

Research Article

Comparison of the Efficacy and Safety of Carbonyl Iron and Ferrous Sulphate for the Treatment of Iron Deficiency Anaemia in Pregnancy: A Randomized Controlled Clinical Trial

Ajibola Abdullahi Hamzat¹, Abdulfattah Mohammed Lawal^{1*} and Anas Funtua Rabiul¹¹Obstetrics and Gynaecology Department, Federal Teaching Hospital, Katsina, Nigeria.*Corresponding author: lawalabdufattah@gmail.com

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Abstract

Background: Iron deficiency anaemia in pregnancy is a significant public health issue in low- and middle-income countries and is associated with considerable morbidity and mortality. The treatment for mild to moderate cases typically involves oral iron supplements. There are various iron formulations available, each with differing levels of effectiveness, tolerability and safety, which can impact compliance and treatment efficacy. Therefore, it is essential to evaluate the efficacy and tolerability of these drugs in the treatment of iron deficiency anaemia during pregnancy. **Objective:** This study was designed to compare the efficacy and safety of Carbonyl iron with ferrous sulphate for the treatment of iron deficiency anaemia in pregnancy among pregnant women attending the antenatal clinic of the Federal Teaching Hospital, Katsina. **Methodology:** This study was a prospective, single-blinded randomized clinical trial. One hundred and eighty (180) pregnant women between the gestational ages of 14-28 weeks with Hb<11 g/dl. were recruited during the antenatal booking clinic. They were randomized to receive either 200mg ferrous sulphate or 50mg carbonyl iron twice daily after informed consent has been obtained. Full blood count and malaria RDT were conducted at enrollment, with a repeat of the full blood count at 12 weeks post-therapy. Participants were then followed up till delivery. Data was analyzed using IBM SPSS version 25.0. Descriptive statistical analysis encompassing frequency, percentage, mean, and standard deviations were used to depict results. Prevalence of anaemia in pregnancy was calculated as a percentage of all women with Hb<11 g/dl. A paired t-test was used to assess intra-group improvements, while an unpaired t-test and bivariate analysis were used to evaluate inter-group improvement in haemoglobin concentration, MCV, MCH, and MCHC. A p-value of ≤ 0.05 was used to indicate statistical significance. **Results:** The prevalence of anaemia among participants was 58.2%, with 16.4% classified as mild and 83.6% as moderate anaemia. Both treatments significantly improved haemoglobin levels, with Carbonyl Iron showing a greater increase compared to Ferrous Sulphate ($p = 0.036$). Carbonyl Iron was associated with fewer gastrointestinal side effects, indicating better tolerability ($p = 0.016$ for vomiting). Maternal and neonatal outcomes, including gestational age at delivery, Apgar scores, and birth weight, were comparable between the two groups. **Conclusion:** Carbonyl Iron is more effective and better tolerated than Ferrous Sulphate for managing iron deficiency anaemia in pregnancy. The findings support its use as a preferred treatment option, with implications for improving health outcomes in pregnant women.

1. Introduction

Anaemia is a condition where the number of red blood cells or their oxygen-carrying capacity is insufficient to meet physiologic needs [1]. It is conventionally taken as a haemoglobin (Hb) value that is less than two standard deviations (SD) below the median value for a healthy matched population by age, sex, altitude, smoking, and pregnancy status [1]. The World Health Organization (WHO) defined anaemia in pregnancy as total circulating haemoglobin (Hb) mass in the peripheral blood of 11g/dl (PCV 33%) or less. In developing countries, it is generally accepted to be Hb concentration less than 10g/dl or packed cell volume (PCV) less than 30% [2]. JB Lawson in the 1960s showed that significant maternal and perinatal morbidity and mortality do not occur until haemoglobin concentration fall below 10gm/dl, even though WHO criteria is used to define anaemia in pregnancy in developing countries for standardization and comparison [3].

Serum hemoglobin levels of 10.0–10.9g/dl, 7-9.9g/d, and less than 7.0g/dl are categorized as mild, moderate, and severe anemia, respectively [3]. Some of the major causes of anemia in pregnancy include nutrient deficiencies through inadequate diets or inadequate absorption of nutrients, infections (e.g. malaria, parasitic infestations, tuberculosis, HIV), inflammation, chronic diseases, gynecological and obstetric conditions, and inherited red blood cell disorders. The most common nutritional cause of anaemia is iron deficiency, although deficiencies in folate and vitamins B12, are also important causes [4].

Iron deficiency anaemia during pregnancy increases the risk of maternal and fetal morbidity and mortality, such as postpartum depression, impaired lactation, low birth weight, IUGR and preterm delivery [2]. Treatment options includes oral iron supplementation, parenteral iron and blood transfusions. Iron salts like ferrous sulphate, ferrous fumarate and ferrous gluconate are extensively prescribed for the prevention and treatment of iron deficiency anaemia [3]. This is because iron salts are inexpensive, easy to access, readily available and effective in correcting iron deficiency anaemia [5].

More than 1.6 billion people, almost a quarter of the world's population, are anaemic. Despite considerable economic and scientific advancement during recent decades, there has been, at best, only marginal reduction in the global prevalence of anaemia [6, 7]. The World Health Organization (WHO) estimates that worldwide, 42% of pregnant women are anaemic [6]. In developing countries, prevalence rates in pregnant women ranges between 40% - 60% [8]. It is more common in Sub-Saharan Africa owing to a lower intake of iron and other micronutrients especially during pregnancy [9, 10]. In Nigeria, an overall prevalence of 54.5-62.6% has been observed in the southern region of Nigeria [10]. The prevalence of anaemia was significantly higher in the Northeastern (Jigawa 71.1%, Yobe 88.8%,) and Northwestern states (Zamfara 62.2%, Katsina 61.4%) [11]. This may be attributed to socio-economic disparity, in addition to inadequate child spacing practices [11].

In Africa, Anaemia affects at least 4 in 10 pregnant women and is the underlying cause of approximately 115,000 maternal deaths annually [12]. Subsequently, the 65th World Health Assembly (WHA) approved global targets for maternal, infant, and young child nutrition, with a commitment to halve the prevalence of anaemia in women of reproductive age (15–49 years) by 2025 [13]. The WHO and UNICEF proposed extending this target to 2030 to align with the UN Sustainable Development Goals (SDGs) [12, 13]. In 2020, the prevalence of anaemia in women aged 15–49 years was added as indicator 2.2.3 of the SDGs. Iron deficiency in pregnancy remains one of the risk factors for maternal mortality and overall mortality in the general population [13, 14]. Despite the high incidence of anaemia in pregnancy, only about 58% of pregnant women receive iron supplementation during pregnancy [12]. The prevention of maternal anaemia will subsequently lead to a reduction in the incidence of low birth weight, risk of miscarriage, stillbirth, preterm deliveries and maternal morbidity and mortality [14, 15].

