The use of AI for sperm

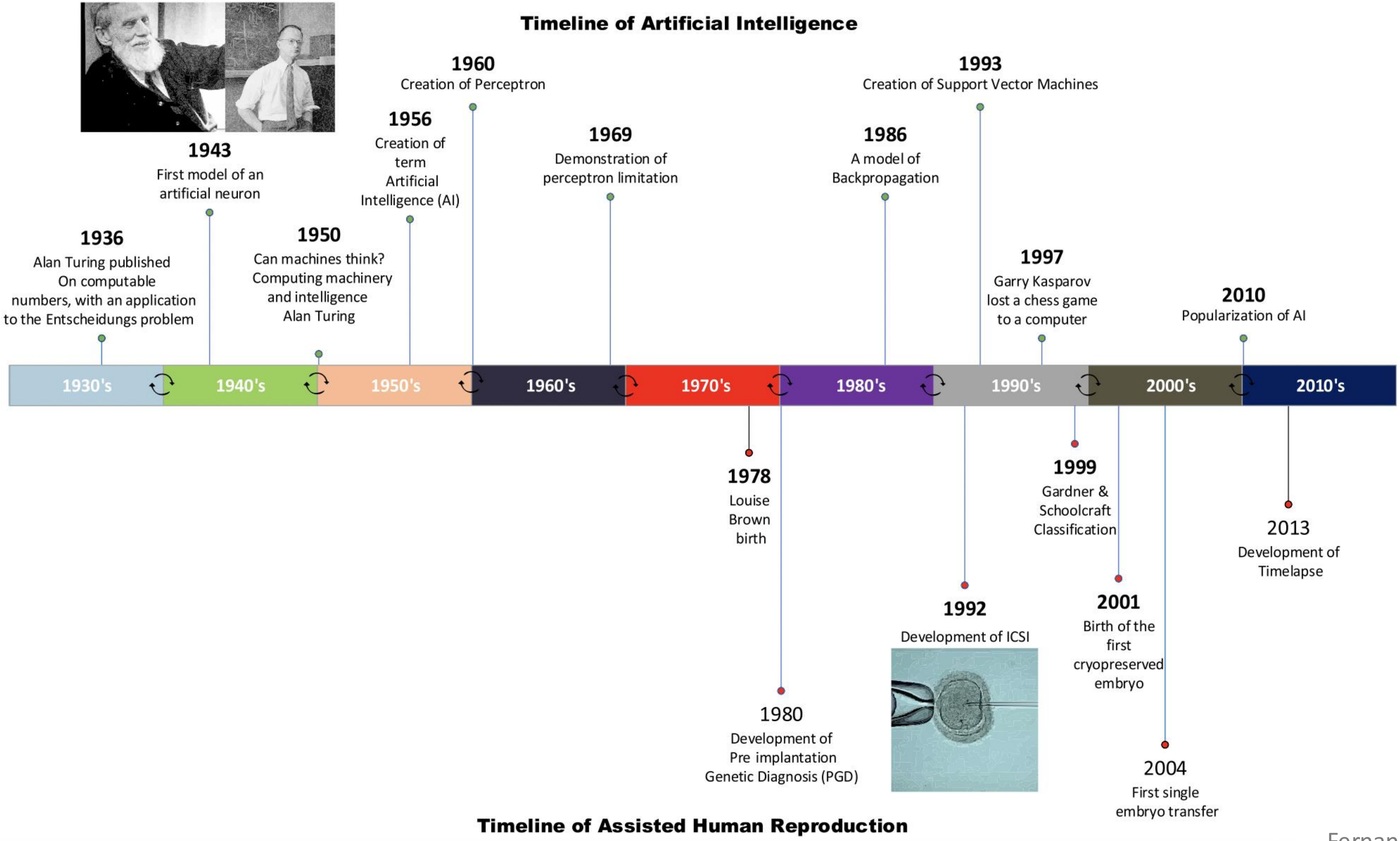
BSRM 2024 Scientific meeting

Wouters Koen

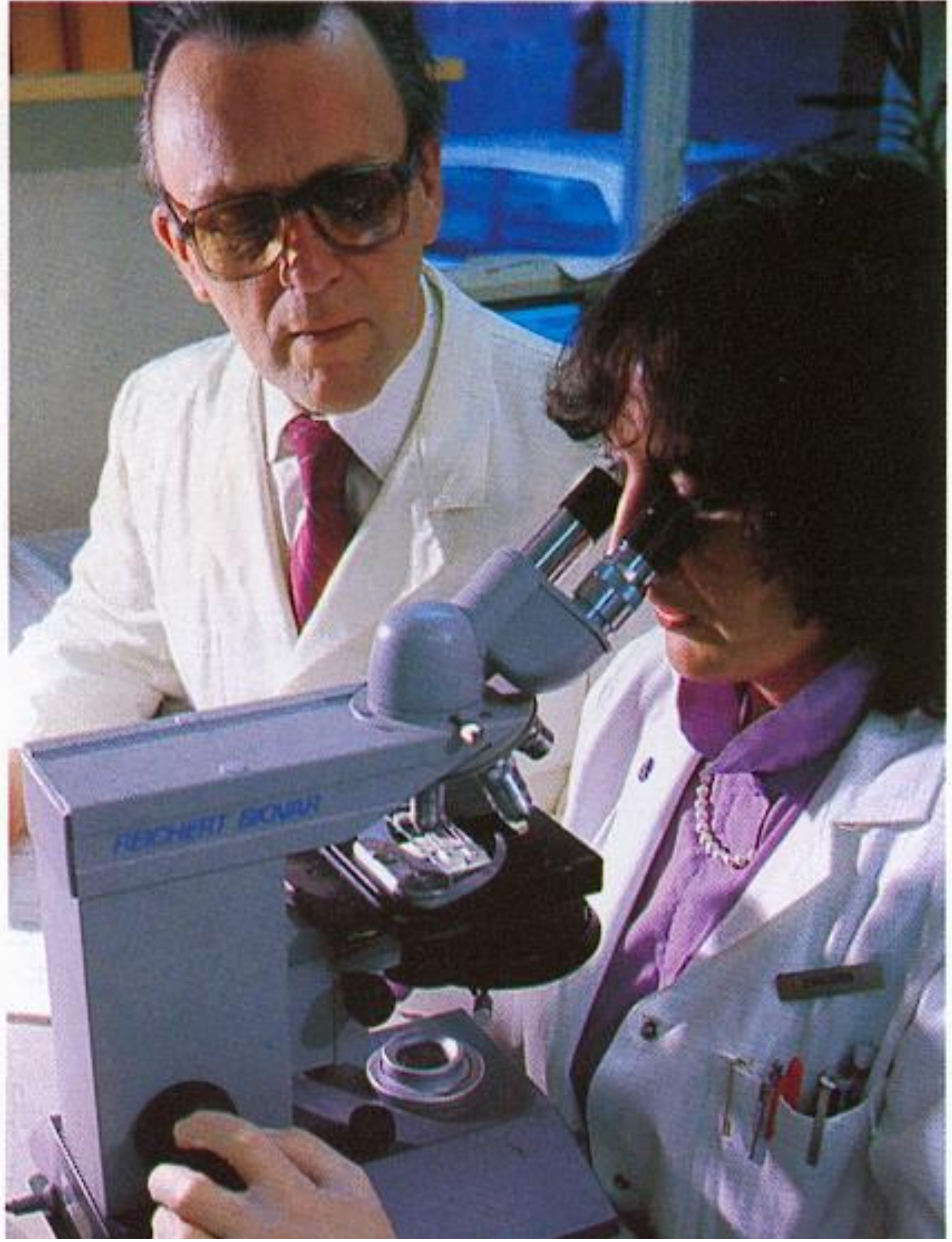
Brussels IVF received funding related to this topic from

