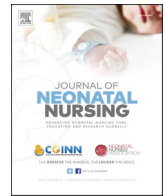




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Extracting the frequent sequential patterns among the factors associated with neonatal birthweight

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ABSTRACT

The objective of this study was to employ the association rules mining technique to find the frequent co-occurrences among maternal factors associated with birthweight. Secondary data consisting of 189 records with predictors that assess the risk factors that influence low neonatal birthweight were employed for association rules mining. The extracted rules show that the different patterns of co-occurrences among these factors: a mother's pre-pregnancy weight, presence/absence of uterine irritability, attendance to antenatal care visits in the first trimester, hypertension history, maternal age, and a history of premature labor often lead to either a low or normal neonatal birthweight. The extracted rules could serve as a reference tool in the education, treatment, and care of pregnant women to ensure positive outcomes related to birthweight. Flowing from these rules, pregnant mothers should be educated about the relationship between their attributes and the probable birthweight of their unborn babies.

1. Introduction

One of the most important measurements taken of a newborn is the birthweight. Other measurements include the head and abdominal circumferences. Birthweight is a strong indicator of the health status of a newborn and that of the mother. The goal of neonatal birthweight measurement is to determine whether there will be a need for emergency interventions (Gladstone et al., 2021). Some emergency interventions include continuous positive airway pressure or positive end-expiratory pressure, and the administration of oral immunoglobulin to treat necrotizing enterocolitis (Foster et al., 2016). Generally, newborns with low birthweight require close monitoring, as they are potentially susceptible to postnatal morbidity and mortality. Morbidity such as macrocephaly, microcephaly, cardiopathy, chromosomal abnormality, pneumonia, anemia, bronchopulmonary dysplasia, and urogenital infections have been associated with low birthweight (Groothuis

and Makari, 2012; Hilaire et al., 2021). Chromosomal abnormality and cardiopathy in babies with low birthweight have been found responsible for mortality (Hilaire et al., 2021). The prevalence of issues related to birthweight varies from one region to another. One of the issues related to birthweight is pre-eclampsia and eclampsia. According to a study by Macedo et al. (2020), the worldwide prevalence of pre-eclampsia/eclampsia is 6.7%. Low- and middle-income countries have the highest prevalence of pre-eclampsia, at 11.5% and 10.6% respectively. In Haiti, a high incidence of pre-eclampsia was found to be responsible for low birthweight (Hilaire et al., 2021). Pre-eclampsia often leads to preterm labor and delivery. Babies born prematurely have a high risk of cerebral palsy, breathing and feeding difficulties because of non-fully developed organs (ACOG, 2020). Pre-eclampsia has been associated with a reduction in fetal growth and women with pre-eclampsia are about 4 times more likely to deliver small for gestational age (SGA) newborns and/or preterm (Ødegård et al., 2000; Xiao

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et al., 2003). Hoodbhoy et al. (2021) affirmed that children exposed to fetal pre-eclampsia suffer cardiovascular dysfunction. There are other socio-economic issues related to low birthweight such as prenatal smoking, poor nutrition and ante-natal care. The global prevalence of smoking in pregnant women is 1.7% and 72.5% of these women are daily smokers (Lange et al., 2018).

To improve the quality of care received by infants with low birthweight, the World Health Organization published guidelines on optimal feeding of infants with low birthweight in middle-income countries (WHO, 2011). There are other guidelines for the management of infants with low birthweight in other regions. For example, the government of Swaziland through the ministry of health partnered with the United Nations International Children's Emergency Fund (UNICEF) and WHO to develop the national neonatal care clinical guidelines (UNICEF, 2018). The guidelines specify how infants with low birthweight should be managed (UNICEF, 2018).

According to the World Health Organization (WHO, 2022a), high birthweight as defined in the 2022 version of the International Classification of Diseases (ICD-11) mortality and morbidity statistics, is a birthweight greater than 4000g (4 kg). It is associated with a gestation period greater than 42 weeks. On the other hand, low birthweight ranges between 1500 and 2499g (1.5–2.499 kg) and is associated with a short gestation period (WHO, 2022b). Apart from short gestation, low birthweight could be associated independently with Intrauterine Growth Retardation (IUGR) or a combination of both. Low birthweight resulting from IUGR could lead to permanent growth and the cognitive deficiency (Kono, 2021; Zimmerman, 2018).

