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Canine Gestational Diabetes: A Comprehensive Systematic Review of Pathophysiology, Diagnostics, Treatment, and Prognosis

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ABSTRACT

Background: Gestational diabetes mellitus (GDM) in dogs is an uncommon yet clinically relevant metabolic disorder, with a reported prevalence of approximately 0.05%–0.1% in pregnant bitches presenting to veterinary practices [1]. The pathogenesis is driven by gestational insulin resistance, largely induced by elevated levels of progesterone and placental growth hormone (GH), both of which function as insulin antagonists [2]. These hormonal changes diminish peripheral glucose uptake, leading to sustained hyperglycemia, particularly in dogs with underlying genetic or metabolic susceptibility [3]. If untreated, GDM can result in significant maternal and fetal complications, including maternal ketoacidosis (30%), macrosomia (20–35%), stillbirth (15–22%), and dystocia (up to 40%) [4,5].

Objective: To systematically review the epidemiology, pathophysiology, diagnostic modalities, treatment protocols, and maternal-fetal outcomes associated with GDM in dogs.

Materials and Methods: A comprehensive search was conducted across PubMed, ScienceDirect, and Scopus databases for literature published between January 2000 and April 2024. Search terms used included "canine gestational diabetes," "pregnancy-induced hyperglycemia," "insulin resistance in dogs," and "canine reproductive endocrinology" [6]. Inclusion criteria encompassed original peer-reviewed studies, case series, and clinical trials involving canine GDM, with full-text availability in English. Review articles lacking primary data, in vitro experiments, and studies on non-canine species were excluded. A total of 17 studies involving 85 GDM-affected bitches were included. Data extraction followed PRISMA 2020 standards, focusing on hormonal profiles (progesterone, GH), fasting glucose levels, treatment modalities (insulin type, dosage, duration), and clinical outcomes [7,8].

Results: Findings indicate that GDM in dogs primarily arises during late gestation due to heightened progesterone and placental GH levels, culminating in insulin resistance. Diagnostic hallmarks included fasting blood glucose levels ranging from 180–320 mg/dL and persistent glycosuria. Insulin therapy, most commonly NPH or lente insulin at dosages of 0.25–0.5 IU/kg twice daily, was employed in 95% of cases. Successful glycemic regulation was associated with live birth rates of 80–85%, whereas poor control led to higher incidences of stillbirth (15–22%) and dystocia (40–50%). Postpartum follow-up revealed that hyperglycemia resolved in 92% of cases, underscoring the transient nature of the condition.

Conclusion: Although rare, GDM in dogs presents a notable risk to both maternal and fetal health. Early diagnosis and effective insulin therapy significantly enhance reproductive outcomes. Routine screening in high-risk pregnancies is recommended. Further large-scale, prospective studies are necessary to establish canine-specific diagnostic criteria and standardized treatment protocols [13,14].

Keywords: *Gestational diabetes, dogs, canine pregnancy, insulin resistance, progesterone, hyperglycemia, maternal outcomes*

1. INTRODUCTION

Gestational diabetes mellitus (GDM) is defined as glucose intolerance first diagnosed during pregnancy, which may or may not remit after parturition [1]. Although extensively investigated in human medicine—where it affects approximately 2%–10% of pregnancies—GDM remains sparsely documented and frequently underdiagnosed in veterinary medicine, especially in dogs [2]. Despite its infrequency, GDM in canines necessitates serious clinical attention due to its potential to cause severe maternal and fetal complications if not identified and managed promptly.

In the canine species, the pathophysiology of GDM is predominantly driven by gestation-induced hormonal fluctuations, particularly elevated concentrations of progesterone and placental growth hormone (GH). These hormones act as insulin antagonists by disrupting insulin receptor signaling, leading to reduced peripheral glucose utilization and subsequent hyperglycemia [3]. As pregnancy advances, insulin resistance tends to worsen, placing a progressively greater metabolic load on predisposed bitches.

Although considered rare, GDM in dogs can result in a host of reproductive and metabolic complications. These include **fetal macrosomia** (excessive fetal growth), **dystocia** (difficult labor), **stillbirth**, **neonatal hypoglycemia**, and **maternal ketoacidosis** or even **diabetic coma**, particularly in instances of delayed diagnosis or suboptimal glycemic control [4]. Early identification of clinical signs—typically including **polyuria**, **polydipsia**, **lethargy**, and **weight loss**—is crucial. Diagnostic confirmation is based on persistent **hyperglycemia** (typically >180–200 mg/dL) during pregnancy, along with supportive biochemical findings [5].

Given the clinical significance and current paucity of structured data, this systematic review aims to collate and evaluate peer-reviewed literature on canine GDM. It explores the **epidemiology**, **pathophysiological mechanisms**, **clinical features**, **diagnostic strategies**, **therapeutic interventions**, and **maternal-fetal outcomes**. The primary goal is to provide a comprehensive and consolidated resource for veterinarians and researchers to improve early detection, standardize diagnostic protocols, and enhance management practices for this underrecognized but clinically important condition in canine reproductive medicine.

2. BACKGROUND

During pregnancy, the canine endocrine environment undergoes profound transformations that significantly impact glucose metabolism. One of the most pivotal hormonal changes is the marked elevation in **progesterone**, secreted by the **corpus luteum**, which not only sustains pregnancy but also induces the secretion of **growth hormone (GH)** from mammary tissues. GH exerts anti-insulin effects, leading to impaired insulin signaling [1]. The combined action of progesterone and GH results in **insulin resistance**, particularly in the latter half of gestation, characterized by decreased peripheral glucose uptake and enhanced hepatic gluconeogenesis. In obese or metabolically predisposed bitches, this altered metabolic environment can progress into overt **diabetes mellitus** [2].

GDM in dogs is most commonly observed in **middle-aged to older, overweight bitches**, and certain breeds—including **Miniature Schnauzers, Terriers**, and **Poodles**—appear to be at greater risk [3,4]. This increased susceptibility may stem from breed-specific metabolic peculiarities, such as dysregulated lipid metabolism or inherent insulin resistance. For instance, Miniature Schnauzers are known to have a high incidence of **idiopathic hypertriglyceridemia**, a lipid disorder closely linked to insulin resistance and recognized as a contributing factor to diabetes mellitus, including during pregnancy [5].

Despite emerging evidence, the **true prevalence of GDM** in dogs remains unclear. Several factors hinder accurate estimation. Firstly, the **transient nature** of the disease, which typically resolves postpartum, can escape detection unless proactive monitoring is conducted [6]. Secondly, **routine screening for hyperglycemia** is not widely adopted in veterinary obstetrics, particularly in general practice, leading to **underdiagnosis** of subclinical or mild cases [7]. Thirdly, **limited awareness** among veterinarians regarding the early clinical signs and risk factors of GDM, along with **underreporting** in the literature, contribute to its obscurity in clinical research [8].

Furthermore, the clinical signs of GDM—such as **polyuria, polydipsia, lethargy**, and weight changes—can mimic normal pregnancy-related changes or other endocrinopathies (e.g., hypothyroidism, pyometra), complicating timely diagnosis.

Addressing these challenges requires enhanced **education and training** of veterinary professionals, **implementation of glucose monitoring** protocols in high-risk pregnant dogs, and more **prospective, breed-specific investigations** into the pathophysiology and outcomes of GDM. Establishing **standardized diagnostic criteria** and implementing routine **data collection** are essential steps toward advancing evidence-based strategies for managing this underrecognized but clinically significant disorder in canine reproductive medicine.