Untreated iron deficiency anaemia in pregnancy poses substantial risks, emphasizing the need for effective treatments to improve health outcomes [16]. Ferrous Sulphate is commonly prescribed but it often causes gastrointestinal side effects, leading to non-compliance [15]. Carbonyl iron is a potentially safer option; however, its efficacy and safety remain under-researched, necessitating a comparative analysis. Further research is imperative to assess the effectiveness and tolerability of these iron supplements in pregnant women.

Most reviewed studies demonstrate inadequate follow-up regarding maternal and infant health outcomes. This study intends to evaluate fetal outcomes, haematological parameters, and maternal complications through extended follow-up until delivery. The findings could modify clinical guidelines for managing iron deficiency anaemia in pregnancy, thereby enhancing maternal and infant health. The research aims to deepen the understanding of maternal health and improve treatment strategies for pregnancy-related iron deficiency anaemia. Consequently, this study will compare the efficacy and safety of Carbonyl iron with ferrous sulfate for treating IDA in pregnant women at Federal Teaching Hospital Katsina to provide evidence-based treatment comparisons.

2. Aim and Objectives

2.1. Aim

The aim of this study was to compare the efficacy and safety of Carbonyl iron with ferrous sulphate for the treatment of iron deficiency anaemia in pregnancy among pregnant women attending the antenatal clinic of the Federal Teaching Hospital, Katsina.

2.2. Specific Objectives

1. To determine the prevalence of anaemia among pregnant women attending the antenatal clinic of the Federal Teaching Hospital, Katsina.
2. To determine the effect of carbonyl iron on increase in maternal Hb level, MCV, MCH and MCHC compared with ferrous sulphate.
3. To determine the incidence of adverse drug reactions in both carbonyl iron and ferrous sulphate groups.
4. To compare the incidence of adverse drug reactions of carbonyl iron with ferrous sulphate.
5. To evaluate the maternal and neonatal outcomes of pregnant women on carbonyl iron, compared with those on ferrous sulphate.

2.3. Null Hypothesis (H0)

There is no statistically significant difference in the efficacy and safety of carbonyl iron and ferrous sulphate for treatment of Iron Deficiency Anaemia in pregnant women.

2.4. Alternative Hypothesis (H1)

There is a statistically significant difference in efficacy and safety of carbonyl iron and ferrous sulphate for treatment of Iron Deficiency Anaemia in pregnant women.

3. Methodology

3.1. Study Area

The study was carried out at Obstetrics and Gynaecology department of the Federal Teaching Hospital Katsina (FTHK). It is a 500-bed hospital located in Katsina local government, Katsina state. It is a tertiary health institution that renders all levels of health care services for Katsina and neighboring states such as Kano, Jigawa and Zamfara as well as clients from Niger republic.

The Department of Obstetrics and Gynaecology is one of the major clinical departments of the hospital with 200 beds, about 30% of total hospital beds. The antenatal clinic holds from Monday to Thursday which is rotated among four teams. At each clinic, the nurses register antenatal patients; check their height, weight, blood pressure and urinalysis, while Doctors provides the antenatal contacts. Ferrous sulphate is used for the prevention and treatment of anaemia in pregnancy. It is given orally at a dose of 200mg daily or twice daily for prevention and treatment, respectively. In addition, 5mg of folic acid is given daily to all women attending the antenatal clinic.

The hospital has a Haematology department staffed with consultant haematologists, resident doctors and laboratory scientists. The Haematology laboratory is well-equipped and was used for full blood counts.

3.2. Study Design

This study was a prospective randomized single-blinded clinical trial that compared the efficacy and safety of ferrous sulphate and carbonyl iron for the treatment of Iron Deficiency Anaemia in pregnancy, over four months.

3.3. Sample Size Determination

The minimum sample size required was calculated using the formula for randomized clinical trials where the outcome of interest is continuous. The formula for clinical superiority design was used.

The required minimum sample size for the study was 180.

Eighty-two women were required in each study arm to achieve 80% power and a type 1 error of 0.05. A 10% attrition rate was added to counter potential losses to follow-up, resulting in a required minimum sample size of 90. A total of 180 participants were recruited, with 90 patients allocated to each study arm.

3.4. Study Population

All pregnant women attending antenatal clinic of the obstetrics and gynaecology department of Federal Teaching Hospital Katsina, between 14 – 28 weeks of gestation were included in the study.

3.5. Selection Criteria

Inclusion Criteria

- i. Pregnant women aged 15 – 49 years between 14 to 28 weeks' gestation
- ii. Pregnant women with Hb < 11g/dl
- iii. Pregnant women willing and able to give consent

Exclusion criteria

- 1) Medically confirmed significant bleeding, major surgery, or blood transfusion within the last 3 months.
- 2) Severe anaemia requiring blood transfusion.
- 3) Anaemia confirmed to be from other known causes besides IDA, e.g. sickle cell anaemia.
- 4) Hypersensitivity or known allergy to any forms of iron or known severe drug allergies.
- 5) Severe allergic reactions such as severe asthma.
- 6) History of autoimmune disease, e.g. systemic lupus erythematosus, rheumatoid arthritis.
- 7) Patients with severe, acute or chronic hepatic or renal failure, severe cardiac insufficiency.
- 8) Patients with complications like bleeding piles, excessive emesis, active peptic ulcer disease, diabetes mellitus, hypertension, eclampsia, hypothyroidism, hyperthyroidism, and evidence of any malabsorption diseases.
- 9) Patients with acute febrile illness such as malaria.
- 10) Patients with multiple gestations.

11) Patients who have been on haematinics prior to booking.

3.6. Study Period

The study was carried out over 4-month period, between January 2025 and April 2025.

3.7. Sampling Technique and Recruitment

All participants who visited for booking were screened for anaemia ($Hb < 11\text{g/dl}$). Those who met the inclusion criteria were consecutively recruited and randomly assigned to the study until the target sample size was achieved.

3.8. Randomization and Allocation

Eligible participants were made to undergo individual randomization and allocation. One hundred and eighty serial numbers were randomly assigned to one of 2 study arms, with 90 patients in each arm using simple randomization. Randomization and concealment were done using computer-generated numbers that were randomized in a 1:1 ratio. The study arms were labeled as A and B. The study arms (A or B) were written on a piece of paper and placed in an opaque envelope, and a number was written at the back of the envelope. The envelopes were arranged serially in a box in the antenatal clinic, and one envelope was drawn for each consecutive patient recruited. The patients were then assigned to the study arms written on the envelope.

3.9. Blinding

The researcher, research assistants, and the laboratory scientist involved in the follow-up and assessment of outcome measures were blinded (single-blinded). One of the drugs was labeled as A, while the other was labeled as B. The participants were not blinded as the interventional drug was easily identified.

3.10. Research Protocol

The researcher and six trained assistants were involved in managing participant recruitment and follow-up. The assistants were four resident doctors (one from each team) and two laboratory scientists, including a statistician.

