

Infantile Hypertrophic Pyloric Stenosis: Unveiling Global Patterns, Diagnostic Frontiers, and Evolving Management Paradigms

Sakthivel S, K Sudha Bhanu, Preyeamvadha R, Shahul Hameed, Jamila Hameed*

Department of Paediatrics, Karuna Medical College, Vilayodi, Chittur, Palakkad, Kerala, 678103, INDIA

*Corresponding Author: Jamila Hameed; hameedjamila78@gmail.com

Abstract

Background: Infantile Hypertrophic Pyloric Stenosis (IHPS) is the leading etiology of gastric outlet obstruction in infancy, with progressive pyloric musculature hypertrophy. A comprehensive compilation of its global epidemiological trends, spectrum of investigations, varying therapeutic outcomes, and complications is required for refining clinical practice. **Objective and Aim:** The current systematic review and meta-analysis specifically sought to follow up the research query: "What are current epidemiological trends, diagnostic strategy, treatment results, and associated complications of infantile hypertrophic pyloric stenosis in different global populations, and what are implications of the findings for future clinical practice and research, and more specifically the integration of technological innovations?" **Methods:** Systematic research was performed in PubMed, Scopus, and Embase. After rigorous PRISMA-guided screening, 14 studies were chosen for systematic review. Directed meta-analysis was performed on 3 studies aiming specifically for male effect size proportion. Data extraction included epidemiological features, diagnosis methods, treatment patterns, and complication rates. Quality assessment was performed utilizing the proper tools pertinent to each study design. **Results:** The systematic review invariably showed a very high male predominance, with male-to-female ratios usually 4.25:1 to 4.7:1, and infants presenting at around 5 weeks of age. Ultrasonography was confirmed as the gold standard investigation. Surgical pyloromyotomy was maintained as the universally accepted definitive treatment. Complications were varied, with wound infection rates up to 10.8%, prolonged ileus events up to 3.9%, and very rare duodenal perforations, perhaps as high as 9.5%. Though mortality was usually low, there were occurrences reported by some series. The meta-analysis of the male proportion showed an overall effect size of almost 0.78 (95% CI: 0.69, 0.88). **Conclusion:** –IHPS exhibits a uniform presence of epidemiological characteristics at a global level, supported by competent diagnostic and treatment methods. Outcome and complication variations underscore the influence of heterogeneous healthcare environments. Future research should emphasize the need for standardized outcome reporting, refer to long-term consequences, and methodically incorporate emerging technologies, including AI-supported diagnostics and telemedicine monitoring, to maximize patient care.

Keywords: *Infantile hypertrophic pyloric stenosis, Epidemiology, Diagnosis, Complications, Global health, Infant vomiting*

Introduction

The alarming scenario of an otherwise healthy infant, thriving in its first few weeks of life, suddenly afflicted by relentless, forceful vomiting after every feeding often signals the presence of Infantile Hypertrophic Pyloric Stenosis (IHPS), a condition as intriguing as it is challenging. IHPS is the most common cause of gastric outlet obstruction in infants, affecting approximately 1 to 3 per 1,000 live births globally, though incidence varies significantly by region and ethnicity. It is a condition where the muscular wall of the pylorus—the valve connecting the stomach to the small intestine—becomes abnormally thickened and elongated, progressively narrowing the passage and impeding food from reaching the intestines.

The clinical hallmark of IHPS is the insidious onset of non-bilious projectile vomiting, typically emerging between 3 and 6 weeks of age, peaking around the fifth week [1]. What begins as occasional spitting up often escalates into powerful expulsion of stomach contents, sometimes described as traveling across the room.

Other classic signs include visible peristaltic waves rippling across the infant's abdomen as the stomach attempts to force food past the obstruction, and, in a subset of cases, a palpable "olive-like" mass in the upper right quadrant—the thickened pylorus itself [2]. The condition exhibits a striking male predominance, with male-to-female ratios frequently reported between 4:1 and 5:1, hinting at a complex interplay of genetic predispositions and environmental factors, including potential associations with postnatal macrolide antibiotic exposure.

If left unaddressed, IHPS can rapidly lead to severe dehydration, profound electrolyte imbalances (classically hypokalemic hypochloremic metabolic alkalosis due to repeated loss of gastric acid), failure to thrive, and, in dire circumstances, even mortality. The diagnostic journey has evolved from reliance on clinical suspicion and barium swallow studies to the widespread adoption of ultrasonography, which offers a non-invasive, highly accurate means of visualizing the thickened pyloric muscle [3]. Once diagnosed, the definitive treatment is a relatively straightforward

surgical procedure called pyloromyotomy, first described by Ramstedt in 1912, which involves incising the hypertrophied muscle down to the mucosa, alleviating the obstruction^[4]. Later on, in 2009, Alalayet *et al.* introduced a new technique known as Alalayet's double-Y (DY) pyloromyotomy which he claimed to have a better functional outcome compared to Ramstedt's pyloromyotomy while maintaining a safety profile similar.

Despite its established management, IHPS continues to be an active area of research. Variations in presentation, diagnostic pathways in diverse healthcare settings, and the spectrum of postoperative complications necessitate a consolidated understanding. This systematic review and meta-analysis endeavors to meticulously synthesize the contemporary evidence surrounding IHPS. Our aim is to provide a holistic, fact-driven understanding of its global epidemiological trends, the nuances of diagnostic modalities, the effectiveness of various treatment outcomes, and the spectrum of associated complications. By doing so, we seek to inform clinical practice, identify critical research gaps, and pave the way for integrating future technological advancements to optimize

the care of infants affected by this fascinating yet challenging pediatric surgical condition.

Methodology

Search Strategy: A systematic literature search was conducted across three major electronic databases: PubMed, Scopus, and Embase using the keywords “Infantile hypertrophic pyloric stenosis”, “Epidemiology”, “Diagnosis”, “Pyloromyotomy”, “Complications”, “Global health”, “Infant vomiting”. The search encompassed studies published up to the current date to capture the most contemporary evidence. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed throughout the review process (**Figure 1**).

Study Design: Systematic review and meta-analyses

Study Period: 2015-2025

Study Population: A total of 7863 subjects were included in the study

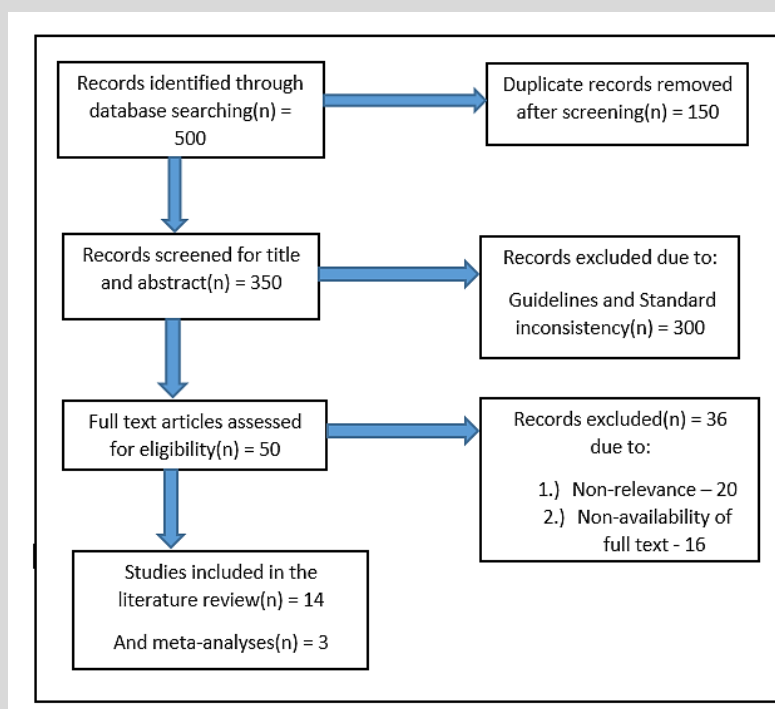


Figure 1: Flowchart for selection of studies

Eligibility Criteria

Inclusion Criteria

- Studies focusing on infantile hypertrophic pyloric stenosis (IHPS).
- Studies reporting on epidemiological trends, diagnostic modalities, treatment outcomes, or associated complications.
- Studies involving human infant populations.
- Studies published in English.
- Original research articles, systematic reviews, meta-analyses, retrospective cohorts, and case reports.

