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ORIGINAL RESEARCH

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Correlation of sperm acrosome integrity rate with semen parameters and *in vitro* fertilization outcomes

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Abstract

Background: This study aimed to evaluate the application value of sperm acrosome integrity rate in male fertility assessment, its impact on *in vitro* fertilization (IVF) outcomes, and its predictive value for low IVF fertilization rates. **Methods**: (1) Semen analysis and sperm acrosome integrity rate testing were performed on 82 male outpatients from the andrology department of our hospital. Correlations between acrosome integrity rate and semen parameters were statistically analyzed. (2) Semen samples from 51 couples undergoing IVF were processed and assessed for both semen parameters and sperm acrosome integrity rate. Correlations between acrosome integrity rate and IVF fertilization outcomes were examined. **Results**: (1) The sperm acrosome integrity rate was negatively correlated with abstinence duration ($p < 0.05$) and positively correlated with sperm concentration, progressive motility, and vitality ($p < 0.05$). (2) The sperm acrosome integrity rate showed a significant positive correlation with IVF fertilization rate ($p < 0.05$). (3) Logistic regression analysis demonstrated that sperm acrosome integrity rate had a positive effect on IVF fertilization rate. (4) Receiver operating characteristic (ROC) curve analysis indicated that the optimal threshold of sperm acrosome integrity rate for predicting low IVF fertilization rate (<50%) was 95.75%. **Conclusions**: (1) Sperm acrosome integrity rate is not an independent index but is correlated with semen parameters. (2) It is positively correlated with IVF fertilization rate and can be used as a predictive indicator for low fertilization outcomes in IVF.

Keywords

Acrosome integrity rate; Semen parameters; *In vitro* fertilization; Fertilization outcome

1. Introduction

Infertility is a global health issue affecting approximately 15% of couples of reproductive age with male factors accounting for nearly 40% of identifiable causes [1]. In China, clinical laboratories primarily rely on conventional semen analysis to assess male fertility. However, standard semen parameters provide limited predictive value, leading researchers to investigate additional indicators that more accurately reflect sperm function [2]. One such indicator is the acrosome, a unique cap-like structure covering the sperm nucleus. The acrosome plays a crucial role in the fertilization process, as it is involved in multiple steps throughout fertilization [3]. Acrosome consists of an inner acrosomal membrane (IAM), closely attached to the nuclear surface, an outer acrosomal membrane (OAM), adjacent to the plasma membrane, and an acrosomal matrix rich in hydrolytic enzymes [4]. These components act in concert to support sperm function during fertilization. During acrosome biogenesis, essential molecules are transported and compartmentalized within these regions to ensure fertilization competence. Studying these molecules and their distribution provides valuable insight into sperm function and potential causes of male infertility [5].

For several decades, scientists have believed that only sperm with a fully intact acrosome, a cap-like structure that contains enzymes necessary for sperm penetration, can bind to and penetrate the zona pellucida (ZP), the egg's outer glycoprotein layer, making acrosome integrity a critical determinant of fertilization [6]. Consequently, the acrosome integrity rate has been regarded as an important marker of male fertility potential. Recent evidence also suggests that acrosome integrity correlates with other semen parameters, such as concentration, motility, and morphology, implying that men with higher acrosome integrity rates generally exhibit superior semen quality and higher fertilization potential [7].

With the increasing use of assisted reproductive technologies, particularly IVF, researchers have begun to investigate how sperm acrosome integrity influences fertilization outcomes. Building on this knowledge, the present study examines the relationship between sperm acrosome integrity rate, semen parameters, and IVF fertilization outcomes to test the hypothesis that the sperm acrosome integrity rate may be associated with both semen parameters and IVF fertilization outcomes.

2. Materials & methods

2.1 Study individuals

A total of 82 male outpatients from the Andrology department of West China Second University Hospital were recruited for semen analysis and sperm acrosome integrity rate testing to evaluate correlations with semen parameters. Inclusion criteria required no history of testicular trauma, no family history of genetic infertility disorders, no sexual dysfunction, and no obvious abnormalities in the testes, epididymis, or vas deferens on physical examination. Exclusion criteria included incomplete semen collection, abnormal semen liquefaction, azoospermia or oligozoospermia, and spermatozoa without acrosomes on morphological assessment, as reliable acrosome evaluation requires an adequate sperm count.

