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Review

Gestational diabetes mellitus and its impact on maternal and neonatal outcomes in Indigenous populations: a systematic review and meta-analysis

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ABSTRACT

This systematic review and *meta*-analysis examined the association between gestational diabetes mellitus (GDM) and adverse pregnancy outcomes among Indigenous populations globally. Pooled risk ratios were calculated using a random-effects model, and study quality was assessed using the Newcastle-Ottawa Scale and the CONSIDER Statement. Twenty studies from Canada, the United States, and Australia were included. Results showed that GDM was associated with increased caesarean section (risk ratio 1.83, 95% confidence interval 1.63 to 2.06), shoulder dystocia (3.21, 2.94 to 3.50), large for gestational age (2.35, 1.46 to 3.77), macrosomia (1.75, 1.48 to 2.07), preterm birth (1.36, 1.09 to 1.69), and hypoglycaemia (8.17, 4.39 to 15.22), but decreased risk of low birth weight (0.80, 0.69 to 0.91) and small for gestational age (0.44, 0.39 to 0.50). Four studies had low or medium risk of bias, only 25% of the studies reported Indigenous involvement in the research process. These findings show that Indigenous women with GDM are at greater risk of perinatal complications than those without GDM. This underscores the need for timely, intensive clinical management of GDM, delivered within culturally safe models of care, to reduce these inequities. In line with calls for action, prioritizing the early prevention of GDM is essential.

1. Introduction

Hyperglycaemia in pregnancy (HIP) is classified into pre-pregnancy diabetes, gestational diabetes mellitus (GDM), and diabetes first diagnosed during pregnancy (DIP) [1]. Of these, GDM is the most prevalent, accounting for 80 % of HIP cases globally [2]. In 2021, the pooled global standardized prevalence of GDM was estimated at 14 % [3]. Evidence suggests that GDM is more common in Indigenous women compared to their non-Indigenous counterparts. A recent systematic review and *meta*-analysis, incorporating data from Australia, Canada, New Zealand, and the United States (USA), reported that the pooled unadjusted prevalence odds ratios (PORs) for GDM were 1.41 to 2.04 times higher in Indigenous women [4]. Although the review was limited to studies from four countries and demonstrated considerable heterogeneity, the direction and consistency of the findings across individual studies underscore a significantly elevated risk of GDM among Indigenous pregnant women [5].

A GDM diagnosis is associated with a greater risk of adverse pregnancy outcomes, including hypertensive disorders, such as pre-eclampsia or eclampsia, macrosomia, and caesarean delivery. Infants born to mothers with GDM also face higher risks of preterm delivery, being large for gestational age (LGA), and requiring admission to neonatal intensive care [2,6]. The disproportionately high prevalence of GDM among Indigenous compared to non-Indigenous women further amplifies the burden of pregnancy complications in these communities. Despite this, the most recent systematic review quantifying these risks only focused on general populations, combining data from Indigenous and non-Indigenous women [6]. This aggregated approach may mask

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important disparities and limit the applicability of findings to Indigenous populations, thereby reducing the potential for culturally relevant and effective interventions [7]. Furthermore, while one previous review [8] examined adverse outcomes among Indigenous women with HIP, it did not distinguish between the different HIP subtypes, which have distinct pathophysiologies. Grouping all forms of HIP together may result in inaccurate risk estimates and less targeted clinical and public health strategies. Given that GDM accounts for the majority of HIP cases globally, disaggregating GDM from other HIP subtypes is essential to provide a more accurate understanding of its specific impact and to inform evidence-based policies tailored to the needs of Indigenous communities.

Identifying disparities in pregnancy outcomes among Indigenous women presents an opportunity to highlight progress while directing attention to areas in need of targeted intervention [9]. To address the current evidence gap, the authors undertook a systematic review and *meta*-analysis to quantify the association between GDM and adverse pregnancy outcomes specifically among Indigenous women globally. By synthesising available data, this analysis aims to advance understanding of GDM's impact on these populations and to inform the development of culturally responsive, evidence-based health interventions.

2. Method

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, and the protocol was prospectively registered as a systematic review (PROSPERO ID: CRD42024551293).

2.1. Search strategy and selection criteria

A comprehensive search was conducted on April 10, 2024 (later updated to October 15, 2024) in five databases: MEDLINE (via PubMed), Web of Science, CINAHL, Embase, and Cochrane Library. Controlled vocabulary terms (i.e. Medical Subject Headings terms) and key words for Indigenous people, GDM, maternal adverse outcomes, and neonatal outcomes were used in the searches (Supplemental Table S1). The search was designed with the help of a librarian. TLD additionally searched the reference lists of relevant articles. Restrictions were applied to the publication types. Conference proceedings without a full publication; reviews, editorials, preprints, and letters were excluded from the search results. In addition, we also excluded the publications not specific to health research; studies that did not distinguish GDM from other types of HIP; studies that did not include Indigenous people; and review studies. No language or publication date restrictions were applied to the search. However, reports in languages other than English were excluded.

Studies were included if the following criteria were met:

a. Pregnant women in the studies who were identified as having GDM through an oral glucose tolerance test (OGTT) measure, or self-reported GDM, or recorded in medical records.
b. Included Indigenous pregnant women in the sample.
c. Had at least one adverse maternal and/or neonatal outcome.

The search results from databases were then uploaded to Covidence, to facilitate the screening and selection process. Within Covidence, duplicate studies were removed, and two independent reviewers (TLD and ML) screened titles and abstracts according to predefined eligibility criteria. Full-text articles of potentially relevant studies were then assessed to determine final inclusion in the review. A third reviewer (KMS) resolved any discrepancies in study judgments. When multiple articles from a single study were identified, we considered eligible data from all reports but included each study only once in the *meta*-analysis.

