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ORIGINAL ARTICLE

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Development and validation of a simple algorithm to estimate common gestational age categories using standard administrative birth record data in Ontario, Canada

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ABSTRACT

Gestational age is often incompletely recorded in administrative records, despite being critical to paediatric and maternal health research. Several algorithms exist to estimate gestational age using administrative databases; however, many have not been validated or use complicated methods that are not readily adaptable. We developed a simple algorithm to estimate common gestational age categories from routine administrative data. We leveraged a population-based registry of all hospital births occurring in Ontario, Canada over 2002–2016 including 1.8 million birth records. In this sample, this simple algorithm had excellent performance compared to a verified measure of gestational age; 87.61% agreement (95% CI: 87.49, 87.74). The accuracy of the algorithm exceeded 98% for all of the gestational age categories. Agreement notably increased over time and was greatest among singleton births and infants born at 2500–2999 g. This study provides a straight-forward algorithm for accurately estimating common gestational age categories that is easily adaptable for use in other countries.

KEYWORDS
MOMBABY database; sex-specific; Ontario; algorithm; routine

IMPACT STATEMENT

- **What is already known on this subject?** Gestational age is often incompletely or inaccurately recorded in administrative health databases, despite being critical to the study of many paediatric and maternal health outcomes. Consequently, researchers must rely on various methods to estimate gestational age, many of these methods are either overly simple (i.e. assuming a uniform duration) or analytically complicated and difficult to adapt for new populations (e.g. regression-based approaches).
- **What the results of this study add?** This study, based on a population-based registry of all 1.8 million births occurring in Ontario, Canada 2003–2016, found that a simple, sex-specific algorithm using three commonly recorded birth record characteristics performs almost perfectly compared to a clinical estimate recorded near birth.
- **What the implications are of these findings for clinical practice and/or further research?** This study suggests that a straight-forward, sex-specific algorithm based on routinely collected birth record data is able to accurately estimate common gestational age categories (i.e. extreme preterm, <28 weeks; very preterm, 28–32 weeks; moderate-to-late preterm, 33–26 weeks; and term, 37 weeks of completed gestational age). This work will be of greatest interest to perinatal researchers using routinely collected health administrative data.

Introduction

The data routinely collected during healthcare delivery or epidemiological surveillance have generated novel opportunities for health research (Margulis et al. 2013; Eberg et al. 2017). However, such databases only contain information collected by providers at the time of care or otherwise relevant to the main purpose of data collection. For example, large administrative or clinical databases often contain incomplete or inaccurate information regarding gestational age at delivery, despite this being critical for the study of many maternal and child health outcomes (Margulis et al. 2013; Eberg et al. 2017). Consequently, researchers (Lynch and Zhang 2007; Callaghan and Dietz 2010; Margulis et al. 2013; Eberg et al. 2017) using health administrative data have relied on estimates of pregnancy duration using the best data available. The most common estimation methods for gestation age include: (1) assigning a uniform duration (i.e. 270–280 days); (2) estimation based solely on birthweight (i.e. growth charts); (3) estimation based on delivery codes for short gestation; (4) estimation based on routine prenatal care claims; and (5) combinations of the above methods (Margulis et al. 2013; Eberg et al. 2017).

The objective of this study was to develop a simple algorithm using standard administrative fields to estimate

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commonly applied gestational age categories. Further, we validated this algorithm relative to the gold standard clinical estimate of gestational age, as recorded on the delivery discharge record, using the data from a population-based birth registry.

Materials and methods

Data sources

Our study population comprised all of the hospital live births in Ontario, Canada, between the January 1 2003 and the December 31 2016. All of the interactions with Ontario's publicly funded health care system are recorded in various administrative databases. These datasets were linked using unique encoded identifiers and analysed at ICES. The Mother-Baby database (MOMBABY) links maternal hospital delivery and infant birth records; the deterministic linkage rate for MOMBABY consistently exceeded 98.09% during the study period (ICES 2019).