Patients who fulfilled the inclusion criteria and presented for booking at the antenatal clinic were counseled about the study and informed consent obtained. A self-designed, semi-structured questionnaire was administered to obtain information about personal data and other relevant information. The Gestational age of the patient was calculated by either the last menstrual period (LMP) or an early first-trimester ultrasound scan. Blood samples for full blood count was taken via aseptic technique, and 5 ml of venous blood was collected in EDTA bottles for the estimation of full blood count at the Haematology unit of the Federal Teaching Hospital, Katsina, using MINDRAY Haematology Autoanalyzer, Model BC 5300, China. Participants were screened for malaria at enrolment using Malaria Ag P. f rapid diagnostic test kit and those who screened positive were treated with an artemisinin-based combination therapy and subsequently placed on intermittent preventive therapy (IPT) to minimize the risk of recurrence, while those who screened negative for malaria were only placed on IPT.

3.11. Group A (Control Group) and Group B (study Group)

Each group consists of 90 participants, and each of them received 200 mg of ferrous sulphate tablets twice daily for a duration of 12 weeks, sourced from the hospital pharmacy (Group A), and 50 mg of carbonyl iron tablets twice daily for a duration of 12 weeks, sourced from the hospital pharmacy (Group B). Those who did not deliver after 12 weeks were asked to continue the medication until delivery. The drugs were stored in the hospital pharmacy, and all participants obtained their medications from the same facility. They were instructed to take the iron tablets thirty minutes before meals and to avoid consuming them with tea, coffee, or milk.

The efficacy of the different iron therapies was evaluated at enrollment and again at 12 weeks by measuring the full blood count. The primary outcome was an increase in maternal hemoglobin levels at the end of the treatment period. Clinical safety was assessed based on the type and severity of adverse effects observed during the therapy and evaluated at the end of the study period for both ferrous sulphate and carbonyl iron.

At the time of delivery, the following data were collected for the neonates: birth weight, Apgar scores, and gestational age at delivery.

3.12. Data Analysis

The collected data were coded, entered into an Excel spreadsheet, and analyzed using IBM SPSS version 25 (Statistical Package for Social Sciences; SPSS Inc., Chicago, IL). Descriptive statistical analysis encompassed frequency, percentage, mean, and standard deviation. The prevalence of anemia in pregnancy was calculated as a percentage of all women who had $Hb < 11\text{ g/dL}$. A paired t-test was used to assess intra-group improvements, while an unpaired t-test and bivariate analysis were used to evaluate inter-group improvements in haemoglobin concentration, MCV, MCH, and MCHC. A p-value of ≤ 0.05 was used to indicate statistical significance. Per protocol analysis was used in analysis of the results.

3.13. Ethical Consideration

Approval for the study was obtained from the research ethics committee of Federal Teaching Hospital, Katsina. The study was registered with the Pan African Clinical Trial Registry with trial identification number **PACTR202407830762218**.

4. Results

A total of 272 pregnant women were screened for anaemia (haemoglobin concentration < 11 g/dL). Approximately 180 participants were randomly assigned to either the carbonyl iron or ferrous sulfate group, with 90 participants allocated to each group. 171 participants (93%) completed the study, while 9 participants (7%) were lost to follow-up. In the carbonyl iron group, 86 participants (93%) completed the study, and in the ferrous sulfate group, 85 participants (93%) completed the study. All participants were monitored until delivery, as illustrated in the flow chart below. The CONSORT flow chart of the participants through the study in Figure 1.

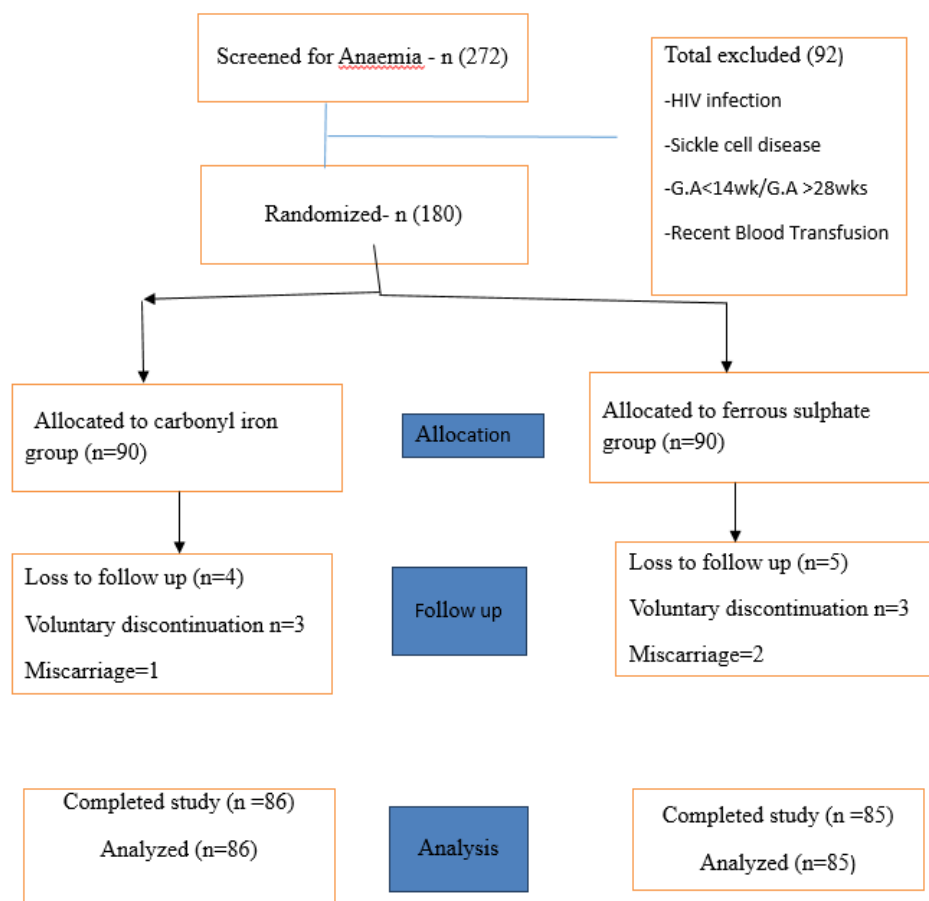


Figure 1: The CONSORT flow chart

Majority of participants in both groups were within the 20–29 age range, accounting for 43(50.6%) in the ferrous sulphate group and 38 (44.2%) in the carbonyl iron group. There was no statistically significant difference in age distribution ($p=0.698$), suggesting both groups were age matched. The majority of participants were married, with 80 (94.1%) in the ferrous sulphate group and 82 (95.3%) in the carbonyl iron group (p -value =0.540). No significant differences were observed in tribe ($p = 0.446$), religion ($p = 0.09$), occupation ($p = 0.090$), and educational status ($p = 0.061$) Table 1.