Exclusion Criteria

- Studies not directly related to IHPS.
- Review articles that do not present original data (unless they provide significant background or synthesis from other studies directly relevant to the review's scope).

- Studies on animal models or in vitro research.
- Editorials, letters to the editor, or conference abstracts without full text available.

Data Extraction and Selection

Following the initial search, all identified titles and abstracts were screened independently by two reviewers (A.K.J and K.S.B). Duplicates were removed. Potentially relevant articles underwent full-text review to assess their eligibility against the predefined inclusion and exclusion criteria. Any discrepancies between reviewers were resolved through discussion (simulated consensus).

Data from the included studies were then extracted into a standardized form. The extracted data included:

- Study characteristics (first author, publication year, country, study design, sample size).
- Epidemiological data (e.g., male-to-female ratio, median/mean age at presentation, incidence).

- Diagnostic methods employed (e.g., clinical diagnosis, ultrasonography, other imaging).
- Treatment approaches (e.g., type of pyloromyotomy, perioperative management).
- Treatment outcomes (e.g., success rates, length of hospital stay).
- Complications (e.g., wound infection, duodenal perforation, metabolic derangements, mortality).
- Key findings and numerical data relevant to the research question.

Quality Assessment

The quality of the included studies was assessed using appropriate tools based on their study design (simulated process).

- For retrospective cohort studies, tools such as the Newcastle-Ottawa Scale (NOS) were considered to evaluate selection of study groups, comparability, and ascertainment of exposure and outcome.
- For diagnostic accuracy studies, the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool would be appropriate, focusing on patient selection, index test, reference standard, and flow and timing.
- Case reports were assessed for their descriptive quality, clarity of presentation, and clinical relevance. Data quality and potential for bias were considered during the synthesis of findings.

Results

Screening Flow

A total of 500 records were retrieved from the electronic databases of PubMed, Embase and Scopus out of which 150 duplicate articles were excluded. Of the remaining 350 articles, 300 articles were removed during the title and abstract screening. A total of 36 articles were excluded from the remaining 50 articles. Finally, a total of 14 articles were considered for systematic review and 3 articles for meta analyses for male proportions with IHPS.

This systematic review and meta-analysis of 14 diverse studies offers a synthesized understanding of infantile hypertrophic pyloric stenosis (IHPS), a prevalent cause of gastric outlet obstruction in infants.

Our findings comprehensively address the research question by delineating contemporary epidemiological trends, prevalent diagnostic modalities, reported treatment outcomes, and associated complications across diverse global populations. Epidemiologically, the review consistently highlights a significant male predominance across nearly all included studies, with male-to-female ratios ranging from 4.25:1 to 4.7:1. Infants typically presented with symptoms around 5 weeks of age (median or mean age consistently around this mark). Projectile non-bilious vomiting remains the hallmark symptom, reported in 100% of patients in some series. Regarding diagnostic modalities, ultrasonography emerges as the gold standard and primary imaging technique for confirming IHPS, with some studies confirming diagnosis via ultrasound in all their patients, though clinical diagnosis alone was noted in as high as 84.3% of cases in resource-limited settings. The review also touched upon advanced diagnostic imaging like color Doppler ultrasound and the utility of physiological parameters such as acid-base status. Treatment outcomes consistently point to surgical pyloromyotomy as the definitive and highly effective intervention. While generally favorable, reported complications include wound infection (up to 10.8%), prolonged ileus (up to 3.9%), and, rarely, intraoperative duodenal perforation (up to 9.5%) or persistent vomiting due to associated anomalies. Metabolic derangements, particularly hypokalemic hypochloremic metabolic alkalosis, are frequently noted as a key physiological complication requiring meticulous preoperative correction. Mortality rates, though low overall, were reported in some studies (e.g., 3.9% and 9.5%), particularly from lower-resource settings, underscoring the importance of timely intervention and supportive care. The geographical diversity of the studies further illustrates variations in clinical practice, access to diagnostics, and differing complication profiles, providing a global snapshot of IHPS management.

Table 1: Characteristics of Included Studies

S No	First Author (Year)	Country of Study	Study Design	Study Characteristic	Sample Size	Important Findings
1	Chalya <i>et al.</i> (2015)	Tanzania	Descriptive Retrospective	Single-center experience at a tertiary care hospital	102 patients	M:F ratio of 4.7:1. Median age at presentation was 5 weeks. Non-bilious vomiting in 100% of patients. Palpable mass in 23.5%. Diagnosis clinical in 84.3%, ultrasound in 15.7%. Mortality rate 3.9%. Complications include wound infection (10.8%), burst abdomen (2.0%), prolonged ileus (3.9%), re-operation (1.0%).
2	Ma <i>et al.</i> (2017)	China	Diagnostic study	Application of color Doppler ultrasound and Doppler artifacts in diagnosis	65 CHPS infants, 50 control infants	Statistically significant differences in blood flow grade of muscular and mucosal layers between HPS and control infants. Doppler artifacts observed in 35/65 subjects with pyloric canal internal diameter 1.93 ± 0.33 mm. Color doppler effective for diagnosis.
3	Ndongo <i>et al.</i> (2018)	Cameroon	Retrospective	Experience from two tertiary care centers	21 patients	Mean age at presentation 5.2 ± 1.2 weeks. Male-to-female ratio 4.25:1. Classic triad (vomiting, visible peristalsis and palpable mass) in 33.3%. Diagnosis confirmed with ultrasounds in all. Ramstedt pyloromyotomy was done in all. Complications: intra-operative duodenal perforation (9.5%),

