Received: 2 April 2019 | Revised: 24 June 2019 | Accepted: 1 July 2019

DOI: 10.1111/ppe.12571

SPECIAL ISSUE: MATERNAL HEALTH

Paediatric and Perinatal Epidemiology WILEY

Identifying cardiovascular severe maternal morbidity in epidemiologic studies

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Funding information
Funding for this study was provided by the Women & Infants Hospital of Rhode Island Constance A. Howes Innovation Research Fund Award.

Abstract

Background: Cardiovascular severe maternal morbidity (CSMM) is rising and has become the leading cause of maternal mortality. Research using administrative data sets may allow for better understanding of this critical group of diseases.

Objective: To validate a composite variable of CSMM for use in epidemiologic studies.

Methods: We analysed delivery hospitalisations at an obstetric teaching hospital from 2007 to 2017. We utilised a subset of indicators developed by the Centers for Disease Control and Prevention based on ICD codes to form the composite variable for CSMM. Two expert clinicians manually reviewed all qualifying events using a standardised tool to determine whether these represented true CSMM events. Additionally, we estimated the number of CSMM cases among delivery hospitalisations without qualifying ICD codes by manually reviewing all hospitalisations with severe preeclampsia, a population at high risk of CSMM, and a random sample of 1000 hospitalisations without severe preeclampsia. We estimated validity of the composite variable.

Results: Among 91 355 admissions for delivery, we captured 113 potential CSMM cases using qualifying ICD codes. Of these, 65 (57.5%) were true CSMM cases. Indicators for acute myocardial infarction, cardiac arrest, and cardioversion had the highest true-positive rates (100% for all). We found an additional 70 CSMM cases in the 2102 admissions with severe preeclampsia and a single CSMM case in the random sample. Assuming a rate of 1 CSMM case per 1000 deliveries in the remaining cohort, the composite variable had a positive predictive value of 57.5% (95% CI 47,9, 66.8), a negative predictive value of 99.8% (95% CI 99.8, 99.9), a sensitivity of 29.0% (95% CI 23.2, 35.4), and a specificity of 100% (95% CI 99.9, 100.0).

Conclusion: A novel composite variable for CSMM had reasonable PPV but limited sensitivity. This composite variable may enable epidemiologic studies geared towards reducing maternal morbidity and mortality.

KEYWORDS

cardiovascular disease, maternal mortality, severe maternal morbidity, validation study

1 | BACKGROUND

The Centers for Disease Control and Prevention (CDC) has reported a rise in pregnancy-related deaths estimated at 18 per 100 000 livebirths in 2014 as compared to 7.2 per 100 000 livebirths in 1987.[1] Cardiovascular conditions, responsible for at least 15.2% of these deaths in the United States (US), have emerged as the leading cause of maternal mortality.[2] Similar trends have been observed in other high-income countries such as Canada, the United Kingdom, and the Netherlands.[3-5]

While maternal mortality remains a rare event, the World Health Organization (WHO) has recommended a focus on maternal morbidity to monitor and improve the quality of obstetric care.[6] Severe maternal morbidity is defined as an unintended outcome of the process of labour and delivery, resulting in significant short-term or long-term consequences to a woman's health.[7] In addition to being on the pathway to mortality, severe maternal morbidity may be associated with increased direct medical costs, extended length of hospital stay, and long-term rehabilitation.[8] Between 1993-1994 and 2012-2014, the United States experienced a twofold increase in severe maternal morbidity.[9] This trend could be explained by transformations within the obstetric population since advanced maternal age, obesity, chronic medical conditions, and use of caesarean section delivery have become more prevalent.[2] Importantly, several cardiovascular indicators of severe maternal morbidity, such as cardiac arrest and myocardial infarction, have contributed to this rise.[9] Further research aimed at better understanding this critical group of diseases and its true burden across populations is required.

Administrative data sets represent increasingly used and cost-effective data sources to study severe maternal morbidity in epidemiologic studies given the relative rarity of this outcome.[10,11] They allow for efficient assessment of disease incidence as well as temporal and regional trends.[10,12] Yet, the use of administrative data in maternal morbidity research has been limited by the fact that establishing the diagnosis of severe maternal morbidity often calls upon clinical judgement requiring medical record review.[10] The CDC has established indicators for identifying severe maternal morbidity in administrative data, but there are currently no guidelines for identifying cardiovascular severe maternal morbidity (CSMM) specifically. As a first step, we sought to develop and validate a composite variable for CSMM based on a subset of severe maternal morbidity indicators developed by the CDC for future use in epidemiologic studies.

