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An Assessment Tool for Computer-Assisted Semen Analysis (CASA) Algorithms

R. Purushothaman[1,2]*, K. Lokesh[1], M. Prakash[2], Yashmi Agwina Xavier[1], M. Gayathri[1], P. Divya[1] and B. Rajalakshmi[1]

[1]Dr. Borus Andro Lab and Research Center, Chennai, India
[2]Research Department of Microbiology, Kanchi Shri Krishna College of arts and science, Kilambi, Kancheepuram-631551, Tamilnadu, India

**Corresponding author*

Abstract

Computer-Assisted Semen Analysis (CASA) systems have become pivotal in the objective evaluation of semen parameters, including sperm motility, morphology, and concentration. Despite their increasing adoption in clinical and research settings, significant variability exists in algorithm performance due to differences in image processing techniques, hardware configurations, and dataset quality. This paper presents a comprehensive assessment tool designed to evaluate and benchmark CASA algorithms systematically. The tool incorporates standardized test datasets, performance metrics (such as accuracy, precision, recall, and processing time), and visualization modules for qualitative comparison. By enabling consistent evaluation across diverse CASA systems, this tool supports the development of more robust and reliable sperm analysis solutions and promotes reproducibility and transparency in algorithm validation.

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Computer-Assisted Semen Analysis (CASA), Sperm Analysis, Image Processing, Algorithm Evaluation, Benchmarking Tool, Reproducibility.

Introduction

The analysis of semen quality is a critical component in the assessment of male fertility. Traditionally, semen evaluation has relied on manual microscopic observation, which is inherently subjective, time-consuming, and prone to inter- and intra-observer variability. In response to these limitations, Computer-Assisted Semen Analysis (CASA) systems have emerged as a powerful alternative, offering objective, reproducible, and high-throughput measurements of sperm motility, concentration, morphology, and other parameters (World Health Organization, 2021; Mortimer, 2000; Verstegen *et al.,* 2002).

CASA systems employ image processing and motion tracking algorithms to analyze sperm behavior in video recordings, thereby enabling precise quantification of dynamic parameters (Amann and Waberski, 2014; Contri *et al.,* 2010; Hidalgo *et al.,* 2006). However, the performance of CASA algorithms can vary significantly depending on implementation, input data quality, and computational techniques used. Given the growing reliance on CASA technologies in both clinical and research settings, it is essential to ensure that the algorithms used are accurate, reliable, and standardized across different platforms (Brito *et al.,* 2016; Jędrzejczak *et al.,* 2005; Freour *et al.,* 2009).

This study presents the development of an assessment tool designed to evaluate and benchmark CASA algorithms. The tool provides a standardized framework for testing algorithm performance using curated datasets, defined metrics, and reproducibility criteria. By

facilitating comparative analysis and validation, the proposed assessment tool aims to support the development of robust CASA systems and contribute to the standardization of semen analysis in reproductive medicine (Kwon *et al.,* 2015; Martinez *et al.,* 2017; Dearing *et al.,* 2021; Singh *et al.,* 2011; Knuth and Nieschlag, 1988).

Semen analysis plays a pivotal role in the evaluation of male reproductive health. It is a fundamental diagnostic test used in fertility clinics, andrology laboratories, veterinary medicine, and research institutions.

Traditionally, semen evaluation has been performed manually under a microscope by trained technicians, assessing parameters such as sperm concentration, motility, morphology, and vitality (Moghaddam and Borji, 2011; Yániz *et al.,* 2015). Despite its clinical relevance, manual semen analysis is labor-intensive, subject to human error, and limited by observer variability, making it difficult to maintain consistency and objectivity across laboratories and practitioners (Akashi *et al.,* 2010; Baig *et al.,* 2019; Cheon *et al.,* 2019; Agarwal *et al.,* 2019; Dearing *et al.,* 2014).