In addition, 51 couples undergoing IVF treatment between December 2018 and March 2019 at the Reproductive Medical Center of West China Second University Hospital were included to investigate correlations between sperm acrosome integrity rate and IVF fertilization outcomes. Inclusion criteria specified normal karyotypes in both partners, female partners diagnosed with tubal factor infertility, female age $\leq$35 years at ovarian stimulation, and treatment under a conventional long pituitary downregulation protocol [8]. Exclusion criteria included (1) incomplete semen collection on the day of oocyte retrieval, abnormal semen liquefaction, azoospermia or oligozoospermia, spermatozoa lacking acrosomes; (2) females with pelvic endometriosis, adenomyosis, diminished ovarian reserve, or complications such as pelvic effusion; (3) IVF cycles with $\leq$4 retrieved oocytes to ensure sufficient samples for fertilization outcome analysis.

2.2 Semen analysis and preparation

Semen samples were collected by masturbation after an abstinence period of 2–7 days. For IVF patients, samples were collected on the day of oocyte pickup (OPU). After 30 minutes of liquefaction, outpatient semen samples were analyzed for sperm concentration and motility using computer-aided sperm analysis (CASA, SSA-II, Suijia, Beijing, China), morphology using the modified Papanicolaou staining method, and survival rate using the eosin staining method. For IVF patients, semen was prepared using standard discontinuous density gradient centrifugation (45% and 90%, Percoll, Vitrolife) followed by direct swim-up to isolate motile sperm. The prepared samples were then evaluated for sperm concentration, motility, and morphology. An aliquot of the motile sperm fraction was reserved for acrosome integrity testing. It is crucial to note that these spermatozoa, while selected for motility, were incapacitated at the time of assessment.

2.3 Acrosome integrity rate determination

Sperm with intact acrosomes retain an unruptured acrosomal structure at the anterior head, with enzymes fully enclosed by the acrosomal membrane. In contrast, sperm undergoing the acrosome reaction exhibit fusion and rupture of the outer acrosomal membrane with the plasma membrane, releasing acrosomal enzymes. Following the World Health Organization (WHO) laboratory manual, acrosomes were stained using fluorescein isothiocyanate-labeled *Pisum sativum* agglutinin (FITC-PSA) (L0770, Sigma-Aldrich, St. Louis, MO, USA) [9].

Liquefied semen samples from outpatients were processed using a simple washing method to prepare smears, while IVF group smears were made from motile sperm prepared as described above. After air-drying for 30 minutes, smears were fixed in 95% alcohol, and 100 μL FITC-PSA working solution (25 μg/mL) was applied. Slides were incubated at 4 °C in the dark for at least 2 hours, washed with running water, and mounted with antifluorescence quenching reagent. Acrosomes were examined under a confocal microscope (FV1000, OLYMPUS, Hamburg, Germany) at 1000$\times$ magnification with a band pass (BP) 450–490 nm excitation filter. At least 200 spermatozoa were observed per sample. The spermatozoa are categorized as acrosome-intact (AI) and acrosome-reacted (AR) (Fig. 1). AI% = AI/(AI + AR)%.

2.4 Oocyte retrieval and IVF procedure

All patients underwent controlled ovarian stimulation using the gonadotropin-releasing hormone (GnRH) agonist long protocol. Oocyte retrieval was performed 36 hours after human chorionic gonadotropin (HCG) administration, and fertilization was carried out 39 hours later. Fertilization was assessed 16~18 hours post-insemination, and embryo development was observed on day 3. Embryo quality was classified according to established criteria, including blastomere number, symmetry, and cytoplasmic fragmentation percentage. High-quality embryos were defined as those with $\geq$6 blastomeres, $<$20% fragmentation, and regular, symmetric morphology. The number of retrieved oocytes, two pronuclei (2PN) fertilized oocytes, cleavage-stage embryos, and high-quality embryos was recorded. Fertilization rate (FR = 2PN oocytes/total metaphase II (MII) oocytes), cleavage rate (CR = cleaved embryos/2PN oocytes), and good-quality embryo rate (GQER = high-quality embryos/cleaved embryos) were calculated.

2.5 Statistical analysis

Statistical analysis was conducted using IBM SPSS software (version 22.0, Armonk, NY, USA). Shapiro-Wilk test was used for checking the normality of a data set quantitatively. Descriptive statistics were expressed as counts and percentages for categorical variables, while non-normally distributed quantitative data were presented as medians with interquartile ranges. Group differences were assessed using *t*-tests, ANOVA, or the Wilcoxon rank-sum test, as appropriate. Pearson's correlation analysis was applied to normally distributed quantitative variables, whereas Spearman's correlation was used for non-normally distributed data. Logistic regression analysis and receiver operating characteristic (ROC) curve analysis were performed to identify predictive variables and determine optimal cut-off values. A two-tailed $p < 0.05$ was considered statistically significant.