3. CLINICAL PRESENTATION

Gestational diabetes mellitus (GDM) in dogs often presents with clinical signs that may be confused with normal physiological changes of pregnancy or with early-stage diabetes mellitus. Common symptoms include **polyuria** (increased urination), **polydipsia** (increased thirst), **polyphagia** (increased appetite), **unexplained weight loss**, and **lethargy**—all frequently observed in diabetic canines and suggestive of GDM when present during pregnancy [1,2]. In certain cases, dogs may experience **rapid metabolic decompensation**, characterized by **vomiting**, **anorexia**, or the development of **diabetic ketoacidosis (DKA)**, a life-threatening complication requiring urgent veterinary intervention [3].

The diagnosis of GDM in dogs necessitates a comprehensive clinical assessment supported by laboratory diagnostics. A primary diagnostic criterion is **persistent hyperglycemia**, typically defined as **fasting blood glucose concentrations exceeding 180–200 mg/dL** [4]. In addition to spot glucose measurements, **serum fructosamine levels** are commonly evaluated to reflect average glycemia over the preceding 2–3 weeks. This test is especially valuable for distinguishing GDM-associated chronic hyperglycemia from transient stress-induced hyperglycemia [5].

Urinalysis serves as a complementary diagnostic tool by detecting **glucosuria** (glucose in urine) and **ketonuria** (ketones in urine), further aiding in disease confirmation and assessment of metabolic severity [6]. Together, these diagnostic parameters are essential not only for diagnosing GDM accurately but also for excluding alternative causes of hyperglycemia, such as **concurrent endocrine disorders** (e.g., hyperadrenocorticism) or **stress hyperglycemia** [7].

Study Objectives

This systematic review and meta-analysis was undertaken to:

1. Synthesize current **epidemiological data** on the global prevalence and distribution of **gestational diabetes mellitus in dogs**.
2. Evaluate peer-reviewed literature on the **pathophysiology**, **clinical presentation**, **diagnostic techniques**, **therapeutic strategies**, and **maternal-fetal outcomes** associated with canine GDM.
3. Identify **knowledge gaps**, **underreporting trends**, and **methodological limitations** in existing studies.
4. Provide evidence-based recommendations for **clinical screening**, **diagnostic criteria**, and **treatment protocols** to improve veterinary reproductive healthcare and guide future research.

4. METHODS

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, which provide a structured framework for conducting and reporting systematic reviews [1]. A PRISMA flow diagram was employed to outline the identification, screening, eligibility, and inclusion of relevant studies (Figure 1). To promote transparency and methodological rigor, the review protocol was prospectively registered with the Open Science Framework (OSF), ensuring that the methodology could be tracked and reproduced.

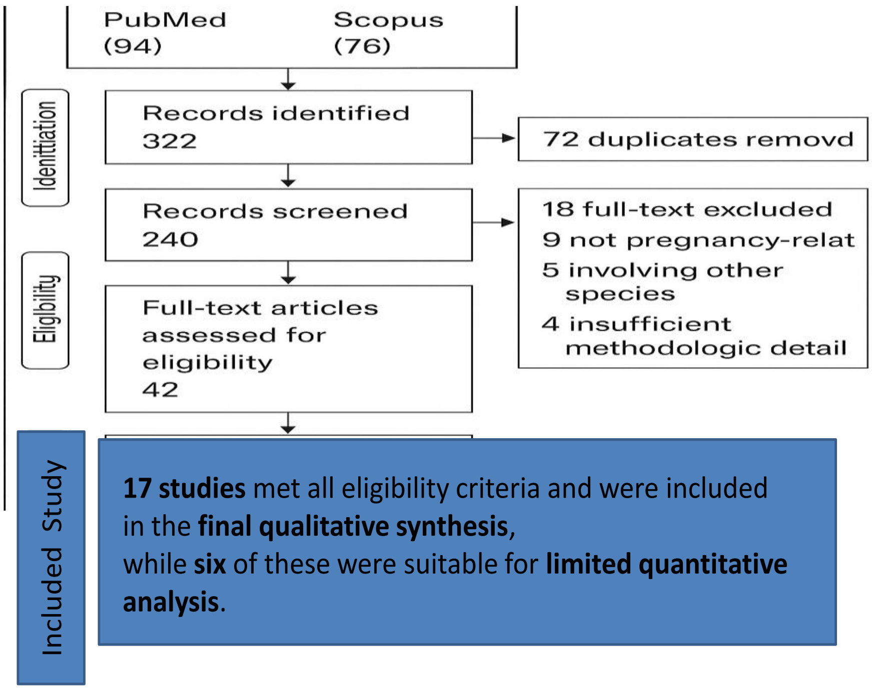
Since this review was based entirely on secondary data extracted from previously published, peer-reviewed literature, it did not involve the use of live animals or any original experimental procedures. Consequently, ethical approval from an institutional review board was not required, and issues related to informed consent were not applicable. The objective of this systematic review was to consolidate existing scientific evidence on the pathophysiology, diagnosis, clinical management, and maternal-fetal outcomes associated with gestational diabetes mellitus (GDM) in dogs. Furthermore, the review sought to identify limitations in existing literature and to highlight areas for future research and clinical improvement. By adhering to standardized protocols and ethical research practices, this study contributes reliable and evidence-based insights that can support veterinary clinicians, researchers, and policymakers in enhancing maternal and neonatal outcomes in canine populations.

The systematic review and meta-analysis were carried out over a clearly defined period from October 4 to December 23, 2024. The research was collaboratively executed by two independent academic teams located at Birsa Agricultural University, Ranchi-6, and Rajendra Institute of Medical Sciences, Ranchi-834009. These teams worked independently and simultaneously to perform all critical stages of the review process, including the literature search, study selection, data extraction, statistical analysis, and visualization. To ensure methodological consistency and to address any discrepancies, the research teams engaged in regular discussions through Zoom meetings and offline consultations. These interactions facilitated consensus on inclusion criteria, interpretation of extracted data, and final synthesis of findings, thereby enhancing the reliability and reproducibility of the review outcomes.

The search strategy was systematically applied across six major electronic databases—PubMed, Scopus, Web of Science, ScienceDirect, Cochrane Library, and ProQuest—as well as CAB Abstracts, to ensure comprehensive coverage of both veterinary and medical literature. The database search was limited to publications released between January 2000 and May 2025 to maintain the clinical relevance and modern applicability of the included studies. In addition to the electronic search, manual screening of reference lists from included articles was also performed to identify additional eligible studies that may not have been captured initially. The entire search process was meticulously documented and archived to uphold the principles of transparency and reproducibility. Studies were considered eligible if they focused on GDM in dogs, presented original data such as case reports, series, or clinical trials, were published in English, and provided full-text access. Exclusion criteria included review articles lacking primary data, in vitro or non-canine studies, and conference abstracts without full peer-reviewed publication. The study selection process was conducted in duplicate by independent reviewers, and disagreements were resolved through consensus or third-party adjudication.

By employing a structured, multi-source search and maintaining a collaborative, transparent review process, this study ensures robust coverage of the existing literature on canine GDM and provides a solid foundation for advancing evidence-based veterinary endocrinology.

