14.6) |  | 182 (17.1) | 346 (9.9) |  |
| Mymenshing | - | - |  | 543 (9.4) | 158 (4.8) |  | - | - |  |
| Rajshahi | 189 (12.5) | 656 (10.3) |  | 610 (10.5) | 429 (13.0) |  | 148 (13.9) | 406 (11.6) |  |
| Rangpur | 104 (6.9) | 788 (12.3) |  | 650 (11.2) | 319 (9.7) |  | 108 (10.2) | 440 (12.6) |  |
| Sylhet | 66 (4.4) | 547 (8.6) |  | 636 (11.0) | 153 (4.7) |  | 88 (8.3) | 604 (17.3) |  |
| **Mother’s education** | | | | | | | | | |
| None | 80 (5.3) | 1378 (21.6) | <0.001 | 102 (3.1) | 673 (11.6) | <0.001 | 43 (4.0) | 571 (16.4) | <0.001 |
| Primary incomplete | 78 (5.2) | 964 (15.1) |  | - | - |  |
| Primary | 142 (9.5) | 1096 (17.1) |  | 419 (12.7) | 1646 (28.4) | 145 (13.7) | 1112 (31.8) |  |
| Secondary incomplete | 660 (44.0) | 2360 (36.9) |  | - | - | 572 (53.9) | 1580 (45.2) |  |
| Secondary complete/ higher | 539 (36.0) | 594 (9.3) |  | 2768 (84.2) | 3471 (60.0) | 302 (28.4) | 232 (6.6) |  |
| **Wealth index** | | | | | | | | | |
| Richest | 735 (48.6) | 847 (13.3) | <0.001 | 1172 (35.6) | 1654 (28.6) | <0.001 | 471 (44.4) | 437 (12.5) | <0.001 |
| Richer | 351 (23.2) | 1046 (16.5) |  | 800 (24.3) | 1275 (22.0) |  | 275 (25.9) | 673 (19.3) |  |
| Middle | 192 (12.7) | 1308 (20.6) |  | 622 (18.9) | 1094 (18.9) |  | 165 (15.5) | 709 (20.3) |  |
| Poorer | 136 (9.0) | 1436 (22.6) |  | 438 (13.3) | 996 (17.2) |  | 99 (9.3) | 763 (21.8) |  |
| Poorest | 98 (6.5) | 1717 (27.0) |  | 257 (7.8) | 770 (13.3) |  | 52 (4.9) | 913 (26.1) |  |
| **Body mass index (mother)** | | | | | | | | | |
| Underweight | 50 (3.3) | 320 (5.0) | <0.001 | 151 (4.6) | 309 (5.3) | <0.001 | 153 (14.5) | 1005 (28.9) | <0.001 |
| Normal | 1034 (68.4) | 4934 (77.2) |  | 2221 (67.5) | 4283 (74.0) |  | 568 (53.7) | 2051 (58.9) |  |
| Overweight | 427 (28.3) | 1138 (17.8) |  | 917 (27.9) | 1197 (20.7) |  | 336 (31.8) | 426 (12.2) |  |
| **Breastfeeding status** | | | | | | | | | |
| Yes | 1483 (98.2) | 6208 (97.1) | 0.020 | 3273 (99.5) | 5769 (99.6) | 0.374 | 891 (83.9) | 3011 (86.1) | 0.018 |
| No | 27 (1.8) | 183 (2.9) |  | 16 (0.5) | 21 (0.4) |  | 171 (16.1) | 484 (13.9) |  |
| **Sex of the children** | | | | | | | | | |
| Male | 784 (51.9) | 3226 (50.5) | 0.331 | 1758 (53.5) | 2914 (50.3) | 0.004 | 575 (54.1) | 1768 (50.6) | 0.205 |
| Female | 727 (48.1) | 3166 (49.5) |  | 1531 (46.5) | 2876 (49.7) |  | 487 (45.9) | 1727 (49.4) |  |
| **Child’s age group in months** | | | | | | | | | |
| 0-11 | 766 (50.7) | 3138 (49.1) | 0.264 | 1677 (51.0) | 2688 (46.4) | <0.001 | 372 (35.0) | 1090 (31.2) | 0.168 |
| 12-23 | 744 (49.3) | 3254 (50.9) |  | 1450 (44.1) | 2702 (46.7) |  | 375 (35.3) | 1182 (33.8) |  |
| 24-35 | - | - |  | 161 (4.9) | 400 (6.9) |  | 315 (29.7) | 1223 (35.0) |  |
| **Size at birth** | | | | | | | | | |
| Very large | 5 (0.3) | 6 (0.1) | <0.001 | 60 (1.8) | 53 (0.9) | <0.001 | 23 (2.2) | 78 (2.2) | 0.009 |
| Larger than average | 326 (22.0) | 718 (12.2) |  | 435 (13.3) | 479 (8.4) |  | 154 (14.5) | 327 (9.4) |  |
| Average | 881 (59.4) | 3794 (64.6) |  | 2188 (66.8) | 4089 (71.4) |  | 710 (66.8) | 2379 (68.1) |  |
| Smaller than average | 228 (15.4) | 1134 (19.3) |  | 933 (16.3) | 933 (16.3) |  | 118 (11.1) | 480 (13.7) |  |
| Very small | 44 (3.0) | 222 (3.8) |  | 173 (3.0) | 173 (3.0) |  | 57 (5.4) | 230 (6.6) |  |
| **Weight at birth** | | | | | | | | | |
| Low | 306 (22.8) | 560 (37.0) | <0.001 | 2292 (73.2) | 1080 (66.6) | <0.001 | - | - | - |
| Normal | 1037 (77.2) | 952 (63.0) |  | 838 (26.8) | 541 (33.4) |  | - | - |  |