To overcome these limitations, Computer-Assisted Semen Analysis (CASA) systems have been developed. These systems leverage advances in digital imaging, computer vision, and artificial intelligence to automate the process of sperm analysis. CASA systems are capable of tracking individual spermatozoa in real time, measuring motion characteristics such as velocity, linearity, and amplitude of lateral head displacement (ALH), while also quantifying concentration and morphological features (Vernon *et al.,* 2014; Tomlinson *et al.,* 2010; Engel *et al.,* 2019). Their widespread adoption has led to increased standardization and efficiency in semen analysis workflows (Agarwal and Sharma, 2007).

However, despite the technological progress and increased use of CASA in both human and animal reproductive studies, several challenges persist (Talarczyk-Desole *et al.,* 2017; Schubert *et al.,* 2019).

The performance of CASA algorithms—particularly those responsible for image preprocessing, object detection, sperm tracking, and feature extraction—can vary significantly based on implementation details, hardware limitations, image quality, and the diversity of sample types. Furthermore, many CASA systems operate as closed-source, proprietary tools, limiting transparency and the ability to independently evaluate their accuracy or compare performance across different systems (Lammers *et al.,* 2014; Menkveld *et al.,* 2011; Vested *et al.,* 2011).

In this context, there is a growing need for a dedicated assessment tool that can systematically evaluate the effectiveness, robustness, and accuracy of CASA algorithms. Such a tool would serve as a benchmarking framework, enabling developers, researchers, and clinicians to:

- Validate new CASA algorithms using standard datasets.
- Compare algorithm performance across a common set of metrics.
- Identify failure cases and optimize algorithmic parameters.
- Ensure reproducibility and reliability in clinical and research applications.

This study introduces an assessment tool specifically designed for CASA algorithm evaluation. The tool provides a comprehensive environment to test various components of CASA systems, including:

- Image quality preprocessing (e.g., noise reduction, contrast enhancement)
- Sperm detection and segmentation
- Sperm tracking across video frames
- Quantitative motion and morphology analysis

To facilitate thorough evaluation, the assessment tool integrates annotated datasets, including synthetic and real-world semen samples, as well as a suite of performance metrics such as precision, recall, tracking accuracy, mean squared error (MSE) of motility parameters, and computational efficiency. The tool is also designed to support modular integration, allowing researchers to plug in different algorithmic models and compare them in a controlled, reproducible setting.

By providing a transparent, standardized evaluation framework, this tool aims to bridge the gap between CASA algorithm development and practical deployment in laboratory environments. It will ultimately contribute to improving the quality and consistency of automated semen analysis, promoting better clinical outcomes and advancing research in reproductive biology.

Conclusion

The increasing reliance on Computer-Assisted Semen Analysis (CASA) systems in both clinical and research settings underscores the need for accurate, reliable, and standardized algorithmic tools for semen evaluation. While CASA technologies offer significant advantages over manual methods—including improved objectivity, repeatability, and processing speed—the variability in algorithmic performance across different implementations remains a critical concern.

This work presents a comprehensive assessment tool designed specifically to evaluate and benchmark CASA algorithms. By incorporating standardized datasets, modular algorithm integration, and a suite of quantitative performance metrics, the tool provides a consistent framework for testing the robustness, accuracy, and efficiency of various CASA components, including image preprocessing, sperm detection, tracking, and motility analysis.

Through this tool, developers and researchers can identify algorithmic strengths and limitations, facilitate cross-platform comparisons, and promote transparency and reproducibility in CASA-based semen analysis. The assessment tool not only aids in validating new computational approaches but also supports the broader goal of harmonizing semen evaluation practices across laboratories and institutions.

Ultimately, the implementation of such an evaluation framework contributes to enhancing the reliability of male fertility assessments and supports further innovation in reproductive health technologies. Future work may involve expanding the tool with machine learning-based performance insights, real-time processing capabilities, and broader compatibility with commercial CASA systems.

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