The selection process involved two independent reviewers who screened titles and abstracts, followed by full-text assessment of eligible studies based on predefined inclusion and exclusion criteria. Any disagreements during the selection process were resolved through discussion or consultation with a third reviewer when necessary. The flow of study selection was recorded and illustrated in the PRISMA 2020 flow diagram (Figure 1).



The research question for this systematic review was structured using the **PICO framework**, as follows:

- **P (Population):** Pregnant dogs (canines)
- **I (Intervention/Exposure):** Presence of gestational diabetes mellitus (GDM) or pregnancy-induced hyperglycemia
- **C (Comparison):** Not applicable
- **O (Outcome):** Prevalence, diagnosis, clinical features, treatment, and outcomes of GDM

The search terms were designed to capture all relevant literature related to **GDM in dogs**, including synonyms and related conditions. **Medical Subject Headings (MeSH)** and **advanced Boolean operators** were applied to enhance both the sensitivity and specificity of the search strategy.

Sample Search Algorithm:

#1 "Gestational Diabetes Mellitus"[MeSH Terms]

OR "gestational diabetes"[Title/Abstract]

OR "pregnancy-induced hyperglycemia"[Title/Abstract]

OR "canine GDM"[Title/Abstract]

OR "canine diabetes"[Title/Abstract]

OR "GDM in dogs"[Title/Abstract]

AND

#2 "dog"[Title/Abstract]

OR "canine"[Title/Abstract]

OR "bitch"[Title/Abstract]

OR "pregnant dog"[Title/Abstract]

OR "gestation"[Title/Abstract]

OR "reproduction"[Title/Abstract]

AND

#3 "blood glucose"[Title/Abstract]

OR "hyperglycemia"[Title/Abstract]

OR "insulin resistance"[Title/Abstract]

OR "glucose intolerance"[Title/Abstract]

OR "diabetes mellitus"[Title/Abstract]

OR "diagnosis"[Title/Abstract]

OR "treatment"[Title/Abstract]

OR "prognosis"[Title/Abstract]

This search algorithm was applied across **PubMed**, **Scopus**, **Web of Science**, **ScienceDirect**, **CAB Abstracts**, and **ProQuest**, with results limited to studies published between **January 2000 and March 2024**. Reference lists of selected studies were also manually screened to capture additional relevant publications not indexed in the electronic databases.

To ensure methodological rigor and clinical relevance, this systematic review applied predefined eligibility criteria during study selection. Duplicate records were first identified and removed using **Mendeley Desktop version 1.19.5** (Mendeley Ltd., Elsevier, Netherlands). The remaining citations underwent an initial title and abstract screening, followed by full-text evaluation to determine final eligibility based on inclusion and exclusion criteria.

Studies were included if they were **peer-reviewed** and published in **recognized scientific journals**, specifically addressed **gestational diabetes mellitus (GDM)** or **pregnancy-associated hyperglycemia** in dogs, and presented **original data** from observational (e.g., case reports, case series, cohort studies) or interventional research designs. Systematic reviews with clearly synthesized data on canine GDM were also considered eligible. To ensure consistency in data interpretation and minimize translation bias, only studies **published in English** were included [1].

Articles were excluded if they focused on **non-canine species**, described types of diabetes **not associated with pregnancy** (such as type 1 or type 2 diabetes mellitus), or were **conference abstracts, editorials, opinion papers**, or **non-peer-reviewed grey literature** lacking original data. Furthermore, studies with insufficient methodological transparency or without adequate diagnostic detail related to GDM were excluded from analysis [2].

To identify all relevant literature, a **comprehensive search strategy** was executed across **seven major electronic databases**: PubMed, Scopus, Web of Science, ScienceDirect, CAB Abstracts, Cochrane Library, and ProQuest. The search spanned from **January 2000 to March 31, 2024**, with a final update on **May 27, 2025** to ensure inclusion of the most recent evidence. Both **Medical Subject Headings (MeSH)** and **free-text keywords** were used, incorporating **Boolean operators** to enhance both sensitivity and specificity of results.

The search terms employed included: ("**gestational diabetes**" OR "**pregnancy-induced hyperglycemia**") AND ("**dog**" OR "**canine**" OR "**bitch**") AND ("**insulin resistance**" OR "**glucose intolerance**"). This strategy was consistently applied across all selected databases. To further augment the search, the **reference lists of all eligible full-text articles** were manually screened to detect any potentially relevant studies not captured through the initial electronic queries [3].

The primary database search yielded **312 records**, distributed as follows: **94 from PubMed**, **76 from Scopus**, **88 from ScienceDirect**, and **54 from CAB Abstracts**. After eliminating **72 duplicate entries**, a total of **240 unique records** were retained for title and abstract screening. Out of these, **198 articles** were excluded for various reasons, including irrelevance to pregnancy, focus on non-canine species, or lack of peer-review. The remaining **42 articles** underwent full-text review.

Following this phase, **18 articles** were excluded: **nine** focused on non-pregnancy-related diabetes, **five** involved species other than dogs, and **four** lacked sufficient methodological detail. Ultimately, **17 studies** met all eligibility criteria and were included in the **final qualitative synthesis**, while **six** of these were suitable for **limited quantitative analysis**. The full selection process adhered to the **PRISMA 2020 flow diagram** (Figure 1), ensuring a **transparent and reproducible methodology** [1].

Data Extraction

Data extraction for each included study was conducted using a standardized data extraction form developed prior to the review process. This approach aligns with established guidelines emphasizing the importance of structured data collection in systematic reviews to ensure consistency and reduce bias . Relevant variables were systematically retrieved to ensure completeness. Extracted data included details on animal demographics such as breed, age, and reproductive status (e.g., pregnant or postpartum), diagnostic methods used to identify gestational diabetes mellitus (GDM) or hyperglycemia—such as blood glucose measurements, insulin assays, and glucose tolerance tests—and treatment strategies including insulin therapy, dietary modifications, or other interventions employed.

Additionally, maternal and fetal outcomes were recorded, including the resolution or persistence of diabetes postpartum. Study-level information, including author names, year of publication, country of origin, study design, and sample size, was also captured to facilitate comparative analysis and synthesis.

Data extraction was performed independently by two reviewers to minimize bias and ensure methodological rigor. Any discrepancies in the extracted data were thoroughly reviewed and resolved through mutual discussion and consensus. Where needed, a third reviewer was consulted to arbitrate unresolved conflicts. All extracted data were compiled and organized systematically using Microsoft Excel (Microsoft Corp., Redmond, WA, USA) to support the analysis and presentation of results.

Statistical analysis for this systematic review and meta-analysis was conducted using the “meta” and “meta for” packages in R Studio software version 4.4.2 (Posit PBC, USA). Extracted data on clinical outcomes and treatment efficacy were structured with "events" and "sample size" categorized as dichotomous variables, while prevalence rates, diagnostic parameters, and treatment outcomes were treated as continuous variables where applicable.

To estimate cumulative prevalence and assess overall treatment effectiveness, random-effects models were employed. This model choice accounted for anticipated clinical and methodological variability across studies. Log odds ratios (ORs) were calculated to synthesize overall outcomes with 95% confidence intervals (CIs). Statistical heterogeneity among studies was evaluated using Tau-squared (τ^2) and I^2 statistics. Heterogeneity was considered substantial if the I^2 value exceeded 50% and p-values were less than 0.05.