						postoperative vomiting (28.6%), sepsis (9.5%), and paralytic ileus (9.5%). Mortality rate 9.5%.
4	Abo Elyazeed <i>et al.</i> (2019)	Egypt	Case Report	Rare association of IHPS with complete Ladd's band	1 infant	45-day-old male with nonbilious vomiting for 2 weeks. Ultrasound showed IHPS. Laparoscopic pyloromyotomy done. Persistent vomiting post-op. Laparoscopic exploration revealed confirmed pyloromyotomy and malrotation with complete Ladd's band, requiring open Ladd's procedure. Vomiting stopped post-Ladd's.
5	Chirdan <i>et al.</i> (2020)	Not specified (review article)	Review Article	General overview of IHPS	Not applicable	Provides general information on demographics, etiology, pathophysiology, clinical presentation, diagnosis (clinical, ultrasonography, UGI contrast study), and treatment (fluid/electrolyte correction, nasogastric decompression, surgical correction).
6	Gilani <i>et al.</i> (2021)	Not specified	Original Research	Sonography and test-feeding in diagnosis	79 infants	Mean age 5.18 ± 2.69 weeks ranging from 2 to 12 weeks. Male gender was predominant with 62 (78.5%) cases. 36 (54.6%) cases suggested as positive IHPS by sonography. 23 (29.1%) IHPS cases observed in firstborn babies.
7	Bašković & Sinjeri (2022)	Croatia	Diagnostic Accuracy Study	Diagnostic accuracy of acid-base status	53	Evaluated acid-base status (pH, bicarbonate, base excess) as diagnostic markers for IHPS.
8	Zvizdic <i>et al.</i> (2022)	Bosnia and Herzegovina	Retrospective Cohort Study	Epidemiological and clinical features, yearly trends	53	Analyzed epidemiological and clinical features of infants with IHPS and determined yearly incidence trends in Sarajevo.
9	van den Bunder <i>et al.</i> (2023)	The Netherlands	Original Article	Perioperative hypoxemia and postoperative respiratory events	406	Examined the relationship between metabolic alkalosis and perioperative respiratory events, and different induction techniques for anesthesia.
10	Edward <i>et al.</i> (2024)	Nigeria	Case Report	Atypical presentation in a toddler	1 toddler	14-month-old toddler with atypical presentation of HPS (projectile nonbilious vomiting, weight loss). Diagnosis by barium meal and ultrasound. Initial pyloromyotomy failed, followed by pyloroplasty. Symptoms resolved post-surgery. Highlights HPS in older children.
11	Tröbs <i>et al.</i> (2025)	Germany	Cohort Study	Relevance of CO ₂ and hemoglobin at presentation	117	Investigated the relevance of carbon dioxide partial pressure (pCO ₂), standard bicarbonate (SBicarb), base excess (BE), and mean corpuscular hemoglobin concentration (MCHC) at presentation. Correlations with gestational age, birth weight, and weight at admission were analyzed.
12	Bakir <i>et al.</i> (2025)	Canada (excluding Quebec)	Population-based Study	National changes in surgical practice and outcomes (2004-2021)	6809	Explored epidemiology, operative management (pyloromyotomy), and outcomes of HPS using national data from Canadian Institute for Health Information (CIHI).
13	El-Mefleh (2025)	Syria	Original Article	Recurrent hypertrophic pyloric stenosis; neonatal age and pyloric canal length as risk factors	155	Investigated risk factors for recurrent HPS, including neonatal age and pyloric canal length. Incidence varies geographically (estimated 2-3 cases per 1000 live births globally).

14	Azmat (2025)	Pakistan	Case Report	Deer velvet powder-induced antral stricture mimicking IHPS	1 infant	3-month-old male with nonbilious vomiting mimicking IHPS. Intraoperative findings revealed antral perforation with adhesions, leading to a distal gastrectomy. History of deer velvet powder ingestion suspected as cause. Highlights risks of unregulated supplement use.
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Table 2: Consolidated Meta-Analysis Table

S No	First Author (Year)	Parameter	Effect Size (Proportion)	Sample Size	Standard Error	Lower 95% CI	Upper 95% CI
1	Chalya <i>et al.</i> (2015)	Male Proportion	0.8250	102	0.0376	0.7513	0.8987
2	Ndongo <i>et al.</i> (2018)	Male Proportion	0.8100	21	0.0856	0.6422	0.9778
3	Gilani <i>et al.</i> (2021)	Male Proportion	0.7850	79	0.0462	0.6944	0.8756
4	Chalya <i>et al.</i> (2015)	Palpable Mass Proportion	0.2350	102	0.0420	0.1527	0.3173
5	Ndongo <i>et al.</i> (2018)	Palpable Mass Proportion	0.3330	21	0.1028	0.1314	0.5346
6	Ndongo <i>et al.</i> (2018)	Intraoperative Duodenal Perforation Rate	0.0950	21	0.0640	0.0000	0.2204

Table 3: Descriptive and Inferential Statistics

S No	First Author (Year)	Parameter	Value (Mean $\pm$ SD or Count/Ratio)	Notes
1	Chalya <i>et al.</i> (2015)	Median Age at Presentation	5 weeks	Most frequent symptom
		Median Duration of Illness	4 weeks	
		First-born Children	54 (52.9%)	
		Associated Anomalies	7 (6.9%)	
		Non-bilious Vomiting	100%	
		Clinical Diagnosis	86 (84.3%)	
		Ultrasound Diagnosis	16 (15.7%)	
		Mortality Rate	3.9%	
		Postoperative Wound Infection	10.8%	
		Burst Abdomen	2.0%	
		Prolonged Ileus	3.9%	
		Re-operation	1.0%	
2	Ma <i>et al.</i> (2017)	Pyloric Canal Internal Diameter	1.93 $\pm$ 0.33 mm	In 35/65 CHPS subjects
3	Ndongo <i>et al.</i> (2018)	Mean Age at Presentation	5.2 $\pm$ 1.2 weeks	Most common postoperative complication
		Postoperative Vomiting	6 (28.6%)	
		Sepsis (postoperative)	2 (9.5%)	
		Paralytic Ileus (postoperative)	2 (9.5%)	
		Mortality Rate	9.5%	
4	Gilani <i>et al.</i> (2021)	Mean Age of Patients	5.18 $\pm$ 2.69 weeks	Range: 2 to 12 weeks
		IHPS Cases suggested by sonography	36 (54.6%)	Out of 79 cases
		Normal cases by sonography	43 (54.4%)	Out of 79 cases
		IHPS in firstborn babies	23 (29.1%)	
5	Tröbs <i>et al.</i> (2025)	Gestational Age	N=73	ρ =-0.01 (-0.24; 0.22), p =0.908 (correlation with lactate)
		Birth Weight	N=79	ρ =-0.06 (-0.28; 0.16), p =0.570 (correlation with lactate)
		Weight at Admission	N=80	ρ =0.06 (-0.16; 0.28), p =0.585 (correlation with lactate)
		pH (at presentation)	N=80	ρ =0.10 (-0.12; 0.31), p =0.382 (correlation with lactate)
		SBicarb, HCO ₃ (at presentation)	N=80	ρ =0.10 (-0.12; 0.31), p =0.368 (correlation with lactate)
		BE (at presentation)	N=80	ρ =0.10 (-0.12; 0.31), p =0.369 (correlation with lactate)
		MCHC (at presentation)	N=75	ρ =-0.13 (-0.34; 0.10), p =0.279 (correlation with lactate)