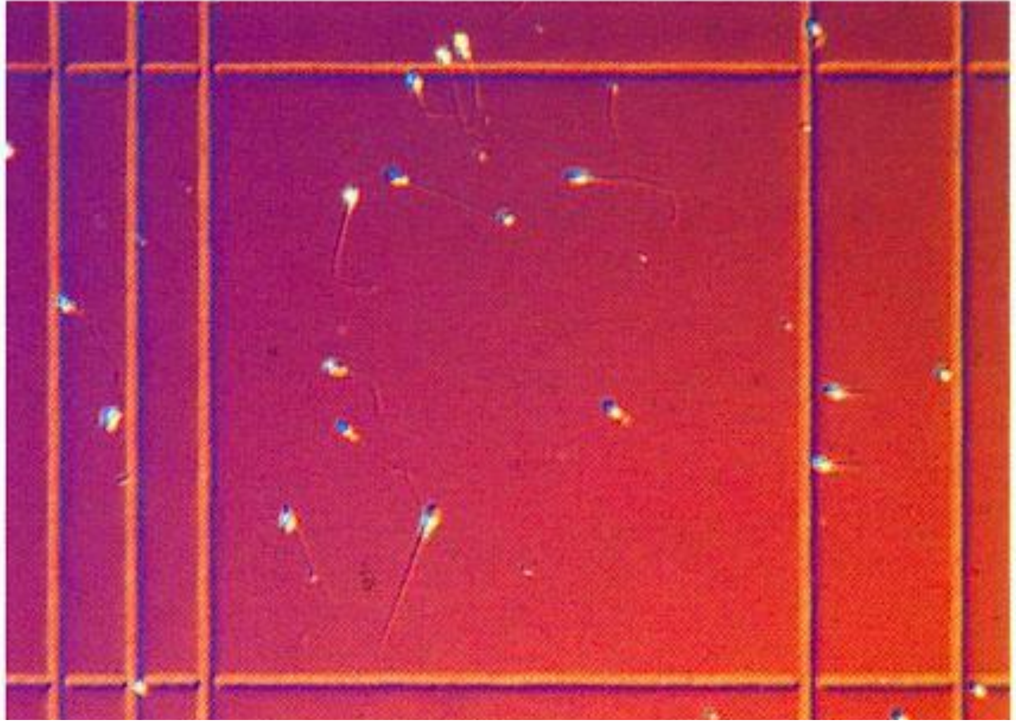
innoviris .brussels we fund your future

VLAIO



Fernandez et al, JARG 2020





WHO laboratory manual for the
examination and processing of human semen

Sixth Edition

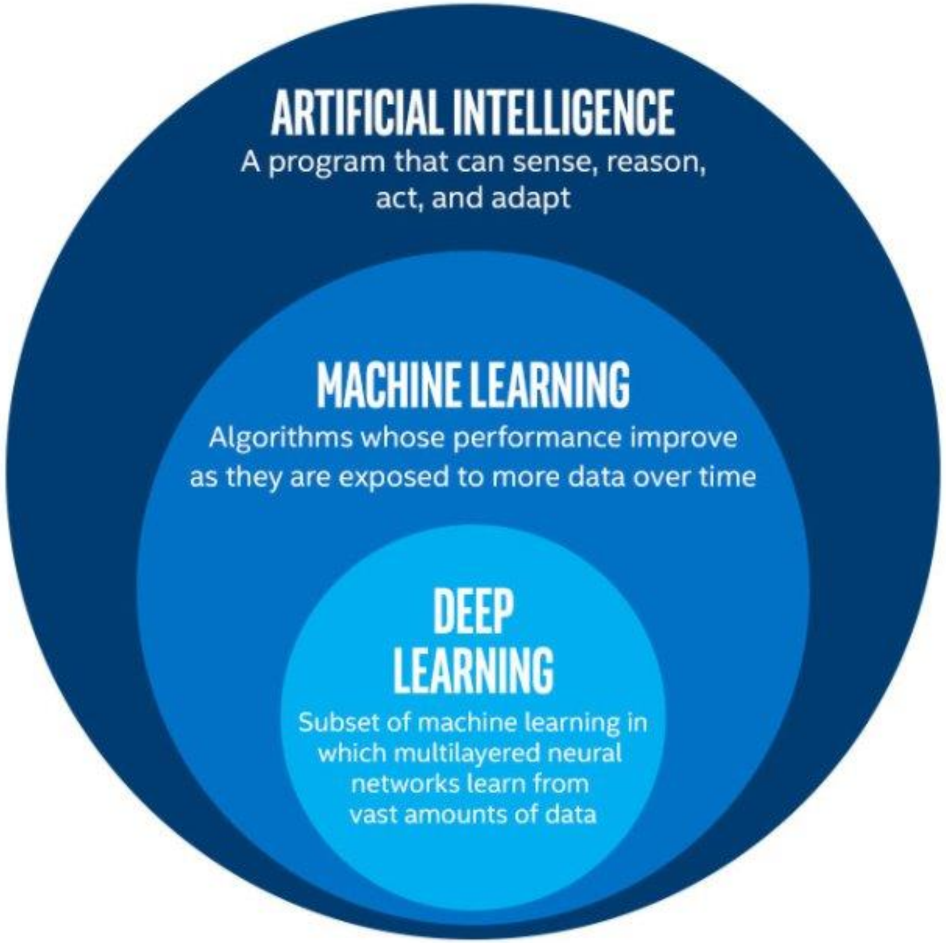