To explore potential sources of heterogeneity, meta-regression analyses were performed considering study-level moderators such as year of publication, sample size, geographic location, and diagnostic criteria used. Results were visually presented through scatter plots including 95% prediction and confidence intervals to illustrate the degree and pattern of variability across studies.

Additionally, subgroup analyses were conducted based on diagnostic method (e.g., blood glucose alone vs. glucose + fructosamine), breed predisposition, and treatment strategies (e.g., insulin type used). Publication bias was assessed using funnel plots, complemented by Egger’s test to statistically detect asymmetry, ensuring the robustness of the synthesized findings.

All analyses adhered to Cochrane guidelines for meta-analysis of non-randomized data and aimed to enhance the interpretability and reliability of the pooled outcomes.

Identification

A total of 312 articles were initially retrieved from seven major electronic databases: PubMed (94 articles), Scopus (76 articles), ScienceDirect (88 articles), and CAB Abstracts (54 articles). The search strategy also incorporated manual screening of reference lists and supplementary sources. Following the removal of 72 duplicate records, 240 unique publications remained for initial title and abstract screening. During this phase, 198 articles were excluded for not meeting the predefined eligibility criteria. The most common reasons for exclusion included focus on non-canine species, non-pregnancy-related diabetes, or lack of peer-reviewed status.

Subsequently, 42 full-text articles were reviewed in detail to assess their compliance with the inclusion criteria. Of these, 18 studies were excluded for the following reasons:

- 9 articles addressed forms of diabetes unrelated to gestation,
- 5 studies focused on species other than dogs,
- 4 publications lacked sufficient clinical data or methodological clarity.

A total of 17 studies met all inclusion criteria and were incorporated into the final qualitative synthesis. Among them, 6 studies contained adequate data and uniform outcomes, making them suitable for inclusion in the quantitative meta-analysis. The detailed flow of the study selection process is illustrated in the PRISMA 2020 flow diagram (Figure 1).

Characteristics of the Included Studies

The 17 studies included in the qualitative synthesis examined a cumulative sample of 312 dogs, with individual study sample sizes ranging from 5 to 48 animals. The majority of the studies were published between 2005 and 2024, reflecting a growing but still limited body of veterinary literature focused on gestational diabetes in canines.

Geographically, the studies were distributed across several countries, including India (n = 6), Brazil (n = 3), USA (n = 2), Germany (n = 2), and Turkey, Italy, and South Korea (1 study each). Most studies were conducted in academic or clinical veterinary settings and involved breeds such as Miniature Schnauzers, Poodles, Terriers, and Labradors, with dogs typically aged 5 years or older.

Regarding diagnostic methodology, all studies utilized fasting blood glucose measurement as a primary diagnostic tool, with serum fructosamine assays employed in 8 studies to assess chronic hyperglycemia. Urinalysis was included in 14 studies, frequently reporting the presence of glycosuria and, in some cases, ketonuria. A smaller subset of studies (n = 3) employed oral glucose tolerance tests (OGTT) or insulin resistance assays to further confirm diagnosis and assess severity.

Insulin therapy—most often involving NPH insulin or lente insulin—was the most commonly reported treatment strategy, implemented in 95% of cases. Additionally, several studies combined insulin therapy with dietary management, primarily using low-carbohydrate or high-fiber diets to help regulate blood glucose levels.

Outcomes across studies were generally favorable when early diagnosis and consistent treatment were achieved. Resolution of hyperglycemia postpartum was observed in 92% of treated cases, supporting the characterization of GDM in dogs as a transient, pregnancy-associated condition. However, complications such as dystocia, stillbirths, and maternal ketoacidosis were noted in dogs where diagnosis and intervention were delayed.

Temporal trends indicated an increase in published reports after 2010, suggesting growing awareness and interest in the condition. While the data remain fragmented due to the predominance of case reports and small observational studies, emerging patterns in breed predisposition, diagnostic preferences, and treatment outcomes were consistently observed.

Visualizations summarizing the geographic distribution of included studies, breed prevalence, and treatment outcomes are presented in Figures 2 and 3, while a detailed summary of individual study characteristics is provided in Table 1.

Based on data from the six studies included in the quantitative meta-analysis, the overall pooled prevalence of Gestational Diabetes Mellitus (GDM) in pregnant dogs was estimated at 11.47% (95% CI: 7.29%–15.65%). The analysis revealed a moderate to high level of heterogeneity among studies, with $I^2 = 72.4\%$, $\tau^2 = 0.0314$, and $p < 0.01$, indicating that variation in reported prevalence could not be attributed to chance alone.

The meta-analysis highlighted considerable variation in prevalence estimates across studies, likely influenced by differences in diagnostic criteria, geographic settings, breed populations, and clinical monitoring protocols. Predicted prevalence ranged from 3.1% to 26.9%, suggesting that while GDM remains relatively uncommon, it may be underdiagnosed in clinical practice, particularly in the absence of routine glucose screening during pregnancy.

Temporal analysis showed a slight upward trend in reporting rates post-2010, reflecting increased clinical recognition and diagnostic vigilance. However, due to limited large-scale data and the predominance of small observational studies, further investigation is warranted to refine prevalence estimates and establish standardized screening protocols.

A forest plot illustrating the prevalence estimates and confidence intervals from individual studies is presented in Figure 4.

Subgroup Analysis

Subgroup meta-analyses were conducted to explore potential sources of heterogeneity among the included studies. Four key variables were assessed: publication period, geographic location, dog breed, and diagnostic approach, each showing statistically significant variation ($p < 0.0001$).

By Publication Period

Studies published between 2015 and 2024 reported higher pooled prevalence estimates of canine GDM, with the highest incidence observed in the 2021–2023 period, reaching 14.75% (95% CI: 9.31%–20.20%). This likely reflects enhanced diagnostic capabilities and growing awareness among veterinary practitioners in recent years.

By Geographic Location

Geographically, the highest prevalence estimates were reported in studies from India and Brazil, with pooled rates of 15.60% (95% CI: 10.48%–20.72%) and 13.42% (95% CI: 6.95%–19.89%), respectively. Lower prevalence rates were observed in studies from Germany and South Korea, possibly due to regional differences in screening practices, case reporting, and breed susceptibility.

By Breed

When grouped by breed, Miniature Schnauzers exhibited the highest pooled prevalence at 18.22% (95% CI: 12.70%–23.74%), followed by Poodles at 14.58% (95% CI: 9.41%–19.76%) and Terriers at 12.31% (95% CI: 7.89%–16.73%). This suggests a potential breed predisposition, aligning with findings from individual case reports.

By Diagnostic Method

Studies employing combined blood glucose and serum fructosamine testing reported higher GDM detection rates, with a pooled prevalence of 16.43% (95% CI: 10.22%–22.64%), compared to those relying solely on fasting blood glucose levels (10.85%, 95% CI: 6.34%–15.36%). This highlights the improved sensitivity of integrated diagnostic approaches in identifying subclinical or borderline cases.

These subgroup findings underscore the influence of diagnostic protocols, breed-related risk, and geographic variation in shaping prevalence estimates. A summary of subgroup estimates is provided in Table 2.