3. Results

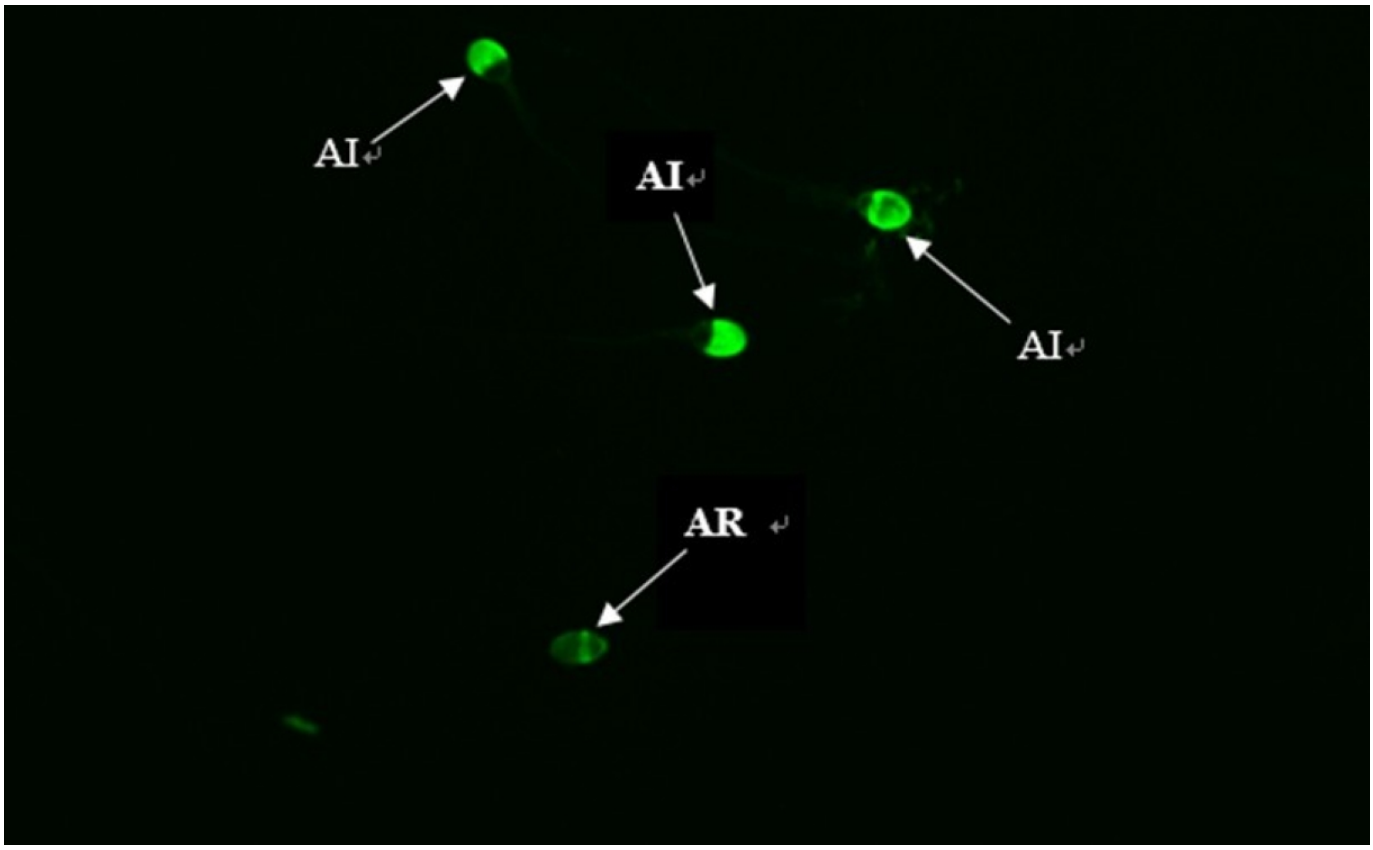

FIGURE 1. Sperm PSA-FITC staining model (×1000 under confocal microscope). Spermatozoa with fluorescent coverage >50% on the head is defined as AI. Spermatozoa with only a fluorescent band at the equatorial segment or no fluorescence in the acrosomal region is defined as AR. AI: acrosome-intact; AR: acrosome-reacted.

3.1 Correlation of sperm acrosome integrity rate with semen parameters

The general characteristics, semen parameters, and acrosome integrity rates of participants from the Andrology Department are summarized in Table 1.

Mean ± Standard Deviation for the acrosome integrity rate (%) is 94.3 ± 3.9. The Shapiro-Wilk test showed significant deviation from a normal distribution ($p < 0.0001$). Spearman's correlation analysis revealed that the sperm acrosome integrity rate was negatively correlated with abstinence duration ($p < 0.05$) and positively correlated with sperm concentration, progressive motility, and vitality ($p < 0.05$) (Table 2).