The effects of low birthweight on the neonate's health, development, and the health of the mother are of great importance to public health. Further, the frequency of occurrence of low birthweight in each society is very important to public health. In 2015, about 20.5 million babies suffered from low birthweight globally (UNICEF-WHO, 2020). This represents about 15% of the total births in 2015. Of the 20.5 million babies with low birthweight, 1 million (7.2%) were born in more developed regions such as North America, Europe, Japan, Australia, and New Zealand. About 12.8 million (17.3%) were born in Asia, 1.4 million (9.9%) in Oceania, and 5.7 million in Africa (Blencowe et al., 2019; UNICEF-WHO, 2020). The prevalence of low birthweight in both developed and developing countries are said to be on the increase. For instance, the prevalence of low birthweight in southern Europe is 7.6% and 4.68% in eastern Europe (Erasun et al., 2021). A study by DeMarco et al. (2021) reported a 53% increase in the prevalence of low birthweight among adolescent pregnancies in Canada. In a survey conducted in 35 sub-Saharan countries in Africa including South Africa, Namibia, Angola, Cameroun, Ethiopia, Kenya, Nigeria, Senegal, and so on, findings revealed a 9.7% prevalence of low birthweight (Tessema et al., 2021). This is higher than the prevalence rates in eastern (4.68%) and southern Europe (7.6%). As of 2016, the prevalence rate of low birthweight in Taiwan was 8.4% (Waits et al., 2021). Adverse birthweight has a debilitating effect on the health and development of the child which could result in death. A study conducted by Woelile et al. (2021) in Ethiopia revealed that two out of every seven low birthweight neonates die during follow-up.

Considering the importance of birthweight, the objective of this study was to deploy the association rules mining technique on a secondary birthweight dataset to determine how maternal attributes associated with birthweight co-occur. The study extracted association rules that show the most frequent co-occurrences among the factors associated with birthweight. Association rules mining is an unsupervised machine learning activity that is anchored on the theory that if item X occurs then item Y is very (or less) likely to occur (Atsa'am and Wario, 2022a). The extracted rules provide useful insight on the maternal factors that frequently occur together to lead to either low or adequate birthweight. This can be a reference tool for pregnant mothers and health practitioners on how adverse birthweight outcomes can be avoided.

1.1. Related literature

Several studies have been conducted to identify and understand neonatal birthweight. Some of such studies have focused on the characteristics of pregnant mothers that influence birthweight (Balogun et al., 2020). Afaya et al. (2021) observed that the phenomenon of low birthweight (LBW) of neonates over the past decade has not seen any decline in sub-Saharan Africa. In the same vein, Goldenberg and Culhane (2007) held that studies related to low birthweight are a good measure to address child mortality or morbidity. Extant literature has established a relationship between a mother's socio-demographic characteristics, lifestyle, and neonatal birthweight (Atsa'am et al., 2022; Balogun et al., 2020; Singh et al. 2009; Wang et al., 2020). Many researchers have focused on comparing one or more maternal factors and their contribution to birthweight. A review of studies focused on identifying mother's characteristics, lifestyle, attributes, and their effect on the weight of the new-born are presented in this section.

1.2. Association between a mother's age, initial weight, and neonatal birthweight

Studies indicate that a mother's age (Balogun et al., 2020) and weight at their last menstrual period before pregnancy (Shin et al., 2013) influence the birthweight of their child (Singh et al., 2009). Metgud et al. (2012) reported that as maternal age increases, the chances of LBW also increase, at a prevalence rate of 22%. Senthilkumar and Paulraj (2015) used a dataset collected from a hospital in Massachusetts, USA to predict the risk factors associated with LBW. The study reported that a mother's weight before pregnancy and their age are useful in predicting LBW. Further, in ranking the factors useful in predicting the likelihood of a LBW, a mother's last weight before pregnancy ranked top, with 100.00%, while a mother's age ranked second, with 98.00%. This implies that a mother's weight and age are highly influential to birthweight. Additionally, the weight or body mass index (BMI) of a mother before pregnancy was observed as a factor that can influence the weight of their neonate (Goldenberg and Culhane, 2007). Specifically, mothers with a high BMI usually have neonates with a high birthweight and vice-versa (Goldenberg and Culhane, 2007; Sutan et al., 2014). Related to this, Mayo Foundation for Medical Education and Research ([MFMER], 2022) outlined pre-pregnancy BMI in the following categories: below 18.5 [underweight], 18.5–24.9 [healthy weight], 25–29.9 [overweight], and 30 or more [obese].

1.3. Association between a mother's smoking status, history of hypertension, and neonatal birthweight

Several studies have separately established a strong relationship between maternal smoking during pregnancy and low birthweight Bernstein et al. (2005); Cliver et al. (1995); Cnattingius (2004); Xi et al. (2020). The separate findings from these studies infer that the more the foetus is exposed to primary or passive smoking by the mother, the higher the chances of a low birthweight.

Steer et al. (2004) found an association between low birthweight and maternal hypertension during pregnancy. The researchers argued that birthweight is optimal when the highest diastolic blood pressure of the mother is between 70 and 90 mmHg during pregnancy. Thus, mothers who experience high or low blood pressure during pregnancy are likely to deliver a baby with LBW. In a related study, Metgud et al. (2012) observed that neonates delivered by mothers who were exposed to passive smoking and experienced pregnancy-induced hypertension were likely to have a LBW. Furthermore, a study conducted to determine the factors associated with LBW in Malaysia identified young maternal age and hypertension as having a significant association with LBW (Sutan et al., 2014). The authors employed a multivariate conditional logistic regression approach to identify the associated outcomes. When adjusted with mother's age, gestational age and history of previous LBW,

hypertensive mothers were found to be 4.52 times more likely than non-hypertensive mothers to deliver a baby with LBW (Sutan et al., 2014). In a related study, Khan and Jamal (2003) reported that young maternal age and hypertension independently affect birthweight negatively.