There was no statistically significant difference in gestational age (GA) at booking between the Ferrous Sulphate and Carbonyl Iron groups ($p=0.127$). However, the booking rates before 20 weeks of gestation were notably different, with 18 (21.2%) in the Ferrous Sulphate group compared to only 6 (7.0%) in the Carbonyl Iron group. Majority of the participants in both groups booked between 20–28 weeks: 78.9% and 93.0% in the ferrous sulphate and carbonyl iron groups, respectively. This indicated that most of the participants booked late in both groups. Parity distribution showed no statistically significant difference ($p=0.182$) between the groups. About 35 (41.2%) were primiparous in ferrous sulphate group, compared to 24 (27.9%) in carbonyl iron group. The highest proportion in carbonyl iron group were women with 2–4 previous deliveries 40 (46.5%). Grand multiparity (para ≥ 5) was similar between groups 19 (22.4%) vs. 22 (25.6%) Table 2.

Table 1: Socio-Demographic Characteristics of the Participants

Variables	Control Group FS (n=85)	Study Group CI (n=86)	Chi-square (χ^2)	P-value
Age (years)				
< 20	13 (15.3%)	12 (14.0%)	1.432	0.698
20–29	43 (50.6%)	38 (44.2%)		
30–39	19 (22.4%)	26 (30.2%)		
> 39	10 (11.8%)	10 (11.6%)		
Mean Age	27 $\pm$ 8	28 $\pm$ 8		
Marital status				
Married	80 (94.1%)	82 (95.3%)	2.162*	0.540
Single	1 (1.2%)	0 (0.0%)		
Divorced	3 (3.5%)	4 (4.7%)		
Widowed	1 (1.2%)	0 (0.0%)		
Tribe				
Hausa	81 (95.3%)	82 (95.3%)	2.667*	0.446
Yoruba	4 (4.7%)	2 (2.3%)		
Igbo	0 (0.0%)	1 (1.2%)		
Others	0 (0.0%)	1 (1.2%)		
Religion				
Islam	80 (94.1%)	83 (96.5%)	2.335*	0.311
Christianity	5 (5.9%)	3 (3.5%)		
Others	0 (0.0%)	0 (0.00%)		
Occupation				
Unemployed	73 (85.9%)	58 (67.4%)	14.336	0.061
Self-employed	3 (3.5%)	20 (23.3%)		
Employed	9 (10.6%)	8 (9.3%)		
Educational status				
No formal education	50 (58.8%)	65 (75.6%)	6.484	0.090
Primary	26 (30.6%)	13 (15.1%)		
Secondary	3 (3.5%)	2 (2.3%)		
Tertiary	6 (7.1%)	6 (7.0%)		

*Fisher's exact test. *Other tribe: Kanuri, *Other religion: Traditional

Table 2: Obstetrics Characteristics of the Participants

Variables	Control Group FS(n=85)	Study Group CI(n=86)	Chi-Square	P-value
GA at booking (weeks)				
<20	18 (21.2%)	6 (7.0%)	7.208	0.127
20-28	65 (78.9%)	77 (93.0%)		
Parity				
Para 0–1	35 (41.2%)	24 (27.9%)	3.405	0.182
Para 2–4	31 (36.5%)	40 (46.5%)		
Para $\geq$ 5	19 (22.4%)	22 (25.6%)		

Table 3: Baseline Haematological Parameters in Both Groups

Variables	Mean at Booking (Mean $\pm$ SD)	T-test	P-value
Hb (g/dl)			
Control Group (FS)	9.5 $\pm$ 0.6	2.113	0.076
Study Group (CI)	9.7 $\pm$ 0.6		
MCV (fl)			
Control Group (FS)	83.3 $\pm$ 5.9	0.211	0.833
Study Group (CI)	83.5 $\pm$ 3.9		
MCH (pg)			
Control Group (FS)	29.6 $\pm$ 1.4	-0.248	0.805
Study Group (CI)	29.5 $\pm$ 1.8		
MCHC (g/dl)			
Control Group (FS)	32.5 $\pm$ 2.1	1.808	0.072
Study Group (CI)	33.0 $\pm$ 1.2		

Table 3 compares the baseline haematological parameters haemoglobin (Hb), mean corpuscular volume (MCV), mean corpuscular

haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC) between the control group (Ferrous Sulphate, FS) and the study group (Carbonyl Iron, CI) at the time of recruitment. The mean baseline haemoglobin level was slightly higher in the CI group (9.7 ± 0.6 g/dl) compared to the FS group (9.5 ± 0.6 g/dl), and the difference was not statistically significant ($p = 0.076$). This indicates that participants in the CI group began the trial with a marginally higher haemoglobin level, which may have influenced the post-treatment outcomes and should be considered when interpreting the result. For the red cell indices (MCV, MCH, and MCHC), there were no statistically significant differences between the groups. MCV was comparable (FS: 83.3 ± 5.94 fl vs. CI: 83.5 ± 3.9 fl; $p = 0.833$), indicating similar average red cell values at baseline. Likewise, MCH values were similar in both groups (FS: 29.6 ± 1.4 pg vs. CI: 29.5 ± 1.8 pg; $p = 0.805$), suggesting comparable haemoglobin content per red cell. However, MCHC was slightly higher in the CI group (33.0 ± 1.2 g/dl) than in the FS group (32.5 ± 2.1 g/dl). However, this difference was not significant ($p = 0.072$).

Table 4: Changes in Haematological Parameters

Variables	At Booking	At 12 Week	Paired t-test	P-value
Hb (g/dl)	(Mean $\pm$ SD)	(Mean $\pm$ SD)		
Control Group (FS)	9.5 ± 0.6	11.5 ± 0.6	-32.357	0.012*
Study Group (CI)	9.7 ± 0.6	11.9 ± 0.7	-7.24	0.015*
MCV (fl)				
Control Group (FS)	83.3 ± 5.9	83.5 ± 3.2	-6.624	0.013*
Study Group (CI)	83.5 ± 3.9	90.1 ± 3.5	-2.61	0.020*
MCH (pg)				
Control Group (FS)	29.6 ± 1.4	30.3 ± 1.6	-5.247	0.010*
Study Group (CI)	29.5 ± 1.8	30.7 ± 1.8	-3.51	0.041*
MCHC (g/dl)				
Control Group (FS)	32.5 ± 2.1	33.0 ± 1.6	-5.286	0.023*
Study Group (CI)	33.0 ± 1.2	34.2 ± 1.5	-7.61	0.017*

Both groups demonstrated statistically significant improvements in Hb, MCV, MCH and MCHC levels ($p < 0.05$) indicating effective correction of iron deficiency anaemia. However, the study group (CI) consistently showed greater improvement than the control group (FS). For haemoglobin level, the mean increased from 9.5 ± 0.6 to 11.5 ± 0.6 g/dl in the FS group, and from 9.7 ± 0.6 to 11.9 ± 0.7 g/dl in the CI group, indicating a more marked increase in the CI group, and the difference was statistically significant. ($p < 0.05$). Similarly, MCV improved substantially in the CI group (83.5 ± 3.9 to 90.1 ± 3.5 fl) compared to a marginal change in the FS group (83.3 ± 5.9 to 83.5 ± 3.2 fl). The improved MCV in the CI group reflects better red cell volume normalization, and this difference was statistically significant. Similarly, MCH and MCHC showed a significantly higher mean increases in the CI group compared to FS group. MCH improved from 29.5 ± 1.8 to 30.7 ± 1.8 pg, and MCHC from 33.0 ± 1.2 to 34.2 ± 1.5 g/dl in the CI group, The difference was statistically significant. Suggesting more efficient iron incorporation into red cells Table 4.