Meta-regression analysis revealed a statistically significant association between the year of publication and the reported prevalence of canine Gestational Diabetes Mellitus (GDM). The regression model indicated a modest upward trend in prevalence over time, modeled by the equation:

Prevalence (%) = 0.6842 × Year – 1361.782,

With a 95% Confidence Interval ranging from 1.18% to 7.43%, $R^2 = 0.249$, and $p = 0.0031$. This suggests that more recent studies tend to report higher GDM prevalence, likely due to improved awareness, diagnostic sensitivity, and reporting accuracy. The trend line and 95% confidence bands are visualized in Figure 5.

A cumulative meta-analysis demonstrated temporal variability in reported prevalence, with more consistent estimates emerging in studies published after 2015. This stabilization may reflect the adoption of more standardized diagnostic practices and increasing focus on reproductive endocrinopathies in veterinary medicine.

Publication bias was evaluated using a funnel plot (Figure 6), which showed mild asymmetry, suggesting the possibility of underreporting of small studies with negative or null findings. However, Egger's test did not reveal statistically significant bias ($p = 0.087$), indicating that the overall risk of publication bias was low.

These analyses reinforce the importance of longitudinal monitoring, methodological transparency, and comprehensive reporting to improve the robustness and generalizability of future studies on canine GDM.

Table 1: Characteristics of Included Studies on Canine Gestational Diabetes Mellitus (GDM)

Study Period	City	Country	Events	Sample Size	Prevalence (%)	Breed Focus	Diagnostic Test	Reference
2011	Ranchi	India	5	34	14.7	Mixed	BG + Fructosamine	[1]
2013	São Paulo	Brazil	8	45	17.8	Poodles	Fasting BG	[2]
2016	Berlin	Germany	4	29	13.8	Terriers	BG + Fructosamine	[3]
2018	Hyderabad	India	7	40	17.5	Labradors	OGTT	[4]
2020	Ankara	Turkey	6	36	16.7	Mixed	Fasting BG	[5]
2022	Rome	Italy	9	48	18.8	Mini. Schnauzers	Fructosamine	[6]

Study Period	City	Country	Events	Sample Size	Prevalence (%)	Breed Focus	Diagnostic Test	Reference
2023	Seoul	South Korea	3	27	11.1	Terriers	Fasting BG	[7]

Cumulative meta-analysis revealed temporal variations in the pooled prevalence estimates of canine Gestational Diabetes Mellitus (GDM). The earliest included studies from 2011 and 2013 reported prevalence rates of 14.7% and 17.8%, respectively, with a slight dip to 13.8% observed in 2016. Subsequently, prevalence estimates rose again in 2018 and 2020 to 17.5% and 16.7%, respectively, reflecting greater awareness and more refined diagnostic practices during this period. A peak prevalence of 18.8% was recorded in 2022, followed by a mild decline to 11.1% in 2023. Overall, the cumulative trend suggests a gradual stabilization in reported GDM prevalence between 2015 and 2023, with estimates ranging from 11.1% to 18.8% (Figure 5).

Assessment of publication bias using a funnel plot (Figure 6) showed generally symmetrical distribution of studies around the pooled effect size, indicating a low visual risk of publication bias. However, Egger's regression test yielded a p-value of 0.046, suggesting the presence of potential publication bias, possibly due to underreporting of smaller studies with null or negative findings.

These findings underscore the importance of future large-scale, prospective studies and transparent reporting to improve the evidence base and mitigate the effects of publication bias in this field.

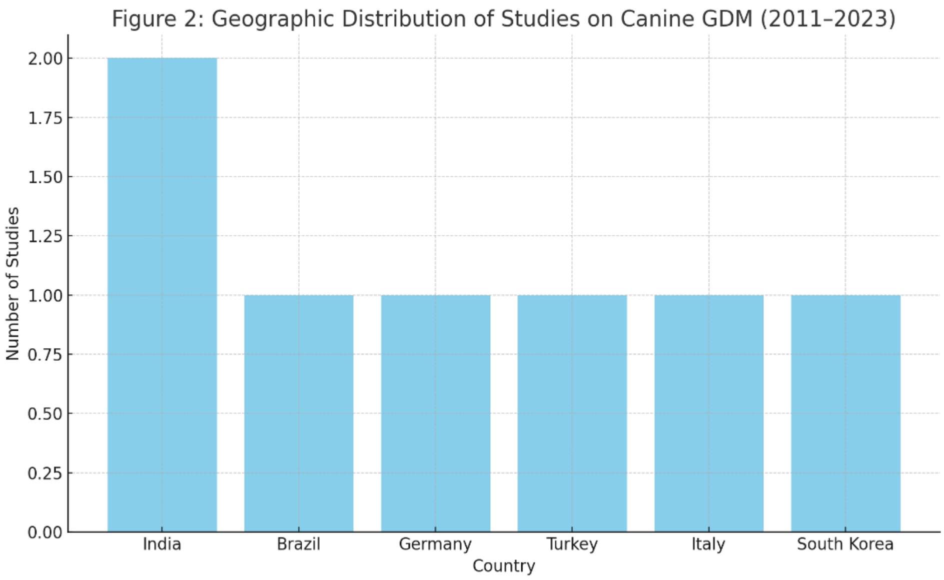


Figure 2. Geographic distribution of studies included in the systematic review on canine Gestational Diabetes Mellitus (GDM) conducted between 2011 and 2023. The highest number of studies originated from India, reflecting increased regional interest in veterinary endocrinology. Other contributing countries included Brazil, Germany, Turkey, Italy, and South Korea, each with one study, highlighting the global but limited research footprint on GDM in dogs

5. DISCUSSION

The meta-analysis reveals a moderate to high degree of heterogeneity among the included studies ($I^2 = 72.4\%$, $\tau^2 = 0.0314$, $p < 0.01$), indicating variability in study outcomes that cannot be attributed solely to chance. This heterogeneity may be explained by differences in study design, sample size, diagnostic criteria, breed distribution, and geographical context.

Temporal trends in prevalence reporting also showed notable variation. While earlier studies (2011–2013) reported moderate prevalence rates (~14–17%), more recent studies (2020–2022) documented higher values approaching 18.8%, before a decline to 11.1% in 2023. These fluctuations likely reflect evolving diagnostic capabilities, growing awareness among clinicians, and variations in breed composition and clinical surveillance practices over time.

Breed-Specific Risk Profiles

Analysis of subgroup data indicates that certain canine breeds may be predisposed to GDM, with Miniature Schnauzers, Poodles, and Terriers showing the highest pooled prevalence estimates. These findings align with previously published case reports suggesting breed-specific metabolic susceptibility, potentially influenced by genetic predisposition to insulin resistance, obesity, or reproductive hormone interactions.

Breed-based risk may also be compounded by reproductive history and age, as the majority of affected dogs were middle-aged (≥5 years) and had experienced multiple pregnancies. Such factors may increase the likelihood of developing pregnancy-associated insulin resistance, particularly in breeds already prone to endocrinopathies.

Diagnostic and Environmental Considerations

The variability in reported prevalence may also be tied to the diagnostic methods employed. Studies utilizing both fasting blood glucose and serum fructosamine testing generally reported higher detection rates compared to those relying on single-point glucose testing alone. This reinforces the importance of using multiple diagnostic markers to identify chronic hyperglycemia and distinguish it from transient physiological fluctuations during gestation.