3.2 Correlation of sperm acrosome integrity rate with IVF fertilization outcomes

The general characteristics, semen parameters, acrosome integrity rates, and IVF fertilization outcomes of participants from the Reproductive Medical Center are described in Table 3. Mean ± Standard Deviation for the acrosome integrity rate (%) is 97.3 ± 2.2. The Shapiro-Wilk test showed significant deviation from a normal distribution ($p < 0.0001$). Spearman's correlation analysis indicated that the sperm acrosome integrity rate was positively correlated with the fertilization rate (FR) ($p < 0.05$) (Table 4).

To further evaluate predictive value, an IVF <50% defined as low, and subjects were divided into two categories. Logistic regression analysis demonstrated that sperm acrosome integrity rate was the only independent predictor of low IVF fertilization rate (odds ratio (OR) = 0.641, 95% confidence interval (CI): 0.436–0.941, $p = 0.023$) (Fig. 2).

ROC curve analysis identified 95.75% as the optimal threshold for predicting low IVF fertilization rate, with a sensitivity of 0.625, specificity of 0.860, and an area under the curve (AUC) of 0.699 ($p < 0.05$; 95% CI: 0.441–0.957) (Fig. 3). When study participants were stratified according to acrosome integrity rate (≥95.75% *vs.* <95.75%), a significant difference in IVF fertilization rates was observed between the two groups ($p < 0.01$) (Table 5).

4. Discussion

4.1 Sperm acrosome integrity rate in association with semen parameters

In this study, the median sperm acrosome integrity rate among outpatients in the Andrology Department was 95%. The acrosome integrity rate refers to the percentage of sperm with intact acrosomes and serves as an important indicator of sperm quality and fertilization potential [10]. According to the World Health Organization (WHO) laboratory manual, an integrity rate greater than 15% is considered within the normal range, reflecting the absence of premature spontaneous acrosome reactions [9]. Therefore, an integrity rate of ≥85% suggests that most spermatozoa have not undergone premature acrosomal changes. However, the manual also acknowledges the limited

TABLE 1. General characteristics, semen parameters, and acrosome integrity rate of participants in andrology department (n = 82).

Variable	Median (interquartile range)	Range
Age (yr)	31.0 (6.0)	23.0–46.0
Abstinence days (n)	3.0 (2.0)	2.0–7.0
Testis volume (mL)	15.0 (8.0)	8.0–25.0
Semen volume (mL)	3.6 (2.1)	1.6–9.0
pH (n)	7.4 (0)	6.8–8.0
WBC concentration ($\times 10^6$/mL)	0.3 (0.4)	0.1–6.8
Sperm concentration ($\times 10^6$/mL)	88.5 (97.5)	17.0–585.0
Total sperm number ($\times 10^6$)	280.0 (292.6)	43.2–907.8
Progressively motile sperm (%)	63.5 (32.3)	1.0–85.0
Sperm vitality (%)	82.0 (14.3)	42.0–94.0
Morphologically normal sperm (%)	3.4 (3.0)	0–17.3
Sperm acrosome integrity rate (%)	95.0 (5.0)	80.0–99.5

WBC: white blood cell.

TABLE 2. Spearman's correlation between sperm acrosome integrity rates and general characteristics, semen parameters (n = 82).

	ρ	*p*
Age (yr)	−0.109	0.329
Abstinence days (n)	−0.239	0.008**
Testis volume (mL)	0.031	0.785
Infertility term (yr)	−0.052	0.708
Semen volume (mL)	0.042	0.710
pH (n)	0.104	0.350
WBC concentration ($\times 10^6$/mL)	−0.172	0.122
Sperm concentration ($\times 10^6$/mL)	0.240	0.030*
Total sperm number ($\times 10^6$)	0.208	0.061
Progressively motile sperm (%)	0.409	<0.001***
Sperm vitality (%)	0.325	0.003**
Morphologically normal sperm (%)	0.133	0.233

*ρ: Spearman's correlation coefficient. *p < 0.05; **p < 0.01; ***p < 0.001. WBC: white blood cell.*

TABLE 3. General characteristics, semen parameters, acrosome integrity rate, and IVF fertilization outcomes of participants in reproductive medical center (n = 51).