Synopsis

Study question

Can cardiovascular severe maternal morbidity (CSMM) be studied using administrative data sources in epidemiology research?

What's already known

CSMM has become the leading cause of maternal mortality, and this adverse maternal outcome requires further study. Administrative data sets represent efficient data sources, yet their use is limited because establishing the diagnosis of severe maternal morbidity often requires clinical judgement.

What this study adds

We developed a composite variable for CSMM based on indicators from the Centers for Disease Control and Prevention. We reported a good positive predictive value but a limited sensitivity for this composite variable. Future epidemiologic studies may use the composite CSMM variable to accurately identify severe cardiovascular morbidity among delivery hospitalisations, recognising that the total disease burden may be underestimated.

2 | MATERIALS AND METHODS

2.1 | Data source and study population

Women & Infants Hospital is an obstetric teaching hospital in Providence, Rhode Island, that performs more than 70% of all deliveries in the state. We studied discharges from delivery hospitalisations from 1 January 2007 to 31 October 2017 at this tertiary centre. A database compiled by the National Perinatal Information Center (NPIC) comprising admissions for delivery coded with either the 9th or 10th editions of the International Classification of Diseases diagnosis and procedure codes (ICD-9 and ICD-10) was used for analysis.[13] The database was coded using ICD-9 from the start of the study period until 30 September 2015, and ICD-10 from 1 October 2015 onwards.

2.2 | Definition of the composite outcome variable of cardiovascular severe maternal morbidity

We used a subset of indicators developed by the CDC based on ICD codes to form the composite variable for CSMM.[9] We considered women with ICD codes for at least one of the following CDC indicator groups of CSMM during admission for delivery as potential cases: acute myocardial infarction, aneurysm, cardiac arrest/ventricular fibrillation, conversion of cardiac rhythm, heart failure/arrest during surgery or procedure, puerperal cerebrovascular disorders, and pulmonary oedema/acute heart failure[9] (Table 1). In addition, we included ICD codes from the shock category that were potentially related to cardiogenic shock (Table 1).[9]

2.3 | Identification of cardiovascular severe maternal morbidity in medical record

A standardised electronic data abstraction tool was developed and pilot-tested by two obstetric internists (IM and NM) to determine and record whether potential cases were confirmed as having

TABLE 1 Indicators of cardiovascular severe maternal morbidity selected from the Centers for Disease Control and Prevention List of overall severe maternal morbidity indicators

Severe maternal morbidity indicator	ICD-9	ICD-10
Acute myocardial infarction	410.xx	I21.xx, I22.x
Aneurysm	441.xx	I71.xx, I79.0
Cardiac arrest/ventricular fibrillation	427.41, 427.42, 427.5	I46.x, I49.0x
Heart failure/arrest during surgery or procedure	997.1	I97.12x, I97.13x
Puerperal cerebrovascular disorders	430, 431, 432.x, 433.xx, 434. xx, 436, 437.x, 671.5x, 674.0x, 997.02	I60.xx- I68.xx, O225x, O873, I97.81x, I97.82x
Pulmonary oedema/acute heart failure	518.4, 428.1, 428.0, 428. 21, 428.23, 428.31, 428.33, 428.41, 428.43	J81.0, I50.1, I50.20, I50.21, I50.23, I50.30, I50.31, I50.33, I50.40, I50.41, I50.43, I50.9
Conversion of cardiac rhythm	99.6x	5A2204Z, 5A12012
Cardiogenic shock	785.50, 785.51, 785.59	R57.x, T81.10XA, T81.11XA, T81.19XA

ICD-9 and ICD-10 = International Classification of Diseases 9th and 10th revision, respectively.

