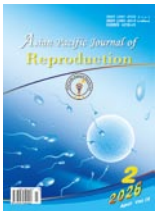

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Pregnancy and live birth rates in ART cycles and their determinants: A retrospective cohort study

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ABSTRACT

Objective: To identify predictors of pregnancy and live birth outcomes in assisted reproductive technology (ART) cycles based on patient characteristics, hormonal profile, and embryo transfer variables.

Methods: This retrospective cohort study included 50 fresh *in vitro* fertilization (IVF)/intracytoplasmic sperm injection (ICSI) cycles selected from ART participants at a single tertiary ART center. Controlled ovarian stimulation was performed using recombinant follicle stimulating hormone (rFSH), gonadotropin-releasing hormone (GnRH) antagonist, and menotropins; oocyte retrieval occurred 36 h after trigger and embryo transfer was performed on day 3 or 5. Outcomes (chemical pregnancy, ongoing pregnancy, abortion, live birth) were compared across groups stratified by maternal age, antral follicle count (AFC), anti-Müllerian hormone (AMH), baseline luteinizing hormone (LH), estradiol (E_2) at trigger, and endometrial thickness. Multivariate regression was used to identify independent predictors of live birth.

Results: A total of 124 ART patients were screened during the study period, of whom 50 participants meeting the eligibility criteria were included in the final analysis. The median age of the participants was 35.8 years [interquartile range (IQR) 32.5–39.6]. The median AFC was 8 (IQR 4–14), AMH level was 1.4 ng/mL (IQR 0.7–2.9), and the median endometrial thickness at embryo transfer was 10.2 mm (IQR 9.0–11.3). Chemical, ongoing, abortion, and live birth rates were 62%, 32%, 12%, and 16%, respectively. Younger maternal age (<35 years), higher AFC (>12), AMH 1–4 ng/mL, and endometrial thickness ≥10 mm were associated with more favorable pregnancy outcomes. In multivariate analysis, higher baseline LH (β=0.089; 95% *CI* 0.017–0.162; *P*=0.02) and greater endometrial thickness (β=0.145; 95% *CI* 0.011–0.278; *P*=0.04) independently predicted live birth, whereas age, AFC, AMH, and E_2 did not.

Conclusions: Maternal age, ovarian reserve markers, LH levels, and endometrial thickness collectively influence ART outcomes. Baseline LH and endometrial receptivity are key independent predictors of live birth and may guide individualized treatment strategies.

KEYWORDS: Assisted reproductive technology; Live birth; Ovarian reserve; Endometrial thickness; Luteinizing hormone

Key Points

Question: Which clinical, hormonal, and endometrial variables predict pregnancy and live birth outcomes in assisted reproductive technology (ART) cycles?

Findings: In this retrospective cohort of fresh *in vitro* fertilization/intracytoplasmic sperm injection (IVF/ICSI) cycles, younger age, higher antral follicle count (AFC), intermediate anti-Müllerian hormone (AMH), and endometrial thickness ≥10 mm were associated with better pregnancy outcomes. In multivariate regression, only baseline luteinizing hormone (LH) and endometrial thickness independently predicted live birth, while age, AFC, AMH, and estradiol (E_2) were not significant.

Meaning: Optimizing baseline LH and endometrial receptivity, alongside personalized ovarian stimulation, may improve live birth rates in ART.

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1. Introduction

Assisted reproductive technology (ART) represents a pivotal advancement in the treatment of infertility, enabling millions of individuals and couples to achieve parenthood. Despite significant progress in ART methodologies, such as *in vitro* fertilization (IVF) and intracytoplasmic sperm injection (ICSI), the variability in pregnancy outcomes remains a major clinical challenge. Success in ART depends on a complex interplay of factors, including patient demographics, ovarian reserve, hormonal profiles, and embryological parameters, which collectively influence implantation, pregnancy progression, and live birth rates. A deeper understanding of these predictors is essential to optimize clinical protocols and enhance treatment success.