Variable	Median (interquartile range)	Range
IVF cycle (n)	1 (0)	1–4
Female age (yr)	31 (4)	23–35
Oocyte (n)	11 (7)	4–31
Male age (yr)	32 (6)	27–51
Sperm concentration ($\times 10^6$/mL)	112 (33)	75–153
Morphologically normal sperm (%)	6.4 (2.5)	0–22.1
Sperm acrosome integrity rate (%)	98.0 (3.5)	89.5–99.5
FR (%)	80.0 (29.3)	22.2–100
CR (%)	100 (0)	75–100
GQER (%)	33.3 (38.9)	0–85.7

FR: fertilization rate; CR: cleavage rate; GQER: good-quality embryo rate; IVF: in vitro fertilization.

TABLE 4. Spearman's correlation between sperm acrosome integrity rates and IVF outcomes (n = 51).

	ρ	*p*
FR (%)	0.285	0.043*
CR (%)	0.148	0.301
GQER (%)	0.098	0.495

*ρ: Spearman's correlation coefficient. FR: fertilization rate; CR: cleavage rate; GQER: good-quality embryo rate. *p < 0.05.*

validation of acrosome status detection, emphasizing the need for additional studies to confirm the clinical reliability and reference values of this measure [9].

Although the acrosome integrity rate is increasingly recognized as a useful marker, its regulation remains complex and not fully understood. Multiple environmental and physiological factors influence acrosome stability [11–13]. For instance, exposure to benzo[a]pyrene, a chemical found in tobacco smoke, had a significant impact on the acrosome integrity rate. Specifically, it was shown to increase the occurrence of premature acrosomal reaction, which ultimately led to a decrease in the overall integrity rate of the acrosome, suggesting a detrimental effect of smoking on male reproductive health [14]. Similarly, obesity has been linked to abnormal acrosome status. High cholesterol levels in the sperm membranes of obese men may promote clustering of estrogen receptors in lipid rafts over the acrosome [15], enhancing sensitivity to elevated estrogen (E2) levels and triggering abnormal spontaneous acrosome reactions. This highlights a potential link between obesity and male fertility issues. Furthermore, research has indicated that there is an association between the seminal plasma proteome (a collection of proteins found in the plasma of semen) and sperm acrosome integrity [16]. Specifically, it has been suggested that the enrichment of the arachidonic acid metabolism pathway and the inhibition of phospholipase (an enzyme involved in lipid metabolism) may be related to the induction of premature acrosomal reaction. These findings hint at the complex biochemical processes involved in maintaining the integrity of the acrosome. Overall, these studies shed light on the various factors that can impact the acrosome integrity rate. From exposure to certain chemicals like benzo[a]pyrene in tobacco smoke to the effects of obesity and biochemical pathways, there are intricate mechanisms that researchers are striving to fully comprehend. To build on these observations, future studies should apply advanced molecular approaches. For example, comparative proteomic profiling of seminal plasma and spermatozoa from men with high versus low integrity rates may identify critical proteins involved in acrosomal stability, such as binding proteins, hydrolytic enzymes, and membrane fusion mediators [17]. Likewise, lipidomic analyses could clarify alterations in acrosomal lipid composition, while single-cell RNA sequencing may reveal transcriptional heterogeneity underlying acrosomal defects [18, 19]. Together, such approaches would move research beyond correlation, offering mechanistic insight into how acrosome integrity is maintained or disrupted in male infertility.

Our analysis demonstrated that the sperm acrosome integrity rate was weakly negatively correlated with abstinence duration. In practical terms, during the 2–7 day abstinence period, the proportion of intact acrosomes decreased as abstinence time increased. These findings are consistent with a previous study of 1800 semen samples, which also reported a decline in acrosome integrity with prolonged abstinence [20].