Agenda

The use of AI for sperm

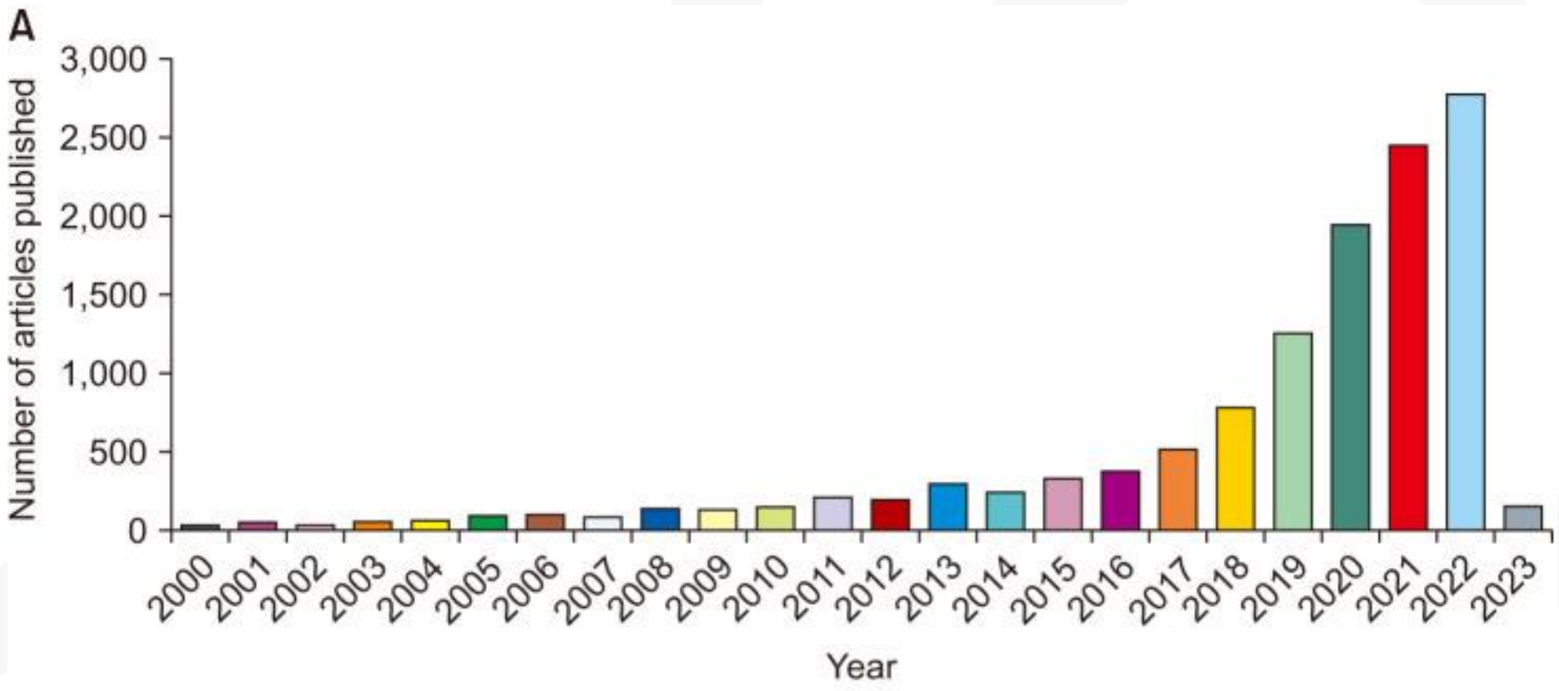
- AI applications in sperm selection
- The advantages and limitations of AI approaches
- Clinical implications and future trends

What is AI?