Maternal age is widely recognized as a critical determinant of ART outcomes. Advanced maternal age is associated with diminished ovarian reserve, decreased oocyte quality, and an elevated risk of chromosomal abnormalities, all of which contribute to reduced implantation and live birth rates[1]. Parameters such as antral follicle count (AFC) and anti-Müllerian hormone (AMH) have emerged as reliable markers of ovarian reserve, providing valuable prognostic insights into the expected response to ovarian stimulation and overall ART outcomes[2]. However, these markers alone cannot fully predict pregnancy success, highlighting the need to evaluate additional factors.

Hormonal dynamics during ART cycles play a crucial role in determining oocyte maturation, endometrial receptivity, and implantation potential. Elevated progesterone (P4) levels during the late follicular phase have been implicated in premature luteinization, disrupting the synchrony between embryo development and endometrial receptivity, ultimately compromising implantation rates[3]. Similarly, estradiol (E_2) levels on the day of trigger and baseline luteinizing hormone (LH) levels influence follicular recruitment and oocyte quality, underscoring the importance of hormonal profiling in ART protocols.

Endometrial receptivity, often assessed through endometrial thickness and hormonal milieu, is another critical factor affecting implantation and pregnancy outcomes. Studies suggest that an endometrial thickness of ≥7 mm is associated with higher implantation rates, while suboptimal thickness or endometrial asynchrony can significantly impair pregnancy success[4]. The number and quality of embryos transferred further contribute to pregnancy outcomes. Although single-blastocyst transfer is increasingly advocated to reduce the risks of multiple pregnancies, its success is highly dependent on the accurate selection of high-quality embryos[5].

This study aims to investigate the predictors of pregnancy outcomes in ART cycles, focusing on clinical parameters such as age and ovarian reserve, hormonal profiles during stimulation, and embryological factors. By stratifying patients into groups based on these variables, this research seeks to elucidate their relationship with key outcomes, including chemical pregnancy, ongoing pregnancy, and live birth rates. The findings are expected to contribute to a more personalized approach to ART, optimizing clinical decision-making and improving overall success rates.

2. Methods

2.1. Study design and setting

This was a retrospective observational cohort study conducted at a single tertiary ART center. From a total of 124 ART cycles screened during the study period (April 2024 to March 2025), 50 fresh IVF/ICSI cycles that met the inclusion criteria were analyzed. All cycles were managed according to the standard clinical and embryology laboratory protocols of the center.

2.2. Participants and eligibility criteria

Eligible participants were women undergoing fresh IVF or ICSI cycles with autologous oocytes and ejaculated partner semen. Inclusion criteria were: female age between 20 and 45 years, availability of complete clinical, hormonal, and embryological records, and embryo transfer performed during the same ovarian stimulation cycle.

Cycles were excluded if donor oocytes or donor sperm were used, if sperm were obtained through surgical retrieval procedures, if preimplantation genetic testing (PGT) was performed, or if major uterine pathology or systemic illness likely to affect implantation was present. From 124 screened ART cycles, 74 cycles were excluded predominantly due to donor gamete use, surgically retrieved semen, PGT cycles, or incomplete clinical records, leaving 50 eligible cycles for the final analysis.

2.3. Ovarian stimulation and ovulation trigger

Controlled ovarian stimulation was initiated after oral norethisterone priming for follicular synchronization. Baseline transvaginal sonography (TVS) and serum E_2 and LH were performed on cycle days 1–2 to confirm ovarian quiescence. Stimulation was started with recombinant follicle stimulating hormone (rFSH) at individualized doses based on age, body mass index, AFC, AMH, and previous ovarian response. A gonadotropin-releasing hormone (GnRH) antagonist was introduced on stimulation day 5 or 6 and highly purified menotropins were added from the following day, according to follicular growth. Final oocyte maturation was triggered when ≥3 follicles reached ≥17 mm using either recombinant human chorionic gonadotropin (hCG) or a GnRH agonist in patients considered at high risk of ovarian hyperstimulation syndrome (OHSS).