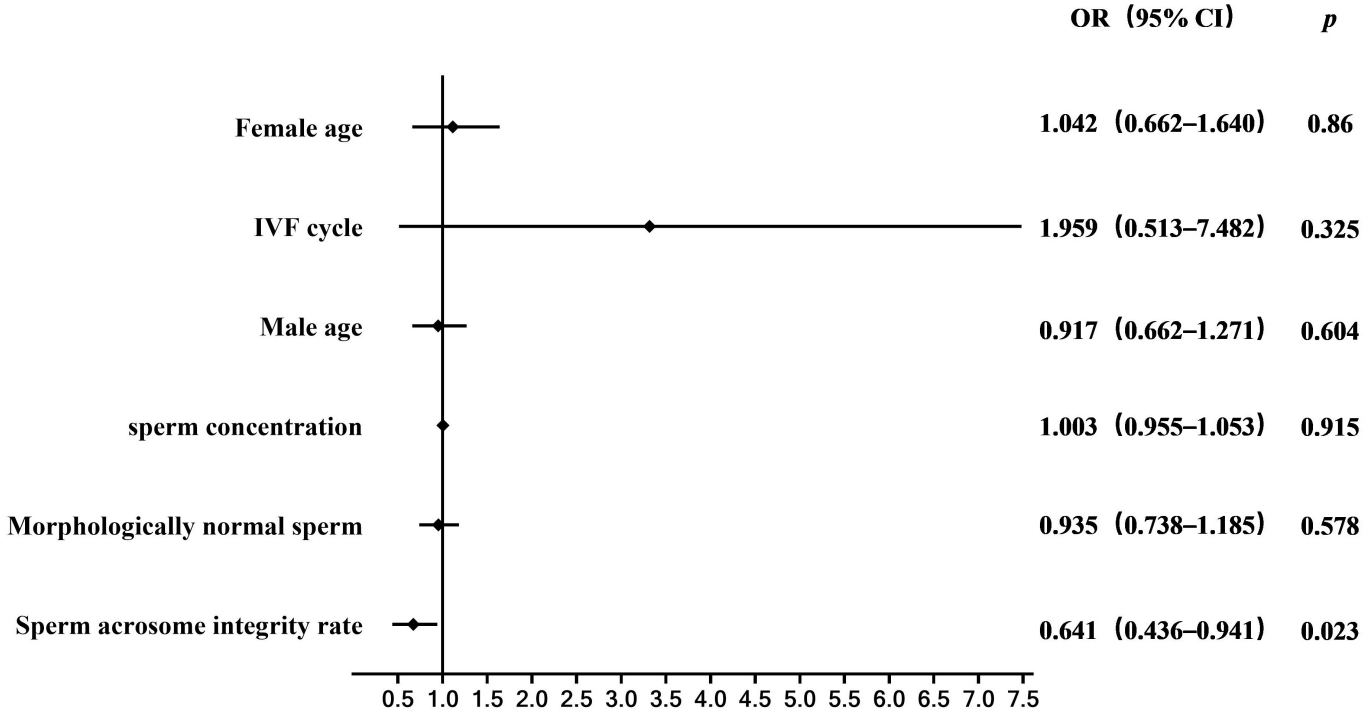

FIGURE 2. Logistic regression analysis results for prediction of low IVF fertilization rate. OR: odds ratio; CI: confidence interval; IVF: *in vitro* fertilization.

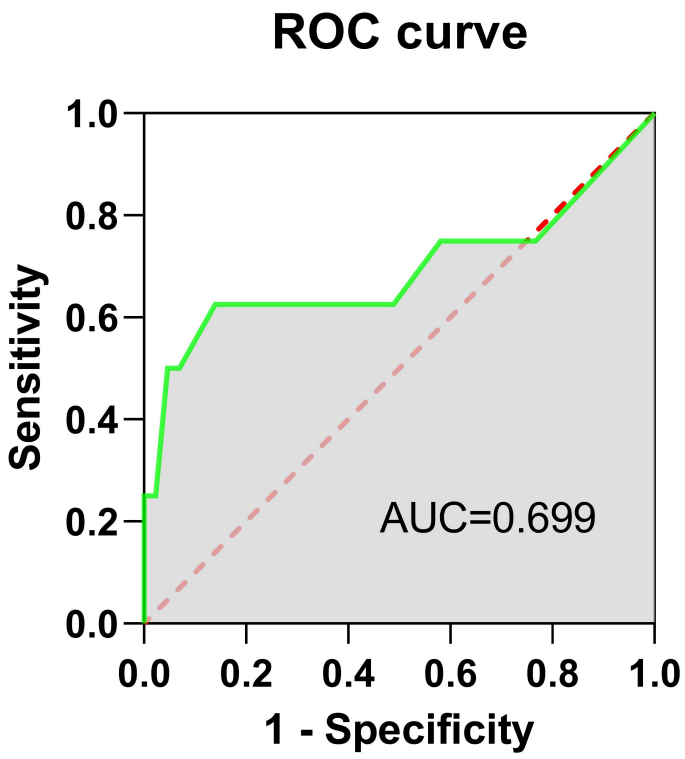

FIGURE 3. ROC curve analysis for acrosome integrity rate in predicting low IVF fertilization rate. ROC: receiver operating characteristic; AUC: area under the curve.

TABLE 5. Comparison of baseline characteristics, semen parameters and IVF fertilization rates between groups based on acrosome integrity rate cut-off value.

