Child-Mother Index: a new risk factor for selected adverse maternal birth outcomes

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BACKGROUND: Over decades, obstetricians have evaluated a range of risk factors to improve the prediction of adverse birth outcomes.

OBJECTIVE: This study aimed to assess the effectiveness of the Child-Mother Index as a risk factor indicator for selected adverse maternal birth outcomes.

STUDY DESIGN: We assessed the Child-Mother Index by multinomial regression models using register-based data containing all singleton births in Denmark in 2009 with a gestational age between 37+0 and 41+6 weeks. The Child-Mother Index is defined as the weight of the newborn divided by the squared maternal height.

RESULTS: Data from 47,007 births were included. Both the Child-Mother Index mean and Child-Mother Index median were 12.6 hg/m² (range, 4.8–22.4). In the multivariable model, the relative risk ratios for Child-Mother Index above 14.1 hg/m² were 2.2 (95% confidence interval, 1.6–3.1) for third- and fourth-degree perineal tears, 2.0 (1.6–2.5) for nonelective cesarean delivery, and 1.0 (0.8–1.3) for instrumental procedures. Equivalent figures for a Child-Mother Index below 11.2 hg/m² were 0.6 (0.4–1.0), 1.0 (0.8–1.2), and 0.7 (0.6–0.9), respectively. By comparing a multivariable model with the Child-Mother Index included with a model without the Child-Mother Index included using a likelihood ratio test, a statistically significant difference was found in favor of the Child-Mother Index inclusion (P<.001).

CONCLUSION: The Child-Mother Index constitutes a potential useful risk factor indicator for statistical analyses on data after birth. The value of the Child-Mother Index based on the estimated fetal weight before birth deserves evaluation.

Keywords: delivery, index, instrumental delivery, perineal tears

Introduction

The risk for adverse maternal outcomes related to childbirth is always a matter of concern, for instance, adverse outcomes such as acute cesarean deliveries (CDs), tears, and bleeding conditions. It is an important clinical task to be able to predict which women are at special risk for adverse maternal outcomes. Many former studies have focused on predictive factors associated with different adverse maternal birth outcomes.1-10 For instance, maternal age,11,12 abnormal fetal position,13 and physical activity level14 have been suggested to be important risk factors for acute CDs, and factors such as fetal head position and maternal position at birth have been associated with the risk for tears and maternal bleeding.15,16

The height of the mother and the birthweight17-20 have been found to be independently associated with several adverse maternal birth outcomes such as dystocia, cephalopelvic disproportion, shoulder dystocia, and perineal tears.4,5 However, the association between a combined measurement of these 2 variables and the adverse maternal birth outcomes has not yet been assessed.

Inspired by the definition of the body mass index (BMI), we therefore defined a Child-Mother Index (CMI) as the child’s birthweight in 100 g (ie, hectograms, hg) divided by the squared maternal height in meters. For example, the CMI for a birthweight of 3850 grams and maternal height of 167 cm is calculated by taking 38.5 and dividing it by 2.79 (1.67 × 1.67), giving a CMI of 13.8 hg/m².

This study aimed to investigate the potential of this innovative index as a variable according to which a regression model could be adjusted in future research.
Materials and Methods

Study design

Test cohort data (example data). Data were collected from the Danish Medical Birth Register\textsuperscript{17,18} for the year 2009. The registry includes gestational age, prepregnancy maternal height and weight, birthweight, and interventions during delivery. The recorded information is based on diagnostic codes, such as those found in the International Classification of Diseases, Tenth Revision (ICD-10) and procedure codes from the Nordic Medico-Statistical Committee classification of surgical procedures. The flowchart (Figure 1) shows the selection process for the inclusion of the 47,007 births used in the analysis.

Classification of maternal birth outcomes. Maternal birth outcomes based on diagnostic and procedure codes registered at birth were classified into the following 7 categories: (1) elective CD, (2) nonelective CD, (3) instrumental delivery, (4) third- and fourth-degree perineal tear, (5) second-degree perineal tear, and (6) other complications (postpartum bleeding and/or unsuccessful instrumental procedures) (S1 Table). All other vaginal births which did not fall into any of the specified categories above constituted the reference (seventh) category of uncomplicated vaginal deliveries. The definitions are hierarchical, following the order given in S1 Table.

Classification of risk factors. Index-related variables were categorized as follows (S2 Table): maternal height (140–, 163–, 167–, 170–, and 174–196 cm), birthweight (1315–, 3160–, 3426–, 3660–, and 3948–5990 g), and CMI, categorized into 5 roughly equally large category sizes (4.8–, 11.2–, 12.1–, 13.0–, and 14.1–22.4 kg/m\textsuperscript{2}) corresponding to the minimum and 20th, 40th, 60th, and 80th percentiles.