1.4. Association between a mother's number of premature labors, physician visits during first trimester, and neonatal birthweight

Preterm birth has been defined as that before 37 weeks of gestation while early preterm birth takes place before 32 weeks of gestation (Yang et al., 2016). A study by Yang et al. (2016) found that pregnant women who experienced either preterm or early preterm delivery were at a high risk of experiencing a recurrence in subsequent pregnancies. Other factors such as old age, underweight BMI, smoking, and short intervals between pregnancies were also associated with recurring preterm deliveries and low birthweight (Fuchs et al., 2018; Simonsen et al., 2013; Spang, 2007). Furthermore, a new guideline for a positive pregnancy outcome has recommended a total of at least eight ante-natal care visits (WHO, 2016). According to WHO (2016), the first among these visits should take place within the first 12 weeks of gestation (first trimester). At each visit, the pregnant women should be counselled on diet and nutrition, smoking and substance use, prevention of malaria and HIV, and so on (WHO, 2016). These have the potential to ensure that a pregnant woman and her baby stay healthy, ultimately resulting in a normal birthweight.

The reviewed literature shows that the association between various maternal attributes and neonatal birthweight have been examined in previous studies. However, these studies were largely concerned with how maternal attributes independently affect birthweight. Furthermore, the most frequent sequential patterns of these factors have not been reported. Clearly, a study that examines the frequently occurring patterns among maternal attributes and their effect on birthweight was lacking. Therefore, the present study sought to address this gap by extracting the association rules that show the maternal attributes that frequently co-occur and the effect on birthweight.

2. Materials and methods

2.1. Data

The research data originated from a medical facility in Springfield, Illinois, USA. It consists of 189 records with eight predictors that assess the risk factors that influence low neonatal birthweight. There is a class variable that indicates the birthweight of the neonate in grams. The data is secondary and freely available in one of the packages in R (Venables and Ripley, 2002). The data variables are given in Table 1.

2.2. Modeling tool: association rules

Association rules mining is a technique that finds interesting relations (e.g., frequent patterns, causal structures) in a dataset (Goh and

Table 1
Research data variables.

Variable	Description	Data Type
age	Mother's age (in years)	Numeric
lwt	Mother's weight at the last menstrual period	Numeric
race	Mother's race; with 1 = white, 2 = black, 3 = other	Categorical
smoke	Mother's smoking status during pregnancy; with 0 = does not smoke, 1 = smoke	Binary
ptl	Number of previous premature labors	Numeric
ht	Mother's history of hypertension; with 0 = no, 1 = yes	Binary
ui	Presence of uterine irritability; with 0 = no, 1 = yes	Binary
ftv	Number of physician visits during the first trimester	Numeric
bwt	Birthweight in grams	Numeric

Ang, 2007). The technique was originally developed for finding the most frequent purchasing patterns of customers from historical transactions data. Subsequently, studies in other fields such as healthcare (Atsa'am & Wario, 2022a), security (Atsa'am et al., 2022), and sociology (Olaleye et al., 2022) have applied association rules to extract the frequently occurring patterns among domain variables.

Mathematically, a rule is represented as $A \Rightarrow B$, where A and B are items that frequently occur together in the dataset, and $A \cap B = \emptyset$. The item(s) on left-hand side (LHS) is called the antecedent while the right-hand side (RHS) is called the consequent (Atsa'am & Wario, 2022b). A combination of the LHS and the RHS is referred to as an itemset. The association rule depicted above implies that "if item A occurs in a transaction, then item B will also likely occur in the same transaction" (Zhou and Yau, 2007). The strength of a rule is measured by the following criteria (Atsa'am & Wario, 2022a; Atsa'am & Wario, 2022b; Goh and Ang, 2007; Zhao and Bhowmick, 2003):

Support: This measures how frequent an itemset appears in the dataset with respect to the total number of transactions in the dataset. It is given in Equation (1).

$$\text{Support} = \frac{\text{number of transactions containing both A and B}}{\text{total number of transactions}} = \frac{P(A \cap B)}{N} \quad (1)$$

Confidence: This measures the likelihood that item B will occur whenever item A occurs. It is given in Equation (2).

$$\text{Confidence} = \frac{\text{number of transactions containing both A and B}}{\text{total number of transactions with A}} = \frac{P(A \cap B)}{P(A)} \quad (2)$$

It is instructive to note that support and confidence are originally reported as ratios (Atsa'am & Wario, 2022b); however, these are interpreted better in percentages by multiplying the values by 100.

Lift: is the ratio of the observed frequency of co-occurrence of the items and the expected frequency. It is given in Equation (3).

$$\text{Lift} = \frac{\text{confidence}}{\text{expected confidence}} = \frac{P(A \cap B)}{P(A).P(B)} \quad (3)$$

Lift can take a score between zero and infinity. When comparing two or more rules, the stronger rule is that which maximizes the values of support, confidence, and lift (Atsa'am & Wario, 2022a; Olaleye et al., 2022).