2.4. Oocyte retrieval, fertilization, and embryo transfer

Transvaginal oocyte retrieval was performed 36 h after trigger using a 17-gauge single-lumen aspiration needle under ultrasound guidance. Standard IVF or ICSI was performed according to semen parameters. Embryo quality was assessed using standard morphological criteria. Cleavage-stage embryos were evaluated based on blastomere symmetry, cell number, and degree of fragmentation. Blastocyst-stage embryos were graded according to the Gardner and Schoolcraft scoring system, which assesses expansion stage, inner cell mass quality, and trophectoderm appearance. Embryo transfer was performed on day 3 (cleavage stage) or day 5 (blastocyst stage) using a soft embryo transfer catheter under transabdominal ultrasound guidance. Luteal phase support was provided with vaginal progesterone and/or oral progesterone according to center protocol until at least the clinical pregnancy scan.

2.5. Variables and outcome measures

The main exposure variables were: maternal age (years), AFC, serum AMH (ng/mL), baseline LH (mIU/mL), serum E_2 (pg/mL) on the day of trigger, endometrial thickness (mm) at embryo transfer, and day of embryo transfer (cleavage *vs*. blastocyst). Continuous variables were categorized for subgroup analyses using clinically relevant cut-offs: age (<35, 35–40, >40 years), AFC (<6, 6–12, >12), AMH (<1, 1–4, >4 ng/mL), baseline LH (1–8, >8 mIU/mL), E_2 (<1000, 1000–4000 pg/mL), and endometrial thickness (<10, ≥10 mm).

Primary outcome was live birth, defined as delivery of a viable infant at ≥24 weeks of gestation. Secondary outcomes were chemical pregnancy (serum β-hCG positive), clinical/ongoing pregnancy (intrauterine gestational sac with fetal cardiac activity), and abortion (pregnancy loss before viability).

2.6. Statistical analysis

Statistical analyses were performed using GraphPad Prism version 9.0 (GraphPad Software, San Diego, CA, USA). Normality of continuous data was assessed using the Shapiro–Wilk test and inspection of histograms. Categorical outcomes (chemical pregnancy, ongoing pregnancy, abortion, and live birth) across subgroups of age, AFC, AMH, LH, E_2, and endometrial thickness were compared using the *Chi*-square test or Fisher's exact test, as appropriate. Continuous variables were expressed as median and interquartile range (IQR) due to non-normal distribution, while categorical variables were presented as number (percentage). Multivariate logistic regression analysis was performed to identify independent predictors of live birth, and results were reported as regression coefficients (β), standard errors (SE), 95% confidence intervals (*CI*), and *P*-values. A two-sided $P<0.05$ was considered statistically significant.

2.7. Ethical approval

This study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Institutional Ethics Committee of Directorate of Health Services, Goa [approval number: DHS/Sp.Cell/24-166(Ethics)/2025-26/1208, dated:19/08/2025]. Given the retrospective design and use of anonymized data, the committee waived the requirement for individual informed consent.

3. Results

3.1. Baseline characteristics

A total of 124 ART cycles were screened during the study period. Seventy-four cycles were excluded due to donor gametes, surgically retrieved sperm, PGT, or incomplete clinical data. The remaining 50 fresh IVF/ICSI cycles met the eligibility criteria and were included in the final analysis (Figure 1).

Baseline clinical and hormonal characteristics of the study cohort are summarized in Table 1. The median age of the participants was 35.8 years [interquartile range (IQR) 32.5–39.6]. The median AFC was 8 (IQR 4–14), and the median AMH level was 1.40 ng/mL (IQR 0.70–2.90). The median E_2 concentration on the trigger day was 466.3 pg/mL (IQR 151.0–1591.3). The median endometrial thickness at embryo transfer was 10.2 mm (IQR 9.0–11.3). Cleavage-stage embryo transfers were performed in 23 cycles (46%) and blastocyst-stage transfers in 27 cycles (54%).