one of the cardiovascular conditions of interest. The tool included whether CSMM events occurred as a result of pregnancy or whether they were present prior to the pregnancy but exacerbated by the pregnant state. The tool also directed how to assess whether diagnostic confirmation had been documented by at least one method including clinical examination, laboratory or radiologic testing, expert consultation, or response to therapy. Women were considered to be non-cases when they had a condition that did not represent severe maternal morbidity based on the *gold standard guidelines for severe maternal morbidity with the use of example-driven definitions*.[14] Specifically, women with administration of oxygen without a pulmonary diagnosis, those with pre-existing cardiac disease without intensive care unit admission, or those with arrhythmia requiring a single dose of intravenous medication were categorised as not having CSMM.[14] In addition, women with intensive care unit admission for observation only were categorised as not having CSMM.[14] Medical records of women identified using ICD codes were reviewed in detail by one of the two expert clinicians using the data abstraction tool. Twenty charts were randomly selected and abstracted by both clinicians to evaluate inter-observer reliability.

2.4 | Identification of false and true negatives

Given that the totality of delivery admissions during the 10-year study period could not be manually reviewed, trained data abstractors (HS and BB) performed a targeted manual screening of women at highest risk of missed events. Others have shown that the risk of severe cardiovascular morbidity at time of delivery hospitalisation among women with severe preeclampsia was about 3 times higher than among women without hypertensive disorders.[15] Therefore, in order to identify additional CSMM cases that had otherwise been missed by only using ICD codes for CSMM, we screened all medical records of women without ICD codes for CSMM but with ICD codes for severe preeclampsia (including haemolysis, elevated liver enzymes, and low platelet count (HELLP) syndrome, or hypertensive urgency). Moreover, in order to estimate the magnitude of CSMM cases that were missed in the remaining delivery cohort, we screened a simple random sample of 1000 delivery admissions without qualifying ICD codes for CSMM and without ICD codes for severe preeclampsia for additional CSMM cases.

2.5 | Statistical analysis

Inter-observer reliability for the data abstraction tool to identify CSMM was assessed using Cohen's κ coefficient with 95% confidence interval (CI), a measure of agreement. The positive predictive value (PPV) of individual CDC indicators of cardiovascular morbidity was measured as a percentage. When two or more CDC indicators were present during an admission for delivery, the PPV of each individual indicator was separately evaluated. However, each delivery admission only contributed one observation to the overall analysis of composite ICD-based variable validity, using diagnostic confirmation by expert reviewers as the gold standard.

We assessed the proportion of CSMM cases within a random sample of 1000 women without qualifying ICD codes for CSMM and without ICD codes for severe preeclampsia. For the base-case approach, we assumed similar proportions of CSMM cases between the random sample and the total remaining cohort to estimate the PPV, negative predictive value (NPV), sensitivity, and specificity of the CSMM composite variable with 95% confidence intervals (CIs). In

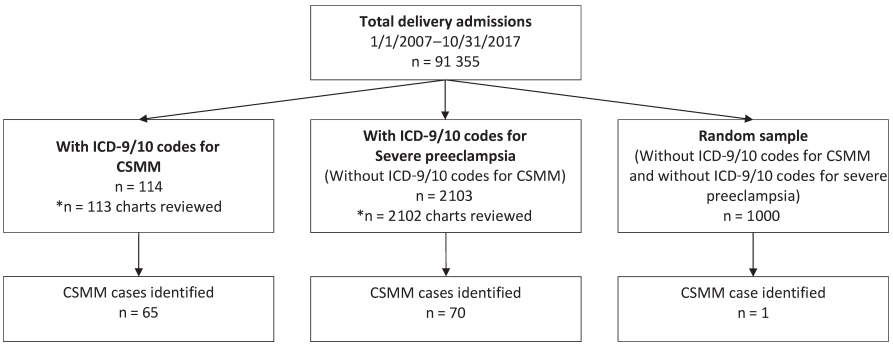

FIGURE 1 Flow chart of study population. *Medical records could not be located for two delivery admissions, leaving 91, 353 total delivery admissions in the study population. CSMM = cardiovascular severe maternal morbidity; ICD = International Classification of Diseases

a sensitivity analysis, we used best-case and worst-case scenario approaches to estimate the upper and lower limits of our measures of accuracy. In order to do so, we calculated the 95% CI of the proportion of CSMM cases in the random sample of 1000 women without qualifying ICD codes for CSMM and without ICD codes for severe preeclampsia. In the best-case scenario, we assumed that the risk of CSMM among unreviewed charts of the remaining cohort was equal to the lower confidence limit of our estimate. In the worst-case scenario, we assumed that the proportion of CSMM among unreviewed charts of the remaining cohort was equal to the upper confidence limit of our estimate.