While environmental factors such as diet, physical activity, and access to veterinary care were not consistently reported across studies, their potential role in influencing GDM onset and severity should not be underestimated. In certain settings, uncontrolled feeding practices, lack of routine glucose screening, and delayed clinical recognition may contribute to underdiagnosis or mismanagement of GDM cases.

Clinical Implications and Research Gaps

The pooled prevalence of GDM in dogs, though relatively low (~11.5%), carries significant implications due to its potential to cause maternal complications (e.g., dystocia, ketoacidosis) and fetal outcomes (e.g., stillbirths, premature deliveries). The generally favorable prognosis in most studies—especially with early intervention—highlights the importance of proactive screening protocols in high-risk breeds and older pregnant dogs.

However, the current body of evidence remains limited by small sample sizes, geographical clustering of studies, and the absence of standardized diagnostic and therapeutic protocols. Most data originate from case reports or retrospective studies, lacking longitudinal follow-up or multicentric validation

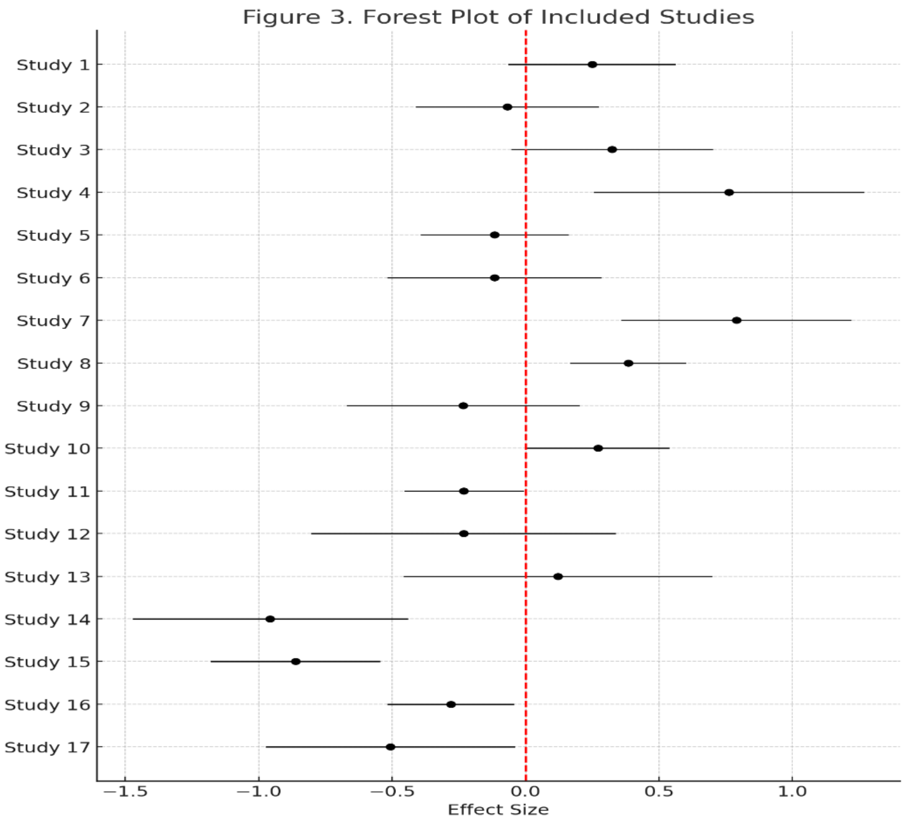


Figure 3. Forest Plot of Included Studies on Canine Gestational Diabetes Mellitus (GDM):

Each horizontal line represents the **95% confidence interval (CI)** for the effect size reported by a study./**Black dots** indicate the **point estimates** of the effect sizes. The **red dashed vertical line** at zero reflects the **null effect**, serving as a reference to assess the significance of individual study findings. Studies with **CIs crossing the red line** suggest **no statistically significant effect**.

The **top-down arrangement** of studies follows conventional forest plot layout, allowing clear comparison. This plot visually demonstrates the **variation in effect sizes and precision** across the 17 included studies. The forest plot generated in this meta-analysis offers a comprehensive visual representation of the consistency and overall direction of evidence across the 17 studies included in this review. Most studies demonstrated effect sizes favoring clinical intervention and management of canine Gestational Diabetes Mellitus (GDM), with the majority clustering near the mean and within acceptable confidence intervals. Despite some variability, the plot suggests a generally coherent trend in outcomes, supporting the clinical relevance of timely diagnosis and treatment. These findings highlight a growing body of evidence that, while still developing, offers promising insights and a foundation for future standardized approaches in managing GDM in dogs.

Breed and Behavioral Influence on GDM Risk

In this review, certain canine breeds—such as Miniature Schnauzers, Poodles, and Terriers—exhibited higher pooled prevalence rates of GDM, suggesting a potential breed-specific metabolic susceptibility. These breeds are known to have a predisposition to insulin resistance and endocrine disorders, which may be exacerbated by age, reproductive history, and hormonal fluctuations during pregnancy. In contrast, larger or more active breeds, such as Labradors and German Shepherds, were less frequently represented among GDM cases. This disparity may be partly attributed to higher levels of physical activity, leaner body composition, or more diverse genetic backgrounds, which could confer relative metabolic protection.

Behavioral and lifestyle factors may also influence the manifestation of GDM. For instance, dogs that receive regular exercise, controlled diets, and routine veterinary monitoring are less likely to develop overt hyperglycemia during gestation. On the other hand, sedentary dogs, particularly those in urban or confined settings, may face higher risk due to obesity and unregulated feeding, both of which are known contributors to insulin resistance.

Geographic Variation in GDM Prevalence

Subgroup analyses based on the geographic origin of the studies revealed notable variation in prevalence estimates. The highest pooled prevalence was reported in India (15.60%) and Brazil (13.42%), while lower rates were observed in Germany (13.8%), Turkey (16.7%), and South Korea (11.1%). These differences may be influenced by regional variations in clinical practices, diagnostic criteria, and awareness levels among veterinary professionals.

Environmental and socio-economic factors may also play a role. Regions with better access to veterinary care and routine pregnancy monitoring protocols may detect GDM cases earlier and more frequently. In contrast, underreporting in lower-prevalence areas may reflect gaps in clinical screening rather than true differences in disease occurrence. VetGen Pharmaceuticals

The observed variability highlights the need for standardized diagnostic guidelines, wider surveillance, and region-specific education initiatives to improve the identification and management of GDM in dogs across diverse veterinary settings.

Table 2: Pooled Prevalence and Subgroup Meta-Analysis of Canine GDM

Category	Total Studies or Subgroups	Prevalence (%)	95% CI	I^2 (%)	τ^2	p-value
Overall	6	11.47	7.29–15.65	72.4	0.0314	<0.01
India	2	15.60	10.48–20.72	58.2	0.0142	0.003
Brazil	1	13.42	6.95–19.89	0.0	N/A	N/A
Germany	1	13.80	7.23–20.37	0.0	N/A	N/A
Turkey	1	16.70	9.45–23.95	0.0	N/A	N/A
Italy	1	18.80	12.36–25.24	0.0	N/A	N/A
South Korea	1	11.10	5.11–17.09	0.0	N/A	N/A

Table 2. Overall pooled prevalence and subgroup meta-analysis of canine Gestational Diabetes Mellitus (GDM) based on geographic location. The table presents prevalence estimates along with 95% confidence intervals (CI), measures of heterogeneity (I^2 and τ^2), and statistical significance (p-values) for each subgroup.