2.2. Data extraction

The data extraction process involved two independent researchers (TLD and ML) utilizing a predesigned form to extract relevant information from the included studies. If the necessary data were not presented within the publications, the researchers contacted the corresponding authors to request access to the missing data. The extracted data included sociodemographic and clinical characteristics, such as year of publication, study location, study design, sample size, screening method and diagnostic criteria for GDM, as well as adjustments for conventional prognostic factors. Any discrepancies between the two researchers during data extraction were resolved through discussion and consensus, with the involvement of a third researcher (KMS) if needed.

2.3. Quality assessment

The methodological quality of the included studies was assessed using a modified Newcastle-Ottawa scale (Supplemental Table S3), which evaluated the selection, comparability, and outcome domains. Two independent reviewers (TLD and ML) scored the studies based on their adherence to the specified criteria. Studies that scored one for selection or outcome, or zero for any of the three domains, were considered to have a high risk of bias. Those scoring two or three for selection, one for comparability, and two for outcome were regarded as medium risk. Studies with four for selection, two for comparability, and three for outcome were deemed to have a low risk of bias, indicating higher quality.

In addition to assessing the inequities experienced by Indigenous populations regarding adverse pregnancy outcomes, we also evaluated the extent to which the included studies demonstrated ethical, cultural, and methodological responsiveness to the communities being studied. To assess this, we utilized the CONSIDER Statement, a 17-item tool originally designed to evaluate the completeness of reporting in studies involving Indigenous people. We collaborated with the tool's original author to modify the 17 statements into a series of Yes/No/Not Clear questions (Supplemental Table S5). For each item, a study was assigned a value of 1 if the item was clearly addressed (*Yes*) and 0 if not addressed or unclear (*No* or *Not clear*). We then calculated the proportion of studies meeting each individual item, expressed as a percentage. The assessment of Indigenous involvement was conducted by two independent researchers, including an Indigenous research fellow with relevant expertise.

2.4. Meta-analysis

Pregnant women were categorized into two groups based on the diagnostic criteria used in each study. We estimated summary risk ratio estimates and their 95 % confidence intervals (CI) using a random effects model with the inverse variance method. Both forest plots and drapery plots graphically displayed the individual and pooled estimates of the studies with a corresponding 95 % CI. Only outcomes that had data from more than two studies were constructed the pooled effect size.

Measures of heterogeneity between studies were presented in the forest plot, including the 95 % prediction interval (PI) to measure how trustworthy the pooled effects are, and Cochran's Q test, Higgins's I^2 test statistic, and τ^2 to quantify respectively the amount and percentage of between studies variation due to true heterogeneity rather than sampling error [10]. Subgroup analyses were done to explore potential sources of heterogeneity [11] such as study country, risk of bias, screening method, and diagnostic criteria for GDM. These subgroup analyses were only feasible for outcomes with data from at least two studies per group. In addition, the Doi plot and Luis-Furuya-Kanamori (LFK) index were employed to evaluate potential publication bias of the included studies in the *meta*-analysis [12]. The outlier detection method of Viechtbauer and Cheung was used to identify studies that

contributed disproportionately to the overall heterogeneity. Moreover, influence analyses, using Baujat plots and leave-one-out *meta*-analysis, highlighted studies with a substantial impact on pooled effects and/or heterogeneity. The results of one-to-one study omission analysis were presented. If there was more than one outlier detected, further sensitivity analysis was performed to understand changes in pooled effect size and heterogeneity when all identified outliers were excluded together.

Furthermore, proportional *meta*-analysis was undertaken to further estimate the pooled prevalence of GDM among Indigenous population in the included studies.

All statistical analyses were performed using meta, metafor, and dmetar packages in the R-programming language, with a significance threshold of $p < 0.05$.

3. Results

3.1. Characteristics of included studies

A PRISMA flow diagram of the inclusion of studies is presented in Fig. 1. A total of 1,308 studies were identified through database and citation searches. After removal of duplicates, 830 articles were screened by title and abstract, resulting in 61 potential articles to be included. After reviewing the full texts of these articles, 20 unique articles (1.5 %) were included in the systematic review and *meta*-analysis [13–32].

Of these 20 studies identified, all were observational, and they were published between 1992 and 2023, with the majority being cohort studies (n = 19 [95 %]) spanning a duration of 2 to 29 years. Data were collected on 279,569 Indigenous pregnant women (96,843 women were excluded from two studies [22,31] which were overlapping populations with other included studies). Five studies (25 %, n = 63,996) were conducted in Australia [13,17,20,26,28], three (15 %, n = 56,176) in the USA [15,16,25], and twelve (60 %, n = 159,397) in Canada [14,18,19,21–24,27,29–32]. Some studies focused exclusively on Indigenous women [15,18,24,25,27,29]; the remaining included a comparison group of non-Indigenous women with the proportion of Indigenous pregnant women within each study ranged from 0.9 % to 47.6 %. Table 1 summarises the characteristics of individual studies.