Unlike many other health administrative databases, MOMBABY captures the clinically assessed gestational age on the newborn discharge record. Currently in Canada, it is recommended that all mothers receive two ultrasound examinations as part of routine care: one during the first trimester to measure nuchal translucency to screen for aneuploidy and one in the second trimester to screen for foetal anomalies (SOGC 2014). In the absence of a dating ultrasound, pregnancy length is determined from reported date of last menstrual period (LMP) (Perinatal Services BC 2017; CIHI 2018). The estimate of gestational age recorded on the newborn record represents the best clinical estimate of gestation including a combination of both ultrasound- and LMP-based estimates (SOGC 2014); see Appendix for a detailed description. Gestational age is a mandatory birth record field in Ontario and electronic entries are verified against the discharge record by a trained medical coder (CIHI 2018).

Statistical analysis

We developed an algorithm following a simple Boolean logic, which included three indicators identified from the newborn record (Table 1): diagnostic codes indicating preterm or extreme preterm birth; diagnostic codes indicating small/light or heavy for gestational age; and sex-specific birthweight cut-offs based on the most recent growth charts published for Canadian infants (Kramer et al. 2000). We were specifically interested in estimating the following common gestational age categories: extremely preterm, <28 wGA; very preterm, 28–32 wGA; moderate-to-late preterm, 33–36 wGA; and term, 37+ wGA (WHO 2012).

During the study period, all of the diagnoses were coded using the International Classification of Diseases, 10th revision, Canada (ICD-10CA). Specifically, we considered the following diagnostic codes for short gestation: extreme immaturity, P07.2; and preterm newborn (other), P07.3. In Canada, the fifth ICD digit is not regularly recorded; however, the fifth digits for P07.2 correspond to births occurring at or before 27 wGA and P07.3 to births occurring between 28 and 36 wGA, inclusive. Further, we considered the following diagnostic codes for heavy or light for gestational age: disorders of newborn related to long gestation and high birth weight, P08○; and those related to slow foetal growth and foetal malnutrition, P05○. All of the diagnostic fields recorded on the birth record were considered.

Given that the diagnostic code indicating preterm birth encompasses all infants born between 28 and 36 wGA, we ensured that weight cut-offs for children bordering the very preterm (28–32 wGA) and moderate-to-late preterm (33–36 wGA) categories did not overlap by taking the average of the two mean weights reported in the sex-specific growth charts, where necessary. For example, a male infant weighing 2000 g at delivery with no preterm diagnostic codes and no heavy or light for age weight diagnostic codes identified on their newborn discharge record would be considered moderate-to-late preterm according to the algorithm, while a male infant of the same weight with a preterm diagnostic code

Table 1. Sex-specific algorithm using three standard birth record fields for the estimation of common gestational age categories: extremely preterm, very preterm, moderate-late preterm and term births.

Criteria	Prematurity flag[a]	Weight flag[b]	Gestational weight, g[c,d] Male	Female
Extreme preterm (<28 wGA)				
1	Extremely preterm	–	–	–
2	No preterm flag recorded	Light for GA	≤763	≤717
3	No preterm flag recorded	Heavy for GA	≤1444	≤1346
4	No preterm flag recorded	Missing	≤1103	≤1042
Very preterm (28–32 wGA)				
1	Preterm	Light for GA	≤1444	≤1346
2	Preterm	Heavy for GA	1445–2579	1347–2493
3	Preterm	Missing[e]	≤1802	≤1715
4	No preterm flag recorded	Light for GA	764–1443	718–1345
5	No preterm flag recorded	Heavy for GA	1445–2579	1347–2493
6	No preterm flag recorded	Missing	1104–1801	1043–1714
Moderate-late preterm (33–36 wGA)				
1	Preterm	Light for GA	1445–2321	1347–2227
2	Preterm	Heavy for GA	≥2580	≥2494
3	Preterm	Missing[e]	1803–3664	1716–3542
4	No preterm flag recorded	Light for GA	1445–2321	1347–2227
5	No preterm flag recorded	Heavy for GA	2580–3664	2494–3542
6	No preterm flag recorded	Missing[e]	1803–2206	1716–2112
Term (37+ wGA)				
1	No preterm flag recorded	Light for GA	≥2322	≥2228
2	No preterm flag recorded	Heavy for GA	≥3665	≥3543
3	No preterm flag recorded	Missing	≥2207	≥2113