Overall, 31 cycles (62%) achieved chemical pregnancy, 16 (32%) progressed to ongoing pregnancy, 6 (12%) resulted in abortion, and 8 cycles (16%) achieved live birth.

3.2. Pregnancy outcomes according to clinical, hormonal, and embryological variables

3.2.1. Pregnancy outcomes according to maternal age

Pregnancy outcomes varied across the three maternal age categories (Table 2). Women younger than 35 years contributed the largest proportions of chemical pregnancy (13 cycles), ongoing pregnancy (6 cycles), and live birth (5 cycles). Women aged >40 years had the lowest observed success, with only 1 live birth and 4 ongoing pregnancies. Outcomes in the 35–40 years group were intermediate. These findings align with the known age-related decline in reproductive potential.

3.2.2. Pregnancy outcomes across AFC subgroups

AFC-based stratification showed variable performance across outcomes. The <6 AFC group represented many chemical pregnancies (16 cycles) and ongoing pregnancies (11 cycles). Higher AFC groups contributed fewer pregnancies overall,

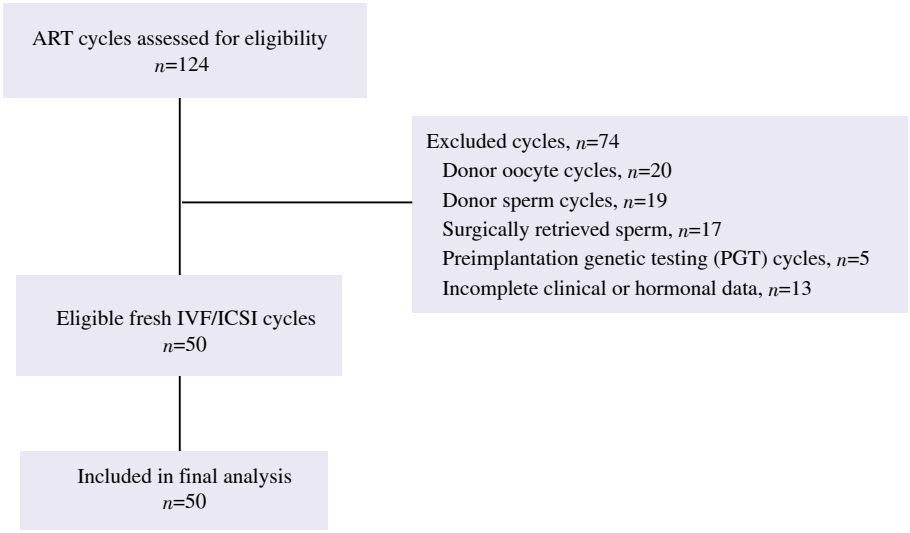

Figure 1. Flowchart of participant screening and inclusion. ART: assisted reproductive technology; IVF: *in vitro* fertilization; ICSI: intracytoplasmic sperm injection.

Table 1. Baseline clinical and hormonal characteristics of the study cohort.

Characteristic	*n*=50
Maternal age, years	
Median (IQR)	35.8 (32.5–39.6)
<35	22 (44.0)
35–40	20 (40.0)
>40	8 (16.0)
Antral follicle count (AFC)	
Median (IQR)	8 (4–14)
<6	18 (36.0)
6–12	16 (32.0)
>12	16 (32.0)
Anti-Müllerian hormone (AMH), ng/mL	
Median (IQR)	1.40 (0.70–2.90)
<1	22 (44.0)
1–4	19 (38.0)
>4	9 (18.0)
Baseline luteinizing hormone (LH), mIU/mL	
Median (IQR)	6.3 (4.8–7.9)
1–8	36 (72.0)
>8	14 (28.0)
Estradiol (E_2) on trigger day, pg/mL	
Median (IQR)	466.3 (151.0–1 591.3)
<1 000	28 (56.0)
1 000–4 000	22 (44.0)
Endometrial thickness at embryo transfer, mm	
Median (IQR)	10.2 (9.0–11.3)
<10	14 (28.0)
≥10	36 (72.0)
Number of embryos transferred	
Median (IQR)	2 (2–3)
1 embryo	5 (10.0)
2 embryos	34 (68.0)
≥3 embryos	11 (22.0)
Day of embryo transfer	
Cleavage (day 2/3)	23 (46.0)
Blastocyst (day 5/6)	27 (54.0)