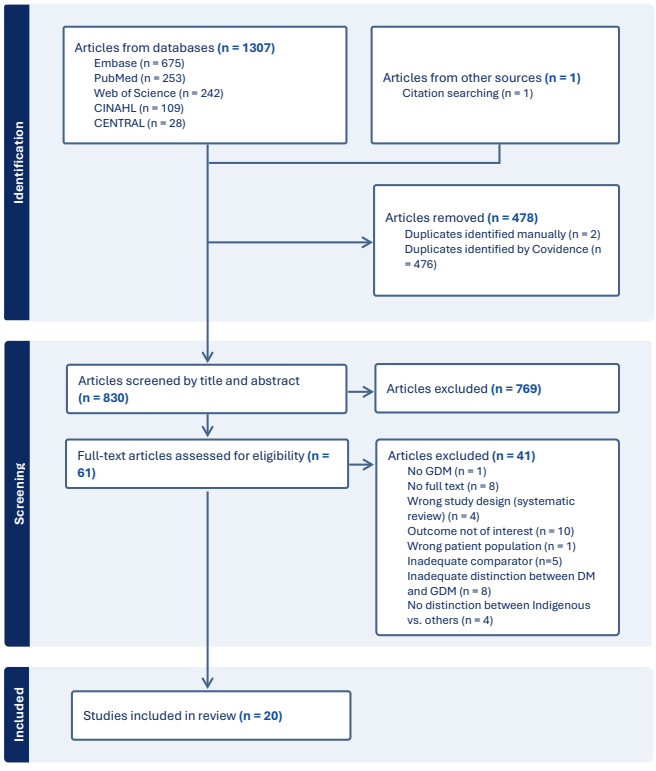

Fig. 1. PRISMA diagram outlining the search strategy and selection of studies included in this review.

Among the 20 included studies, 9 (45 %) focused on maternal outcomes, while 19 (95 %) examined neonatal outcomes (Supplemental Table S8). Canadian studies consistently comprised the largest number in all outcome categories, while studies from the USA contributed data only for preterm birth, macrosomia, and LBW.

Screening methods for GDM varied: one study (5 %) used a universal one-step screening approach, six (30 %) used the universal glucose challenge test (GCT), and thirteen (65 %) did not specify the screening method used. Diagnostic criteria for GDM were inconsistently reported, with 11 studies (55 %) not clearly specifying criteria; however, 6 of these 11 studies indicated diagnoses based on ICD codes (Table 1).

Fig. 2 indicated a network illustration the total number of studies and the country distribution in each outcome. Accordingly, macrosomia was the outcome explored most in the studies (13/20 studies). Preterm birth, C-section, congenital malformation, and LBW were also the outcomes of interest in most of the studies. However, there is an inequity in the number of studies and total sample size across countries, with Canada contributing disproportionately more data than others. In contrast, instrumental delivery and several neonatal outcomes such as neonatal death, NICU admission, and neonatal jaundice were rarely investigated regarding the impact of GDM to maternal and offspring's health among Indigenous population.

3.2. Proportion of GDM among included studies

The pooled prevalence of GDM among Indigenous women across 20 included studies was approximately 0.08, or 8 % (95 %CI: 0.06 to 0.12) (Supplemental Fig. S7). A substantial heterogeneity was observed (I^2 = 100 %, $\tau 2 = 0.69$, Cochran's Q: $P < 0.001$, 95 % PI: 0.01 to 0.34), indicating the need for caution in interpreting the pooled estimate. However, the included studies may not be representative of all population-based prevalence studies. Subgroup analysis by country did not reveal statistically significant differences across countries; however, substantial heterogeneity was observed within countries.

3.3. Association between GDM and adverse outcomes of pregnancy in Indigenous populations

The analysis revealed a significant association between GDM and increased risk of adverse maternal outcomes. Indigenous mothers with GDM had an elevated risk of caesarean section (RR: 1.83, 95 % CI 1.63 to 2.06), with a 95 % PI indicating that the effect size in future studies is likely to fall between 1.40 and 2.39. The risk of shoulder dystocia was substantially higher compared to those without GDM (3.21, 2.94 to 3.50; 2.63 to 3.92).

Regarding neonatal outcomes, infants of mothers with GDM had an increased risk of being LGA (2.35, 1.46 to 3.77; 0.64 to 8.65), macrosomia (1.75, 1.48 to 2.07; 0.95 to 3.22), and preterm birth (1.36, 1.09 to 1.69; 0.77 to 2.38). GDM in Indigenous mothers was also associated with increased risks of their newborn's hypoglycaemia (8.17, 4.39 to 15.22), though the 95 % PI suggests that the effect size in future studies may vary widely, from 0.68 to 98.66. However, the risks of low birth weight (LBW) (0.80, 0.69 to 0.91; 0.59 to 1.08) and being small for gestational age (0.44, 0.39 to 0.50; 0.17 to 1.14) were lower among infants born to mothers with GDM (Fig. 3).

Drapery plots (Supplemental Fig. S2) illustrate the individual study estimates alongside the pooled estimates and shaded prediction intervals, plotted across various significance thresholds. Compared to Indigenous women without GDM, Indigenous women with GDM have significantly increased risks of caesarean section, shoulder dystocia, hypoglycaemia, LGA, macrosomia, and preterm birth. Conversely, the risks of LBW and being small for gestational age are significantly

Table 1
Characteristics of included studies on gestational diabetes mellitus and adverse pregnancy outcomes among Indigenous populations.