Table 5: Mean Difference in Haematological Parameters in Both Groups

Variables	Mean Diff (Mean $\pm$ SD)		T-test	P-value
	FS	CI		
Hb (g/dl)	1.1 ± 0.6	2.2 ± 0.7	2.113	0.036*
MCV (fl)	0.2 ± 0.4	6.6 ± 0.3	0.211	0.033*
MCH (pg)	1.7 ± 0.2	1.6 ± 0.8	0.248	0.805
MCHC (g/dl)	0.5 ± 0.3	1.2 ± 0.5	1.808	0.042*

A statistically significant difference was observed in haemoglobin (Hb) levels, with the study group showing a higher mean increase (2.20 ± 0.70 g/dl; $p = 0.036$). The differences in MCV and MCHC for red cell indices between groups were also statistically significant. The mean difference in MCV (CI group) was 6.60 ± 0.30 fl ($p = 0.033$), while MCH showed a negligible decrease in the CI group compared to FS; the difference was not statistically significant (p -value > 0.05). MCHC showed a moderate increase in the CI group (1.20 ± 0.50 g/dL), and the difference was statistically significant (p value < 0.05) Table 5

Table 6: Drug-related adverse effects associated with the use of Carbonyl Iron compared with Ferrous Sulphate

Variable	Carbonyl Iron (n=86)	Ferrous Sulphate (n=85)	Chi-Square Value (χ^2)/ Fisher exact test	P-Value
Nausea				
Yes	9 (10.5%)	11 (12.9%)	0.254	0.614
No	77 (89.5%)	74 (87.1%)		
Vomiting				
Yes	7 (8.1%)	18 (21.2%)	5.821	0.016*
No	79 (91.9%)	67 (78.8%)		
Diarrhoea				
Yes	4 (4.7%)	4 (4.7%)	1.064*	0.986
No	82 (95.3%)	81 (95.3%)		
Epigastric Pain				
Yes	2 (2.3%)	6 (7.1%)	2.148*	0.143
No	84 (97.7%)	79 (92.9%)		
Constipation				
Yes	0 (0.0%)	3 (3.5%)	3.089*	0.079
No	86 (100.0%)	82 (96.5%)		
Metallic Taste				
Yes	1 (1.2%)	5 (5.9%)	2.812*	0.094
No	85 (98.8%)	80 (94.1%)		
Headache				
Yes	1 (1.2%)	7 (8.2%)	4.795*	0.029*
No	85 (98.8%)	78 (91.8%)		
Dizziness				
Yes	1 (1.2%)	5 (5.9%)	2.812*	0.094
No	85 (98.8%)	80 (94.1%)		

*Fisher's exact test

Table 6 presents the comparison of the incidence of drug-related adverse effects between participants treated with carbonyl iron and those treated with ferrous sulphate.

The incidence of diarrhea and epigastric pain were comparable between the two groups, with no statistically significant differences, indicating similar tolerability. Although epigastric pain was lower in the carbonyl iron group, this difference was not statistically significant ($P > 0.05$). Carbonyl iron group reported no cases of constipation, while the ferrous sulphate group had three cases 3 (3.5%), but no statistically significant difference ($P > 0.05$).

The incidence of metallic taste was higher in the ferrous sulphate group 5 (5.9%) compared to carbonyl iron 1 (1.2%), but this difference was also not statistically significant ($P > 0.05$). The findings indicate that carbonyl iron was significantly associated with a lower incidence of headaches compared to ferrous sulphate (1.2% vs. 8.2%). Dizziness was reported in 1 (1.2%) for carbonyl iron and 5 (5.9%) for ferrous sulphate, indicating a higher incidence in the latter, yet this difference was not statistically significant ($P > 0.05$).

Table 7: Maternal and Neonatal Outcomes in Both Groups

Variable	Carbonyl Iron (n=86)	Ferrous Sulphate (n=85)	Chi-square χ^2	P-Value
GA at Delivery (weeks)				
≥ 37	84(97.7%)	84 (98.8%)	0.327*	0.567
< 37	2 (2.3%)	1(1.2%)		
Apgar Score at 1 min				
Severe Asphyxia (< 4)	0 (0.0%)	1 (1.2%)	2.530*	0.282
Moderate Asphyxia (4–7)	30 (34.9%)	22 (25.9%)		
Normal (> 7)	56 (65.1%)	62 (72.9%)		
Birth Weight (kg)				
Low (< 2.5)	2 (2.3%)	3 (3.5%)	0.218*	0.64
Normal (≥ 2.5)	84 (97.7%)	82 (96.5%)		
NICU Admission				
Yes	0(0.00%)	1(1.2%)	0.310*	0.571
No	86(100)	84(98.8%)		
Need for Blood Transfusion				
Yes	0 (0.0%)	2 (2.4%)	2.047*	0.152
No	86 (100.0%)	83 (97.6%)		

*Fisher's exact test

Table 7 evaluates the maternal and neonatal outcomes among participants who received either carbonyl iron or ferrous sulphate.

Across all variables, both groups demonstrated similar outcomes, with no statistically significant differences observed ($p > 0.05$ in all cases). Gestational age at delivery showed that the majority of women in both groups delivered at term (≥ 37 weeks), with 84 (97.7%) in the carbonyl iron group and 84 (98.8%) in the ferrous sulphate group. Apgar scores at one minute showed no case of severe asphyxia in the carbonyl iron group compared to one case (1.2%) in the ferrous sulphate group.

Moderate asphyxia was observed in 30 (34.9%) of neonates in the carbonyl iron group and 22 (25.9%) in the ferrous sulphate group. Although these differences were not statistically significant ($p = 0.282$), birth weights were similar, with normal birth weights (≥ 2.5 kg) recorded in 84 (97.7%) of babies in the carbonyl iron group and 82 (96.5%) in the ferrous sulphate group. The incidence of Low birth weight was low in both groups. Regarding maternal need for blood transfusion, no participants in the carbonyl iron group required blood transfusions, whereas two women (2.4%) in the ferrous sulphate group required transfusions. However, this observed difference between the groups was not statistically significant ($p = 0.152$). Furthermore, there were no Neonatal Intensive Care Unit (NICU) admissions in the carbonyl iron group, while one case (1.2%) of NICU admission was recorded in the ferrous sulphate group. This difference was not statistically significant ($p = 0.571$).