Data are expressed as *n*(%) unless otherwise specified.

although the >12 AFC subgroup demonstrated similar numbers of ongoing pregnancies and live births compared with the 6–12 group, highlighting heterogeneity between ovarian response and final outcomes (Table 2).

3.2.3. Pregnancy outcomes across AMH groups

Women with AMH <1 ng/mL contributed the largest number of pregnancies (17 chemical and 9 ongoing), while both pregnancy and live birth numbers decreased markedly in the >4 ng/mL subgroup (2 chemical, 2 ongoing, 0 live birth). A statistically significant difference was observed for chemical pregnancy. Moderate AMH levels (1–4 ng/mL) yielded a favorable balance of implantation and progression to live birth. These trends reflect the complex influence of ovarian reserve markers on post-implantation success (Table 2).

3.2.4. Pregnancy outcomes according to endometrial thickness

A thicker endometrium (≥10 mm) was associated with more favorable outcomes. This group accounted for 25 chemical pregnancies, 12 ongoing pregnancies, and 6 live births, whereas only 2 live births occurred among women with endometrium <10 mm. These outcomes reinforce the importance of adequate endometrial preparation for optimal implantation (Table 2).

3.2.5. Impact of baseline LH levels

Baseline LH levels also demonstrated clinically relevant differences. Lower LH levels (1–8 mIU/mL) were associated with higher numbers of chemical (20 cycles) and ongoing pregnancies (12 cycles). In contrast, the >8 mIU/mL group achieved more live births (5 cycles), suggesting the possibility of a differential role of LH in achievement *versus* maintenance of pregnancy (Table 2).

Table 2. Pregnancy outcomes across clinical and embryological subgroups.

Variables	Chemical pregnancy *n* (%)	Aborted pregnancy *n* (%)	Ongoing pregnancy *n* (%)	Live birth *n* (%)
Maternal age, years				
<35	13 (59.1)	2 (9.1)	6 (27.3)	5 (22.7)
35–40	11 (55.0)	3 (15.0)	6 (30.0)	2 (10.0)
>40	6 (75.0)	1 (12.5)	4 (50.0)	1 (12.5)
P value	0.62	0.84	0.48	0.51
Antral follicle count (AFC)				
<6	16 (88.9)	3 (16.7)	11 (61.1)	2 (11.1)
6–12	6 (37.5)	0 (0.0)	3 (18.8)	3 (18.8)
>12	8 (50.0)	3 (18.8)	3 (18.8)	3 (18.8)
P value	0.006	0.20	0.010	0.78
Anti-Müllerian hormone (AMH), ng/mL				
<1	17 (77.3)	3 (13.6)	9 (40.9)	5 (22.7)
1–4	11 (57.9)	3 (15.8)	5 (26.3)	3 (15.8)
>4	2 (22.2)	0 (0.0)	2 (22.2)	0 (0.0)
P value	0.02	0.46	0.48	0.29
Endometrial thickness at embryo transfer, mm				
<10	6 (42.9)	0 (0.0)	4 (28.6)	2 (14.3)
≥10	25 (69.4)	6 (16.7)	12 (33.3)	6 (16.7)
P value	0.11	0.17	>0.99	>0.99
Baseline luteinizing hormone (LH), mIU/mL				
1–8	20 (55.6)	2 (5.6)	12 (33.3)	3 (8.3)
>8	11 (78.6)	2 (14.3)	4 (28.6)	5 (35.7)
P value	0.20	0.31	>0.99	0.03
Estradiol (E_2) on trigger day, pg/mL				
<1 000	20 (71.4)	2 (7.1)	10 (35.7)	5 (17.9)
1 000–4 000	11 (50.0)	1 (4.5)	6 (27.3)	3 (13.6)
P value	0.15	>0.99	0.56	>0.99
Day of embryo transfer				
Cleavage (Day 2/3)	8 (34.8)	1 (4.3)	4 (17.4)	3 (13.0)
Blastocyst (Day 5/6)	23 (85.2)	4 (14.8)	12 (44.4)	6 (22.2)
P value	<0.001	0.36	0.07	0.48