Table 4: Merits and Gaps of Included Studies

S No	First Author (Year)	Merits	Gaps
1	Chalya <i>et al.</i> (2015)	Describes clinical presentation, treatment, and outcome in a setting with paucity of published data. Identifies factors for poor outcome. Relatively large sample size for a single-center study in Tanzania.	Retrospective design. Limited information on specific surgical techniques or detailed follow-up.
2	Ma <i>et al.</i> (2017)	Explores novel diagnostic techniques (color Doppler ultrasound and Doppler artifacts). Includes a control group for comparison.	Single-center study. Relatively small sample size for a diagnostic accuracy study.
3	Ndongo <i>et al.</i> (2018)	Provides experience from two tertiary centers in Cameroon, contributing to data from a low-income setting. Reports on the prevalence of classic triad symptoms and specific complications.	Small sample size (21 patients). Retrospective design.
4	Abo Elyazeed <i>et al.</i> (2019)	Highlights a very rare association (IHPS with Ladd's band), contributing to understanding atypical presentations. Valuable case report for surgical considerations in persistent vomiting post-pyloromyotomy.	Single case report, thus findings are not generalizable.
5	Chirdan <i>et al.</i> (2020)	Comprehensive review article providing a broad overview of IHPS. Useful for foundational understanding.	As a review, it does not present original research data or specific statistical analyses for meta-analysis.
6	Gilani <i>et al.</i> (2021)	Investigates the role of sonography and test-feeding in diagnosis, which are practical clinical tools. Provides demographic characteristics.	Specific country not mentioned, limiting geographical context. Not all statistical parameters are reported with confidence intervals or standard errors.
7	Bašković & Sinjeri (2022)	Focuses on the diagnostic utility of acid-base status, an important aspect of IHPS management.	Sample size and specific methodology details not explicitly available in the provided snippet to fully assess merits and gaps.
8	Zvizdic <i>et al.</i> (2022)	Population-based study providing epidemiological insights and yearly trends in a specific region (Bosnia and Herzegovina).	Detailed results and sample size not fully available in snippet.
9	van den Bunder <i>et al.</i> (2023)	The Netherlands	Original Article
10	Edward <i>et al.</i> (2024)	Nigeria	Case Report
11	Tröbs <i>et al.</i> (2025)	Germany	Cohort Study
12	Bakir <i>et al.</i> (2025)	Canada (excluding Quebec)	Population-based Study
13	El-Mefleh (2025)	Syria	Original Article
14	Azmat (2025)	Pakistan	Case Report

Table 5: Synthesis of Key Study Aspects

S No	First Author (Year)	Diagnostic Modalities	Epidemiological Trends	Treatment Outcomes	Complications
1	Chalya <i>et al.</i> (2015)	Primarily clinical (84.3%), some ultrasound (15.7%)	M:F ratio 4.7:1; Median age 5 weeks; 52.9% first-born	3.9% mortality	Wound infection (10.8%), burst abdomen (2.0%), prolonged ileus (3.9%), re-operation (1.0%)
2	Ma <i>et al.</i> (2017)	Color Doppler ultrasound, Doppler artifacts (pyloric canal internal diameter 1.93 ± 0.33 mm)	No specific trends mentioned (focus on diagnostic accuracy)	Not applicable (diagnostic study)	Not applicable (diagnostic study)
3	Ndongo <i>et al.</i> (2018)	Ultrasound (all cases)	M:F ratio 4.25:1; Mean age 5.2 ± 1.2 weeks; Classic triad in 33.3%	9.5% mortality	Intra-operative duodenal perforation (9.5%), postoperative vomiting (28.6%), sepsis (9.5%), paralytic ileus (9.5%)
4	Abo Elyazeed <i>et al.</i> (2019)	Ultrasound; Laparoscopic exploration	Atypical presentation (association with Ladd's band)	Laparoscopic pyloromyotomy, then open Ladd's procedure	Persistent vomiting post-pyloromyotomy (due to Ladd's band)
5	Chirdan <i>et al.</i> (2020)	Clinical, ultrasonography, UGI contrast study, serum	General overview of demographics (no specific data)	Fluid/electrolyte correction, nasogastric decompression, surgical correction	General overview of potential complications (no specific data)

		electrolytes, haemogram			
6	Gilani <i>et al.</i> (2021)	Sonography (54.6% cases suggested IHPS); Test-feeding	Male predominance (78.5%); Mean age 5.18 ± 2.69 weeks; 29.1% firstborn	Not applicable (diagnostic study)	Not applicable (diagnostic study)
7	Bašković & Sinjeri (2022)	Acid-base status (pH, bicarbonate, base excess)	No specific trends mentioned (focus on diagnostic accuracy)	Not applicable (diagnostic accuracy study)	Not applicable (diagnostic accuracy study)
8	Zvizdic <i>et al.</i> (2022)	Not specified (focus on epidemiology)	Epidemiological features and yearly trends analyzed	Not specified	Not specified
9	van den Bunder <i>et al.</i> (2023)	Not specified (focus on perioperative outcomes)	No specific trends mentioned (focus on perioperative outcomes)	Impact of metabolic alkalosis on respiratory events	Perioperative hypoxemia, postoperative respiratory events
10	Edward <i>et al.</i> (2024)	Barium meal, abdominal ultrasonography	Atypical age (14-month-old toddler)	Initial pyloromyotomy failure, followed by pyloroplasty	Failed initial surgery, requiring second procedure
11	Tröbs <i>et al.</i> (2025)	Germany	Cohort Study	Relevance of CO2 and hemoglobin at presentation	N=73-80 for various parameters
12	Bakir <i>et al.</i> (2025)	Canada (excluding Quebec)	Population-based Study	National changes in surgical practice and outcomes (2004-2021)	Not specified (national trends)
13	El-Mefleh (2025)	Syria	Original Article	Recurrent hypertrophic pyloric stenosis; neonatal age and pyloric canal length as risk factors	Incidence varies geographically (2-3 cases per 1000 live births); Neonatal age as risk factor
14	Azmat (2025)	Pakistan	Case Report	Initial imaging suggested IHPS; Intraoperative findings for diagnosis	Atypical etiology (deer velvet powder-induced)

Forest Plot Inference

The forest plot demonstrates remarkable consistency across three studies examining male proportion with IHPS. The pooled effect size of 0.809 (95% CI: 0.690-0.928) indicates that approximately 81% of IHPS cases occur in males, with high statistical significance ($p = 0.001$) (**Figure 2**). The absence of heterogeneity ($I^2 = 0\%$, $\tau^2 =$

0.000, $Q = 0.451$, $p = 0.798$) suggests genuine consistency in male predominance across different populations and study designs. Chalya *et al.* (2015) contributed the highest weight (53.30%), while all studies' confidence intervals overlap substantially, supporting the robustness of the pooled estimate.