5. Discussion

This study offers a comparative analysis of Carbonyl Iron (CI) and Ferrous Sulphate (FS) supplementation in pregnant women with iron deficiency anaemia, assessing socio-demographic similarities, treatment efficacy, adverse effect profile, and maternal-neonatal outcomes over four months. The socio-demographic and obstetric characteristics of the women in the two groups were comparable. The women were similar with regards to their age, occupation, educational status, as well as the parity and gestational age. This showed that the socio-demographic variables between groups were well matched, supporting the internal validity of the study and that the observed differences in the results were not due to the differences in their socio-demographic and obstetric characteristics.

In this study, out of 272 pregnant women screened, 180 were anaemic, giving a prevalence rate of 58.2% based on a haemoglobin cut-off of < 11 g/dl. This finding correlates with the estimated global prevalence rate of 40% to 60%, and an overall prevalence rate of 54.5% to 62.6% in Nigeria [6, 10]. The prevalence rates observed in our study are similar to those reported in Zamfara (62.2%), Katsina (61.4%), Rivers (66.7%), and Lagos (41.2%) [10, 11, 14, 16]. However, these findings are inconsistent with the higher prevalence rates reported in Jigawa, Yobe, and Kano, where the prevalence rates of anaemia were 71%, 88%, and 72.0%, respectively [10, 11]. The lower prevalence found in our study could be explained by differences in study design, as these studies were cross-sectional, as against randomized controlled trial. Furthermore, our use of stringent exclusion criteria may have contributed to this disparity.

Our study demonstrates that Carbonyl Iron (CI) is more effective than Ferrous Sulphate (FS) in treating iron deficiency anaemia, as evidenced by significant improvements in haematological parameters. The CI group showed a greater increase in haemoglobin levels compared to the FS group. In addition, the CI group exhibited a significant improvement in Mean Corpuscular Volume (MCV), indicating a better correction of microcytosis, which is a hallmark of iron deficiency anaemia. Despite the CI group having a slightly higher baseline haemoglobin level, the consistent improvements across multiple red blood cell indices suggest that Carbonyl Iron elicits a stronger erythropoietic response than Ferrous Sulphate, which has important implications for the clinical management of iron deficiency anaemia. These findings correlate with previous research conducted by Ahmad et al., Geetha R. et al., Radhika et al., and Chandrika et al., who reported that carbonyl iron was more effective in correcting haematological parameters when compared to ferrous sulphate [17–20]. The effectiveness of carbonyl iron can be attributed to the similar findings across these studies, which underscores its reliability as a treatment option. Conversely, the study conducted by Gamad et al. in Chandigarh, India, reported that ferrous sulphate and carbonyl iron were comparably effective in treating iron deficiency anaemia (IDA) [21]. This suggests that while carbonyl iron is a viable option, ferrous sulphate remains a competitive alternative in the management of IDA. This difference may be attributable to the smaller sample size employed in their study.

This study revealed that the incidence of nausea in the carbonyl iron and ferrous sulphate groups was comparable, while carbonyl iron had a significantly lower incidence of vomiting. These results conform with the report by Ahmad et al. and Mirunalini et al., who observed that ferrous sulphate had a higher incidence of gastrointestinal side effects such as nausea, vomiting, constipation, metallic taste, and black stools [20, 22]. The observed similar findings across these studies can be attributed to ferrous sulphate's tendency to induce oxidative stress in the gastrointestinal lining, which results from the rapid release of ferrous ions and can cause symptoms such as nausea, vomiting, epigastric discomfort, diarrhea, and constipation [23]. However, the results reported by Sudakshina et al., regarding lower gastrointestinal side effects in the ferrous sulphate group, differ from our findings [5]. This discrepancy may be attributed to the fact that the researchers primarily compared various oral preparations, including ferrous sulphate, ferrous fumarate, and ferrous ascorbate, with parenteral iron sucrose.

Both formulations reported similar incidence of diarrhea, but carbonyl iron showed a lower incidence of epigastric pain, with no cases of constipation or metallic taste compared to ferrous sulphate. This was consistent with the randomized controlled trial by Geetha et al., who reported a higher incidence of side effects, including black stools, constipation, headaches, and metallic taste, among different iron supplement groups, and concluded that carbonyl iron demonstrated greater tolerability compared to ferrous sulphate and ferrous fumarate [17]. The similarity in these findings may be because carbonyl iron is absorbed more slowly and steadily in the gastrointestinal tract, leading to a reduced likelihood of gastrointestinal problems [5, 23]. In contrast, Naveen et al. reported a high incidence of epigastric pain in the carbonyl iron group [24]. This discrepancy may stem from methodological differences between the studies.

In this study, carbonyl iron was associated with fewer cases of headaches and a lower incidence of dizziness. This was consistent with the findings of Sudakshina et al. and Govindappagari et al. [5, 25]. Being randomized control trials and facility-based studies could explain the similarities. However, this result is at variance with the observations of other researchers who reported a higher incidence of dizziness and headaches [5, 9]. This observation may be explained mainly due to differences in patient populations and methodologies used to collate gastrointestinal adverse effects. Our findings suggest that carbonyl iron may be associated with a lower incidence of certain adverse effects, particularly vomiting and headaches, compared to ferrous sulphate. The observation indicates that carbonyl iron could be a more favourable option for patients who are likely to have gastrointestinal side effects commonly associated with iron supplementation. Although ferrous sulphate is effective in treating iron deficiency anaemia, healthcare providers should consider the gastrointestinal side effects when prescribing iron supplementation. The evidence in this study suggests that carbonyl iron may be a more tolerable alternative, potentially enhancing patient adherence to other iron salt supplementation regimens.

Our study revealed that the gestational age at delivery was comparable in both groups. The study noted that the majority of the participants in both groups delivered at term. This suggests that both treatments are equally effective in ensuring pregnancies reach term. The incidence of low birth weight was not significantly different between the carbonyl iron and ferrous sulphate groups. This aligns with the findings of Bimochondra et al., who also reported no significant differences in the incidence of preterm labour or low birth weight between the groups [26]. This similarity in results can be attributed to their comparable study designs and diagnostic protocols, both studies were randomized controlled trials and used the WHO diagnostic threshold of <11 g/dL for participant selection. The findings contrast with the study conducted by Chen et al., which identified statistically significant differences in birth weight and rates of preterm delivery [27]. The discrepancy in the observed results may be attributed to the comparison of intravenous iron with oral iron in this study.

This study observed that the carbonyl iron group showed no reported cases of severe asphyxia but exhibited a higher incidence of moderate asphyxia compared to the ferrous sulphate group. This finding is consistent with the observations of Bimochondra et al., who reported similar results [26]. This similarity may be attributed to the pharmacokinetic properties of carbonyl iron, which requires enzymatic conversion to ferrous iron in the gastrointestinal tract [28]. This conversion process can lead to suboptimal iron absorption, resulting in reduced bioavailability. Consequently, this may contribute to insufficient maternal-fetal iron stores, thereby increasing the risk of fetal hypoxia and subsequent asphyxia [29]. In contrast, Debella et al. reported no statistically significant differences in neonatal adverse outcomes, including rates of moderate asphyxia, between the treatment groups [28]. However, the conclusions of this study may be limited by its small sample size, which reduces the statistical power to detect true differences between the groups. Additionally, the analysis did not account for potential confounders, such as maternal comorbidities or concurrent medications, which may have influenced neonatal outcomes.