2.3. Data and variables preprocessing

The research data was preprocessed and transformed into a transaction format prior to the deployment of association rules mining technique. For the categorical and binary variables (mother's race, smoking status, history of hypertension, presence of uterine irritability), each category was represented as a separate item (variable) in the new format. For the numeric variables (mother's age, weight, number of previous premature labors, number of physician visits during the first trimester, birthweight), literature evidence was used to create categories that represent new items. For example, mother's age was categorized into three as ≤ 19 , 20–34, and ≥ 35 . The categorization is supported by WHO (2020) where pregnancy outcomes have been associated with these age ranges. Further, the number of physician visits during the first trimester was categorized into two as "no visit", and "one or more visits". This categorization is supported by a new WHO guideline that encourages one ante-natal care visit during the first trimester (WHO, 2016). In the new format, data points were represented with the new category name corresponding to the original value. Blank spaces were entered where the category did not occur in the original data. The preprocessed data variables in transaction format are shown in Table 2.

2.4. Rules mining

R programming language version 4.1.3 was utilized for mining the

Table 2
Preprocessed data items.

Item	Description
teenage-mother	Pregnant mother aged below 20 years
mother-aged-20-to-34-years	Pregnant mother aged 20–34 years
mother-aged-35-years-or-above	Pregnant mother aged 35 or above
mother-below-40kg	Weighs below 40 kg before pregnancy
mother-40kg-or-above	Weighs 40 kg or above before pregnancy
white-race	Mother is white race
black-race	Mother is black race
Other-race	Mother is other race
non-smoker	Mother does not smoke during pregnancy
smokes	Mother smokes during pregnancy
no-previous-premature-labor	No previous premature labor(s)
one-previous-premature-labor	One previous premature labor(s)
two-or-more-previous-premature-labor	Two or more previous premature labor(s)
no-history-of-hypertension	No history of hypertension
history-of-hypertension	History of hypertension
uterine-irritability-absent	No uterine irritability
uterine-irritability-present	Uterine irritability present
No-ANC-visit	No physician visit in first trimester
one-or-more-ANC-visits	One or more physician visit(s) in first trimester
low-birthweight	Birthweight below 2.5 kg
normal-birthweight	Birthweight 2.5 kg or more

association rules in this study. The *apriori* algorithm was invoked on the preprocessed data, using the minimum thresholds of 0.01 and 0.5 for support and confidence, respectively. A support threshold of 0.01 means that any rule extracted had the same pattern of risk factors occurring together (itemset) in at least 1% of the total records. Similarly, a confidence threshold of 0.5 means that the rules extracted had the same consequent in at least 50% of the records consisting of the same antecedents. The support and confidence thresholds effectively streamlined the number of rules returned by the algorithm. More than 200 rules were generated from the birthweight data. After eliminating the redundant, weak, and repetitive rules, the four strongest rules presented in Table 3 were retained.

Table 3
Association rules.

Rule	LHS	RHS	Support	Confidence	Lift
1	{mother-below-40kg, uterine-irritability-present, no-ANC-visit}	=> {low-birthweight}	0.01	1.00	6.75
2	{no-history-of-hypertension, mother-aged-20-to-34-years, mother-below-40kg, uterine-irritability-present}	=> {low-birthweight}	0.01	1.00	3.20
3	{mother-aged-35-years-or-above, one-or-more-ANC-visits, mother-40kg-or-above, one-previous-premature-labor}	=> {normal-birthweight}	0.01	1.00	2.12
4	{mother-below-40kg, no-ANC-visit, no-previous-premature-labor}	=> {low-birthweight}	0.01	1.00	1.89

3. Results

The preprocessed data consisted of 21 new set of variables, each representing an item in the birthweight data, as shown in Table 2.

Table 3 presents the rules that show the frequent co-occurrences among the factors associated with birthweight. It is instructive to note that the factors could be positive or negative. The rules show the frequent patterns of occurrences of these factors plus the birthweight outcome.

Rule 1 indicates that the co-occurrence of these maternal factors, namely, a pre-pregnancy weight below 40 kg, uterine irritability during pregnancy, and not attending to ANC visit in the first trimester, often results to a low birthweight.

Rule 2 shows that the pattern of occurrence of the maternal factors where the pregnant mother has no history of hypertension, aged 20–34 years, has a pre-pregnancy weight below 40 kg, and the presence of uterine irritability, often results to low neonatal birthweight.

Rule 3 shows that a sequential pattern of these maternal factors, namely, maternal age of 35 years or above, a pre-pregnancy weight equal to or above 40 kg, and attendance to one or more ANC visit(s) during the first trimester, often results to a normal birthweight.

Rule 4 established that a sequential co-occurrence of the following factors often leads to a low birthweight: low pre-pregnancy weight (below 40 kg), a lack of ANC visits in the first trimester, and no previous premature labor.