Variable	Group 1 (AI rate ≥95.75%) (n = 40)	Group 2 (AI rate <95.75%) (n = 11)	*p*
Female age (yr)	31 (4)	30 (5)	0.452
Male age (yr)	32 (6)	33 (7)	0.678
Sperm concentration ($\times 10^6$/mL)	115 (35)	105 (29)	0.301
Morphologically normal sperm (%)	6.5 (2.6)	5.9 (2.1)	0.415
Sperm acrosome integrity rate (%)	98.5 (2.0)	93.0 (3.0)	<0.001***
IVF fertilization rate (%)	85.7 (26.3)	70.0 (40.0)	0.001**

Data are presented as Median (Interquartile Range). AI: Acrosome-intact; IVF: in vitro fertilization.
p-value derived from Mann-Whitney U test for non-normally distributed data.
****p < 0.001; **p < 0.01.*

In contrast, we observed a moderate positive correlation between acrosome integrity rate and progressive motility, indicating that sperm with intact acrosomes were more likely to exhibit active forward movement. Weak positive correlations were also found with sperm concentration and vitality, suggesting that higher rates of intact acrosomes tend to accompany higher sperm counts and greater viability. The observed positive correlations between acrosome integrity and parameters like sperm concentration, progressive motility, and vitality may reflect a common underlying etiology rooted in spermatogenic efficiency and cellular health. The acrosome is a Golgi-derived secretory organelle, and its proper formation during spermiogenesis is a complex process that requires precise intracellular trafficking and energy metabolism. It is plausible that underlying cellular pathologies, such as oxidative stress, mitochondrial dysfunction, or aberrant apoptosis, could simultaneously impair acrosomal biogenesis, reduce sperm production (concentration), and compromise the structural and functional integrity of the flagellum (motility) [21, 22]. Therefore, a low acrosome integrity rate might be a marker of a generalized state of sperm dysfunction, rather than an isolated defect.

Interestingly, unlike some earlier reports, our study did not detect any correlation between acrosome integrity and normal morphology [23, 24]. This discrepancy may be attributed to several factors. First, the subjectivity inherent in morphological assessment can lead to inter-laboratory variability in classification [25]. Second, and more importantly, our morphology assessment followed the WHO strict criteria, which classify a wide range of head defects. It is possible that acrosome

integrity is specifically associated with certain subtypes of head defects (*e.g.*, vacuolated heads, amorphous heads) that were not analyzed separately in our cohort, and their signal was diluted within the broader "normal" *vs.* "abnormal" classification. Third, the acrosome itself is only one part of the sperm head, and its integrity might not be perfectly correlated with the overall head shape as defined by morphological criteria. A sperm can have a normally shaped head but a prematurely reacted acrosome, and *vice versa*. Future studies employing more objective morphometric analyses or focusing on specific teratozoospermic subtypes could help clarify this relationship.

4.2 Sperm acrosome integrity rate in association with IVF fertilization outcomes

In the IVF cohort, the median sperm acrosome integrity rate was 98%, slightly higher than values reported in studies using a single sperm preparation procedure [24, 26]. Previous comparisons have shown that combining discontinuous density gradient centrifugation with the swim-up method yields sperm with better motility and fewer fragments or leukocytes than either technique alone [27, 28]. This methodological advantage may explain the higher integrity rate observed in our samples.

Importantly, we evaluated acrosome integrity and IVF fertilization outcomes using the same sperm population, ensuring a direct and reliable comparison between sperm function and fertilization success. To minimize confounding, female participants were restricted to women aged $\leq$35 years with tubal factor infertility, excluding other potential influences such as maternal age or systemic disease [29]. Under these controlled conditions, we identified a positive correlation between sperm acrosome integrity rate and IVF fertilization rate, showing that higher acrosome integrity increased the likelihood of successful fertilization. Logistic regression analysis further revealed that a higher integrity rate significantly reduced the risk of low fertilization ($<$50%). These results reinforce the view that acrosome integrity is not only a marker of sperm quality but also a meaningful predictor of IVF outcomes [30]. The molecular mechanism by which acrosome damage impairs fertilization is primarily linked to its indispensable role in ZP penetration. An intact acrosome contains hydrolytic enzymes like acrosin and hyaluronidases. Upon binding to the ZP, a physiologically triggered acrosome reaction releases these enzymes locally, allowing the sperm to digest a path through the ZP. Sperm with prematurely reacted or damaged acrosomes lack this enzymatic arsenal and are thus incapable of penetrating the egg's vestments [31, 32].