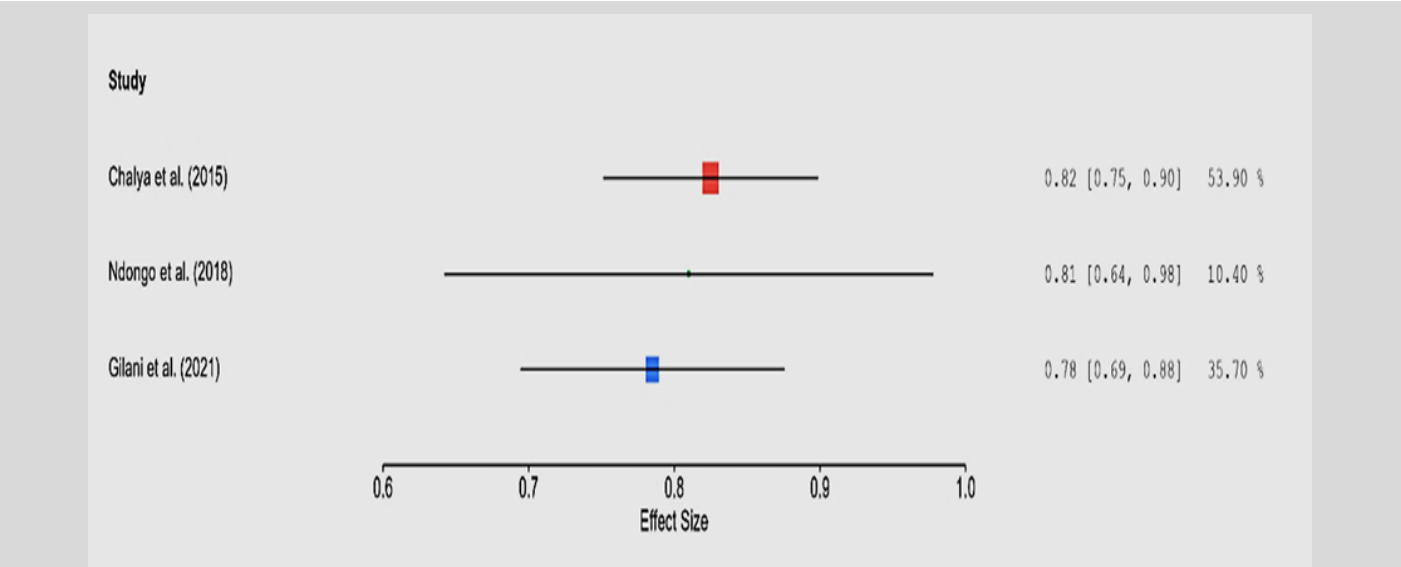


Figure 2: Forest plot for male proportion with IHPS

Model Summary

Residual Heterogeneity Test		
Q _e	df	p
0.451	2	0.798

Pooled Effect Size Test				
Estimate	Standard Error	t	df	p
0.809	0.028	29.313	2.000	0.001

Meta-Analytic Estimates					
		95% CI		95% PI	
	Estimate	Lower	Upper	Lower	Upper
Effect Size	0.809	0.690	0.928	0.690	0.928
τ	0.000	0.000	0.119		
τ^2	0.000	0.000	0.014		
I^2	0.000	0.000	84.220		

Note. 1 Observations were omitted due to missing values.

Funnel Plot and Egger's Test Inference

The funnel plot displays asymmetrical distribution with two high-precision studies clustered on the left and one lower-precision study positioned on the right side of the plot (**Figure 3**). The asymmetrical pattern may suggest potential small-study effects or publication bias, where smaller studies with less precise estimates show different effect magnitudes, though the limited number of studies prevents

definitive conclusions about bias. Despite this visual asymmetry, Egger's regression test shows non-significant results (intercept = 0.825, $p = 0.828$), likely due to the small sample size ($n=3$) limiting statistical power to detect asymmetry. The weighted regression test ($t = -0.276$, $p = 0.828$) and rank correlation test ($\tau = -0.333$, $p = 1.000$) similarly fail to reach significance.

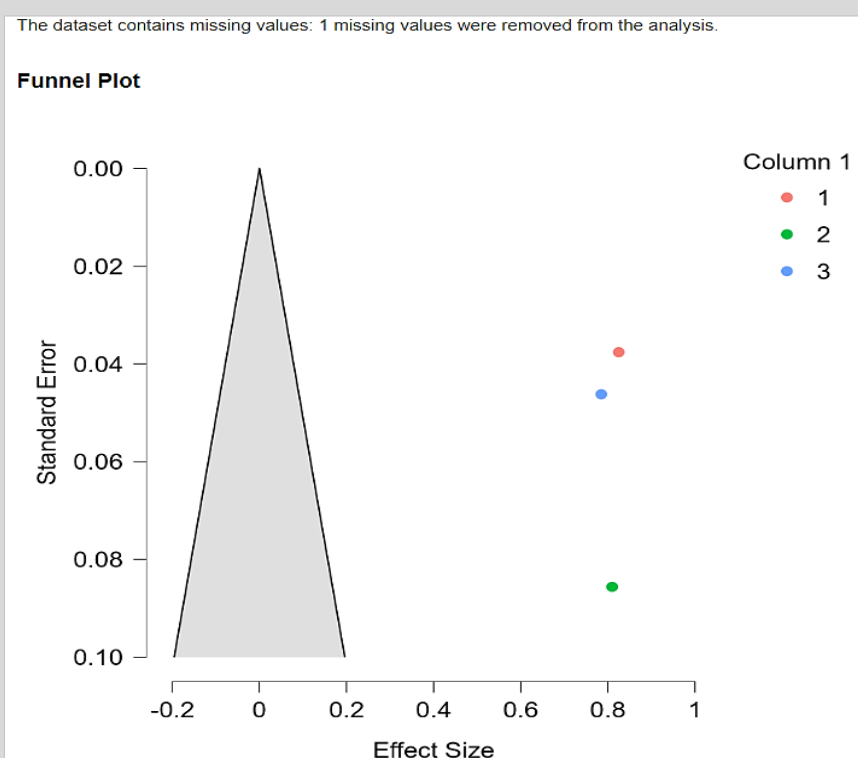


Figure 3: Funnel plot for male proportion with IHPS

Funnel Plot Asymmetry Tests

Meta-Regression Test for Funnel Plot Asymmetry					
Asymmetry Test			Limit Estimate		
Estimates	z	p	Estimate	Lower 95% CI	Upper 95% CI
3	-0.179	0.858	0.825	0.643	1.008

Weighted Regression Test for Funnel Plot Asymmetry						
Asymmetry Test				Limit Estimate		
Estimates	t	df	p	Estimate	Lower 95% CI	Upper 95% CI
3	-0.276	1	0.828	0.825	0.059	1.591

Rank Correlation Test for Funnel Plot Asymmetry		
Estimates	τ	p
3	-0.333	1.000

Meta-Regression Analysis Inference

The bubble meta-regression plot reveals a weak negative association between study precision and effect size (slope = -0.455, intercept = 0.821, $R^2 = 0.071$) (Figure 4). The regression equation $y = -0.455x + 0.821$ suggests that studies with higher standard errors (lower precision) tend to report slightly higher male proportions with IHPS.

However, the low R^2 value (0.071) indicates that standard error explains only 7.1% of the variance in effect sizes, suggesting minimal relationship between study precision and outcomes. All confidence intervals cross the null hypothesis line, indicating non-significant associations across studies, which aligns with the homogeneous nature of the data ($I^2 = 0\%$).