4. Discussion

The LHS of each rule show the patterns of co-occurrence of certain maternal factors that often produce a specific birthweight outcome (shown on the RHS). Each of the four rules has a confidence of 100%. This indicates that in all the records of the research data where either low or normal birthweight was the consequent, the exact sequence of maternal factors could be observed. Furthermore, each rule has a lift score greater than 1.0. A lift score above 1.0 is an indication that both the LHS and RHS of the rule often occur together more than expected. The confidence and lift scores show that each of the four rules is strong and can be generalized.

It is instructive to note that three out of the four rules have their consequent as low neonatal birthweight – Rules 1, 2, and 4. It could be observed that a lack of ANC visits appears in two out of these three rules – Rules 1 and 4. This underscores the importance of ANC visits in taming the possibility of a low birthweight. ANC visits to a health facility help to monitor the health conditions of pregnant mothers and provide them with the required support and care. However, inability of some mothers to attend ANC visits has been attributed to their family economic status and level of education (Ghaemmaghmi et al., 2013).

It could be observed that low maternal pre-pregnancy weight (below 40 kg) appears in all the three rules where low birthweight is the consequent. This agrees with Shin et al. (2013) and Singh et al. (2009) who averred that a mother’s weight at their last menstrual period before pregnancy has an influence on the birthweight of their child. ANC visits are strongly recommended for this category of pregnant mothers where they could receive counselling, support, and care required for pregnancy weight-gain. This is in line with Tela et al. (2019) who found that weight-gain during pregnancy is strongly associated with birthweight. There are two negative attributes in Rule 3, namely, advanced maternal age (35 years and above) and a history of premature labor. However, the rule shows that a co-occurrence of these negative factors with two positive factors, namely, ANC visit(s) in the first trimester and a good pre-pregnancy weight, often results to a normal birthweight.

Though the experimental dataset consists of several maternal attributes, it could be deduced that uterine irritability, low pre-pregnancy weight, and lack of ANC visits are the most frequent negative factors that often co-occur with other attributes to influence low birthweight. Pregnant mothers and maternal care givers ought to note the frequently

occurring negative attributes that often result to an unwanted birthweight.

4.1. Limitations of the study

The findings of the present study are limited to the eight risk factors contained in the secondary data at our disposal. Furthermore, the sample size consists of only 189 observations on some pregnant women who attended antenatal care at a medical facility in Springfield, Illinois, USA. It is not clear whether or not the findings could be generalized for all pregnant mothers from other regions of the world. These limitations set the pace for future research with data that encompass a larger set of maternal factors across participants of diverse origins.

5. Conclusion

Association rules mining was deployed on some existing maternity data to extract rules that show the maternal attributes that frequently co-occur and influence birthweight. The extracted rules show that a mother's pre-pregnancy weight, presence/absence of uterine irritability, attendance to antenatal care visits in the first trimester, history of hypertension, age, and history of premature labor co-occur in different patterns that lead to either a low or normal neonatal birthweight. These rules can be used as a reference tool in the implementation of programs and interventions for pregnant mothers to ensure positive pregnancy outcomes related to birthweight. There is the need for medical practitioners to educate pregnant mothers on how their attributes affect neonatal birthweight. Further, the findings of this study should remind pregnant mothers that even when there are some positive attributes to their credit, a co-occurrence with one or more specific negative attributes could negatively influence birthweight. The findings are based on some secondary data from a medical facility in the USA where the participants were limited to certain demographics. A similar study is required on some data with a more representative demographics across participants.

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Declaration of competing interest

None.