A posteriori, we performed two exploratory analyses to optimise the validity of the CSMM algorithm. First, we modified the CDC coding algorithm by removing individual ICD codes that had the lowest PPV. Second, since the majority of missed CSMM events were

TABLE 2 Positive predictive value for individual indicators of cardiovascular severe maternal morbidity[a]

Cardiovascular indicators	Screened positive	True positive	PPV
Acute myocardial infarction	1	1	100%
Conversion of cardiac rhythm	7	7	100%
Cardiac arrest/ventricular fibrillation	4	4	100%
Pulmonary oedema/acute heart failure	60	51	85%
Puerperal cerebrovascular disorders	33	6	18%
Heart failure/arrest during surgery or procedure	12	2	17%
Aneurysm	1	0	0%
Cardiogenic shock	1	0	0%

[a]Four patients had more than one CDC indicator for CSMM: 1 patient had cardiac arrest/ventricular fibrillation and pulmonary oedema/acute heart failure; 2 patients had cardiac arrest/ventricular fibrillation and conversion of cardiac rhythm; 1 patient had cardiac arrest/ventricular fibrillation, acute heart failure/pulmonary oedema, heart failure/arrest during surgery or procedure, and conversion of cardiac rhythm.

TABLE 3 Cross-tabulation of ICD screening versus medical record diagnosis of cardiovascular severe maternal morbidity in the base-, best-, and worst-case scenario

	Medical record diagnosis		
	Positive	Negative	Total
Base-case scenario			
ICD screening			
Positive	65	48	113
Negative	159[a]	91 081	91 240
Total	224	91 129	91 353
Best-case scenario			
ICD screening			
Positive	65	48	113
Negative	70[b]	91 170	91 240
Total	135	91 218	91 353
Worst-case scenario			
ICD screening			
Positive	65	48	113
Negative	605[c]	90 635	91 240
Total	670	90 683	91 353

[a]In the base-case scenario, there were 70 CSMM events among 2102 women with severe preeclampsia and an estimated 89 CSMM events in the remaining cohort of 89 138 (ie, 1 missed CSMM events per 1000 deliveries).
[b]In the best-case scenario, there were 70 CSMM events among 2102 women with severe preeclampsia and no additional CSMM events in the remaining cohort of 89 138 (ie, 0 missed CSMM events per 1000 deliveries).
[c]In the worst-case scenario, there were 70 CSMM events among 2102 women with severe preeclampsia and an estimated 535 CSMM events in the remaining cohort of 89 138 (ie, 6 missed CSMM events per 1000 deliveries).

cases of severe preeclampsia with pulmonary oedema, we assessed whether the sensitivity of the CSMM coding algorithm could be improved by considering women with codes for severe preeclampsia in combination with at least one previously validated code for acute respiratory distress as having pulmonary oedema.[10] We ascertained validity of these two modified CSMM composite variables using a similar approach as the one described above.

Study data were collected and managed using REDCap electronic data capture tool hosted at Care New England.[16] Statistical analysis was performed using SAS 9.4 and STATA 15.

2.6 | Ethical considerations

Approval by the Institutional Review Board of the Women & Infants Hospital was obtained for this study (IRB# WIH 17-0103).