Artificial intelligence is the simulation of human intelligence processes by machines, especially computer systems



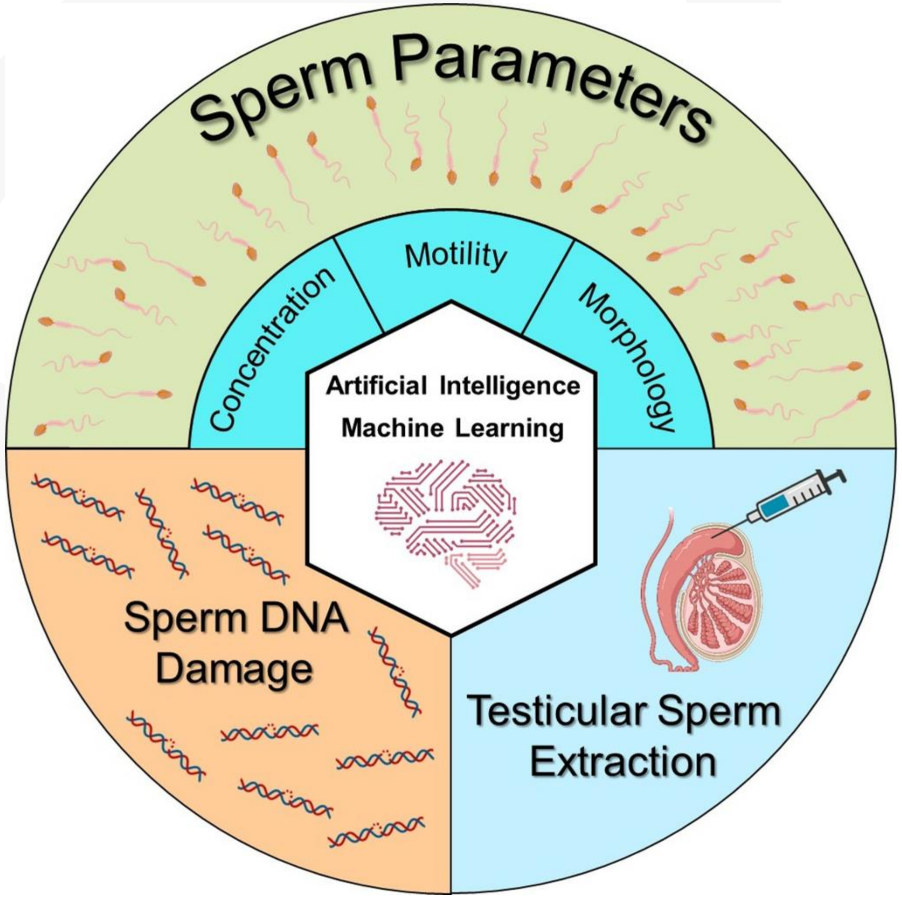
Rising interest of AI in healthcare



Ghayda RA et al, 2024

AI in Sperm Selection

- Computer vision for morphological analysis
  - Pattern recognition, predictive analytics
- Deep learning algorithms for motility prediction
- Automation of sperm grading and sorting



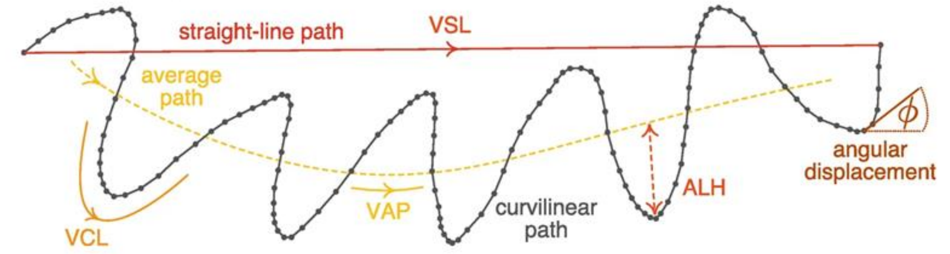
Panner Selvam et al, 2024

Types of Automated sperm analysis

Several approaches of automated sperm analysis on the global market. 3 big groups based on the principle they use to determine semen parameters:

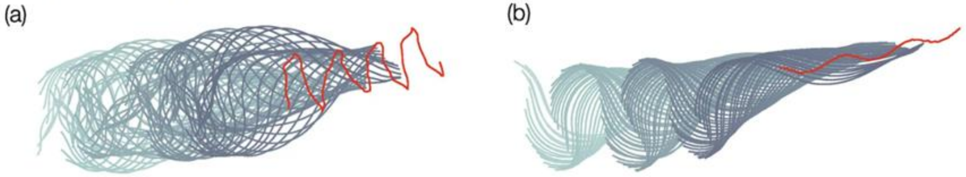
- **Computer-assisted sperm analysis (CASA)**
- **Photometric system-based sperm analysis (SQA Vision)**
- **Artificial intelligence (AI) based tools (e.g. Automated LensHooke X1 PRO Semen Quality Analyzer) – newest and still developing technique on the market. Based on the machine learning algorithms.**