Note: Outcome categories are not mutually exclusive; ongoing pregnancy and live birth are subsets of chemical pregnancy. Therefore, counts within each subgroup may not sum to the total number of patients.

Table 3. Multivariate logistic regression analysis for predictors of live birth.

Variables	Regression coefficient (β)	SE	95% *CI*	*P*-value
Intercept	-2.423	1.291	-5.135 to 0.290	0.08
Maternal age, years	0.029	0.023	-0.019 to 0.077	0.22
Antral follicle count (AFC)	-0.003	0.013	-0.030 to 0.024	0.81
Anti-Müllerian hormone (AMH), ng/mL	-0.046	0.049	-0.149 to 0.058	0.37
Baseline luteinizing hormone (LH), mIU/mL	0.089	0.035	0.017 to 0.162	0.02
Estradiol (E_2) on trigger day, pg/mL	-0.003	0.002	-0.007 to 0.001	0.47
Endometrial thickness at embryo transfer, mm	0.145	0.064	0.011 to 0.278	0.04

β represents the regression coefficient obtained from multivariate logistic regression analysis. SE: standard error, *CI*: confidence interval.

3.2.6. Pregnancy outcomes according to E_2 levels

Women with E_2 <1000 pg/mL at trigger contributed more chemical (20 cycles), ongoing (10 cycles), and live births (5 cycles) compared with those in the 1 000–4 000 pg/mL range. These findings suggest that supraphysiological E_2 elevation may not consistently enhance reproductive outcomes (Table 2).

3.2.7. Pregnancy outcomes by day of embryo transfer

Blastocyst-stage transfers demonstrated better performance across most outcomes, with 23 chemical pregnancies, 12 ongoing pregnancies, and 6 live births *versus* 8, 4, and 3 respectively in cleavage-stage transfers. This reflects the advantage of blastocyst selection in promoting developmental competence (Table 2).

3.3. Multivariate analysis outcomes

Multivariate logistic regression showed that only baseline LH and endometrial thickness independently predicted live birth, indicating that hormonal milieu and endometrial receptivity play a more decisive role in treatment success than ovarian reserve alone. Maternal age, AFC, AMH, and E_2 did not retain significance after adjustment, suggesting their observed effects on univariate analysis may be mediated through downstream influences on embryo competence or implantation potential rather than exerting a direct impact on live birth in this cohort (Table 3).

4. Discussion

This study presents a comprehensive analysis of factors influencing pregnancy outcomes in ART cycles. By examining a wide range of clinical and embryological variables, including maternal age, ovarian reserve, hormonal profiles, endometrial thickness, and embryo transfer stage, this research highlights key predictors of ART success and provides valuable insights for optimizing clinical strategies.

Maternal age remains one of the most critical determinants of ART success. This study confirms a decline in live birth rates with advancing age, consistent with previous findings[6]. The differences in chemical and ongoing pregnancy rates across age groups reflect the progressive decline in oocyte quality and cumulative chromosomal abnormalities with age[7]. Importantly, while older women (>40 years) showed higher chemical pregnancy rates, this did not translate into significantly higher live birth rates, underscoring the complex interplay between implantation potential and post-implantation viability. These results reaffirm the need for early interventions, particularly for women over 35 years, such as PGT and personalized ovarian stimulation protocols[8].