Additional risk factors included maternal prepregnancy BMI, categorized using the World Health Organization categories (14.0–18.4, 18.5–24.9, 25.0–29.9, 30–34.9, and ≥35 kg/m\textsuperscript{2}), maternal age (15–24, 25–34, and 35–51 years), prenatal smoking (yes or no), parity (nulliparous or multiparous), and gestational age (37–38 weeks and 39–41 weeks) (S3 Table). The following variables were based on diagnosis and procedure codes registered at birth: induction of labor (yes or no), augmentation of labor with oxytocin infusion during delivery (yes or no), episiotomy (yes or no), fetal sex (male or female), and cephalopelvic disproportion (yes or no). Missing risk factor values were treated as no exposure.

Statistical analysis

The preliminary analyses displayed the relation between maternal height and birthweight in a scatterplot and estimated the Pearson product moment correlation with a corresponding 95% confidence interval (CI). Normality of the CMI was inspected using a normal quantile-quantile plot. Next, each birth category was compared with the reference category using multinomial logistic regression models in which the CMI categories were compared with the middle category of 12–. Relative risk ratios (RRRs) were estimated in 2 separate models. The univariable model contained only the CMI (categorized), whereas the multivariable model also
adjusted for maternal height and birthweight, their interaction, and all other factors mentioned above. For the multivariable approach, a likelihood ratio test was performed for the model with vs without CMI.

Subsequently, we evaluated the (internal) predictive ability of the models with receiver operating characteristic (ROC) curves and estimated the areas under the curve (AUC) with corresponding 95% CIs and tested for equality. Because ROC analysis is designed for differentiation between 2 groups and our multinomial models have 7 outcome categories, we chose the following approach: for each outcome category, the ROC analysis was based on the differentiation between the specific outcome category vs the reference category only, giving 6 different ROC analyses. For illustration purposes, we presented the results for third- and fourth-degree perineal tear and second-degree perineal tear.

All analyses were performed using Stata software version 16 (StataCorp, College Station, TX).18 A P value <.05 was considered statistically significant.

Ethical approval
The cohort study in which the data set originated was approved by the Danish Data Protection Agency (no. 2013-41-1561).19 Complying with European data protection rules, the University of Southern Denmark approved the data processing activities related to this project and registered the project (project number 10.866). According to Danish law, review by an ethics board or patient consent is not required for purely register-based studies.

Results
Data from a total of 47,007 births were included in the test cohort. The births were categorized as follows: 54% were uncomplicated vaginal deliveries (reference category), 8% were elective CDs, 9% were nonselective CDs, 8% were instrumental deliveries, 3% of births with third- and fourth-degree perineal tears, 15% with second-degree perineal tears, and 4% with other complications. The distribution of risk factors within

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**TABLE 1**

Baseline characteristics of the test cohort, separately for all (N=47,007) deliveries and for the group of vaginal deliveries without adverse maternal birth outcomes (reference group in the regression model)

| Characteristics          | All deliveries, 2009 N (%) | Reference group n (%) |
|--------------------------|----------------------------|-----------------------|
| Birthweight (g)          |                            |                       |
| 1315–3159                | 9262 (19.7)                | 5243 (20.8)           |
| 3160–3425                | 9534 (20.3)                | 5349 (21.2)           |
| 3426–3659                | 9310 (19.8)                | 5122 (20.3)           |
| 3660–3947                | 9492 (20.2)                | 4951 (19.6)           |
| 3948–5990                | 9409 (20.0)                | 4544 (18.0)           |
| Maternal height (cm)     |                            |                       |
| 140–162                  | 9282 (19.7)                | 4680 (18.6)           |
| 163–166                  | 9390 (20.0)                | 4970 (19.7)           |
| 167–169                  | 8980 (19.1)                | 4823 (19.1)           |
| 170–173                  | 10,167 (21.6)              | 5599 (22.2)           |
| 174–196                  | 9188 (19.5)                | 5137 (20.4)           |
| CMI (kg/m²)              |                            |                       |
| 4.8–11.1                 | 9254 (19.7)                | 5370 (21.3)           |
| 11.2–12.0                | 8623 (18.3)                | 4905 (19.5)           |
| 12.1–12.9                | 9751 (20.7)                | 5334 (21.2)           |
| 13.0–14.0                | 9845 (20.9)                | 5175 (20.5)           |
| 14.1–22.4                | 9534 (20.3)                | 4425 (17.6)           |
| Maternal BMI (kg/m²)     |                            |                       |
| 14.0–18.4                | 2004 (4.3)                 | 1193 (4.7)            |
| 18.5–24.9                | 29,514 (62.8)              | 16,361 (64.9)         |
| 25.0–29.9                | 9728 (20.7)                | 4937 (19.6)           |
| 30.0–34.9                | 3778 (8.0)                 | 1841 (7.3)            |
| ≥35.0                    | 1983 (4.2)                 | 877 (3.5)             |
| Maternal age (y)         |                            |                       |
| 15–24                    | 5774 (12.3)                | 3305 (13.1)           |
| 25–34                    | 31,816 (67.7)              | 16,934 (67.2)         |
| 35–51                    | 9417 (20.0)                | 4970 (19.7)           |
| Maternal smoking (yes)   | 6133 (13.0)                | 3512 (13.9)           |
| Parity                   |                            |                       |
| Nulliparous              | 20,498 (43.6)              | 8940 (35.5)           |
| Multiparous              | 26,509 (56.4)              | 16,269 (64.5)         |
| Gestational age (wk)     |                            |                       |
| 37–38                    | 24,870 (52.9)              | 13,272 (52.6)         |
| 39–41                    | 22,137 (47.1)              | 11,937 (47.4)         |
| Labor induction (yes)    | 6595 (14.0)                | 3324 (13.2)           |