From: Heads and Tails: Requirements for Informative and Robust Computational Measures of Sperm Motility



A sketch highlighting some of the most common CASA measure terminology

From: Heads and Tails: Requirements for Informative and Robust Computational Measures of Sperm Motility



Characteristic flagellar waveform and track for human sperm swimming in (a) low-viscosity media and (b) high-viscosity mucous analogue. In each panel, the red line shows the path traced out by the centroid of the sperm head as it swims

Rational for testing an Automated sperm analysis system

- Accuracy and Consistency
- Reduction of Human Error
- Efficiency and Speed
- Standardization

How to select the best sperm using AI

- Sperm Concentration
- Sperm Motility
- Sperm Morphology
- Sperm DNA integrity
- Testicular sperm

Systematic review

Sperm Concentration

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Systematic Review

Current Updates on Involvement of Artificial Intelligence and Machine Learning in Semen Analysis

Manesh Kumar Panner Selvam [1,*,†], Ajaya Kumar Moharana [1,2,†], Saradha Baskaran [1], Renata Finelli [3], Matthew C. Hudnall [4] and Suresh C. Sikka [1]

Table 1. Artificial intelligence (AI) and machine learning (ML) algorithms used to evaluate sperm concentration or count.

Studies	Dataset/Sample	Algorithm or Model	Performance or Outcomes
Ory et al., 2022 [26]	Semen	Logistic regression, SVM and RF	Good predictive accuracy with AUC = 0.72
Lesani et al., 2020 [23]	Semen	FSNN, SPNN	Prediction accuracy: SPNN = 86%, FSNN = 93%
Tsai et al., 2020 [27]	Semen	Image recognition algorithm	AI algorithm vs. manual analysis: sperm concentration (r = 0.65, $p < 0.001$), motile sperm concentration (r = 0.84, $p < 0.001$)
Girela et al., 2013 [25]	Semen	ANN	Accuracy = 90%, sensitivity = 95.45%, specificity = 50%, PPV = 93.33%, NPV= 60%

ANN—artificial neural network; AUC—area under the curve; FSNN—full-spectrum neural network; NPV—negative predictive value; PPV—positive predictive value; RF—random forest; SPNN—selected peak neural network; SVM—support vector machine.

- Accuracy of 90% - good correlation to manual evaluation
- False identification of spermatozoa (debris)

Systematic review

Sperm Motility

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Systematic Review

Current Updates on Involvement of Artificial Intelligence and Machine Learning in Semen Analysis

Manesh Kumar Panner Selvam [1,*,†], Ajaya Kumar Moharana [1,2,†], Saradha Baskaran [1], Renata Finelli [3], Matthew C. Hudnall [4] and Suresh C. Sikka [1]

Table 2. Artificial intelligence (AI) and machine learning (ML) algorithms used to evaluate sperm motility.

Studies	Dataset/Sample	Algorithm or Model	Performance or Outcomes
Ottl et al., 2022 [32]	VISEM	SVR, MLP, CNN, RNN	Mean absolute error (MAE): SVR = 9.29, MLP = 9.50, CNN = 9.22, RNN = 9.86
Somasundaram and Nirmala 2021 [33]	Semen	THMA	Accuracy = 97.37%, with minimum execution time of 1.12 s.
Tsai et al., 2020 [27]	Semen	Bemaner AI algorithm	AI algorithm vs. manual analysis: r = 0.90, $p < 0.001$
Valiuškaitė et al., 2020 [34]	VISEM	CNN	MAE for predicted sperm motility = 2.92
Goodson et al., 2017 [29]	Semen	SVM	Accuracy = 89.9%
Girela et al., 2013 [25]	Semen	ANN	Accuracy = 82%, sensitivity = 89.29%, specificity = 43.75%, PPV = 89.29%, NPV = 43.75%

ANN—artificial neural network; CNN—convolutional neural network; MLP—multilayer perceptron; RNN—recurrent neural network; SVM—support vector machine; SVR—linear support vector regressor; THMA—tail-to-head movement algorithm.

- Sperm head movement - Good correlation to manual evaluation
- Novel tail-to-head movement – Accuracy of 97%

Systematic review

Sperm Morphology

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Systematic Review

Current Updates on Involvement of Artificial Intelligence and Machine Learning in Semen Analysis

Manesh Kumar Panner Selvam [1,*,†], Ajaya Kumar Moharana [1,2,†], Saradha Baskaran [1], Renata Finelli [3], Matthew C. Hudnall [4] and Suresh C. Sikka [1]

Table 3. Artificial intelligence (AI) and machine learning (ML) algorithms used to evaluate sperm morphology.