References

- ACOG, 2020. Gestational hypertension and preeclampsia: ACOG practice bulletin, number 222. *Obstet. Gynecol.* 135 (6), e237–e260. <https://doi.org/10.1097/AOG.0000000000003891>.
- Afaya, A., Afaya, R.A., Azongo, T.B., Yakong, V.N., Konlan, K.D., Agbinku, E., Agyabeng-Fandoh, E., Akokre, R., Karim, J.F., Salia, S.M., Kaba, R.A., Ayanore, M.A., 2021. Maternal risk factors and neonatal outcomes associated with low birth weight in a secondary referral hospital in Ghana. *Heliyon* 7 (5), e06962.
- Atsa'am, D.D., Gbaden, T., Wario, R., 2022. Association rules on attributes of illicit drugs, suspect's demographics and offence categories. *J. Drug Issues*. <https://doi.org/10.1177/00220426221140010>.
- Atsa'am, D.D., Wario, R., 2022a. Association rules on the COVID-19 variants of concern to guide choices of tourism destinations. *Curr. Issues Tourism* 25 (10), 1536–1540. <https://doi.org/10.1080/13683500.2021.1951182>.
- Atsa'am, D.D., Wario, R., 2022b. Association rules extraction from the coronavirus disease 2019: attributes on morbidity and mortality. *Int. J. Healthc. Inf. Syst. Inf.* 17 (1), 1–10. <https://doi.org/10.4018/IJHISI.302652>.
- Atsa'am, D.D., Wario, R., Balogun, O.S., 2022. Antenatal care visits: a moderator of the association between a mother's age and the neonate's birth weight. *Int. J. Childbirth* 12 (1), 15–22. <https://doi.org/10.1891/IJC-2021-0019>.
- Balogun, O.S., Atsa'am, D.D., Akingbade, T.J., Kolog, E.A., Agjei, R.O., Devine, S.N.O., 2020. Modeling the effect of mother's characteristics on the weight of a newborn. *Int. J. Childbirth* 10 (4), 206–216.
- Bernstein, I.M., Mongeon, J.A., Badger, G.J., Solomon, L., Heil, S.H., Higgins, S.T., 2005. Maternal smoking and its association with birth weight. *Obstet. Gynecol.* 106 (5 Part 1), 986–991.
- Blencowe, H., Kraveev, J., de Onis, M., Black, R.E., An, X., Stevens, G.A., Borghi, E., Hayashi, C., Estevez, D., Cegolon, L., Shiekh, S., Ponce Hardy, V., Lawn, J.E., Cousens, S., 2019. National, regional, and worldwide estimates of low birth weight in 2015, with trends from 2000: a systematic analysis. *Lancet Global Health* 7 (7), e849–e860. [https://doi.org/10.1016/S2214-109X\(18\)30565-5](https://doi.org/10.1016/S2214-109X(18)30565-5).
- Cliver, S.P., Goldenberg, R.L., Cutter, G.R., Hoffman, H.J., Davis, R.O., Nelson, K.G., 1995. The effect of cigarette smoking on neonatal anthropometric measurements. *Obstet. Gynecol.* 85 (4), 625–630.
- Cnattingius, S., 2004. The epidemiology of smoking during pregnancy: smoking prevalence, maternal characteristics, and pregnancy outcomes. *Nicotine Tob. Res.* 6 (Suppl. 12), S125–S140.
- DeMarco, N., Twynstra, J., Ospina, M.B., Darrington, M., Whippey, C., Seabrook, J.A., 2021. Prevalence of low birth weight, premature birth, and stillbirth among pregnant adolescents in Canada: a systematic review and meta-analysis. *J. Pediatr. Adolesc. Gynecol.* 34 (4), 530–537. <https://doi.org/10.1016/J.JPAG.2021.03.003>.
- Erasun, D., Alonso-Molero, J., Gómez-Acebo, I., Dierssen-Sotos, T., Llorca, J., Schneider, J., 2021. Low birth weight trends in Organisation for Economic Co-operation and Development countries, 2000–2015: economic, health system and demographic conditionings. *BMC Pregnancy Childbirth* 21 (1). <https://doi.org/10.1186/s12884-020-03484-9>.
- Foster, J.P., Cole, M.J., Seth, R., 2016. Oral immunoglobulin for preventing necrotizing enterocolitis in preterm and low birth weight neonates. In: *Cochrane Database of Systematic Reviews* (Vol. 2016, Issue 4). John Wiley and Sons Ltd. <https://doi.org/10.1002/14651858.CD001816.pub3>.
- Fuchs, F., Monet, B., Ducruet, T., Chaillet, N., Audibert, F., 2018. Effect of maternal age on the risk of preterm birth: a large cohort study. *PLoS One* 13 (1), e0191002. <https://doi.org/10.1371/journal.pone.0191002>.
- Ghaemmghami, S.J., Nikniaz, L., Mahdavi, R., Nikniaz, Z., Razmfard, F., Afsharnia, F., 2013. Effects of infants' birth order, maternal age, and socio-economic status on birth weight. *Saudi Med. J.* 34 (9), 949–953. PMID: 24043008.