wGA: weeks gestational age; GA: gestational age; ICD: International Classification of Diseases.
[a]Extreme preterm (short gestation) flag: ICD-10: P07.2; preterm (short gestation) flag: ICD-10: P07.3. All diagnostic fields recorded on the infant's birth record were considered. ICD-10CA codes were exclusively used during our study period. In Canada, the fifth ICD digit is not recorded; however, fifth digits for P07.2 correspond to births occurring at or before 27 wGA and P07.3 to births occurring 28–36 wGA.
[b]Heavy for gestational age (GA) flag: ICD-10: P08○; light for GA flag: ICD-10: P05○. All diagnostic fields recorded on the infant's birth record were considered. ICD-10CA codes were exclusively used during our study period.
[c]Weights exceeding 6000 g were assumed to be misreported in pounds (equivalent to 453.592 g).
[d]Sex-specific gestational weight cut-offs from Kramer et al. (2000).
[e]Given that the preterm newborn flag encompasses all infants born between 28 and 36 wGA, we ensured that weight cut-offs for children bordering the very preterm (28–32 wGA) and moderate-to-late preterm (33–26 wGA) categories did not overlap by taking the average of the two 50th percentile weight cut-offs reported in the sex-specific growth charts, where necessary; i.e. the highest weight cut-off from the lower gestational age category and the lowest weight cut-off from the higher gestational age category.

and heavy-for-gestational age code would be considered very preterm.

Agreement between the estimated and gold standard gestational age categories was quantified using Cohen's kappa statistic and a linearly weighted kappa statistic, which penalises disagreements the further apart they are (Altman 1991). Kappa values range from 0 to 1, where values greater than 0.8 indicate almost perfect agreement, 0.61–0.80 substantial, 0.41–0.60 moderate, 0.21–0.40 fair and 0.20 poor agreement (Altman 1991). Category-specific estimates of sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy were also calculated. All of the statistics were reported with 95% confidence intervals.

A limited missingness was expected as most variables are mandatory fields in Ontario. In the rare case that gestational age could not be classified, these infants were excluded from the analysis. All of the effective sample sizes are provided.

To ascertain whether certain births may be more susceptible to misclassification, we investigated whether agreement varied according to important infant characteristics: sex, singleton *versus* the multiple, birth year and birthweight categories.

All of the analyses were performed in SAS, version 9.4 (SAS Institute Inc., Cary, NC). Approval for the study was obtained from the University of Toronto's Health Sciences Research Ethics Board.

Results

Out of the 1.8 million births which were included in this study, approximately 2600 (0.1%) births were excluded because they did not have valid linkage identifiers. Only 4739 (0.3%) of births were missing either an estimated or a recorded gestational age. Compared to the gold standard, this simple algorithm performed almost perfectly: 87.61% (95% CI 87.49, 87.74); weighted kappa: 89.35% (95% CI 89.24, 89.46) (Table 2). Further, the diagnostic accuracy of the algorithm was considerably high for each category of gestational age; the accuracy of the algorithm exceeded 98% for all categories of gestational age (Table 3). However, based on sensitivity and PPV, the algorithm performed only modestly well for very preterm births; sensitivity: 65.86% (65.19, 66.53) and PPV: 65.61% (65.02, 66.19).