Studies	Dataset/Sample	Algorithm or Model	Performance or Outcomes
Sato et al., 2022 [40]	JSD	DL	Abnormal sperm: sensitivity = 0.881 and PPV = 0.853 Normal sperm: sensitivity = 0.794 and PPV = 0.689
Abbasi et al., 2021 [41]	MHSMA	DTL DMTL	Detection accuracy: head = 84.0%, acrosome = 80.66%, and vacuole = 94.0%
Marín and Chang 2021 [35]	SCIAN-SpermSegGS	DL, U-Net, and Mask-RCNN	Dice coefficient using U-net with transfer learning: head = 0.96, acrosome = 0.94, and nucleus = 0.95
Nygate et al., 2020 [42]	Semen	DL, HoloStain	Virtual (holostain) vs. chemical staining: structural similarity (SSIM) = 0.85 ± 0.03
Valiuškaitė et al., 2020 [34]	VISEM	CNN	Accuracy of sperm head detection = 91.77%
Dubey et al., 2019 [20]	Semen	SVM	Accuracy = 89.93%, sensitivity = 91.18%, and specificity = 88.61%
Javadi and Mirroshandel 2019 [39]	MHSMA	DL	Detection accuracy: acrosome = 76.67%, head = 77.00%, vacuole = 91.33%
Movahed et al., 2019 [43]	SCIAN	CNN and SVM	Dice coefficient: head = 0.90, axial filament = 0.77, acrosome = 0.77, nucleus = 0.78, tail = 0.75, and mid-piece = 0.64
Riordon et al., 2019 [44]	HuSHeM and SCIAN	Deep-CNN, VGG16	Increased true positive rate: HuSHeM dataset = 94.1%, SCIAN dataset = 62%
Mirsky et al., 2017 [45]	Semen	SVM	Good accuracy with AUC = 89.59%
Shaker et al., 2017 [46]	SCIAN and HuSHeM	Dictionary learning	Detection accuracy: HuSeM dataset = 92%, SCIAN dataset = 62%
Shaker et al., 2016 [37]	Semen	Tail point algorithm	Dice coefficient accuracy: heads = 92%, acrosome = 84%, nucleus = 87%, and tail = 96%

AUC—area under curve; CNN—convolutional neural network; DL—deep learning; DTL—deep transfer learning; DMTL—deep multi-task transfer learning; HuSHeM—Human Sperm Head Morphology; JSD—Jikei sperm data set; MHSMA—Modified Human Sperm Head Morphology analysis; R-CNN—region-based convolutional neural network; SVM—support vector machine;.

- Form, shape, size
- Stained images - Con
- Real time analysis - Pro

Systematic review

Sperm DNA integrity

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Systematic Review

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Table 4. Artificial intelligence (AI) algorithms developed to measure or predict sperm DNA integrity or damage.

Studies	Dataset/Sample	Algorithm or Model	Performance or Outcomes
Kuroda et al., 2023 [50]	Semen	CNN	AI algorithm vs. manual scoring (r = 0.97, *p* < 0.001)
Noy et al., 2023 [51]	Semen	MobileNet CNN	Prediction accuracy = 90%, sensitivity = 0.93, specificity = 0.9
McCallum et al., 2019 [49]	Semen	Deep CNN	Sperm cell image vs. DNA quality (bivariate correlation ~0.43)
Wang et al., 2019 [52]	Semen	Logistic regression	Test accuracy = 82.7%

CNN—Convolutional Neural Network.

- Sperm chromatin structure assay (SCSA) – fixation and staining
- Real time evaluation - Good correlation to manual evaluation – Accuracy of 90%

Systematic review
Testicular sperm

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Systematic Review

Current Updates on Involvement of Artificial Intelligence and Machine Learning in Semen Analysis

Manesh Kumar Panner Selvam [1,*,†], Ajaya Kumar Moharana [1,2,†], Saradha Baskaran [1], Renata Finelli [3], Matthew C. Hudnall [4] and Suresh C. Sikka [1]

Table 5. Artificial intelligence (AI) algorithms developed to detect sperm and predict success of testicular sperm extraction.

Studies	Dataset/Sample	Algorithm or Model	Performance or Outcomes
Bachelot et al., 2023 [53]	Semen	DNN	RF model: detected AUC = 0.90, sensitivity = 100%, specificity = 69.2%
Lee et al., 2022 [58]	Semen	CNN	For dissociated micro-TESE samples doped with an abundant quantity of sperm obtained: PPV = 84.0%, sensitivity = 72.7%, F1-score = 77.9% For dissociated micro-TESE samples doped with rare sperm obtained: PPV = 84.4%, sensitivity = 86.1%, F1-score = 85.2%
Wu et al., 2021 [57]	Semen	DNN	Obtained mean average precision (mAP) = 0.741, average recall (AR) = 0.376
Zeadna et al., 2020 [54]	Semen	GBTs	Detected AUC = 0.8, sensitivity = 91%, specificity = 25%
Ramasamy et al., 2013 [56]	Semen	ANN	Achieved ROC = 0.641, accuracy = 59.4%
Samli and Dogan 2004 [55]	Semen	ANN	Prediction accuracy = 80.80%

ANN—artificial neural network; AR—average recall; AUC—area under the curve; CNN—convolutional neural network; DNN—deep neural network; GBTs—gradient-boosted trees; mAP—mean average precision; PPV—positive predictive value; RF—random forest; ROC—receiver operating characteristic.

- Prediction models for the presence of sperm
- Detection and identification of sperm

Other applications using AI for sperm

Mobile AI Applications for Sperm Analysis

Do it yourself

- **Rapid and Cost-Effective**
  - Modern kits are accurate and user-friendly.
  - Do not assess all semen parameters.
    - sperm **concentration** and **motility.**
    - Range from red (not ok) – orange – green (ok)
- **Privacy and Convenience**
  - Lowers the first step for men to go to a fertility clinic.