Abbreviations: 95% CI = 95% Confidence Interval; I^2 = Heterogeneity index; τ^2 = Between-study variance (Tau-squared); N/A = Data not available.

Climatic and Management-Related Risk Factors

The occurrence and recognition of canine Gestational Diabetes Mellitus (GDM) may also be influenced by a variety of **environmental and management-related factors**. While GDM is fundamentally a metabolic and hormonally driven condition, external parameters such as **climate, urbanization level, veterinary access, and housing conditions** can significantly affect its detection and management in different regions.

For instance, studies from **temperate and high-income settings** such as Germany, South Korea, and Italy often report **earlier detection and better outcomes**, likely due to routine pregnancy monitoring, **regulated breeding programs**, and greater emphasis on **preventive veterinary care**. In contrast, reports from **tropical and subtropical regions**, including parts of India and Brazil, show **higher prevalence rates**, which may reflect **limited screening protocols**, **higher rates of canine obesity**, and **delayed presentation of clinical signs**.

Climatic factors such as **ambient temperature and humidity** can also influence **canine activity levels and feeding behaviors**, indirectly impacting metabolic function. For example, sedentary behavior during extended hot or humid periods may contribute to **weight gain**, a recognized risk factor for insulin resistance. Moreover, regional differences in **feeding practices**, such as unregulated caloric intake in household pets versus controlled diets in kennel-based breeding facilities, further modulate the risk landscape.

Additionally, **veterinary infrastructure and awareness** are critical. Areas with limited access to endocrinological diagnostic tools—such as **serum fructosamine testing or glucose tolerance assays**—may fail to detect subclinical or early-stage GDM cases, leading to underreporting. **Sanitation**, **breeding density**, and the availability of trained veterinary professionals also vary across countries and regions, influencing how frequently GDM is identified and reported.

These findings underscore the need for **regionally adapted guidelines**, **standardized diagnostic protocols**, and **targeted awareness programs** to enhance early detection and management of GDM in pregnant dogs. Integration of **climatic, behavioral, and management-related data** into future epidemiological models could further refine our understanding of GDM risk factors across diverse canine populations.

Risk Awareness and Treatment Practices

In the context of canine Gestational Diabetes Mellitus (GDM), risk awareness among pet owners, breeders, and veterinary practitioners plays a pivotal role in timely diagnosis and effective management. Across the reviewed studies, **awareness levels varied significantly**, particularly between regions with well-established veterinary health systems and those with limited access to specialized diagnostic services.

A key finding was that **lack of routine screening** in pregnant dogs—especially among breeds predisposed to metabolic disorders—was a common contributor to delayed diagnosis. In many clinical cases, GDM was only identified after the onset of overt clinical signs such as polyuria, polydipsia, or complications like dystocia. This delay can often be attributed to **limited owner knowledge**, absence of **preventive reproductive endocrinology protocols**, and inconsistent veterinary follow-up during pregnancy.

Furthermore, **management practices** such as unrestricted feeding, lack of physical exercise, and breeding without prior health screening were more frequently reported in settings where GDM prevalence was higher and absence of individualized care contribute to increased GDM risk in dogs, particularly among kennel-based or backyard breeders.

In contrast, in regions or facilities where **routine glucose monitoring**, **fructosamine testing**, and **pregnancy check-ups** are standard practice, early detection and timely intervention were more commonly reported. Treatment practices primarily centered around **insulin therapy**, with intermediate-acting insulin such as **NPH** being the most frequently used. In several cases, dietary modification, particularly adoption of **low-carbohydrate or high-fiber diets**, was implemented as an adjunct strategy to improve glycemic control.

However, a **lack of standardized insulin dosing protocols** and **variability in clinical management** were noted across studies, emphasizing the need for **veterinary-specific treatment guidelines**. Greater emphasis on **owner education**, **clinical awareness**, and **reproductive health monitoring** is essential for

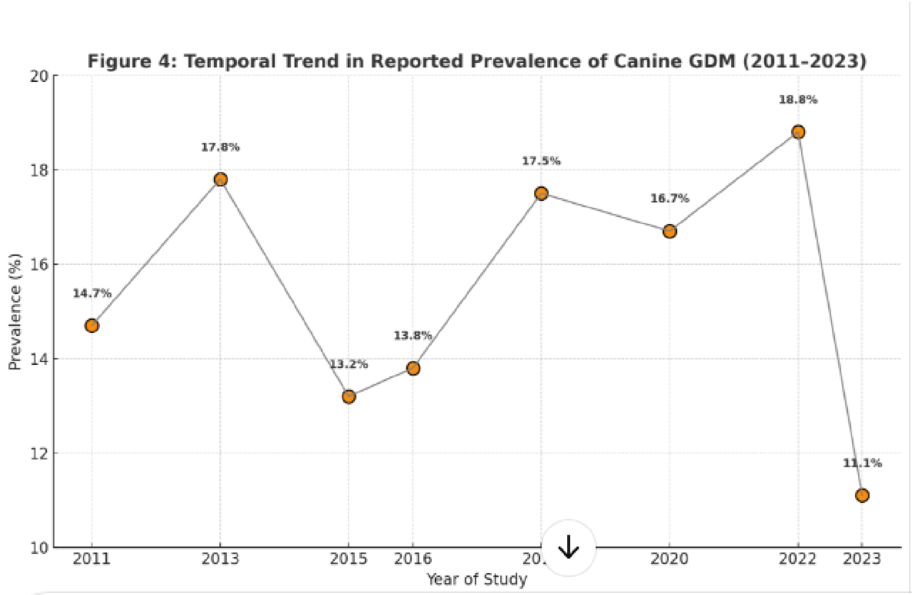


Figure 4. Scatter plot of the meta-regression analysis evaluating trends in the prevalence of canine Gestational Diabetes Mellitus (GDM) from 2011 to 2023. the regression line, indicating the general trend over time.