Study ID	Study (Author, Year)	Country	Design	Time Period	Sample size of Indigenous women[§]		Screening method	Diagnosis criteria	% GDM	Risk of bias
					n	%				
#8	Ahmed et al., 2023	Western Australia	Retrospective	1998–2015	32,751	6.4	NR	NR (ICD-codes)	5.8	Low
#22	Bower et al., 1992	Western Australia	Retrospective	1980–1984	5481	4.9	NR	NR (ICD-codes)	1.3	High
#47	Cynthia et al., 2011	Western Australia	Retrospective	2000–2007	4966	6.1	NR	NR	8.6	High
#99	Ibiebele et al., 2016	Queensland Australia	Retrospective	2005–2011	20,273	5.6	NR	NR	6.6	Medium
#135	Lucas et al., 2021	Northern Territory Australia	Prospective	2011–2017	525	47.6	Universal 1-step	ADIPS 1998/WHO 2013	50.5	High
#11	Altman et al., 2018	USA	Retrospective	2007–2012	10,470	100	NR	NR (ICD-codes)	12.0	High
#13	Anderson et al., 2016	USA	Retrospective	2009–2013	44,570	0.9	NR	NR	4.3	High
#90	Hiratsuka et al., 2022	USA	Retrospective	2007–2013	1136	100	NR	NR (ICD-codes)	13.3	Low
#10	Aljohani et al., 2008	Canada	Retrospective	1985–2004	39,926	12.3	NR	SOGC 1992/CDA 1998/CDA 2003	7.0	High
#30	Caulfield et al., 1998	Canada	Retrospective	1990–1993	741	100	Universal GCT	3rd IWC	9.5	High
#37	Chen et al., 2019	Canada	Retrospective	1996–2010	17,090	7.3	Universal GCT	ADA 2003	10.7	Low
#61	Dyck et al., 2002	Canada	Prospective survey	1998	252	15.6	Universal GCT	NDDG	11.5	High
#64	Dyck et al., 2021	Canada	Retrospective	1980–2009	68,557	16.7	NR	NR (ICD-codes)	4.5	High
#65	Dyck et al., 2020	Canada	Retrospective	1980–2009	69,176	16.7	NR	NR (ICD-codes)	4.4	High
#74	Godwin et al., 1999	Canada	Retrospective	1987–1995	1298	100	Universal GCT	3rd IWC	8.5	High
#111	Kattini et al., 2020	Canada	Retrospective	2012–2017	2073	100	NR	NR	8.2	High
#152	Monteith et al., 2023	Canada	Prospective	2013–2019	150	100	NR	Self-reported	21.1	High
#161	Oster et al., 2016	Canada	Retrospective	2000–2009	28,286	6.6	NR	NR	4.4	High
#0000	Oster et al., 2014	Canada	Retrospective	2000–2009	28,306	6.6	Universal GCT	CDA 2008	4.4	High
#184	Rodrigues et al., 2000	Canada	Retrospective	1995–1997	385	6.4	Universal GCT	NDDG 1979	12.6	High

Note: [§] Count (n) and percentage (%) of Indigenous women were calculated based on the total number of participants in each study.
Dyck et al., 2021 and Dyck et al., 2020 from the same population, Oster et al., 2016 and Oster et al., 2014 from the same population.
Abbreviations: NR: Not reported; ADA: American Diabetes Association; ADIPS: Australian Diabetes in Pregnancy Society; CDA: Canadian Diabetes Association; IWC: International Workshop-Conference on Gestational Diabetes Mellitus; NDDG: National Diabetes Data Group; WHO: World Health Organization.

decreased in infants of mothers with GDM. These associations remain statistically significant at p-values as low as 0.01.

3.4. Heterogeneity Estimation and Exploration

The pooled estimates revealed varying degrees of between-study heterogeneity, as assessed the 95 % PI, I2, τ2 and the Cochran's Q-test, which are depicted in the respective forest plots (Supplemental Fig. S1). Sensitivity and subgroup analyses were conducted to explore potential sources of variation.

Substantial heterogeneity was observed in several outcomes with statistically significant pooled estimates, including LGA ($I^2 = 96$ %, $\tau2 = 0.07$ (95 % CI: 0.02 to 1.37), Cochran's Q: $P < 0.01$, 95 % PI: 0.64 to 8.65), macrosomia ($I^2 = 91$ %, $\tau2 = 0.07$ (95 % CI: 0.03 to 0.22), Cochran's Q: $P < 0.01$, 95 % PI: 0.95 to 3.22), and preterm birth ($I^2 = 87$ %, $\tau2 = 0.03$ (95 % CI: 0.01 to 0.26), Cochran's Q: $P < 0.01$, 95 % PI: 0.77 to 2.38). Outliers were identified for LGA and macrosomia, and their removal led to a noticeable reduction in heterogeneity. While the pooled RR for macrosomia remained stable (from 1.75 [95 % CI: 1.48 to 2.07] to 1.83 [95 %CI: 1.74 to 1.93]), the association with LGA become non-significant after outlier removal (from 2.35 [95 %CI: 1.46 to 3.77] to 2.11 [95 %CI: 0.30 to 14.70]) (Supplemental Fig. S3 and S4).

Subgroup analyses by study country did not reveal significant heterogeneity between subgroups of Indigenous women with and without GDM for most adverse pregnancy outcomes, with the exception of macrosomia ($p < 0.01$) (Table 2 and Supplemental Fig. S5). No significant subgroup-level heterogeneity was observed in analyses stratified by risk of bias or screening method (Table 2 and Supplemental Fig. S5). Subgroup analyses were conducted only for outcomes with data available from at least two studies in each comparison group. Subgroup analysis based on diagnostic criteria was not feasible due to the limited number of studies within each group.

Doi plot analysis (Supplemental Fig. S6) showed minor asymmetry for macrosomia and marked asymmetry for preterm birth, indicating possible publication bias, especially for smaller studies with larger effect sizes.