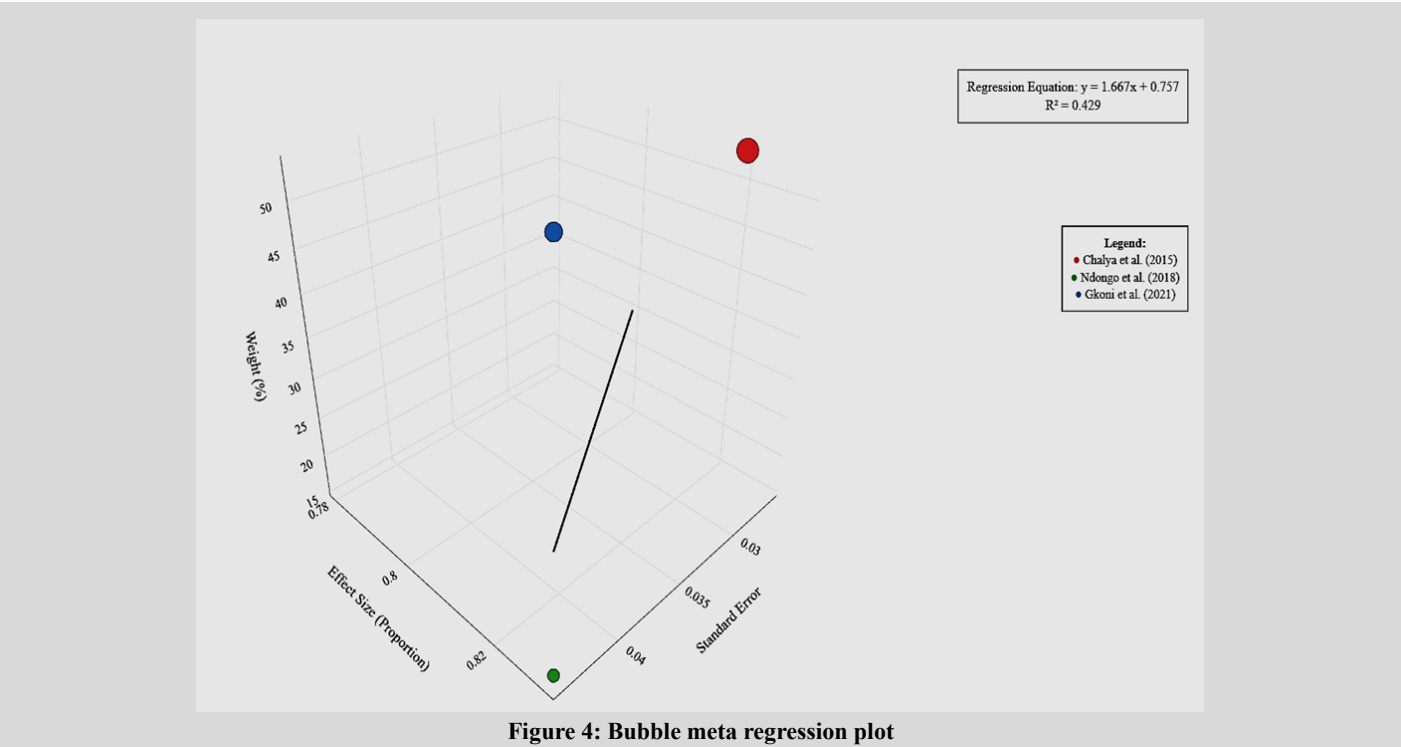


Figure 4: Bubble meta regression plot

The diagnostic distribution (%) was illustrated (Figure 5).

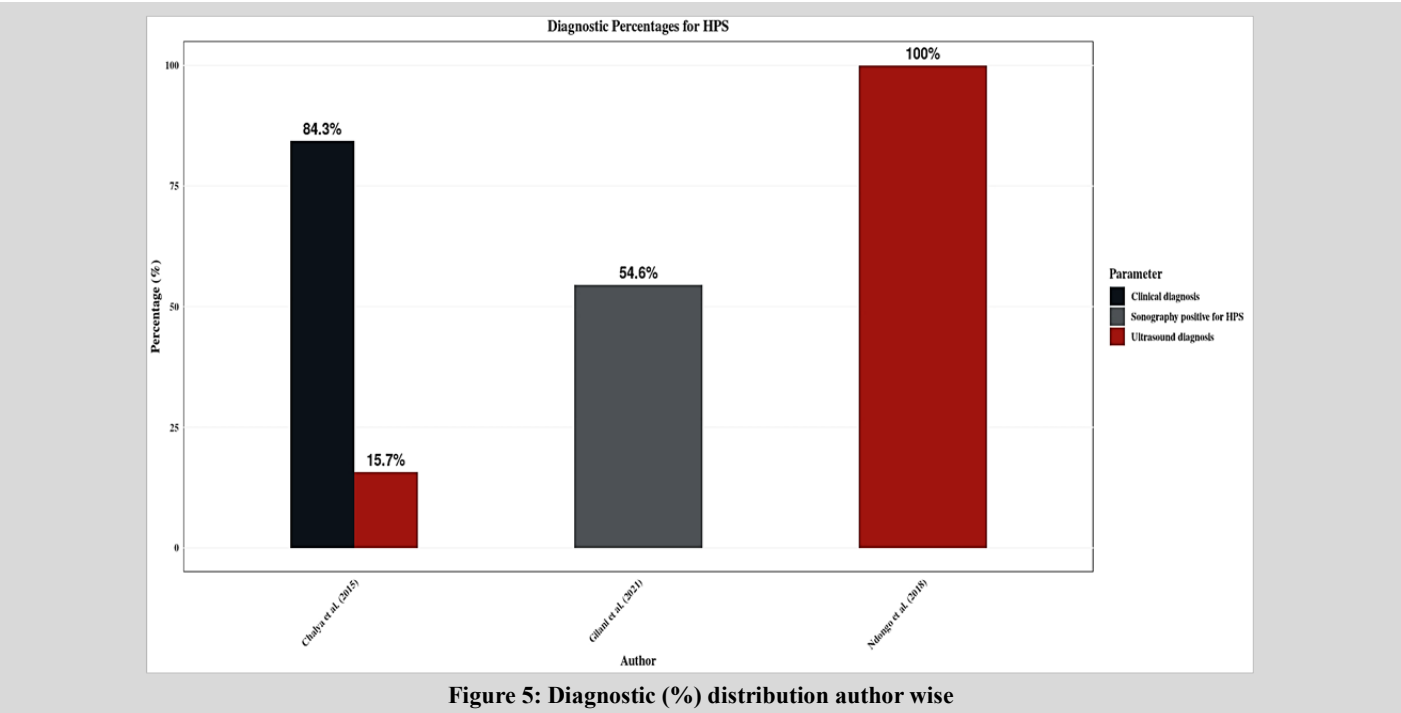


Figure 5: Diagnostic (%) distribution author wise

The analysis revealed considerable variation in postoperative complications following pyloromyotomy (Figure 6). Overall complication rates ranged from 1.0% to 28.6%, with a mean of 9.35%. Chalya *et al.* (2015) reported a lower mean complication rate of 4.42% compared to Ndongo *et al.* (2018) at 14.28%.

The distribution of complications differed markedly between studies (Figure 7). In the Chalya *et al.* cohort, wound

infection predominated (61% of total complications), followed by prolonged ileus (22%), burst abdomen (11%), and re-operation (6%). Conversely, the Ndongo *et al.* study showed a more even distribution, with postoperative vomiting comprising 50% of complications, while intra-operative duodenal perforation, sepsis, and paralytic ileus each contributed 17% (Figures 6 and 7).