- Gladstone, M.E., Salim, N., Ogillo, K., Shamba, D., Gore-Langton, G.R., Day, L.T., Blencowe, H., Lawn, J.E., Shabani, J., Shirima, K., Tarimo, M.N., Mbaruku, G., Masanja, H., Ruysen, H., Peven, K., Gordeev, V.S., Boggs, D., Kong, S., Baschieri, A., et al., 2021. Birth weight measurement processes and perceived value: qualitative research in one EN-BIRTH study hospital in Tanzania. *BMC Pregnancy Childbirth* 21 (1), 1–11. <https://doi.org/10.1186/S12884-020-03356-2/FIGURES/2>.
- Goh, D.H., Ang, R.P., 2007. An introduction to association rule mining: an application in counseling and help-seeking behavior of adolescents. *Behav. Res. Methods* 39 (2), 259–266.
- Goldenberg, R.L., Culhane, J.F., 2007. Low birth weight in the United States. *Am. J. Clin. Nutr.* 85 (2), 584S–590S.
- Groothuis, J.R., Makari, D., 2012. Definition and outpatient management of the very low-birth-weight infant with bronchopulmonary dysplasia. *Adv. Ther.* 29 (4), 297–311. <https://doi.org/10.1007/s12325-012-0015-y>.
- Hilaire, M., Andrianou, X.D., Lenglet, A., Ariti, C., Charles, K., Buitenhuis, S., Van Brusselen, D., Roggeveen, H., Ledger, E., Denat, R.S., Bryson, L., 2021. Growth and neurodevelopment in low birth weight versus normal birth weight infants from birth to 24 months, born in an obstetric emergency hospital in Haiti, a prospective cohort study. *BMC Pediatr.* 21 (1), 1–16. <https://doi.org/10.1186/S12887-021-02605-3/FIGURES/8>.
- Hoodbhoy, Z., Mohammed, N., Rozi, S., Aslam, N., Mohsin, S., Ashiqali, S., Ali, H., Sattar, S., Chowdhury, D., Hasan, B.S., 2021. Cardiovascular dysfunction in children exposed to preeclampsia during fetal life. *J. Am. Soc. Echocardiogr.* 34 (6), 653–661. <https://doi.org/10.1016/J.ECHO.2021.01.008>.
- Khan, N., Jamal, M., 2003. Maternal risk factors associated with low birth weight. *J. Coll. Phys. Surg. Pakistan: JCPSP* 13 (1), 25–28.
- Kono, Y., 2021. Neurodevelopmental outcomes of very low birth weight infants in the neonatal research network of Japan: importance of neonatal intensive care unit graduate follow-up. *Clin. Exp. Pediatr.* 64 (7), 313–321. <https://doi.org/10.3345/cep.2020.01312>.
- Lange, S., Probst, C., Rehm, J., Popova, S., 2018. National, regional, and global prevalence of smoking during pregnancy in the general population: a systematic review and meta-analysis. *Lancet Global Health* 6 (7), e769–e776. [https://doi.org/10.1016/S2214-109X\(18\)30223-7](https://doi.org/10.1016/S2214-109X(18)30223-7).
- Macedo, T.C.C., Montagna, E., Trevisan, C.M., Zaia, V., de Oliveira, R., Barbosa, C.P., Laganà, A.S., Bianco, B., 2020. Prevalence of preeclampsia and eclampsia in adolescent pregnancy: a systematic review and meta-analysis of 291,247 adolescents worldwide since 1969. *Eur. J. Obstet. Gynecol. Reprod. Biol.* 248, 177–186. <https://doi.org/10.1016/j.ejogrb.2020.03.043>.
- Metgud, C.S., Naik, V.A., Mallapur, M.D., 2012. Factors affecting birth weight of a newborn—a community based study in rural Karnataka, India. *PLoS One* 7 (7), e40040.
- MFMER, 2022. Pregnancy Weight Gain: What's Healthy? <https://www.mayoclinic.org/healthy-lifestyle/pregnancy-week-by-week/in-depth/pregnancy-weight-gain/art-20044360>.
- Ødegård, R.A., Vatten, L.J., Nilsen, S.T., Salvesen, K.Å., Austgulen, R., 2000. Preeclampsia and fetal growth. *Obstet. Gynecol.* 96 (6), 950–955. [https://doi.org/10.1016/S0029-7844\(00\)01040-1](https://doi.org/10.1016/S0029-7844(00)01040-1).
- Olaleye, S.A., Ukpabi, D.C., Olawumi, O., Atsa'am, D.D., Agjei, R.O., Oyelere, S.S., Sanusi, I.T., Agbo, F.J., Balogun, O.S., Gbadegeshin, S.A., Adegbite, A., Kolog, E.A., 2022. Association rule mining for job seekers' profiles based on personality traits and Facebook usage. *Int. J. Bus. Inf. Syst.* 40 (3), 299–326.
- Senthilkumar, D., Paulraj, S., 2015. Prediction of low birth weight infants and its risk factors using data mining techniques. March. In: *Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management*, pp. 186–194.