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the birth categories can be found in S3 (corresponding distribution between all births and reference category in Table 1). The CMI ranged from 4.8 to 22.4 with a mean of 12.6 (standard deviation, 1.8), a median of 12.6 (lower quintile, 11.4 and upper quintile, 13.8), and an overall good agreement with the normal distribution (S1 Fig). The relationship between the 2 index components, birthweight and maternal height (Figure 1), corresponds to an estimated Pearson correlation coefficient of 0.22 (95% CI, 0.21–0.22) (S1 Fig).

Table 1 and S1 show baseline characteristics of the test cohort, separately for all delivery (N=47,007) and for the group of vaginal deliveries (n=25,209) without adverse maternal birth outcomes (reference group in the regression model) (Table 1). In the univariable setting, a CMI of vaginal deliveries (n=25,209) without adverse maternal birth outcomes (reference group in the regression model) (Table 1), the AUCs were again larger and comparable to other functional relationships that we did not rigorously explore and compare other functional relationships between birthweight and maternal height in addition to the CMI.

To illustrate how well the models discriminate between one outcome category and reference category only, we present ROC curves for second-degree perineal tear (upper Figure 2) and third- and fourth-degree perineal tear (lower Figure 2). The dots are estimates for model M1, which only includes birthweight (categorized), and the curves are based on estimates for the multivariable model M2. For second-degree perineal tear, differences between red (model with CMI) and blue (model without CMI) are visually nonexistent regardless of model complexity. For M1, the corresponding AUCs were estimated to be 0.54 (95% CI, 0.54–0.55) (blue dots, model without CMI) and 0.55 (0.54–0.55) (red dots, model with CMI) (P=.14). For the multivariable model, the AUCs were generally larger, and without CMI (blue curve), it was determined to be 0.64 (95% CI, 0.63–0.65), whereas with CMI it was 0.64 (95% CI, 0.63–0.65) (red curve, model with CMI) (P=.06).

For third- and fourth-degree perineal tears, the addition of CMI is very small but visible for both models; this is corroborated by the corresponding AUCs. For M1, the AUCs are estimated to be 0.61 (95% CI, 0.59–0.6204) (blue dots, model without CMI) and 0.6102 (0.5947–0.6258) (red dots, model with CMI) (P=.03). For the multivariable model, the AUCs were again larger and without CMI (blue curve) estimated to be 0.73 (95% CI, 0.72–0.75) and with CMI, 0.74 (0.72–0.75) (red curve, model with CMI) (P=.01).

Discussion

This study showed that a CMI >14.1 kg/m² is associated with an increased risk for all adverse maternal birth outcomes and that a CMI <11.2 kg/m² is associated with a decreased risk for second-degree or third- and fourth-degree perineal tears and instrumental delivery.

The development of the CMI was heavily inspired by the BMI in that the basic idea of linking the weight to the squared height was retained. To take the squared height as the denominator implies that a height difference in the lower range, say between 160 and 150 cm, has a larger impact, that is, a larger difference in BMI or CMI, than a height difference between 180 and 170 cm. The choice of hectograms in the nominator was mostly one of convenience to obtain a decent range for CMI values. It is a limitation of our study that we did not rigorously explore and compare other functional relationships between birthweight and maternal height in addition to the CMI.

A strength of the study is that the test cohort was unselected because it included 99% of all Danish births.17 It is a limitation that not all potentially relevant confounding risk factors were available for the test cohort. For example, maternal medical history and information on gestational diabetes were not included. Furthermore, we do not know the external validity because a much wider range of women has to be included to arrive at valid, worldwide norms. It could also be considered a limitation that the data are from year 2009; however, this is irrelevant because it is a test data set and the relationship between mother’s height and baby’s weight is barely affected over the years.