Review Article
Male reproductive health and infertility
pISSN: 2287-4208 / eISSN: 2287-4690
World J Mens Health 2021 Oct 39(4): 615-625
https://doi.org/10.5534/wjmh.200130
The World Journal of MEN's HEALTH
Check for updates

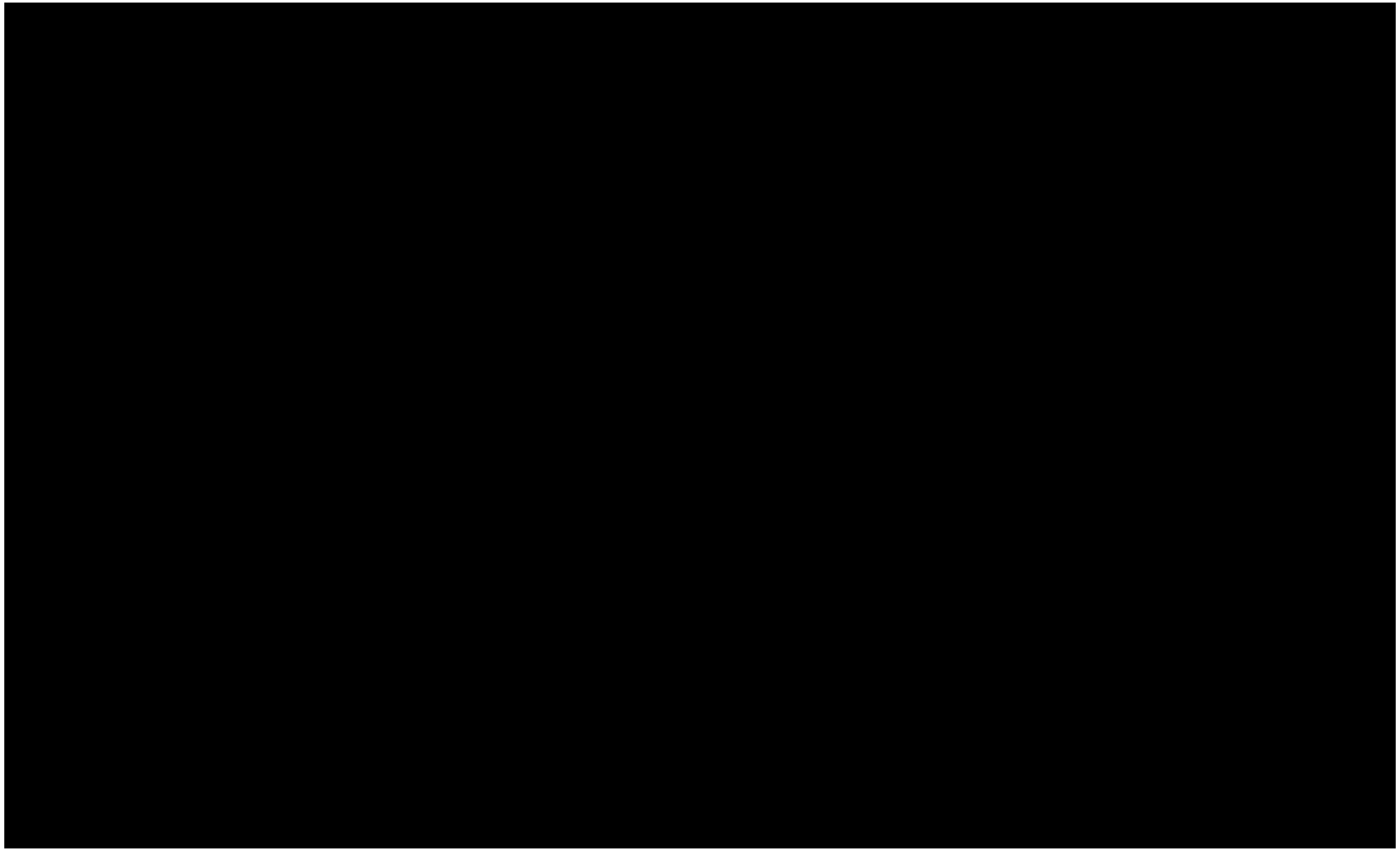
Clinical Update on Home Testing for Male Fertility

Daniel Gonzalez, Manish Narasimman, Jordan C. Best, Jesse Ory, Ranjith Ramasamy
Department of Urology, Miller School of Medicine, University of Miami, Miami, FL, USA

Fig. 4. Men's Loupe (Tenga Health Care) device and smartphone-based SEEM kit. (A) Men's Loupe 0.8 mm diameter ball lens microscope attached to smartphone. (B) Technique for loading semen sample into plastic jacket of ball lens microscope. (C) Magnifying lens semen analysis device with QR code sheet to download the application for operating. (D) Instructions of kit for use. (E) Screenshot of sample test results with concentration and motility.