- Shin, Y.H., Choi, S.J., Kim, K.W., Yu, J., Ahn, K.M., Kim, H.Y., et al., 2013. Association between maternal characteristics and neonatal birth weight in a Korean population living in the Seoul metropolitan area, Korea: a birth cohort study (COCOA). *J. Kor. Med. Sci.* 28 (4), 580–585.
- Simonsen, S.E., Lyon, J.L., Stanford, J.B., Porucznik, C.A., Esplin, M.S., Varner, M.W., 2013. Risk factors for recurrent preterm birth in multiparous Utah women: a historical cohort study. *BJOG An Int. J. Obstet. Gynaecol.* 120 (7), 863–872. <https://doi.org/10.1111/1471-0528.12182>.
- Singh, G., Chouhan, R., Sidhu, K., 2009. Maternal factors for low birth weight babies. *Med. J. Armed Forces India* 65 (1), 10–12.
- Steer, P.J., Little, M.P., Kold-Jensen, T., Chapple, J., Elliott, P., 2004. Maternal blood pressure in pregnancy, birth weight, and perinatal mortality in first births: prospective study. *BMJ* 329 (7478), 1312.
- Spong, C.Y., 2007. Prediction and prevention of recurrent spontaneous preterm birth. *Obstet. Gynecol.* 110 (2), 405–415. <https://doi.org/10.1097/01.AOG.0000275287.08520.4a>.
- Sutan, R., Mohtar, M., Mahat, A.N., Tamil, A.M., 2014. Determinant of low birth weight infants: a matched case control study. *Open J. Prev. Med.* 4 (3), 91–99. <https://doi.org/10.4236/ojpm.2014.43013>.
- Tela, F.G., Bezabih, A.M., Adhanu, A.K., 2019. Effect of pregnancy weight gain on infant birth weight among mothers attending antenatal care from private clinics in Mekelle City, Northern Ethiopia: a facility based follow-up study. *PLoS One* 14 (3), e0212424. <https://doi.org/10.1371/journal.pone.0212424>.
- Tessema, Z.T., Tamirat, K.S., Teshale, A.B., Tesema, G.A., 2021. Prevalence of low birth weight and its associated factor at birth in Sub-Saharan Africa: a generalized linear mixed model. *PLoS One* 16 (3), e0248417. <https://doi.org/10.1371/JOURNAL.PONE.0248417>.
- UNICEF-WHO, 2020. UNICEF-WHO Low birth weight estimates. In: Definitions. <https://www.unicef.org/media/96976/file/UNICEF-WHO-Low-Birth-weight-estimates-2000-2015.pdf>.
- UNICEF, 2018. Neonatal care clinical guidelines. In: Ministry of Health Eswatini. <https://www.unicef.org/eswatini/media/631/file/UNICEF-Sd-Neonatal-Guidelines-report-2018.pdf>.
- Venables, W.N., Ripley, B.D., 2002. *Modern Applied Statistics with S*, 4th ed. Springer, New York.
- Waits, A., Guo, C.Y., Chien, L.Y., 2021. Inadequate gestational weight gain contributes to increasing rates of low birth weight in Taiwan: 2011–2016 nationwide surveys. *Taiwan. J. Obstet. Gynecol.* 60 (5), 857–862. <https://doi.org/10.1016/J.TJOG.2021.07.013>.
- Wang, S., Yang, L., Shang, L., Yang, W., Qi, C., Huang, L., Xie, G., Wang, R., Chung, M.C., 2020. Changing trends of birth weight with maternal age: a cross-sectional study in Xi'an city of Northwestern China. *BMC Pregnancy Childbirth* 20 (1), 1–8.
- WHO, 2011. Guidelines on Optimal Feeding of Low Birth-Weight Infants in Low- and Middle-Income Countries. World Health Organization. <https://www.who.int/publications/i/item/9789241548366>.
- WHO, 2016. New Guidelines on Antenatal Care for a Positive Pregnancy Experience. November 7. World Health Organization. <https://www.who.int/news/item/07-11-2016-new-guidelines-on-antenatal-care-for-a-positive-pregnancy-experience>.
- WHO, 2020. Adolescent Pregnancy. January 31. World Health Organization. <https://www.who.int/news-room/fact-sheets/detail/adolescent-pregnancy>.
- WHO, 2022a. ICD-11 for Mortality and Morbidity Statistics. World Health Organization. <https://icd.who.int/browse11/l-m/en/#/http://id.who.int/icd/entity/153712793>.
- WHO, 2022b. ICD-11 for Mortality and Morbidity Statistics. World Health Organization. <https://icd.who.int/browse11/l-m/en/#/http://id.who.int/icd/entity/2041060050>.
- Woelile, T.A., Kibret, G.T., Workie, H.M., Amare, A.T., Tigabu, A., Aynalem, Y.A., Chanie, E.S., Birlie, T.A., 2021. Survival status and predictors of mortality among low-birth-weight neonates admitted to the neonatal intensive care unit at felege hiwot comprehensive specialized hospital, Bahir dar, Ethiopia, 2020. *Pediatr. Health Med. Therapeut.* 12, 451. <https://doi.org/10.2147/PHMT.S323526>.
- Xi, C., Luo, M., Wang, T., Wang, Y., Wang, S., Guo, L., Lu, C., 2020. Association between maternal lifestyle factors and low birth weight in preterm and term births: a case-control study. *Reprod. Health* 17 (1), 1–9.
- Xiao, R., Sorensen, T.K., Williams, M.A., Luthy, D.A., 2003. Influence of pre-eclampsia on fetal growth. *J. Matern. Fetal Neonatal Med.* 13 (3), 157–162. <https://doi.org/10.1080/jmf.13.3.157.162>.
- Yang, J., Baer, R.J., Berghella, V., Chambers, C., Chung, P., Coker, T., Currier, R.J., Druzin, M.L., Kuppermann, M., Muglia, L.J., Norton, M.E., Rand, L., Ryckman, K., Shaw, G.M., Stevenson, D., Jelliffe-Pawlowski, L.L., 2016. Recurrence of preterm birth and early term birth. *Obstet. Gynecol.* 128 (2), 364–372. <https://doi.org/10.1097/AOG.0000000000001506>.
- Zhao, Q., Bhowmick, S.S., 2003. Association Rule Mining: A Survey. Nanyang Technological University, Singapore, p. 135.
- Zhou, L., Yau, S., 2007. Efficient association rule mining among both frequent and infrequent items. *Comput. Math. Appl.* 54 (6), 737–749.
- Zimmerman, E., 2018. Do infants born very premature and who have very low birth weight catch up with their full term peers in their language abilities by early school age? *J. Speech Lang. Hear. Res.* 61 (1), 53–65. https://doi.org/10.1044/2017_JSLHR-L-16-0150.