Table 4 summarises the sensitivity analyses by the key birth characteristics. There were no sex-specific differences. However, an agreement increased over time, such that the agreement was greatest for children born later in the study period. The agreement was also greater among the singletons. Notable differences were observed by the birthweight, such that the algorithm performed best for the infants born between 2500 and 2999 g and between 3000 and 3499 g. For all other birthweight categories, the algorithm performed substantially well, with unweighted kappa values exceeding 67% and weighted kappa values exceeding 63%.

Discussion

We developed a simple, easily implementable algorithm which estimated common gestational age categories almost as perfectly as the gold standard clinical estimate in this large, population-based sample. Overall, the algorithm also performed well based on measures of sensitivity, specificity

Table 2. Agreement between estimated gestational age (GA) category and recorded GA category, based on continuous number of weeks of completed gestational age (wGA) as recorded by medical professional at the time of birth, for births occurring in Ontario, Canada, January 1 2003 through to December 31 2016.

	Estimated gestational age *N* (row %)				
Recorded gestational age	Extreme preterm	Very preterm	Moderate to late preterm	Term	Total
Extreme preterm	6332	614	67	92	7105
<28 wGA	(89.1)	(8.6)	(0.9)	(1.3)	
Very preterm	404	12,785	5779	444	19,412
28–32 wGA	(2.1)	(65.9)	(29.8)	(2.3)	
Moderate to late preterm	164	5537	99,400	7712	112,813
33–36 wGA	(0.2)	(4.9)	(88.1)	(6.8)	
Term	374	550	10,932	1,652,236	1,664,092
37+ wGA	(0.02)	(0.03)	(0.7)	(99.3)	
Total	7,274	19,486	116,178	1,660,484	1,803,422

Simple kappa (95% CI): 87.61 (87.49, 87.74); Weighted kappa (95% CI): 89.35 (89.24, 89.46). Number of births missing either recorded or estimated GA and excluded from analysis: 4739 (0.3%).

Table 3. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy, with 95% confidence intervals, for each algorithm category compared to clinical estimate of continuous gestational age (GA).

Estimated GA category	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Accuracy (95% CI)
Extreme preterm	89.12	99.95	87.05	99.96	99.90
<28 wGA	(88.37, 89.84)	(99.94, 99.95)	(86.31, 87.76)	(99.95, 99.96)	(99.90, 99.91)
Very preterm	65.86	99.62	65.61	99.63	99.26
28–32 wGA	(65.19, 66.53)	(99.62, 99.63)	(65.02, 66.19)	(99.62, 99.64)	(99.25, 99.27)
Moderate to late preterm	88.11	99.01	85.56	99.21	98.33
33–36 wGA	(87.92, 88.30)	(98.99, 99.02)	(85.37, 85.75)	(99.19, 99.22)	(98.31, 98.35)
Term	99.29	94.08	99.50	91.71	98.89
37+ wGA	(99.27, 99.30)	(93.95, 94.20)	(99.49, 99.51)	(91.57, 91.84)	(98.87, 98.90)

Number of births missing either recorded or estimated GA and excluded from analysis: 4739 (0.3%).

Table 4. Sensitivity analysis of agreement between administrative data-based algorithm and recorded gestational age categories, according to specific infant characteristics.