It would be attractive to compare the performance of the CMI with those of the birthweight per se, the maternal weight per se, and other risk factors. However, new, independent data would be needed to investigate this further; our study provided initial evidence and was designed as an
|                | N     | Second-degree perineal tear | Third- and fourth-degree perineal tear | Instrument  | Nonelective CD | Elective CD | Other | RRR  | 95% CI   | RRR  | 95% CI   | RRR  | 95% CI   | RRR  | 95% CI   | RRR  | 95% CI   |
|----------------|-------|------------------------------|----------------------------------------|-------------|----------------|-------------|-------|------|----------|------|----------|------|----------|------|----------|------|----------|
| **Univariable model** |       |                              |                                         | CMI (hg/m²) |               |             |       |      |          |      |          |      |          |      |          |      |          |
| 4.8—11.1    | 7049  (15.0) | 0.81 (0.74—0.88) | 0.57 (0.46—0.7) | 0.87 (0.78—0.97) | 1.03 (0.93—1.15) | 0.91 (0.81—1.01) | 0.96 (0.83—1.12) |
| 11.2—12.0  | 1255  (2.7)  | 1.00 (0.92—1.09) | 0.85 (0.7—1.03) | 0.89 (0.8—1) | 0.8 (0.71—0.9) | 0.9 (0.81—1.01) | 0.92 (0.79—1.07) |
| 12.1—12.9  | Ref               | Ref             | Ref     | Ref          | Ref          | Ref          |       |
| 13.0—14.0  | 1.11 (1.02—1.2) | 1.2 (1.01—1.42) | 1.01 (0.91—1.12) | 1.23 (1.11—1.37) | 0.95 (0.85—1.05) | 1.13 (0.98—1.31) |
| 14.1—22.4  | 1.18 (1.09—1.29) | 1.74 (1.47—2.05) | 1.13 (1.02—1.26) | 2.22 (2.01—2.45) | 1.15 (1.03—1.28) | 1.46 (1.27—1.68) |
| **Multivariable model** |       |                              |                                         | CMI (hg/m²) |               |             |       |      |          |      |          |      |          |      |          |      |          |
| 4.8—11.1    | 0.82 (0.69—0.97) | 0.65 (0.44—0.97) | 0.72 (0.57—0.9) | 0.98 (0.79—1.22) | 0.88 (0.71—1.1) | 0.99 (0.74—1.33) |
| 11.2—12.0  | 1.01 (0.9—1.14) | 0.86 (0.66—1.12) | 0.81 (0.69—0.96) | 0.85 (0.71—1.01) | 0.87 (0.74—1.03) | 0.91 (0.73—1.13) |
| 12.1—12.9  | Ref               | Ref             | Ref     | Ref          | Ref          | Ref          |       |
| 13.0—14.0  | 1.12 (0.99—1.26) | 1.35 (1.05—1.75) | 0.92 (0.77—1.09) | 1.24 (1.05—1.47) | 0.98 (0.83—1.15) | 1.05 (0.85—1.29) |
| 14.1—22.4  | 1.24 (1.06—1.45) | 2.24 (1.62—3.09) | 1.02 (0.82—1.28) | 2.03 (1.64—2.5) | 1.19 (0.96—1.48) | 1.52 (1.17—1.99) |

RRR and 95% CI compared with the reference group (n=25,209; 53.6%). Total N=47,007 (100%).

CD, cesarean delivery; CI, confidence interval; CMI, Child-Mother Index; Ref, reference; RRR, relative risk ratios.

*Adjusted for maternal height, birthweight, and their interaction, as well as for maternal prepregnancy BMI, maternal age, prenatal smoking, parity, gestational age, induction of labor, augmentation of labor with oxytocin infusion during delivery, episiotomy, fetal sex, and cephalopelvic disproportion.

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initial illustration and evaluation of the benefit of our new index. Thus, it should be noted that the CMI did improve the performance of the multivariable model ($P<0.001$) and showed some evidence of predictive performance. It would also be of interest to identify a risk cutoff for the CMI, that is, to identify the CMI value above which the risk is significantly increased to warrant intervention—in this case, the 90th or 95th percentile might be more valuable than the present 80th percentile.

There is a number of remaining topics to address. These include the association between the CMI and specific fetal-related complications, such as asphyxia or fractures. Furthermore, the prognostic value of the CMI as a pre-birth risk factor indicator needs further investigation, because it will be challenged by the uncertainty of the techniques used for fetal weight estimates.

**Conclusion**

This study indicated that the CMI may be useful as a risk factor indicator in statistical analyses on data after birth. Further studies are needed to evaluate the predictive performance of the CMI before the time of birth.

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**Supplementary materials**

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.xagr.2022.100090.

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