Heterogeneity was also present in outcomes with non-significant pooled estimates, including congenital malformations, postnatal death, and stillbirth. For congenital malformations and stillbirth, removing identified outliers reduced I^2, suggesting these studies may have inflated the observed heterogeneity; however, the pooled effect estimates remained non-significant after exclusion. Subgroup analyses (Supplemental Fig. S5) for these two outcomes did not reveal significant differences between subgroups. Due to the limited number of studies, subgroup analysis for postnatal death was not feasible. However, the symmetrical Doi plot suggested the presence of potential publication bias for this outcome (Supplemental Fig. S6).

3.5. Quality assessment and risk of bias

Among the 20 included studies, 4 studies (20 %) were at low or medium risk of bias. The remaining 80 % were deemed to be at high risk

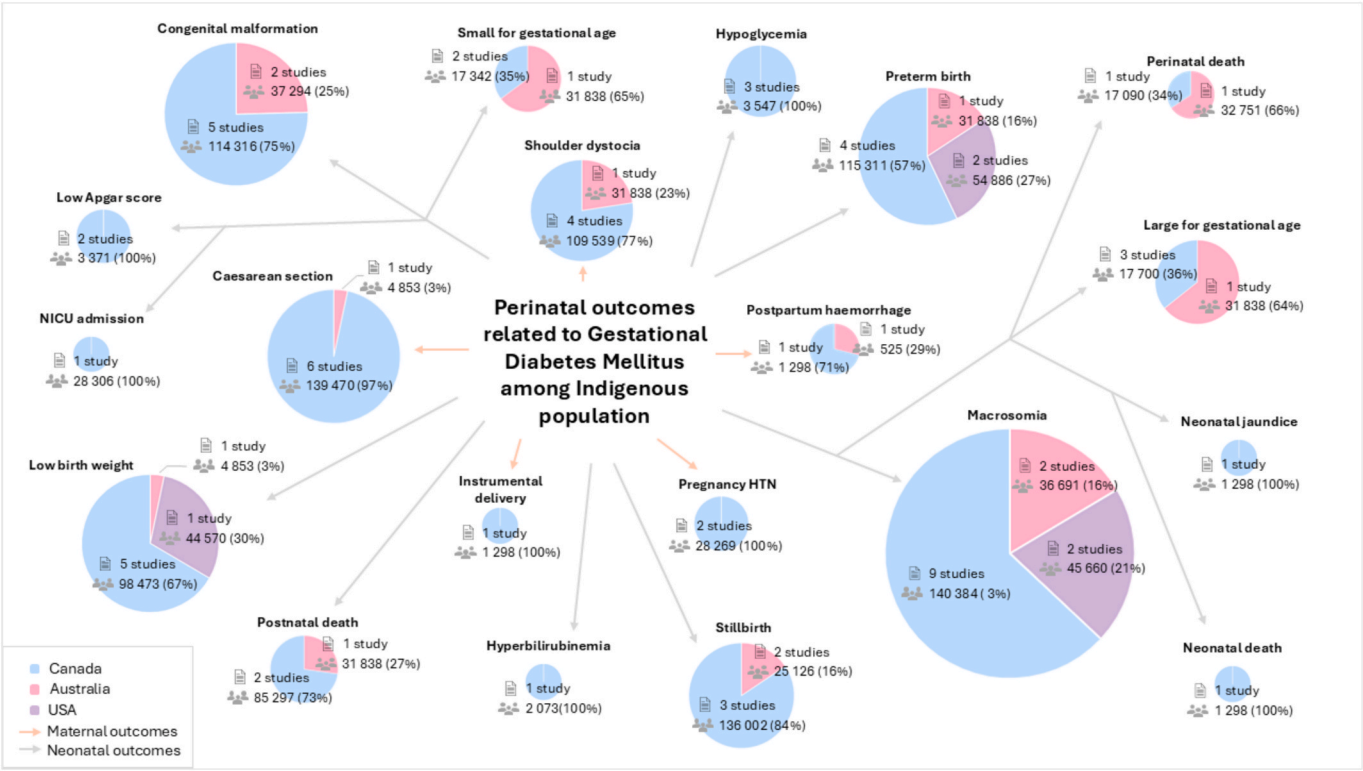

Fig. 2. Network illustration indicating the total number of studies (size of circles), and the country and sample size distribution in each outcome.

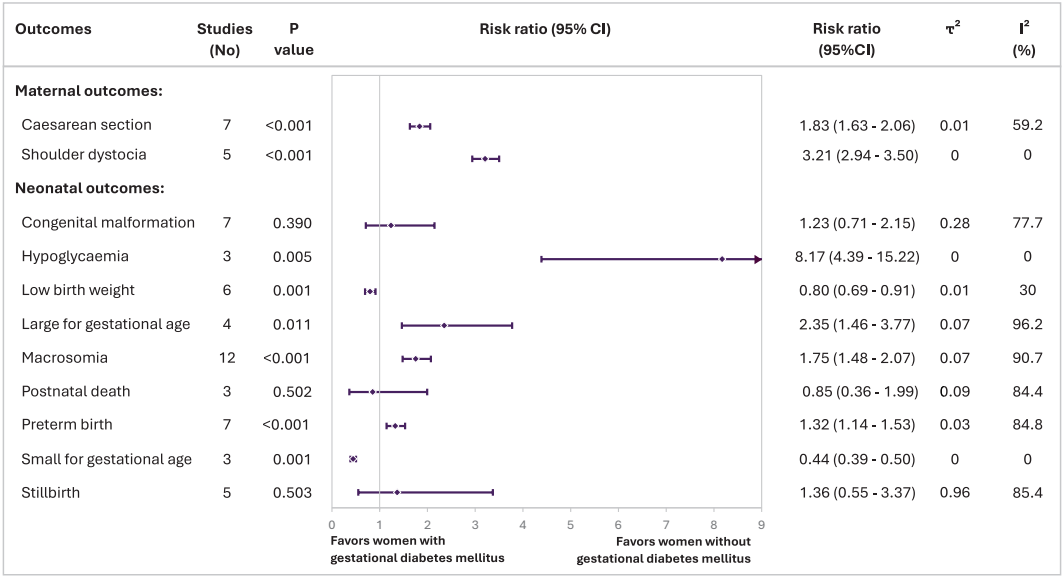

Fig. 3. Forest plot of adverse pregnancy outcomes between Indigenous women with and without gestational diabetes mellitus.

of bias due to a lack of clarity and transparency in reporting, and issues with confounding (n = 16). Grading assigned by the authors is recorded in Table 1 and Supplemental Table S4.