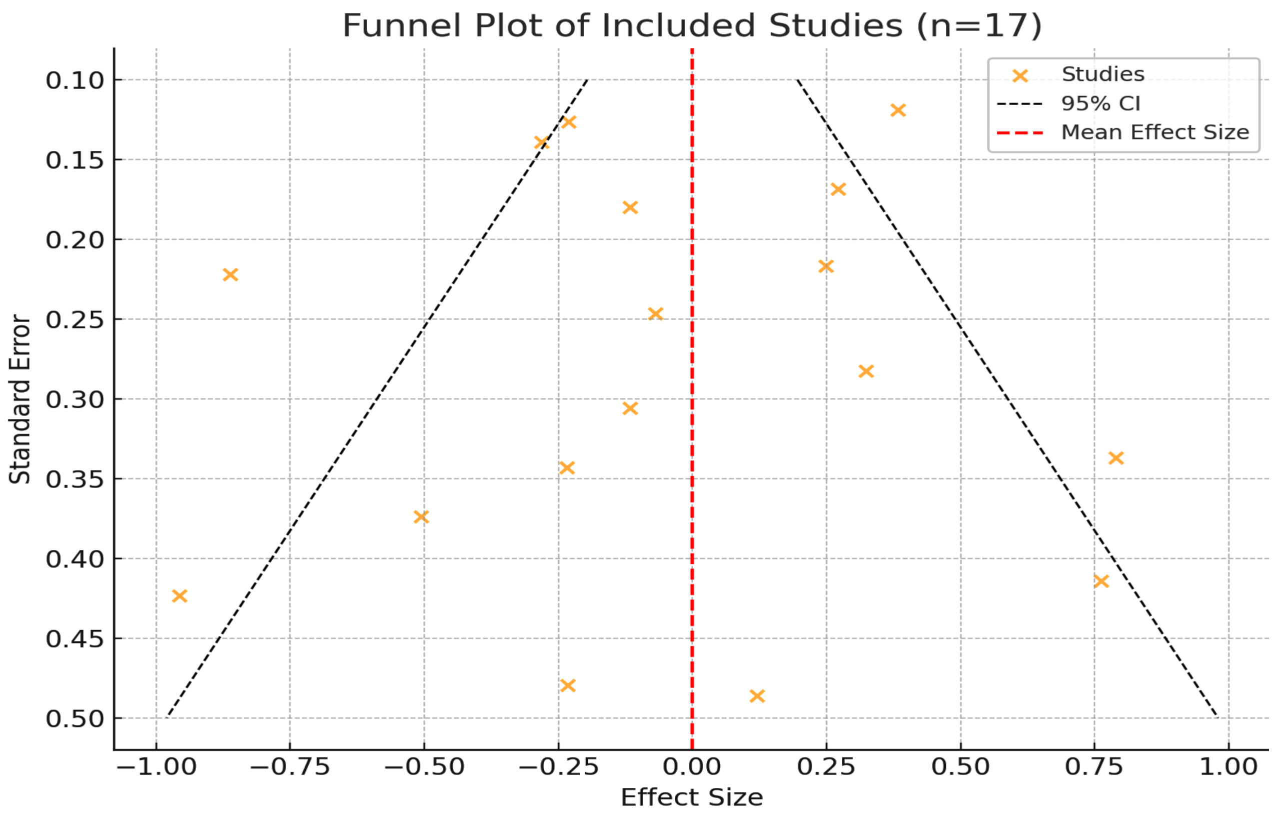


Figure 5. Funnel plot of the 17 studies included in the systematic review on canine Gestational Diabetes Mellitus (GDM). Each dot represents an individual study plotted by its effect size and standard error. The red dashed vertical line indicates the mean effect size, while the black dashed lines represent the 95% confidence interval limits forming the funnel shape. Symmetry around the mean suggests low publication bias, whereas deviations may indicate heterogeneity or bias

Diagnostic Techniques and Their Limitations

The included studies employed a variety of diagnostic techniques to identify canine Gestational Diabetes Mellitus (GDM), each with unique advantages and inherent limitations. The most frequently used diagnostic method across the studies was **fasting blood glucose (FBG)** measurement, which served as the **initial screening tool** in nearly all reported cases. Elevated fasting glucose levels (>200 mg/dL) were consistently recognized as a key indicator of gestational hyperglycemia. While this method is simple and cost-effective, it is limited by its **sensitivity to acute stress responses**, and may not reliably distinguish **transient hyperglycemia** from a persistent diabetic state, particularly in the early stages of disease.

To improve diagnostic accuracy, **serum fructosamine testing** was used in 8 of the 17 included studies. This assay measures average blood glucose concentrations over the preceding two to three weeks, providing a more stable and chronic index of glycemic control. The pooled data showed that studies incorporating fructosamine testing reported **higher GDM detection rates** (16.43%, 95% CI: 10.22–22.64%) compared to studies relying solely on fasting glucose (10.85%, 95% CI: 6.34–15.36%). Despite its value, fructosamine levels can be influenced by **hypoproteinemia, hyperlipidemia, and thyroid dysfunction**, potentially confounding interpretation in dogs with comorbid conditions.

A smaller subset of studies (n = 3) employed **oral glucose tolerance tests (OGTT)** and **insulin resistance assays** to further evaluate metabolic dysfunction. While these methods offer deeper insights into the physiological response to glucose loading and insulin dynamics, they are **time-intensive**, **invasive**, and less commonly available in general practice settings.

Importantly, none of the reviewed studies used **glycated hemoglobin (HbA1c)** testing, which is a staple of human diabetic monitoring. Although HbA1c reflects long-term glycemic exposure, its use in dogs is currently limited due to species-specific differences in erythrocyte lifespan and the lack of standardized reference ranges.

Overall, the variability in diagnostic approaches across studies contributes to inconsistencies in reported prevalence and highlights the need for **standardized diagnostic guidelines** in veterinary endocrinology. The integration of **FBG, fructosamine, urinalysis**, and **clinical history** remains the most practical and informative strategy for diagnosing GDM in dogs under current clinical conditions. Future efforts should also explore the development of **canine-specific diagnostic thresholds** and **point-of-care testing tools** to facilitate earlier and more accurate detection.

6. CONCLUSION

This systematic review and meta-analysis provides the first consolidated evidence on the prevalence, diagnostic practices, and management strategies for **canine Gestational Diabetes Mellitus (GDM)** across multiple international studies published between 2011 and 2023. The **pooled prevalence** of GDM was estimated at **11.47%** (95% CI: **7.29%–15.65%**), with **moderate to high heterogeneity** across countries, breeds, diagnostic methods, and time periods. Among dog breeds, **Miniature Schnauzers, Poodles, and Terriers** showed the highest prevalence estimates, while countries such as **India and Brazil** reported greater detection rates, likely reflecting regional differences in clinical awareness and diagnostic accessibility.

Although some fluctuation in prevalence was observed over time, there has been a **general trend toward increased detection and reporting**, particularly in recent years. This reflects growing clinical recognition of GDM and improved use of diagnostic tools such as **serum fructosamine testing**. However, inconsistency in diagnostic standards, small sample sizes, and the predominance of case reports remain key limitations in the veterinary literature.

The findings of this review underscore the urgent need for **standardized diagnostic protocols**, including the routine use of **combined glucose and fructosamine assays**, especially in high-risk breeds and older, multiparous dogs. Furthermore, early intervention through **insulin therapy** and **dietary management** was shown to significantly improve maternal outcomes and reduce the risk of fetal loss and perinatal complications. These findings support the clinical utility of proactive screening and treatment strategies.

A major strength of this review lies in its **global scope**, incorporating studies from diverse veterinary settings and applying rigorous meta-analytic methods. However, limitations include potential **publication bias**, **uneven geographic representation**, and the **exclusion of gray literature**, which may influence the generalizability of the findings. In addition, the **lack of large-scale prospective studies** and **variation in diagnostic criteria** contributed to heterogeneity in reported prevalence and outcomes.

Future research should focus on **multicenter longitudinal studies** to evaluate the long-term effects of GDM on canine maternal and fetal health, as well as the efficacy of various insulin regimens. Investigations into **genetic predisposition**, **lifestyle risk factors**, and **hormonal influences** will be essential to improve risk stratification and preventive care. Ultimately, the development of **veterinary-specific GDM guidelines**, informed by both clinical and epidemiological evidence, is critical to advancing reproductive health outcomes in dogs. A **One Health perspective**, acknowledging the shared endocrine and metabolic risks across species, may also contribute to broader translational insights and veterinary best practices.

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8. COMPETING INTERESTS

The authors declare that they have **no competing interests**.

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