3 | RESULTS

3.1 | Study population

We identified 91 355 delivery admissions during the study period. Medical records could not be located for two delivery admissions, leaving 91, 353 delivery admissions in the study population (Figure 1). In total, 119 potential CSMM events were distributed among 113 potential CSMM cases. After manual review, 71 CSMM events were confirmed in 65 CSMM cases (Figure 1). Of 2102 delivery admissions with ICD codes for severe preeclampsia without any ICD code for CSMM, CSMM was confirmed in 70 cases (Figure 1). Within the simple random sample of 1000 delivery admissions without ICD codes for CSMM and without ICD codes for severe preeclampsia, one CSMM case was confirmed (Figure 1). Thus, the estimated rate of missed CSMM cases in the remaining delivery cohort was 1 CSMM (95% CI (0-6)) case per 1000 deliveries. A total of 142 CSMM events were found by manual review in 136 CSMM cases. The most frequent conditions among the 142 confirmed CSMM events were pulmonary oedema (n = 122; 85.9%), conversion of cardiac rhythm (n = 7; 4.9%), and cerebrovascular disorders (n = 6; 4.2%). Cardiac arrest/ventricular fibrillation, heart failure/arrest during surgery or procedure, and acute myocardial infarction, respectively, occurred in four, two, and one delivery admission. A summary of the CSMM cases identified with the 3 different search strategies can be found in Figure S1.

3.2 | Identification of CSMM events

There was 95% agreement between the two expert reviewers. This yielded a Cohen's κ coefficient of 0.89 (95% CI: 0.69, 1.00). Indicators with the highest PPV were acute myocardial infarction (100%), conversion of cardiac rhythm (100%), cardiac arrest/ventricular fibrillation (100%), and pulmonary oedema/acute heart failure (85.0%) (Table 2). Of the 48 women with positive ICD CSMM screening who were not confirmed CSMM cases, 27 (56.3%) did not have a new condition or a condition exacerbated by pregnancy, 17 (35.4%) did not have any of the cardiovascular conditions of interest, 9 (18.8%) were non-cases by the gold standard guidelines for severe maternal morbidity with the use of example-driven definitions, and 3 (6.3%) were missing diagnostic confirmation. Table S1 describes the diagnoses of women without any of the cardiovascular conditions of interest.

3.3 | Accuracy of the composite variable

With the base-case approach, we estimated that 159 CSMM cases remained among women without qualifying CSMM codes, for a total of 224 cases of CSMM in the total cohort (Table 3). Thus, the CSMM composite variable had a PPV of 57.5% (95% CI 47.9, 66.8), a NPV of 99.8% (95% CI 99.8, 99.9), a sensitivity of 29.0% (95% CI 23.2, 35.4), and a specificity of 100% (95% CI 99.9, 100) (Table 4). Results for the best- and worst-case scenario approaches are presented in Table 4. As expected with this rare event, the range of values for false negatives (from 70 to 605 CSMM cases in the remaining cohort) had a major influence on overall estimated sensitivity.

3.4 | Optimisation of the coding algorithm

The ICD-9 code 997.1 for 'cardiac complications not elsewhere classified', included as an indicator of heart failure/arrest during surgery or procedure, was found to represent sinus tachycardia or sinus bradycardia in most cases (see Table S1). Moreover, ICD-9 codes 671.51 or 671.52 for "other phlebitis and thrombosis complicating pregnancy and the puerperium", included as indicators of puerperal cerebrovascular disorders, were often used to designate thrombotic events that did not involve the neurologic system and did not represent CSMM (see Table S1). After removal of those three ICD codes from the composite variable, its PPV increased to 66% (95% CI 55.7, 75.3) (Table 4). The NPV, sensitivity, and specificity of this revised CSMM variable remained essentially unchanged (Table 4). After considering the combination of codes for severe preeclampsia and codes for acute respiratory distress as a proxy for pulmonary oedema, the sensitivity of the algorithm marginally improved (30.4%, 95% CI 24.4, 36.8), but the PPV decreased (53.1%, 95% CI 44.1, 62.0) (Table 4). Cross-tabulation of ICD screening versus medical record diagnosis of CSMM using both optimisation methods can be found in Tables S2 and S3.

4 | COMMENT

4.1 | Principal findings

Cardiovascular indicators of severe maternal morbidity developed by the CDC using ICD codes were regrouped to form a composite variable for CSMM. In a large population sample in the United States over the last decade, this composite variable was found to have good PPV but limited sensitivity for the diagnosis of CSMM events. Optimisation of the coding algorithm for CSMM increased its PPV without substantially decreasing its sensitivity. Sensitivity could not be improved without decreasing the PPV of the algorithm.