Admissions to the Neonatal Intensive Care Unit (NICU) was observed only in the ferrous sulphate group. Similarly, the need for blood transfusions was comparable between the groups, with no transfusions required in the carbonyl iron group, whereas some women in the ferrous sulphate group required transfusions. The findings in the current study concur with an earlier report by Ataide et al [28]. Both studies focused on pregnant women with mild-to-moderate iron deficiency anaemia, and this can explain the similarity observed in both studies. However, these findings contrast with the study conducted by Chen et al., which identified statistically significant differences in several outcomes, including the need for blood transfusions, Apgar scores, birth weight, and rates of preterm delivery [30]. In their study, participants with severe anaemia were recruited. This condition may independently increase the need for blood transfusions and the risk of preterm delivery, potentially amplifying the observed differences in outcomes. Our study revealed that maternal and neonatal outcomes were comparable between the groups, with no statistically significant differences in Apgar scores, birth weight, need for blood transfusion, and NICU admission, indicating that both treatments were equally safe for fetal development. The discrepancy in this study compared to some previous studies highlights the complexity of interpreting maternal and neonatal outcomes and suggests that further investigation may be necessary to reconcile these differing results.

The findings of this study on Carbonyl Iron (CI) versus Ferrous Sulphate (FS) for treating iron deficiency anemia (IDA) in pregnancy have important policy and practice implications. The study reveals that CI is a more effective and better-tolerated option. This has significant implications for clinical guidelines and public health policies aimed at enhancing maternal and neonatal health, especially in areas with high IDA prevalence. The clinical guidelines should be revised to recommend CI as the preferred first-line oral iron supplement for pregnant women diagnosed with IDA. This change could lead to improved patient compliance and better treatment outcomes due to CI's superior efficacy and reduced gastrointestinal side effects, which often hinder treatment adherence. Moreover, while FS is typically chosen for its lower cost, the long-term benefits of CI, including better tolerability and higher compliance rates, should be considered in cost-effectiveness analyses. The reduced side effects associated with CI may also decrease the need for additional medical interventions, potentially lowering overall healthcare costs. To support these changes, it is crucial to educate healthcare providers about the advantages of CI over FS, ensuring they are equipped to make informed prescribing decisions, leading to improved health outcomes for mothers and their infants.

5.1. Strengths of the Study

- The use of a randomized controlled trial (RCT) design enhances the reliability of the findings by minimizing bias and ensuring that the results are attributable to the interventions rather than confounding factors.
- Multiple haematological parameters (Hb, MCV, MCH, MCHC) were assessed, providing a thorough understanding of the treatments' effects on iron status and red blood cell indices. This assessment also evaluates haematological improvements and maternal and neonatal outcomes, offering a holistic view of the impacts of the treatments.
- The study included a detailed assessment of adverse effects, highlighting the tolerability of both treatments, which is crucial for patient compliance and overall treatment success.
- The findings could inform clinical practice and guidelines for managing iron deficiency anemia in pregnancy, potentially leading to improved health outcomes for pregnant women.
- The study adhered to ethical standards, ensuring informed consent and confidentiality, which enhanced the integrity of the research process.

5.2. Limitations of the Study

- Out-of-hospital delivery constituted a minor and unavoidable challenge. It posed challenges in assessing birth weight, affecting data completeness and outcome validity. To improve future research, a reliable data collection system is needed. Developing a user-friendly mobile application for healthcare providers to enter data in real-time, along with using portable digital scales for accurate measurements at delivery sites, can enhance data quality and reliability.

6. Conclusion

The results suggest that Carbonyl Iron is more effective than Ferrous Sulphate in managing iron deficiency anaemia during pregnancy. It offers better haematologic correction, improved tolerability, and comparable maternal and neonatal outcomes. The significant improvement in haemoglobin levels and reduced side-effect burden reinforce its clinical utility, especially in settings where compliance is a concern.

Therefore, the alternative hypothesis was accepted.

Recommendations

- The recommendation to adopt carbonyl iron as the preferred oral iron formulation in antenatal care protocols is based on recent evidence showing its superior efficacy and tolerability compared to ferrous sulfate in treating anaemia during pregnancy. Carbonyl Iron is recommended as a preferred treatment for anaemia in pregnancy due to its effectiveness in increasing haemoglobin levels and integrating it into routine care for antenatal women could improve health outcomes by enhancing maternal health and better fetal outcomes, thereby contributing to a healthier population. Healthcare providers are encouraged to consider incorporating Carbonyl Iron into their treatment protocols for pregnant women with anaemia.
- Larger, multi-centre trials are recommended to corroborate these findings and further explore the long-term maternal and neonatal benefits of Carbonyl Iron supplementation.

Article Information

Ethical Approval: The study was approved by the Research and Ethics Committee of Federal Teaching Hospital Katsina, with approval number EHR FTHKTHREC.REG.24/06/22C/121, dated 15/12/2023.

Informed Consent: We received informed consent from all participants for the study.

Consent for Publication: Written informed consent for dissemination was obtained from the participants.

Data Availability: The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Clinical Trial Registration: The study was registered with Pan African Clinical Trial Registry (PACTR) with registration number 202407830762218.

Conflict of Interest: The authors declare that they have no conflict of interest.

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Author Contributions: A.A.H. - Conceptualization, Methodology, Data Curation, Formal Analysis, Resources, Writing – Original Draft, Writing – Review & Editing, Project Administration; A.M.L. - Conceptualization, Methodology, Formal Analysis, Resources, Writing – Review & Editing, Supervision; A.F.R. - Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Resources, Writing – Original Draft, Writing – Review & Editing, Supervision.

