SPERM SELECTION FOR ICSI BASED ON MORPHOLOGY, MOTILITY AND DNA-FRAGMENTATION

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We introduce a novel, clinically applicable technique for simultaneous assessment of morphology, motility, and DNA fragmentation in live human sperm cells at the single-cell level. The method combines quantitative stain-free interferometric imaging with multiple deep-learning frameworks to provide comprehensive sperm evaluation without the need for chemical staining.In current clinical practice, only motility is routinely evaluated in live cells, while morphology and DNA fragmentation require separate, destructive assays, preventing integrated analysis of the same cell.

Consequently, correlations between these critical parameters remain largely unexplored.Our approach enables the non-invasive, real-time evaluation of all three parameters in individual sperm cells, including virtual staining for morphological assessment. We demonstrate that the proportion of sperm cells meeting each individual criterion does not predict the proportion that meet all three simultaneously—highlighting the importance of per-cell, multi-parameter evaluation for accurate male fertility assessment. This stain-free, AI-assisted method has the potential to reduce uncertainty in fertility diagnostics and to improve sperm selection for assisted reproduction procedures such as ICSI.

Take Home Messages

- Simultaneous evaluation of sperm morphology, motility, and DNA fragmentation is now feasible on live cells using a stain-free interferometric approach.
- Deep learning enables accurate, label-free assessment and virtual staining of individual sperm cells.
- Per-cell, multi-parameter analysis enhances diagnostic accuracy and supports improved sperm selection for ICSI.
- The technique is clinic-ready and may significantly impact both fertility evaluation and ART outcomes.

ROLE OF THE CENTROSOME IN FERTILITY

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The centrosome plays a pivotal role in fertilization and early embryonic development, yet its contribution to human fertility remains underexplored in routine clinical assessment. Serving as the main microtubule-organizing center of the cell, the centrosome is essential for sperm motility, oocyte activation, pronuclear migration, and the first mitotic divisions after fertilization.

In humans, the sperm provides the functional centrosome to the zygote, and defects in its structure or function may lead to fertilization failure or impaired embryo development. In our recent work, we performed live-cell staining using centrosome-specific fluorescent probes, combined with quantitative phase diferential (QPD) imaging, to localize and characterize the centrosome within individual sperm cells in real time. This correlative approach enables precise mapping of centrosomal position and dynamics relative to the sperm's morphological and optical features.
Our findings highlight the centrosome's crucial contribution to male fertility and demonstrate the feasibility of non-destructive, quantitative centrosomal analysis in living sperm.

Take Home Messages

- The sperm-derived centrosome is essential for successful fertilization and early embryonic development.
- Centrosomal abnormalities can underlie unexplained male infertility and ICSI failure.
- Live-cell fluorescent labeling combined with QPD imaging allows direct visualization and characterization of the centrosome in viable sperm cells.
- This correlative, non-destructive approach bridges molecular and biophysical assessments of sperm quality.
- Evaluating centrosome integrity may improve diagnostic precision and guide sperm selection in ART.

FROM OOCYTE TO BLASTOCYST- ADVANCED IMAGING, TIME-LAPSE & ARTIFICIAL INTELLIGENCE TO SELECT THE BEST EMBRYOS

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Selecting the most competent embryos remains one of the major challenges in assisted reproduction. The integration of advanced imaging, time-lapse monitoring, and artificial intelligence (AI) now offers unprecedented opportunities to assess embryonic development dynamically and non-invasively. Previous studies used time-lapse studies on human embryos and molecular fluorescent markers to visualize critical events during oocyte maturation, fertilization, and preimplantation development. These studies have provided unique insights into the timing, synchronization, and molecular dynamics that underlie successful embryogenesis.

Additionally, we performed a pilot study using tomographic imaging on 8-cell-stage embryos, aiming to visualize intracellular density distributions and organelles such as the nucleus. Although this initial attempt did not yield successful reconstructions, it demonstrated the technical feasibility and highlighted the challenges of applying volumetric imaging to delicate embryonic structures. The combination of high-resolution time-lapse imaging, molecular labeling, and AI-based analysis paves the way for objective, data-driven embryo selection, with the potential to improve implantation rates and outcomes in ART.

Take Home Messages

- Time-lapse imaging with molecular fluorescent markers enables real-time visualization of key developmental events from oocyte maturation to blastocyst formation.
- Correlation of dynamic cellular and molecular parameters provides deeper understanding of embryonic competence.
- Preliminary tomographic imaging of 8-cell embryos suggests the potential—and technical challenges—of visualizing subcellular architecture in living embryos.
- Artificial intelligence can integrate morphokinetic and molecular imaging data for more accurate embryo selection.
- Advanced, non-invasive imaging approaches are reshaping the future of embryo assessment in assisted reproduction.