TABLE 4 Accuracy of the original and optimised composite variables for cardiovascular severe maternal morbidity in the base, best and worst-case scenario

	NPV (95% CI)	NPV (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)
Base-case scenario				
Original CSMM variable	57.5 (47.9, 66.8)	99.8 (99.8, 99.9)	29.0 (23.2, 35.4)	100 (99.9,100)
Optimised CSMM variable by Method #1[a]	66 (55.7, 75.3)	99.8 (99.8, 99.9)	28.7 (22.9, 35.1)	100 (99.9,100)
Optimised CSMM variable by Method #2[b]	53.1 (44.1, 62.0)	99.8 (99.8, 99.9)	30.4 (24.4, 36.8)	99.9 (99.9, 100)
Best-case scenario				
Original CSMM variable	57.5 (47.9, 66.8)	99.9 (99.9, 99.9)	48.1 (39.5, 56.9)	99.9 (99.9,100)
Optimised CSMM variable by Method #1[a]	66.0 (55.7, 75.3)	99.9 (99.9, 99.9)	47.8 (39.1, 56.6)	100 (99.9,100)
Optimised CSMM variable by Method #2[b]	53.1 (44.1, 62.0)	99.9 (99.9, 99.9)	50.4 (41.6, 59.1)	99.9 (99.9, 100)
Worst-case scenario				
Original CSMM variable	57.5 (47.9, 66.8)	99.3 (99.3,99.4)	9.7 (7.6, 12.2)	100 (99.9,100)
Optimised CSMM variable by Method #1[a]	66.0 (55.7, 75.3)	99.3 (99.3, 99.4)	9.6 (7.4, 12.1)	100 (99.9,100)
Optimised CSMM variable by Method #2[b]	53.1 (44.1, 62.0)	99.3 (99.3, 99.4)	10.1 (8.0, 12.7)	99.9 (99.9, 100)

CI, confidence interval; CSMM, cardiovascular severe maternal morbidity; PPV, positive predictive value; NPV, negative predictive value.
[a]Method #1: We removed ICD-9 codes 997.1, 671.51, and 671.52 from the CSMM algorithm.
[b]Method #2: We used a combination of codes for severe preeclampsia and codes for acute respiratory distress as a proxy for pulmonary oedema.

4.2 | Strengths of the study

This study had several strengths. It evaluated validity of a novel composite variable for CSMM, including estimated sensitivity measures from the entire study cohort of delivery hospitalisations. It used a standardised data abstraction tool in order to determine whether cardiovascular events captured represented true severe maternal morbidity, which was found to have excellent inter-observer reliability.

4.3 | Limitations of the data

The study was limited by the fact that the two reviewers were not blinded to patient's ICD diagnoses, which may have led to an overestimation of PPV and sensitivity. Small numbers of patients in specific CSMM subcategories may have led to imprecise estimates of these indicators' individual PPV. In addition, precision of the estimated false-negative rate based on a random sample of 1000 delivery hospitalisations was limited. This study reflected the validity of discharge billing codes of a single institution in Rhode Island, which reduced its external validity.

4.4 | Interpretation

In order to standardise population-based surveillance and facilitate cross-country comparisons, the WHO developed the Maternal Near Miss Tool, which comprises three identification methods for severe maternal morbidity.[17] The first uses a disease-specific approach, the second focuses on critical interventions and intensive care unit admissions, and the third proposes an organ dysfunction-based definition of severe maternal morbidity.[17] The organ dysfunction-based approach was initially thought to be the most promising identification method given its ability to parallel confidential enquires into maternal death systems, to establish patterns of diseases, and to identify new and emerging disease priorities.[18] However, subsequent validation studies in high- and in low-income settings have found the disease-specific approach to have higher detection rates than both the organ dysfunction-based and the critical intervention-based definition.[19,20] By using disease-specific indicators developed by the CDC, regrouped under a unifying system-based definition (ie, cardiovascular dysfunction), our composite variable for CSMM was able to combine and integrate these two approaches to define

severe maternal morbidity. In turn, our strategy could be applied to other system-based approaches such as haematologic dysfunction or respiratory dysfunction.