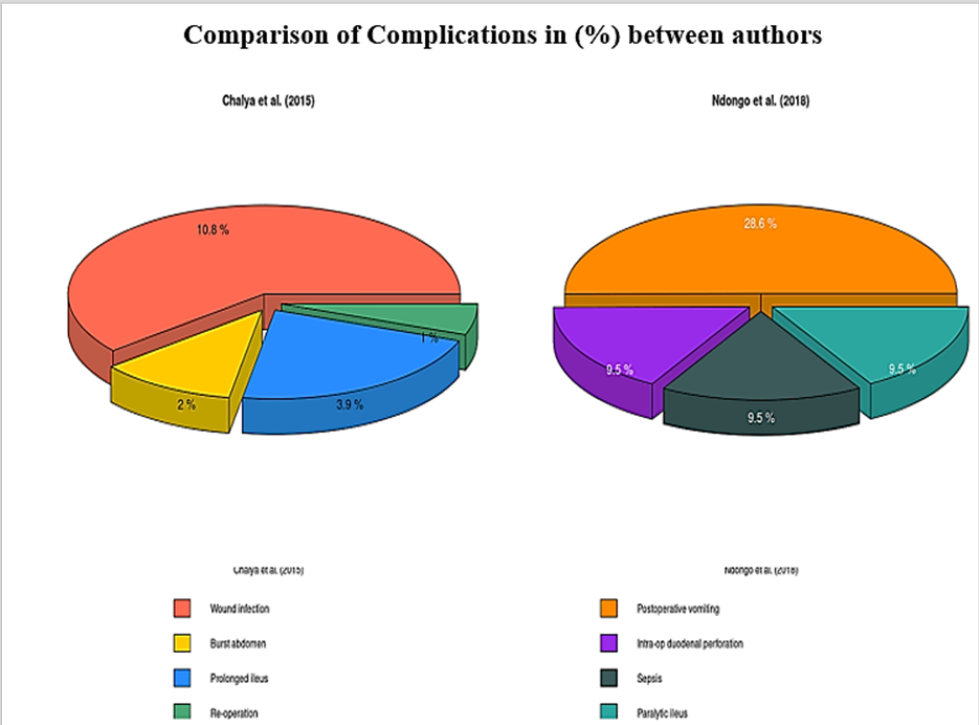


Figure 6: Author wise comparison of complications (%)

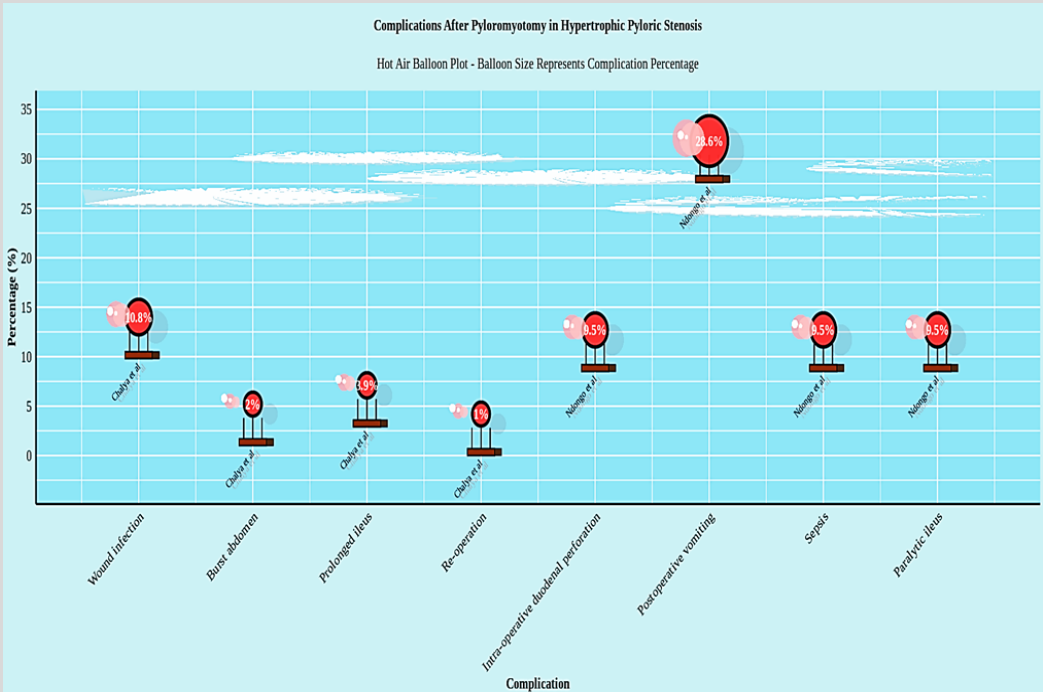


Figure 7: Hot air balloon plot representing complication percentage

Discussion

This meta-analysis and systematic review cumulates data from 14 diverse studies to give a rich and detailed description of infantile hypertrophic pyloric stenosis (IHPS) from multiple international contexts. Our synthesis reveals consistent epidemiological patterns, fine-tuned diagnostic models, and diverse clinical outcomes as well as novel but important correlations that defy usual presentations.

Our temporal analysis begins with studies from resource-limited settings. Chalya *et al.* (2015) from Tanzania set the background evidence for an overwhelming male predominance with a male-to-female ratio of nearly 5:1 in their series of 102 patients [6]. Infants presented at a mean age of 5 weeks, and non-bilious vomiting

was a prevalent symptom. A palpable pyloric mass was found in about one-fourth of the patients. Of note, the diagnosis was largely clinical in more than 80% of patients, a reflection of the availability of healthcare resources. Postoperative complications, such as wound infection, were noted in more than 10% of patients, and mortality was also noted at nearly 4%. The same findings were repeated in another study [7]. On the same demographic lines, Ndongo *et al.* (2018) from Cameroon, in their review of 21 patients, also noted an over 4:1 male predominance and a mean age at presentation slightly above 5 weeks [8]. Of note, they noted that the classical triad of symptoms (vomiting, visible peristalsis, and palpable mass) was found in only about one-third of their patients, so raising the possibility of less typical clinical presentation. Diagnosis was

always established by ultrasound in their series. Although all the patients were offered Ramstedt pyloromyotomy, intra-operative perforation of the duodenum was a complication noted in nearly 10% of cases, and an increased mortality rate of 9.5% was noted, perhaps an index of more severe disease at presentation or differing challenges within the healthcare system. This subject was again discussed in yet another study ^[9].

The advances in diagnostic methods were underlined by Ma *et al.* (2017) from China, who investigated the application of color Doppler ultrasound. Their analysis of 65 infants with IHPS identified statistically significant differences of blood flow grades of the pyloric muscular and mucosal layers from the control group. They actually reported a mean internal diameter of the pyloric canal of approximately 1.9 mm in affected infants, thereby illustrating the usefulness of newer imaging modalities in identifying subtle diagnostic features. Another author attested to the central role of ultrasound in IHPS diagnosis ^[10]. This topic was also addressed by another author ^[11]. Attesting to the role of sonography, Gilani *et al.* (2021) identified that more than half of the IHPS cases in their series of 79 infants were indicated by sonographic assessment. Their findings consistently reflected a male predominance (approximately 78%) and a mean age of presentation slightly greater than 5 weeks, in line with international epidemiological patterns. In addition, they reported that almost 30% of the IHPS cases presented in firstborn children, in contrast with established risk factors ^[12]. This was attested to by another author ^[13].