3.6. *Indigenous engagement and participation*

Various countries, including Australia, New Zealand, Canada, the USA, and most recently Norway, have developed guidelines to promote best practices in Indigenous research, emphasizing Indigenous values, traditions, and knowledge, along with active community participation.

In our systematic review, all eligible full-text articles were carefully examined by both an Indigenous and a non-Indigenous researcher to assess meaningful Indigenous involvement. While 60 % (n = 12) of studies were initiated based on priorities identified by Indigenous stakeholders, governing bodies, or empirical evidence, only 15 % (n = 3) explicitly described their research as a collaborative partnership with Indigenous communities. Indigenous governance and approval processes were documented in 40 % (n = 8) of studies, with involvement from Indigenous reference groups, advisory boards, or tribal councils. Traditional knowledge and values were integrated into research methodologies in 35 % (n = 7) of studies, and 45 % (n = 9) described using a critical inquiry and strength-based approach that incorporated

Table 2
Subgroup analysis according to study country, screening method, and risk of bias for adverse outcomes of pregnancy in Indigenous women with gestational diabetes mellitus compared with Indigenous women without gestational diabetes mellitus.

Outcome	Study country				Risk of bias			Screening method		
	Australia	Canada	USA	p-value	High	Low	p-value	Universal GCT	Not reported	p-value
Maternal outcomes										
Caesarean section								3 1.71 (1.52 – 1.91)	4 1.88 (1.50 – 2.36)	0.20
Shoulder dystocia								2 2.92 (0.25 – 33.67)	3 3.21 (2.71 – 3.81)	0.62
Neonatal outcomes										
Congenital malformation	2 1.87 (0.00 – 6696.25)	5 1.07 (0.62 – 1.84)	0 NA	0.41	5 1.28 (0.50 – 3.27)	2 1.10 (0.27 – 4.56)	0.68	4 0.97 (0.45 – 2.11)	3 1.66 (0.32 – 8.63)	0.24
LBW								2 0.84 (0.68 – 1.04)	4 0.80 (0.63 – 1.00)	0.73
LGA					2 2.11 (0.30 – 14.71)	2 2.59 (0.11 – 60.15)	0.48			
Macrosomia	2 2.47 (2.24 – 2.71)	8 1.63 (1.35 – 1.97)	2 1.48 (1.30 – 1.70)	**< 0.01**	10 1.71 (1.42 – 2.05)	2 1.94 (1.09 – 3.44)	0.68	4 1.55 (1.07 – 2.25)	8 1.88 (1.58 – 2.23)	0.36
Preterm birth					5 1.40 (1.16 – 1.69)	2 1.17 (1.01 – 1.36)	0.14	2 1.50 (1.10 – 2.03)	5 1.25 (1.06 – 1.46)	0.30
Stillbirth	2 1.60 (0.09 – 28.14)	3 1.24 (0.82 – 1.87)	0 NA	0.86						

Note: Data are number of studies, and risk ratios (95% confidence intervals).
GCT: glucose challenge test; LBW: low birth weight; LGA: large for gestational age; NA: calculation of effect estimates not applicable.
p-value measures intergroup interaction. Subgroup analyses were performed only for outcomes with data from at least two studies per group.

Indigenous perspectives (Fig. 4).

Indigenous representation and leadership within research teams were often unclear, with only 30 % (n = 6) of studies reporting Indigenous-affiliated authorship. Furthermore, only 25 % (n = 5) explicitly described Indigenous involvement in key research stages such as design, funding, implementation, analysis, dissemination, or recruitment. Notably, dissemination of findings to Indigenous governing bodies and communities was reported in just 10 % (n = 2) of studies (Fig. 4), highlighting a gap in ensuring that research outcomes are meaningfully shared with Indigenous peoples.

4. Discussion

The aim of this paper was to identify and describe the maternal and neonatal outcomes associated with GDM in Indigenous women globally, through a comprehensive systematic review and *meta*-analysis.

To our knowledge, this is the first study to systematically examine the association between GDM and adverse pregnancy outcomes in Indigenous populations. This review identified 20 peer-reviewed papers representing 18 individual studies originating from three countries published since 1992. Compared to Indigenous pregnant women without GDM, those with GDM were at higher risk of caesarean section and shoulder dystocia. These findings align with previous systematic reviews in the general population, which also reported increased these risks associated with GDM. However, our results suggest that the strength of these associations may be greater among Indigenous women. For example, the pooled risk of shoulder dystocia in our review was 3.21 – nearly three times higher than the estimate reported for the general population (1.29) [6]. Infants of Indigenous mothers with GDM also had significantly higher risks of adverse outcomes compared to infants of Indigenous mothers without GDM. Although similar associations have been found in the general population [6], the magnitude of these risks appeared higher among Indigenous populations in our review. Notably, the pooled risk of LGA was 2.35 in Indigenous populations, compared to 1.61 reported in the prior *meta*-analysis of the general population [6]. Furthermore, while neonatal hypoglycaemia was not addressed in previous general population reviews [6], our findings indicate that infants born to Indigenous mothers with GDM had more than an eightfold increased risk of this condition. These pronounced differences underscore a substantial clinical concern that may be unique to, or more severe in, Indigenous populations. They highlight the urgent need for culturally responsive antenatal care strategies and early interventions tailored to the specific needs of Indigenous communities.