Birth characteristic	Simple kappa (95% CI)	Weighted kappa (95% CI)	Effective sample size
Multiple birth set			
Singleton birth	87.41 (87.26, 87.55)	88.95 (88.82, 89.09)	1,744,582
Multiple birth	80.85 (80.43, 81.26)	84.47 (84.12, 84.82)	58,840
Birth sex			
Female	87.46 (87.27, 87.65)	89.16 (88.98, 89.33)	877,926
Male	87.74 (87.57, 87.91)	89.51 (89.36, 89.66)	925,496
Birth year			
2003	84.19 (83.63, 84.74)	86.87 (86.39, 87.36)	124,099
2004	84.71 (84.18, 85.25)	86.96 (86.48, 87.44)	127,001
2005	85.08 (84.56, 85.61)	87.31 (86.84, 87.78)	127,970
2006	85.54 (85.03, 86.04)	87.48 (87.02, 87.94)	129,630
2007	86.53 (86.04, 87.02)	88.39 (87.95, 88.83)	131,902
2008	87.08 (86.60, 87.55)	88.83 (88.40, 89.26)	133,046
2009	87.69 (87.21, 88.17)	89.52 (89.09, 89.94)	123,301
2010	87.62 (87.15, 88.09)	89.34 (88.91, 89.76)	130,778
2011	89.08 (88.64, 89.52)	90.55 (90.15, 90.94)	130,408
2012	89.31 (88.87, 89.74)	90.65 (90.25, 91.05)	131,459
2013	89.27 (88.83, 89.71)	90.80 (90.41, 91.19)	128,977
2014	89.72 (89.28, 90.15)	91.05 (90.65, 91.45)	128,645
2015	90.00 (89.57, 90.43)	91.35 (90.97, 91.74)	127,785
2016	90.15 (89.73, 90.57)	91.52 (91.14, 91.89)	128,421
Birthweight			
<1500 g	67.05 (66.02, 68.08)	63.27 (62.24, 64.30)	18,040
1500–2499 g	67.05 (66.61, 67.49)	69.84 (69.45, 70.23)	96,491
2500–2999 g	91.49 (91.28, 91.70)	91.23 (91.01, 91.45)	293,705
3000–3499 g	86.88 (86.48, 87.28)	86.08 (85.65, 86.51)	665,993
3500–3999 g	71.56 (69.83, 73.29)	69.15 (67.37, 70.93)	532,517
4000–4499 g	67.72 (63.65, 71.79)	63.32 (59.18, 67.46)	169,972
4500+ g	74.21 (67.95, 80.47)	74.61 (68.57, 80.65)	31,198

PPV, NPV and accuracy. The algorithm performed noticeably better over time but differentially depending on birthweight and for the singletons *versus* the multiples.

This work adds to a growing body of literature of gestational age algorithms, including those leveraging administrative databases. For example, Margulis et al. (2013) found that estimating preterm births (<37 wGA) based only on ICD-9/10 codes for short gestation and low birthweight alone had a sensitivity and specificity of 91% and 98%, respectively, compared to a clinical estimate. Others (Lynch and Zhang 2007; Callaghan and Dietz 2010; Eberg et al. 2017), have proposed more complicated algorithms, such as those based on prenatal visits, ultrasound, and specific maternal or child characteristics. However, many of these factors are not readily available in administrative databases and rely on methods that are not easily transferrable. When choosing the best of these methods, authors must balance the need for accuracy with ease of implementation (Callaghan and Dietz 2010; Margulis et al. 2013; Eberg et al. 2017); e.g. regression-based methods may be more accurate but somewhat more complicated to implement, particularly in settings other than those for which they were developed (Lynch and Zhang 2007). Unlike more complicated methods, the Boolean criteria used to develop this algorithm are straight-forward, are easy to implement and are readily adaptable; e.g. revised for different birthweight distributions. Similarly, the included ICD codes are commonly used in many jurisdictions but could be easily adapted for other medical coding systems.

There as some limitations to consider. Most notably, this algorithm was developed and validated among live births; it is not intended for the estimation of pregnancy duration for stillbirths or abortions. In other databases, more detailed information on weeks of gestational age can be ascertained; i.e. by using the fifth ICD digit. Perhaps because of this data limitation, this algorithm performed less well for the infants born very term and those with very light or heavy birthweights. Similarly, this may have reduced the sensitivity of the test for correctly identifying infants born very preterm (28–32 wGA); i.e. sex-specific birthweight was an important factor for distinguishing 28–32 from 33 to 36 wGA births, which is less accurate than the combined use of diagnostic codes and birthweight distributions. Further, information on the means of clinical estimation of gestational age was not available in this database. While the majority of births in Ontario have at least one ultrasound examination to support the estimation of gestational age, some clinical estimates may be based solely on LMP, which is known to be less precise than ultrasound-based methods (SOGC 2014). Lastly, this algorithm is only intended to estimate four common gestational age categories. While it is more informative than a simple binary classification of preterm births, it is also not as sophisticated as methods for estimating a continuous measure of weeks of completed gestational age.