The validity of the coding algorithm for CSMM was comparable to the validity of the larger CDC coding algorithm for severe maternal morbidity (after exclusion of ICD codes for transfusions), which has been previously described.[14] In keeping with the relatively low incidence of severe maternal morbidity, both algorithms had a specificity and NPV of at least 99%.[14] The PPV of our optimised CSMM algorithm (66.0%), however, was higher than the PPV of the larger CDC algorithm (57.0%).[14] Due to high rates of false negatives, both coding algorithms failed to detect at least half of the cases that they were meant to identify.[14] The sensitivity of both algorithms remained limited by the underlying quality of the ICD coding in administrative data sets. The issue of undercoding of medical conditions in administrative data sets appears to be rather generalised since sensitivities <40% have been reported for the ICD codes of several medical conditions during pregnancy including seizure disorders, thrombocytopenia, sepsis, and VTE.[11] Given that accurate coding heavily relies on documentation in medical records,[11] informing treating teams about the importance of explicitly stating severe maternal morbidity diagnoses in their clinical documentation would be a paramount measure to improve accuracy of CDC indicators.

Severe cardiovascular morbidity affects 3.4 (95% CI 3.2, 3.5) per 1000 deliveries in normotensive women and 10.9 (95% CI 9.9, 11.9) per 1000deliveries in women with a hypertensive disorder of pregnancy.[15] In our cohort, women with pulmonary oedema/acute heart failure composed the majority of CSMM cases not captured by qualifying CDC codes. Pulmonary oedema, which complicates 3% of pregnancies with preeclampsia,[21] is a diagnostic criterion for severe preeclampsia.[22,23] Therefore, ICD codes for pulmonary oedema may have been omitted among women with severe preeclampsia because pulmonary oedema was assumed to be implied by the severe preeclampsia codes. Because of its under-diagnosis in women with severe preeclampsia, the national incidence of congestive heart failure or pulmonary oedema may be higher than the currently reported incidence of 2.4/10 000 delivery hospitalisations in 2014.[9]

The use of administrative data in maternal morbidity research has previously been limited by diagnostic codes not accurately reflecting the true degree of severity of diseases.[10,24] Several CDC indicators were found to have a low PPV, which was mostly due to conditions not being new or exacerbated by pregnancy or ICD codes not capturing the severely morbid conditions that they were meant to detect. In order to maximise PPV of the composite variable for CSMM, three problematic ICD codes were removed. Omission of ICD-9 code 997.1 for heart failure/arrest during surgery or procedure (frequently designating benign arrhythmia) and ICD-9 codes 671.51/671.52 for puerperal cerebrovascular events (mostly capturing non-neurologic thrombotic events) was found to increase the PPV of the CSMM variable without affecting its detection rate. As such, the optimised CSMM composite variable allowed for better capture of true morbidity, without overestimating the burden of maternal disease. Three problematic ICD-9 codes but no problematic ICD-10 codes were found, and this may have reflected a longer observation period for the use of ICD-9 than for the use of ICD-10 codes. Additionally, the ICD-9 CDC algorithm may have been less precise than the ICD-10 CDC algorithm for certain specific conditions, such as cerebral venous thrombosis. Indeed, codes 671.51/671.52 used as indicators of cerebrovascular disorders as part of the ICD-9 CDC algorithm referred to 'other phlebitis and thrombosis occurring during pregnancy and the puerperium'. In contrast, codes O22.5x and O87.3 used as indicators of cerebrovascular disorders as part of the ICD-10 CDC algorithm explicitly referred to cerebral vein thrombosis.

5 | CONCLUSIONS

The concept of a composite variable for CSMM was empirically assessed. While this variable had adequate specificity and PPV, it had a limited sensitivity. As a result, the true incidence of CSMM is likely higher than currently reported. Three diagnostic codes were found to be associated with a low true-positive rate, and these should be used with caution in future severe maternal morbidity research. The optimised CSMM composite variable may enable future epidemiologic studies geared towards reducing maternal morbidity and mortality and help prepare for refinements to enhance sensitivity. Further research is required to ascertain the extent of its external validity in different data sets.

CONFLICT OF INTEREST

The authors do not have any conflict of interest to declare.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Malhamé I, Mehta N, Raker CA, et al. Identifying cardiovascular severe maternal morbidity in epidemiologic studies. *Paediatr Perinat Epidemiol*. 2020;34:452–459. https://doi.org/10.1111/ppe.12571