However, this result suggests that the breadth of these studies is limited by focusing on a relatively small number of outcomes such as caesarean section, macrosomia, preterm birth, or congenital malformation; or concentrating on a single outcome. Issues such as neonatal respiratory distress syndrome, which can result from GDM delaying the secretion of phosphatidylglycerol and thus disrupting foetal pulmonary surfactant, were not investigated. Regarding maternal adverse outcomes, although the direct relationship between GDM and pre-eclampsia remains uncertain [33], a previous review indicated that women with GDM were 1.24 times more likely (95 % CI: 0.94 to 1.63) [6] to develop preeclampsia. However, none of the studies in our review specifically explored this association in Indigenous populations. One potential reason for this gap is that most of the included studies were retrospective and relied on administrative datasets, which often lack detailed clinical information on the timing of diagnosis. This limitation makes it difficult to determine whether GDM precedes pre-eclampsia or if both conditions share common risk factors. Understanding the association between GDM and preeclampsia among Indigenous women is helpful for improving pregnancy outcomes, which warrants further studies.

Indigenous peoples reside in approximately 90 countries worldwide [34]; however, our search across five major electronic databases yielded studies from only three countries—Canada, Australia, and the USA –

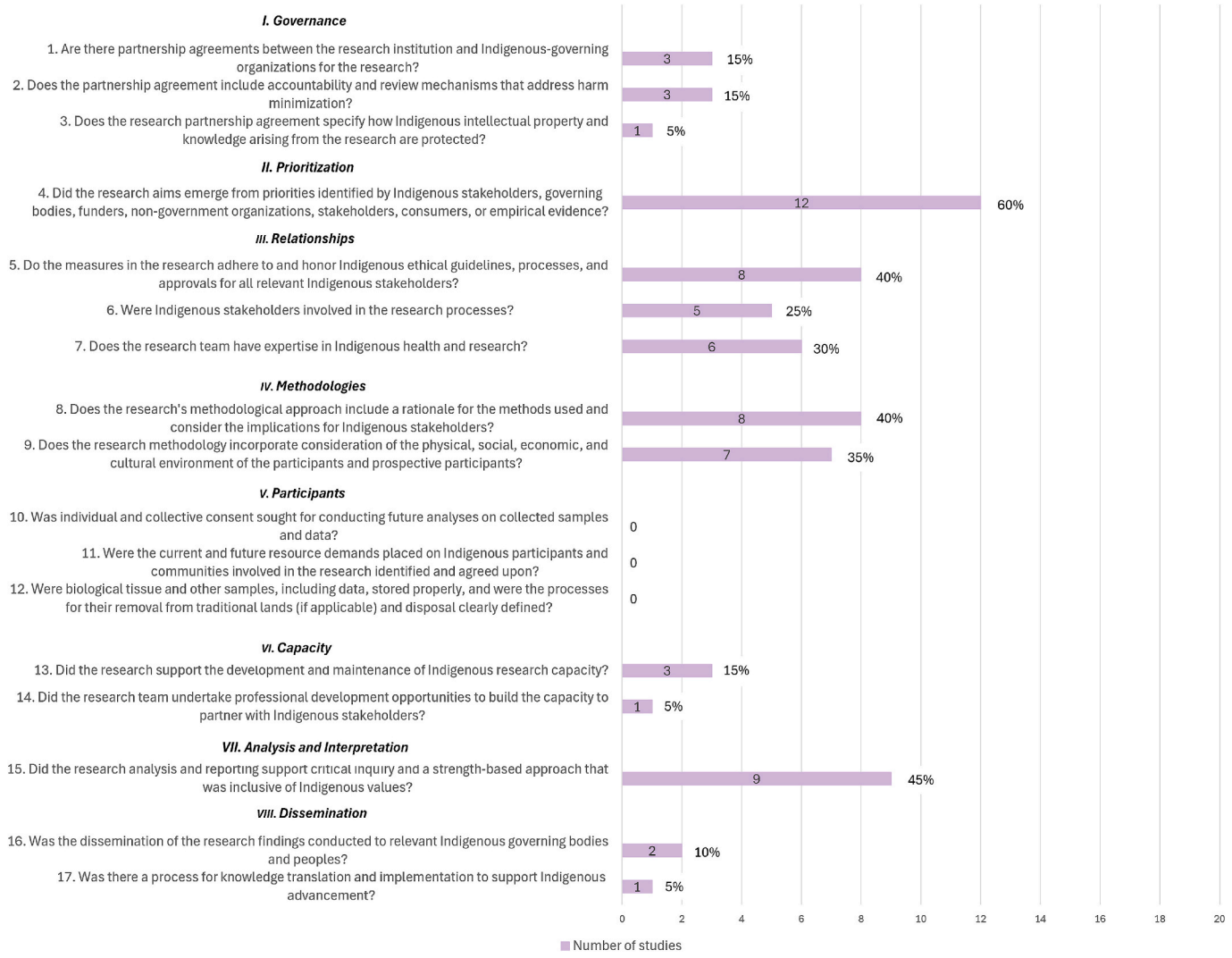

Fig. 4. Indigenous involvement in the research process according to the modified CONSIDER Statement.