Conclusions

A simple algorithm using commonly recorded administrative birth fields can be used to estimate common categories of gestational age almost as perfectly as a clinical estimate. Based on this population-based cohort of 1.8 million births, this algorithm was able to accurately classify all categories of gestational age. This work has broad applicability for maternal and child health researchers using administrative and other health data where clinically assessed estimates of gestational age may be missing or incomplete.

Registration

Note that this observational study was not registered but, as per our institutional research guidelines, a detailed study protocol was developed from which we did not deviate. We would be pleased to share this protocol, if of interest.

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Disclosure statement

The authors report no conflict of interest.

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Appendix. Detailed description of clinical estimation guidelines for gestational age in Canada

***Gestational age, in completed weeks, is calculated as follows*:**

1. If the date of last menstrual period (LMP) is recorded on the medical chart and there is no ultrasound, use the gestational (GA) estimate based on LMP.
2. If LMP is recorded on the medical chart but there is no early ultrasound: if the clinical exam of the baby (performed near birth) gives a GA at least 3 weeks different than the LMP-based estimate, the GA estimate from clinical exam should be used.
3. If LMP is recorded and equal to GA (in weeks) based on the ultrasound examination at <14 weeks gestation, use the GA estimate based on LMP. If these estimates are not equal, use the GA estimate based on ultrasound.
4. If LMP is recorded and within 1 week of the GA estimate (in weeks) based on ultrasound at 14–20 weeks gestation, use the GA estimate from LMP. If the difference is more than 1 week, use the GA estimate from ultrasound examination.
5. If LMP is recorded and within 2 weeks of GA estimate (in weeks) based on ultrasound examination at 14–20 weeks gestation, use the GA estimate based on LMP. If this difference is more than 2 weeks, use the GA estimate based on ultrasound examination.
6. If LMP is not recorded but a GA estimate based on ultrasound examination occurring <22 weeks gestation is recorded, use the GA estimate based on ultrasound examination.
7. If LMP and early ultrasound are not recorded, use the GA estimate from the newborn clinical exam.
8. If LMP, early ultrasound, and newborn clinical exam are not recorded, use the GA estimate from the newborn chart documentation.
9. If all are missing or out of range, GA sound be recorded as missing.

Note: Only LMP-based estimates between 15 and 45 weeks and ultrasound-based estimates between 17 and 43 weeks are considered valid for the purposes of the above calculation.

***The final gestational age estimate is chosen according to the following*:**

1. Use the gestational age from mother's LMP if GA estimate based on LMP date and calculated GA by first ultrasound date differ by less than 7 days.
2. If the difference between GA by LMP and early ultrasound is greater than 1 week but less than 2 weeks, then:
   a. Use GA estimate according to early ultrasound, if the ultrasound was done at less than 12 weeks gestation.
   b. Use the GA estimate according to LMP if the ultrasound was done 12–19 weeks gestation.
3. If the difference between the GA estimate according to LMP and early ultrasound is greater than or equal to 2 weeks, then the GA estimate according to early ultrasound should be used.
4. If no GA estimated based on LMP is recorded, then GA from early ultrasound is used.
5. If no GA estimate from LMP or early ultrasound is recorded, then the GA estimate from the newborn exam should be used.
6. If no GA estimate is recorded from LMP, early ultrasound or newborn exam, then the GA estimate from the maternal chart documentation should be used.

References: SOGC (2014)*;* Perinatal Services BC (2017).