Based on ROC curve analysis, we determined that a sperm acrosome integrity threshold of sperm, in cases with a low IVF fertilization rate, was found to be 95.75%. This means that if the acrosome integrity of sperm is below this threshold, it may contribute to a decreased likelihood of successful fertilization during IVF procedures. Regarding the clinical utility of the 95.75% cut-off value, it is essential to clarify that its application is prospective and preemptive, rather than retrospective. Since fertilization outcomes are indeed directly observed after insemination, the value of this parameter lies in its potential for risk assessment prior to an IVF cycle. For example, a patient with persistently low integrity rates could be advised about a higher likelihood of suboptimal fertilization and may be offered alternative interventions such as intracytoplasmic sperm injection (ICSI) to bypass acrosome-related dysfunction. While the predictive power of this threshold is not absolute, it represents a practical tool for risk stratification, enabling clinicians to tailor treatment strategies and optimize patient expectations before an IVF cycle.

However, it is important to note that the predictive ability of this cut-off value was modest, as reflected by the Area Under the Curve (AUC) value [33]. While the AUC demonstrated some predictive potential, it also suggested that additional factors contribute to fertilization success. This underscores that the acrosome integrity rate, although valuable, is not the sole determinant of IVF outcomes. The moderate AUC likely reflects the inherently multifactorial nature of fertilization, which depends not only on acrosomal integrity but also on processes such as sperm-oocyte fusion, chromosomal integrity of the sperm, oocyte quality, and the capacity for oocyte activation. Thus, the acrosome integrity rate should be interpreted as one element within a broader diagnostic and prognostic framework rather than as a standalone predictor. Further analysis revealed that individuals with a sperm acrosome integrity rate below 95.75% exhibited a significantly lower IVF fertilization rate compared with those above this threshold. This finding highlights the negative impact of reduced acrosome integrity on fertilization outcomes. It is worth noting, however, that fertilization rates below 70% are not always pathological, though they remain suboptimal for achieving favorable IVF outcomes [34]. This observation suggests that while diminished acrosome integrity contributes to reduced fertilization success, other biological and clinical variables also influence the final result.

The present study also has limitations that must be acknowledged. One limitation relates to data timeliness. While the central strength and key conclusion of this work lie in establishing a biological correlation between acrosome integrity and fertilization outcomes, clinical and laboratory practices evolve continuously. The methods used in this study-including FITC-PSA staining for acrosome assessment, CASA-based semen analysis, and the definition of fertilization via 2PN observation-are standardized and remain valid. The biological relationship we investigated is rooted in fundamental reproductive physiology (the necessity of an intact acrosome for zona pellucida binding and penetration in conventional IVF), which is immutable. Therefore, the existence and direction of the correlation we report are unlikely to be invalidated by the passage of time alone. However, the potential impact of data timeliness is most relevant to the generalizability and clinical application of our findings in the contemporary IVF landscape. First, clinical and laboratory protocols continuously evolve (*e.g.*, improvements in culture media, ovarian stimulation strategies). A more significant consideration is the increasing and often preferential use of Intracytoplasmic Sperm Injection (ICSI), even for non-male factor infertility [35]. Because ICSI bypasses the acrosome reaction entirely, the predictive value of acrosome integrity rate is likely diminished in ICSI cycles. Thus, the threshold of 95.75% identified here is most relevant to patients undergoing conventional IVF. The declining proportion of conventional IVF procedures in

modern reproductive medicine may therefore limit the broad applicability of this cut-off value.

5. Conclusions

In conclusion, our research has provided evidence supporting the notion that sperm acrosome integrity rate is not an independent index but correlates with several semen parameters. Importantly, it showed a positive correlation between the acrosome integrity rate and the IVF fertilization rate. This observation suggests that the integrity of the sperm acrosome has an impact on the success of IVF fertilization. Our findings suggest that sperm acrosome integrity rate can serve as a predictive factor for low fertilization outcomes in IVF, thereby offering potential utility in pre-IVF evaluations. By incorporating acrosome integrity testing, clinicians may better identify patients at risk of suboptimal fertilization and design more personalized treatment strategies. To strengthen the clinical applicability of these findings, future research should include multi-center studies with larger sample sizes. In addition, investigations using emerging molecular and imaging technologies will help clarify the mechanistic role of acrosome integrity in fertilization, ultimately contributing to the refinement of assisted reproductive technologies.

AVAILABILITY OF DATA AND MATERIALS

The authors confirm that the data supporting the findings of this study are available within the article.

AUTHOR CONTRIBUTIONS

FM—conceptualization; writing–review and editing. YW, YF, ZYH—formal analysis and investigation. LY—writing–original draft preparation; methodology. LY, JPH, YLW—resources. All the authors agree and consent to the publication of this study.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study has been approved by the ethics committee of the West China Second University Hospital of Sichuan University, Chengdu, China (No. 2015020). All subjects gave written informed consent in accordance with the Declaration of Helsinki. All methods were carried out in accordance with relevant guidelines and regulations in the declaration of Helsinki.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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