\*Hinduism, Buddhism, Christianity

**Table 2: Model selection criteria for Poisson and NB model**

|  |  |  |  |
| --- | --- | --- | --- |
| **Data** | **Model** | **AIC** | **BIC** |
| **MICS (2012)** | Poisson | 24684.24 | 24698.17 |
| **NB** | **24610.48** | **24621.38** |
| **MICS (2019)** | Poisson | 27400.02 | 27421.40 |
| **NB** | **27165.02** | **27179.27** |
| **BDHS (2014)** | Poisson | 13348.55 | 13361.40 |
| **NB** | **12565.08** | **12584.35** |

\*NB: Negative Binomial, AIC: Akaike information criterion, BIC: Bayesian information criterion

**Table 3: Association between C-section (vs normal delivery) and common childhood diseases from the crude and adjusted NB models**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **MICS 2012** | | **MICS 2019** | | **BDHS 2014** | |
| **Model** | **Exposure** | **RR (95% CI)** | **p-value** | **RR (95% CI)** | **p-value** | **RR (95% CI)** | **p-value** |
| **Crude Model** | C-section vs.  normal delivery | 1.05  (1.02-1.08) | <0.001 | 1.16  (1.14-1.18) | <0.001 | 1.08  (0.97-1.19) | 0.159 |
| **Adjusted Model\*** | C-section vs.  normal delivery | 1.01  (0.97-1.04) | 0.071 | 1.14  (1.11 - 1.17) | <0.001 | 1.15  (1.05 - 1.27) | 0.004 |

RR: Risk Ratio, NB: Negative Binomial, \*Model adjusted for possible confounding factors

**Table 4: Association between C-section (vs normal delivery) and common childhood diseases from crude and adjusted PS models**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **MICS 2012** | | **MICS 2019** | | **BDHS 2014** | |
| **Model** | **Exposure** | **ARR (95% CI)** | **p-value** | **ARR (95% CI)** | **p-value** | **ARR (95% CI)** | **p-value** |
| **Crude Model** | C-section vs.  Normal delivery | 1.12  (0.94-1.31) | 0.201 | 1.02  (0.87-1.20) | 0.080 | 1.11  (1.01-1.23) | 0.042 |
| **Adjusted Model** | C-section vs.  Normal delivery | 1.02  (0.90-1.14) | 0.082 | 1.01  (0.98-1.03) | 0.075 | 1.17  (1.05-1.29) | 0.030 |

PS: Propensity Scores

**SUPPLEMENTARY MATERIAL**

**Table S1: Unadjusted LR statistics for type 3 analysis**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **MICS 2012** | | **MICS 2019** | | **BDHS 2014** | |
| **Source** | **Chi-Square** | **P-value** | **Chi-Square** | **P-value** | **Chi-Square** | **P-value** |
| **Type of Delivery** | 11.58 | <0.001 | 226.75 | <0.001 | 1.88 | 0.170 |