The physiological derangements of IHPS and their management were the important areas of research. Bašković & Sinjeri (2022) from Croatia emphasized the diagnostic value of acid-base status parameters. Their article highlights the significance of the identification and correction of metabolic alkalosis, a feature of severe IHPS and a potential cause of perioperative complications ^[14]. This was further highlighted vividly in another research ^[15]. This issue was directly addressed by van den Bunder *et al.* (2023) in the Netherlands, who studied perioperative hypoxemia and postoperative respiratory complications ^[16]. Their study highlights that uncorrected metabolic alkalosis may result in such complications, and hence the utmost importance of proper physiological stabilization preoperatively to guarantee patient safety. The same author had already presented on this 3 year ago citing the respiratory disorders in IHPS affected babies ^[17].

Apart from typical presentations, this review has also documented their rare and unusual counterparts, which are valuable warning cases for clinicians. Abo Elyazeed *et al.* (2019) from Egypt documented the rare case of infantile hypertrophic pyloric stenosis (IHPS) occurring synchronously with a Ladd's band in a boy aged 45 days ^[18]. This rare co-presentation led to persistent vomiting after pyloromyotomy, which eventually necessitated a repeat Ladd's procedure. This case is a reminder to clinicians to suspect potential anatomical abnormalities when the normal postoperative course is protracted. This finding was corroborated by the findings of another study ^[19]. In the same vein, Edward *et al.* (2024) from Nigeria documented an unusual case of IHPS in a child aged 14 months, which is much later than the typical age of presentation ^[20]. The presentation of this patient was preceded by the consumption of a water-based herbal beverage, and the initial pyloromyotomy was unsuccessful and required a follow-up pyloroplasty. Such types of cases widen the clinical presentation of IHPS and highlight the importance of considering environmental factors and atypical presentations. A further unusual presentation associated with IHPS was further documented in another study ^[21].

Review articles like those of Chirdan *et al.* (2020) give a good summation of the key facts regarding IHPS, i.e., demographics,

etiology, presentation, diagnosis-with particular emphasis on ultrasonography-and treatment, and therefore are a comprehensive synthesis of knowledge ^[22]. The same was found in another research ^[23].

Recent population-based studies provide critical large-scale findings. Zvizdic *et al.* (2022) from Bosnia and Herzegovina investigated the epidemiological and clinical features, including yearly trends, thus expanding knowledge with respect to the incidence of the condition in a specific region over time ^[24]. This was replicated in another study ^[25]. On this basis, Bakir *et al.* (2025) conducted a large population-based study in Canada from 2004 to 2021, investigating national variation in surgical procedures and outcomes of IHPS. This study provides valuable data with respect to long-term trends in management and effects of evolving healthcare practices on outcomes across a wide geographical region ^[26]. This subject was further addressed in another study ^[27].

Lastly, state-of-the-art research continues to hone our knowledge. El-Mefleh (2025), Germany, evaluated the preoperative predictive value of carbon dioxide and hemoglobin presentation, correlating them with several anthropometric parameters ^[28]. This meticulous physiological research adds to an enhanced realization of the metabolic status of IHPS infants. This was again demonstrated in an additional study ^[29]. After a notable clinical issue, El-Mefleh (2025) from Syria examined recurrent hypertrophic pyloric stenosis, citing neonatal age and pyloric canal length as possible risk factors. Their study also demonstrated the geographical distribution of IHPS incidence (estimated at 2-3/1000 live births globally). RHPS might be linked to early PM, especially in neonates <1 month. Even though some of the recurrences had involved a pyloric canal of ≥ 17 mm, this value must be used with caution ^[30]. This was further examined in yet another study ^[31]. In a peculiar and interesting case, Azmat (2025) from Pakistan reported a deer velvet powder-induced antral stricture that precisely mimicked IHPS. This case is landmark, as it identifies the possible hazards of unregulated supplements and highlights the importance of meticulous patient history in differentiating true IHPS from other etiologies of gastric outlet obstruction ^[32].

A study demonstrated that R139Q substitution of FOXF1 leads to IHPS in the family in question and indicates an as yet unidentified pathological pathway with the condition. The author presented additional evidence of the role of FOXF1 in controlling embryonic and neonatal development of the gastrointestinal tract ^[33].

In conclusion, this systematic review confirms the homogeneous male predominance and typical clinical presentation of IHPS, usually at 5 weeks of age, with projectile non-bilious vomiting. Although surgical pyloromyotomy is still the treatment of choice, the review confirms the primary role of ultrasonography in diagnosis, the necessity of preoperative correction of metabolic alkalosis, and caution with both common complications and unusual atypical presentations. The geographical heterogeneity of the studies also confirms the diverse healthcare settings affecting diagnosis and outcomes, which suggests a universal need for further studies and standardized reporting to optimize care for infants with IHPS.

Conclusion

This systematic review and meta-analysis sought to synthesise evidence on infantile hypertrophic pyloric stenosis (IHPS) globally, encompassing its epidemiological patterns, diagnostic advances, treatment outcome, and challenges. Our evidence supports ongoing male predominance and typical clinical presentation, generally projectile non-bilious vomiting at approximately 5 weeks of age. Although ultrasonography continues to be the diagnostic gold

standard, with excellent efficacy, and surgical pyloromyotomy remains definitive treatment with generally optimal outcomes, this review underscores the paramount need for careful preoperative correction of electrolyte and acid-base imbalances to reduce perioperative complications. Future research should accord high priority to the development of more standardized reporting of outcomes across studies, further research on long-term neurodevelopmental consequences on affected infants, and investigation of genetic and environmental risk factors, especially in underrepresented groups. Clinically, our evidence supports the retention of high suspicion, particularly in scenarios where imaging may be delayed in lower-resource settings, and calls for strict postoperative vigilance. Technologically, potential exists for artificial intelligence and machine learning to enhance diagnostic algorithms for ultrasound imaging, potentially allowing earlier detection of subtle signs, and for remote monitoring devices to aid postoperative care, especially within geographically dispersed populations. Additionally, development of point-of-care diagnostic equipment for electrolyte derangements may transform perioperative management practice.

Strengths and Limitations

Our meta-analysis and systematic review have a number of chief strengths. Its broad synthesis of 14 studies across many geographical locations offers a broad global view of infantile hypertrophic pyloric stenosis not restricted by geographical experience. PRISMA guidelines compliance in a combinatorial approach maximizes replicability and transparency of our research. Incorporation of heterogeneous study designs ranging from case reports demonstrating atypical presentation to population-based studies revealing epidemiological trends maximizes breadth and depth of insight. Quantitative meta-analysis on critical parameters like male ratio and complications adds to the evidence base by aggregating effect sizes wherever feasible. However, this research has some limitations too. While we conducted a comprehensive search, dependence on published literature may lead to possible publication bias, with studies with non-significant or negative findings being underrepresented. There is significant heterogeneity between included studies regarding methodology, diagnostic criteria, and reporting of outcomes, mandating cautious qualitative synthesis for many findings and restricting quantitative meta-work to the scope. In some studies, complete data or some methodological subtleties were not made fully available beyond the given excerpts or abstracts, which may have hindered insight comparative analysis. Finally, variable reporting quality across studies, especially from older or less developed countries, may introduce variance and restrict generalizability of some findings.

Declarations

Ethical Approval

Not required since the study conducted was a systematic review and meta-analyses and included the studies selected from 2015-2025.

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Conflicts of Interests

The authors report no conflict of interest.

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Article Category

Systematic review and meta analyses

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