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References

- [1] WHO. Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity. Vitamin and Mineral Nutrition Information System. Technical Report WHO/NMH/NHD/MNM/11.1, Geneva, 2011. URL <https://www.who.int/publications/i/item/WHO-NMH-NHD-MNM-11.1>.
- [2] Haematological disorders. In F. G. Cunningham, K. J. Lenevo, S. L. Bloom, J. C. Hauth, D. J. Rouse, and C. Y. Spong, editors, *Williams's Obstetrics*, pages 2724–2778. McGraw Hill, Philadelphia, 26th edition, 2022.
- [3] A. Agboola. *Textbook of obstetrics and Gynaecology for Medical Students*. Heinemann Educational Books Nigeria Publishers Plc, Ibadan, 3rd edition, 2018.
- [4] B. Froessler, J. Collingwood, N. A. Hodyl, and G. Dekker. Intravenous ferric carboxymaltose for anaemia in pregnancy. *BMC Preg Childbirth*, 14(115):1–5, 2014.
- [5] K. Sudakshina, M. Sakthibalan, S. Arthi, and A. Mangaiarkkarasi. Comparative Study on Efficacy, Tolerability and Cost of Different Iron Supplements among Ante Natal Women with Iron Deficiency Anaemia. *J Res Med Dent Sci*, 10(9):08–13, 2022.
- [6] M. Karami, M. Chaleshgar, and N. Salari. Global Prevalence of Anaemia in Pregnant Women: A Comprehensive Systematic Review and Meta-Analysis. *Matern Child Health J*, 26(7):1473–1487, 2022.
- [7] S. Yadav, A. Deshpande, and H. Mehrotra. A study of the prevalence of anaemia and associated sociodemographic factors in pregnant women in Port Blair, Andaman and Nicobar Islands. *J Family Med Prim Care*, 7(6):1288–1293, 2018.
- [8] C. M. Chaparro and P. S. Suchdev. Anaemia epidemiology, pathophysiology, and etiology in low- and middle-income countries. *Ann NY Acad Sci*, 1450(1):15–31, 2019.
- [9] V. Thuraiarasu, P. Marimuthoo, and S. Kumareswaran. A Pragmatic Approach to Anaemia in Pregnancy: An Overview. *Eur J Med Health Sci*, 5(1):23–27, 2023.
- [10] G. U. Udukwu and P. O. Dienye. Prevalence and socio-demographic factors associated with anaemia in pregnancy in a primary health centre in Rivers State, Nigeria. *Afr J Prm Health Care Fam Med*, 4(1):1–7, 2012.

- [11] M. Y. Gwarzo and E. A. Ugwa. The pattern of anaemia in northern Nigerian pregnant women. *J Med Med Sci*, 4(8):319–323, 2013.
- [12] World Health Organization. Global Nutrition Targets 2025: anaemia policy brief, Geneva. 1-8, 2014.
- [13] C. J. L. Murray, A. Y. Aravkin, and P. Zheng. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet*, 396(10258):1223–1249, 2020. URL [https://doi.org/10.1016/s0140-6736\(20\)30752-2](https://doi.org/10.1016/s0140-6736(20)30752-2).
- [14] A. A. Ajepe, K. Okunade, A. Sekunmade, E. Daramola, M. Beke, O. Ijasan, O. F. Olowoselu, and B. B. Afolabi. Prevalence and foetomaternal effects of iron deficiency anaemia among pregnant women in Lagos, Nigeria. *PLoS One*, 15(1):1–13, 2020. URL <https://doi.org/10.1371/journal.pone.0227965>.
- [15] N. M. Abu-Ouf and M. M. Jan. The impact of maternal iron deficiency and iron deficiency anemia on child's health. *Saudi Med J*, 36(2):146–149, 2015.
- [16] O. A. Babah, O. R. Akinajo, L. Beňová, C. Hanson, A. I. Abioye, V. O. Adaramoye, T. A. Adeyemo, M. R. Balogun, A. Banke-Thomas, H. S. Galadanci, N. A. Sam-Agudu, B. B. Afolabi, and E. C. Larsson. Prevalence of and risk factors for iron deficiency among pregnant women with moderate or severe anaemia in Nigeria: a cross-sectional study. *BMC Pregnancy Childbirth*, 24(1):39–42, 2024. URL <https://doi.org/10.1186/s12884-023-06169-1>.
- [17] R. R. Geetha, S. Parvathavarthini, K. Sowmia, P. Vivekkumar, S. Nagesh, and A. Umamageswari. Comparative Study of Iron Supplements in South Indian Antenatal Women with Iron Deficiency Anemia. *J Adv Zoolog*, 44(4):654–658, 2023.
- [18] N. Chandrika and K. Vasudha. Comparative study of serum ferritin levels after oral supplementation with ferrous sulphate and carbonyl iron in mild iron deficiency anaemia in pregnancy. *Int J Biol Chem Sci*, 4(2):362–370, 2010.
- [19] A. Radhika and K. Souris. Comparative Study of Efficacy of Ferrous Sulphate and Carbonyl Iron in Anaemia of Antenatal Women. *J of Evidence Based Med Hlthcare*, 2(12):1852–1865, 2015.
- [20] T. Ahmed, I. Shahriar, J. Iqbal, M. Rowsha, and R. Yusuf. Comparison of Efficacy and Tolerability of Ferrous Sulfate and Carbonyl Iron in Iron Deficiency Anemia in Pregnant Woman. *Sir Salimullah Med Coll J*, 30(1):83–88, 2022.
- [21] N. Gamad, P. K. Saha, P. Sharma, V. Suri, A. Chakrabarti, and L. Saha. A randomized controlled trial comparing the efficacy, tolerability, and cost of oral iron preparations in iron-deficiency anemia in pregnancy. *J Obstet Gynaecol Res*, 47(11):3828–3841, 2021.
- [22] S. Mirunalini and R. M. Afreen. Efficacy and tolerability of ferrous sulfate – oral iron therapy in the management of Iron deficiency anaemia during pregnancy – a prospective study. *Int J Clin Obstet Gynaecol*, 4(5):267–269, 2020.
- [23] B. Wells, J. DiPiro, T. Schwinghammer, and C. DiPiro. Pharmacotherapy Handbook. In *Mc Grawhill Publishers*, pages 363–390. New York, 10th edition, 2017.
- [24] K. P. Naveen, A. I. Hridya, and P. Raghuvver. Comparison of Efficacy and Safety Profile of Oral Iron Formulations in Patients with Iron Deficiency Anemia. *Int J Pharm Sci Rev Res*, 41(2):248–252, 2016.
- [25] S. Govindappagari and R. M. Burwick. Treatment of iron deficiency anaemia in pregnancy with intravenous versus oral iron: systematic review and meta-analysis. *Am J Perinatol*, 36(4):366–376, 2019.
- [26] L. S. Bimolchandra, K. A. Devi, and J. Ningthoujam. Study of Foetal Outcome in Pregnancy with Iron Deficiency Anaemia. *IOSR J Dental Med Sci*, 16(10):30–33, 2017.
- [27] S. Chen, M. Burd, Boelig M. Julia, and Rupsa. Effects of Intravenous Iron Versus Oral Iron for Treatment of Anemia in Pregnancy on Maternal and Fetal Outcomes: A Systematic Review and Meta-analysis. 1(15):1–8, 2021.
- [28] A. Debella, A. Eyeberu, T. Getachew, G. Atnafe, B. Geda, and M. Dheresa. Perinatal outcomes in anemic pregnant women in public hospitals of eastern Ethiopia. *Int Health*, 15(3):274–280, 2023.
- [29] R. Ataide, K. Fielding, S. R. Pasricha, and C. Bennett. Iron Deficiency, Pregnancy, and Neonatal Development. *International Journal of Gynecology & Obstetrics*, 162(S2):14–22, 2023. URL <https://doi.org/10.1002/ijgo.14944>.
- [30] K. Roemhild, F. von Maltzahn, R. Weiskirchen, R. Knüchel, S. von Stillfried, and T. Lammers. Iron metabolism: pathophysiology and pharmacology. *Trends Pharmacol Sci*, 42(8):640–656, 2021.