**Table S2: Adjusted LR Statistics for Type 3 Analysis**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **MICS 2012** | | **MICS 2019** | | **BDHS 2014** | |
| **Covariates** | **Chi-Square** | **P-value** | **Chi-Square** | **P-value** | **Chi-Square** | **P-value** |
| **Type of Delivery** | 0.08 | **0.071** | 106.25 | **<0.001** | 8.24 | **0.004** |
| **Mother Age** | 10.87 | **0.004** | 0.51 | 0.775 | 2.06 | 0.357 |
| **Religion** | 2.50 | 0.114 | 0.75 | 0.387 | 0.62 | 0.429 |
| **Place of residence** | 0.00 | 0.989 | 0.01 | 0.905 | 0.00 | 0.969 |
| **Geographical Location** | 60.13 | **<0.001** | 91.56 | **<0.001** | 9.48 | 0.148 |
| **Mother's education** | 8.95 | 0.062 | 0.05 | 0.973 | 3.76 | 0.288 |
| **Wealth Index** | 3.21 | 0.524 | 4.26 | 0.372 | 5.71 | 0.222 |
| **Body Mass Index** | 8.93 | **0.012** | 6.64 | **0.036** | 6.41 | **0.041** |
| **Breastfeed** | 0.99 | 0.321 | 2.54 | 0.111 | 2.63 | 0.105 |
| **Sex of the children** | 1.65 | 0.199 | 0.06 | 0.808 | 4.26 | **0.039** |
| **Child age** | 0.55 | 0.459 | 3.23 | 0.199 | 9.71 | **0.008** |
| **Size at birth** | 5.54 | **0.236** | 4.39 | 0.356 | 7.63 | 0.106 |
| **Weight at birth** | 4.02 | **0.045** | 0.10 | 0.750 | - | - |