that met our inclusion criteria. Although these three countries share settler colonial histories and have similarly advanced healthcare and research infrastructure, the cultural, social, and healthcare contexts of Indigenous populations differ substantially across and within each country [35,36]. Moreover, healthcare systems, clinical guidelines, data quality, and social determinants of health may differ between countries [37], potentially influencing how GDM affects maternal and neonatal outcomes. To explore whether the strength or direction of these associations varied geographically, subgroup analyses by country were conducted in our review. However, due to the limited number of studies available for each outcome within individual countries, only a subset of outcomes could be included in the subgroup analysis. Among those, no significant differences were detected between country subgroups, except for macrosomia with Australia reported the highest pooled risks compared to Canada, the USA, and the overall pooled estimates. The imbalance in the number of studies and participants contributing data across countries may have limited the statistical power to detect such differences [38]. In addition, although our review did not restrict the search by country or language, only studies published in English were included in the analysis. This criterion may have limited the inclusion of research from countries where English is not the primary language of academic publication, potentially introducing language bias, a form of publication bias. This could partly explain why the 20 studies included in this review originated from only three countries, despite the impact of GDM on adverse pregnancy outcomes being relevant to many regions globally. Combining research findings from these countries must be done and interpreted cautiously, acknowledging both shared legacies and population-specific differences.

The change in diagnostic criteria for GDM introduced in 2013 [1] may have also led to shifts in how GDM is managed across countries, which in turn could influence its impact on pregnancy outcomes. Although 13 out of the 20 studies included in this review were published after 2013, only three studies utilised data collected entirely from 2013 onwards. This indicates a lack of up-to-date evidence regarding the impact of GDM under the recent diagnostic and management guidelines. Furthermore, inconsistencies in diagnostic criteria both between countries and across studies conducted within the same country complicate efforts to assess how the true impact of GDM on maternal and neonatal outcomes may have evolved over the past decade. These methodological variations highlight the need for more contemporary and standardised research to better understand the current burden of GDM and its implications in diverse Indigenous populations.

Active engagement of Indigenous people, organizations and communities in each step of the research journey is vital. There is a clear need to strengthen study methods that privilege Indigenous views and voices during the research process. Our finding indicated inconsistent levels of engagement across different stages of research. Although we have identified some positive examples of collaborative research, we also found 15 studies that make no reference to the involvement of Indigenous peoples during the course of their research. However, it is

possible that Indigenous governance was in place but not acknowledged in the publications. We assert that it is feasible and reasonable to expect that this information be henceforth included in the methods section of new publications to facilitate critical peer review, and to provide confidence in approaches taken in research are sensitive to the voices of Indigenous communities. Tools assessing adherence to these principles should also be used in the planning, design, implementation and dissemination of research.

While a pooled prevalence of GDM among Indigenous population was calculated, it is important to emphasize that this estimate is based only on the studies included in this review. The absolute frequency of GDM in included studies was generally lower that reported in more comprehensive contemporary publications. As the primary aim of this review was to assess maternal and neonatal outcomes associated with GDM rather than to estimate GDM prevalence, this pooled figure may not be representative of all population-based prevalence studies, and therefore, the reported prevalence may not accurately reflect the true burden of GDM in Indigenous communities.

We acknowledge some limitations to our review. It is possible not all Indigenous pregnant women were identified. For example, there is a well-known history of undercounting or misidentifying Aboriginal and Torres Strait Islander people in administrative data collected in Australia [39]. The conclusions drawn may not fully capture the experiences or health contexts of Indigenous populations in other region globally, as all included studies were conducted in only three countries, which may limit the generalizability of the findings. In addition, the international inconsistency in screening methods and diagnostic criteria for GDM may contribute to the wide variation in data, potentially affecting the statistical power of this *meta*-analysis. Our analysis of study content was also limited to information available in the papers identified, which could mean that we have under-reported some of the domains covered. Despite these limitations, our study is the first study quantifying the association of GDM and adverse pregnancy outcomes of Indigenous populations internationally. The use of questions adapted from critical assessment tools informed by Indigenous perspectives on ethically appropriate and rigorous research is a major strength of this review. It is our intention that these findings be used to inform the future design of research of Indigenous communities with strong Indigenous leadership and participation.

5. Conclusion

We performed a systematic review and *meta*-analysis of the association between GDM and adverse outcomes of pregnancy in Indigenous pregnant women, revealing that GDM contributes to a greater burden of pregnancy complications among Indigenous women compared to their non-GDM counterparts, with the magnitude of these risks exceeding that reported in the general GDM population. Our findings suggest for greater attention to GDM management policies and programs tailored to Indigenous populations, with the aim of reducing pregnancy-related complications. In parallel, further exploring the determinants of GDM in Indigenous communities in future studies would be beneficial to inform more effective and context-specific strategies. This process must also ensure the meaningful participation of Indigenous peoples at all stages of research and program development to honour and privilege Indigenous views and voices during the research process.

Ethical approval

As this study is a systematic review and *meta*-analysis of published data, no ethical approval was required.

Data sharing

The datasets analysed during the current study are available from the corresponding author on reasonable request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author used ChatGPT in order to improve readability and language. After using this tool, the author reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Thuy Linh Duong: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **KM Shahunja:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Minh Le:** Writing – review & editing, Data curation. **David H McIntyre:** Writing – review & editing, Supervision, Conceptualization. **James Ward (a Pitjantjatjara and Narungga man):** Writing – review & editing, Supervision, Conceptualization. **Abdullah A Mamun:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.diabres.2025.112462

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