Markers of ovarian reserve, specifically AFC and AMH, demonstrated an intricate relationship with pregnancy outcomes. While higher AFC was correlated with improved chemical and ongoing pregnancy rates, it failed to predict live births. Similarly, elevated AMH levels were associated with better implantation rates but not live birth rates, particularly in the highest AMH group (>4 ng/mL). These findings resonate with studies suggesting that although AMH is a reliable predictor of ovarian response, it is less effective in predicting pregnancy outcomes due to factors such as poor oocyte quality in high-AMH cases or polycystic ovarian syndrome (PCOS)[9,2]. This study adds to the growing evidence that ovarian reserve markers should be interpreted in the context of additional parameters, such as embryo quality and uterine receptivity.

Baseline LH levels were identified as a significant predictor of live birth outcomes. The positive correlation between LH levels and live births emphasizes the essential role of LH in follicular maturation and oocyte competence[7]. This finding is consistent with prior research showing improved outcomes with optimal LH levels during ovarian stimulation. In contrast, E_2 levels on the day of hCG trigger did not significantly predict live birth outcomes, despite being associated with better chemical pregnancy rates. This could be attributed to supraphysiological E_2 levels potentially impairing endometrial receptivity, as suggested by van Vaerenbergh *et al*[10]. These findings highlight the importance of achieving a balanced hormonal environment during ovarian stimulation to optimize pregnancy outcomes.

Endometrial thickness emerged as a critical determinant of pregnancy success. Women with an endometrial thickness of ≥10 mm showed higher live birth rates, supporting the hypothesis that an adequately thick endometrium is essential for implantation and subsequent pregnancy maintenance[11]. The absence of live births in women with thinner endometria (<10 mm) underscores the importance of uterine receptivity in ART success. Strategies such as endometrial preparation, hysteroscopic evaluation, and hormonal support may be considered to optimize endometrial conditions[12]. This study reinforces the role of endometrial thickness as a modifiable factor and a potential focus for future interventions.

The analysis revealed that blastocyst-stage transfers were associated with significantly higher clinical pregnancy rates compared to cleavage-stage transfers. These findings align with existing evidence suggesting that extended embryo culture enhances the selection of viable embryos and synchronizes embryo-endometrium interactions[13]. However, the lack of a significant difference in live birth rates between the two groups indicates that factors beyond embryo quality, such as uterine receptivity and patient-specific characteristics, play a pivotal role in determining ultimate success[14].

Multivariate regression identified baseline LH levels and endometrial thickness as significant predictors of live birth outcomes. These findings emphasize the interplay between hormonal balance and uterine receptivity as key determinants of ART success. Interestingly, maternal age, AFC, AMH, and E_2 levels were not significant predictors in the regression model, suggesting that their effects are mediated through other variables or are less impactful when analyzed alongside stronger predictors. This underscores the multifactorial nature of ART outcomes and the need for an individualized approach to patient care.

This study has some limitations, including a modest sample size that reduces statistical power, particularly for subgroup comparisons. Cumulative live birth per patient and per retrieval was not assessed, which may better represent overall treatment efficiency. Additionally, embryo quality parameters and certain uterine factors were not included in the multivariate model; therefore, the possibility of residual confounding cannot be excluded. These limitations should be considered when interpreting the findings and when designing future larger studies.

In conclusion, this study highlights the critical roles of LH levels, endometrial thickness, and embryo transfer stage as key predictors of ART success, particularly live birth outcomes. While ovarian reserve markers and maternal age influence early pregnancy rates, their predictive value diminishes when assessing live births. These findings emphasize the need for personalized treatment strategies that optimize hormonal balance, uterine receptivity, and embryo transfer timing to improve ART outcomes.

Conflict of interest statement

The authors have no competing interests to declare.

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Authors' contributions

Chandan V Salunke conceptualized the study, supervised data acquisition, and critically revised the manuscript. Shravani K.S Parker contributed to data collection, performed the statistical analysis, and drafted the initial manuscript. Ameet A Naik assisted in clinical data acquisition, interpretation of findings, and manuscript editing. Abhijit J Kamat supported laboratory data review, literature curation, and final manuscript refinement. All authors reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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