**Table S3: Influence of factors associated with childhood diseases (lower diseases and normal delivery vs. higher diseases due to C-section delivery)**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sources** |  |  | **Adjusted Estimates** | | | | | | | | |
| **MICS 2012** | | | **MICS 2019** | | |  |  | | **BDHS 2014** | |
| **ARR\*** | **95% CI** | **p-value** | **ARR\*** | **95% CI** | **p-value** | **ARR\*** | | **95% CI** | | **p-value** |
|  |  |  |  |  |  |  |  | |  | |  |
| **Type of Delivery** | | | | | | | | | | | |
| C-section | 1.02 | 0.97-1.04 | 0.071 | 1.14 | 1.11-1.17 | <0.001 | 1.15 | | 1.05 - 1.27 | | 0.004 |
| Normal | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Mother’s age group in years at birth** | | | | | | | | | | | |
| 15-19 | 1.04 | 0.97-1.12 | 0.276 | 1.01 | 0.96-1.06 | 0.720 | 1.05 | | 0.95-1.15 | | 0.182 |
| 20-34 | 0.93 | 0.88-0.97 | 0.002 | 0.98 | 0.94-1.02 | 0.510 | 0.96 | | 0.87-1.06 | | 0.376 |
| 35+ | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Religion** | | | | | | | | | | | |
| Islam | 0.95 | 0.90-1.01 | 0.107 | 0.99 | 0.95-1.02 | 0.381 | 1.06 | | 0.92-1.21 | | 0.431 |
| Other religion (Hinduism, Buddhism, Christianity) | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Place of residence** | | | | | | | | | | | |
| Urban | 1.01 | 0.95-1.05 | 0.989 | 1.01 | 0.97-1.03 | 0.905 | 1.00 | | 0.91-1.10 | | 0.969 |
| Rural | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Geographical Location** | | | | | | | | | | | |
| Barishal | 0.94 | 0.82-1.08 | 0.486 | 0.94 | 0.90-0.99 | <0.001 | 1.00 | | 0.85-1.17 | | 0.981 |
| Chattogram | 0.90 | 0.81-0.99 | 0.037 | 0.88 | 0.84-0.92 | 0.017 | 1.07 | | 0.94-1.22 | | 0.319 |
| Dhaka | 0.90 | 0.82-0.99 | 0.029 | 0.95 | 0.90-1.01 | 0.420 | 0.94 | | 0.82-1.07 | | 0.339 |
| Khulna | 1.10 | 0.99-1.21 | 0.164 | 1.02 | 0.95-1.09 | 0.596 | 1.04 | | 0.89-1.21 | | 0.636 |
| Mymenshing | - | - | - | 0.99 | 0.94-1.04 | 0.719 | - | | - | | - |
| Rajshahi | 1.03 | 0.94-1.14 | 0.389 | 0.89 | 0.84-0.94 | 0.016 | 0.96 | | 0.83-1.11 | | 0.554 |
| Rangpur | 1.07 | 0.97-1.18 | 0.075 | 1.02 | 1.02-1.07 | <0.001 | 0.90 | | 0.77-1.01 | | 0.160 |
| Sylhet | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Educational level (mother)** | | | | | | | | | | | |
| None | 0.89 | 0.82-0.96 | 0.042 | 0.99 | 0.94-1.05 | 0.911 | 0.89 | | 0.75-1.05 | | 0.166 |
| Primary incomplete | 0.93 | 0.86-1.01 | 0.091 | 0.91 | | 0.81-1.03 | | 0.154 |
| Primary | 0.97 | 0.91-1.04 | 0.395 | 0.99 | 0.97-1.03 | 0.827 | 0.98 | | 0.87-1.11 | | 0.780 |
| Secondary incomplete | 0.98 | 0.92-1.03 | 0.336 | - | - | - | - | | - | | - |
| Secondary complete/higher | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Wealth Index** | | | | | | | | | | | |
| Richest | 1.04 | 0.99-1.10 | 0.259 | 1.03 | 0.98-1.07 | 0.574 | 1.17 | | 1.03-1.34 | | 0.191 |
| Richer | 1.03 | 0.98-1.09 | 0.150 | 1.02 | 0.97-1.05 | 0.555 | 1.10 | | 0.95-1.28 | | 0.119 |
| Middle | 1.02 | 0.96-1.09 | 0.494 | 1.01 | 0.96-1.02 | 0.249 | 1.11 | | 0.96-1.28 | | 0.148 |
| Poorer | 1.00 | 0.95-1.07 | 0.876 | 1.00 | 0.95-1.03 | 0.678 | 1.11 | | 0.98-1.25 | | 0.110 |
| Poorest | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Body Mass Index (mother)** | | | | | | | | | | | |
| Underweight | 1.11 | 1.04-1.19 | 0.002 | 1.05 | 1.01-1.09 | 0.027 | 1.13 | | 1.01-1.26 | | 0.025 |
| Overweight | 1.12 | 1.03-1.21 | 0.005 | 1.01 | 0.97-1.02 | 0.621 | 1.17 | | 1.03-1.32 | | 0.015 |
| Normal | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Breastfeeding status** | | | | | | | | | | | |
| Yes | 0.91 | 0.76-1.10 | 0.634 | 0.81 | 0.64-1.03 | 0.081 | 0.91 | | 0.81-1.02 | | 0.066 |
| No | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Sex of child** |  |  |  |  |  |  |  | |  | |  |
| Male | 1.03 | 0.99-1.06 | 0.822 | 1.01 | 0.98-1.02 | 0.808 | 1.08 | | 1.00-1.16 | | 0.039 |
| Female | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Child’s age group in months** | | | | | | | | | | | |
| 0-11 | 1.02 | 0.98-1.06 | 0.459 | 1.03 | 0.98-1.08 | 0.199 | 1.15 | | 1.04-1.27 | | 0.006 |
| 12-23 | 1 | - | - | 1.02 | 0.97-1.07 | 0.521 | 1.14 | | 1.04-1.26 | | 0.005 |
| 24-35 | - | - | - | 1 | - | - | 1 | | - | | - |
| **Size at birth** | | | | | | | | | | | |
| Very large | 0.81 | 0.60-1.09 | 0.166 | 0.95 | 0.88-1.03 | 0.411 | 0.93 | | 0.80-1.07 | | 0.314 |
| Larger than average | 0.82 | 0.61-1.10 | 0.223 | 0.95 | 0.88-1.03 | 0.993 | 0.95 | | 0.79-1.14 | | 0.585 |
| Average | 0.83 | 0.62-1.12 | 0.223 | 0.93 | 0.86-1.00 | 0.951 | 0.96 | | 0.73-1.27 | | 0.795 |
| Smaller than average | 0.89 | 0.65-1.21 | 0.461 | 0.95 | 0.86-1.07 | 0.589 | 1.07 | | 0.90-1.27 | | 0.418 |
| Very small | 1 | - | - | 1 | - | - | 1 | | - | | - |
| **Weight at birth** | | | | | | | | | | | |
| Low | 0.96 | 0.92-1.00 | 0.042 | 0.99 | 0.97-1.02 | 0.750 | - | | - | | - |
| Normal | 1 | - | - | 1 | - | - | - | | - | | - |

*RR: Risk Ratio; CI: Confidence Interval; ARR: Adjusted risk ratio*

*\*Model adjusted with Propensity scores \*\*Model adjusted with confounding and/or covariates*