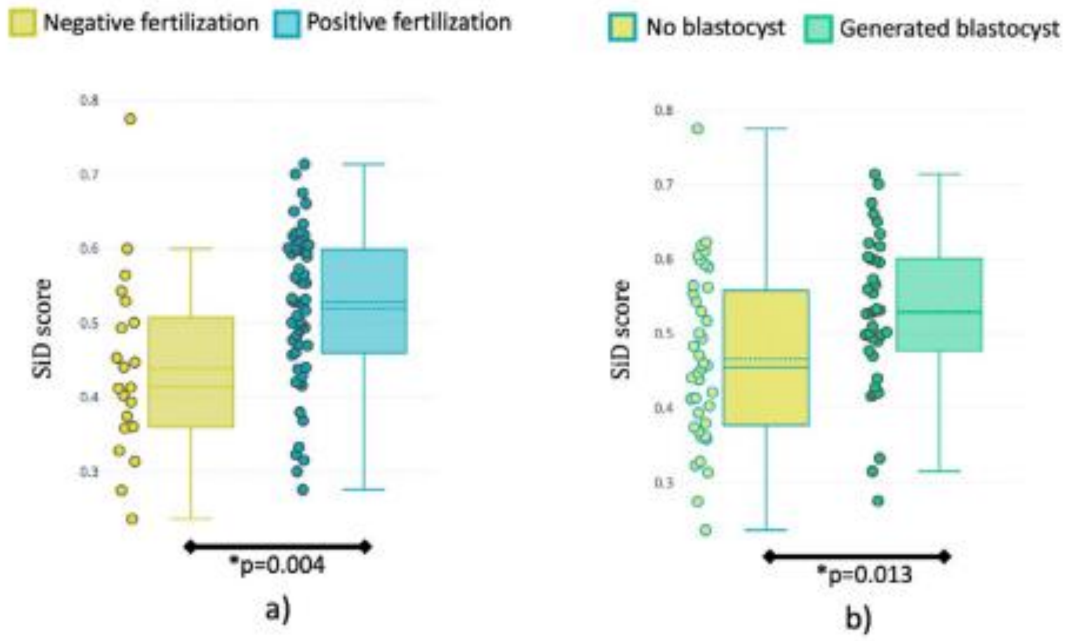
Advanced selection techniques

Sperm identification device SiD



Sperm selection assistant SiD

Retrospective analysis



RBMO

ELSEVIER

ARTICLE

Computer software (SiD) assisted real-time single sperm selection associated with fertilization and blastocyst formation

BIOGRAPHY

Dr Chavez-Badiola graduated with honours from medical school in 1999. He is Medical Director and Founder of New Hope Fertility Mexico (2009), and Founder of IVF 2.0 LTD. His research interests include the meiotic spindle, the fertilization process and the applications of artificial intelligence in reproductive medicine.

Gerardo Mendizabal-Ruiz[1,2], Alejandro Chavez-Badiola[1,3,4,*], Isaac Aguilar Figueroa[2], Vladimir Martinez Nuño[2], Adolfo Flores-Saiffe Farias[1], Roberto Valencia-Murilloa[1], Andrew Drakeley[1,5], Juan Paulo Garcia-Sandoval[6], Jacques Cohen[1,7,8]

- Higher SiD scores gives **higher successful fertilization** (P = 0.004) and **better blastocyst formation** (P = 0.013)
- Real-time **assisting of the ICSI operator**

Sperm selection assistant SiD

Prospective sibling oocyte study

medical sciences
MDPI

Article

Automated Single-Sperm Selection Software (SiD) during ICSI: A Prospective Sibling Oocyte Evaluation

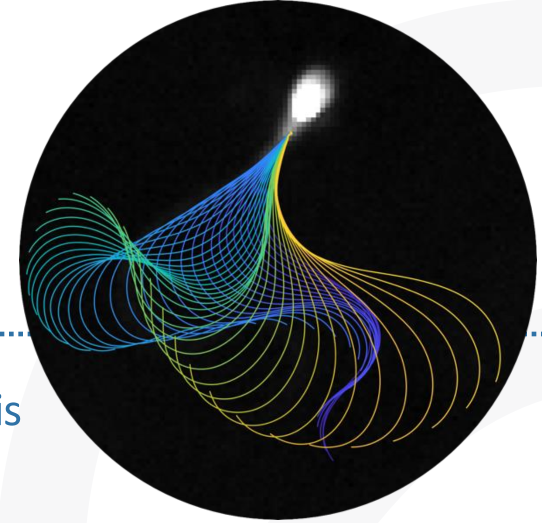
Debbie Montjean [1,*], Marie-Hélène Godin Pagé [1], Carmen Pacios [1], Annabelle Calvé [1], Ghenima Hamiche [1], Moncef Benkhalifa [1,2] and Pierre Miron [1,2]

Table 1. Laboratory outcomes in the ICSI-SiD group (n = 326) compared to the ICSI group (n = 320).
* Includes day 5 and day 6 embryos, ns: non-significant. OR: odds ratio, CI; confidence interval.

Outcome (%)	ICSI-SiD	ICSI	OR	95% CI	*p*-Value
Fertilization rate	83.1	82.4	1.1	0.7–1.6	ns
Cleavage rate	97.6	97.2	1.2	0.4–3.7	ns
Day 2 embryo development rate	70.6	74.6	0.8	0.5–1.2	ns
Top-quality development rate on day 2	48.6	52.8	0.9	0.6–1.2	ns
Day 3 embryo development rate	72.9	70.6	1.1	0.8–1.7	ns
Top-quality embryo development rate on day 3	51.4	51.6	1.0	0.7–1.4	ns
Blastocyst development rate on day 5	49.0	44.8	1.2	0.8–1.7	ns
Good-quality blastocyst development rate on day 5	45.1	41.5	1.2	0.8–1.7	ns
Top-quality blastocyst development rate on day 5	25.9	22.2	1.2	0.8–1.9	ns
Blastocyst development rate *	70.2	62.5	1.4	1.0–2.0	ns
Good-quality blastocyst development rate *	57.3	53.6	1.1	0.8–1.7	ns
Top-quality blastocyst development rate *	29.0	24.2	1.3	0.9–1.9	ns

- **Comparable biological outcomes**
- **Takes out differences between laboratory staff experience**

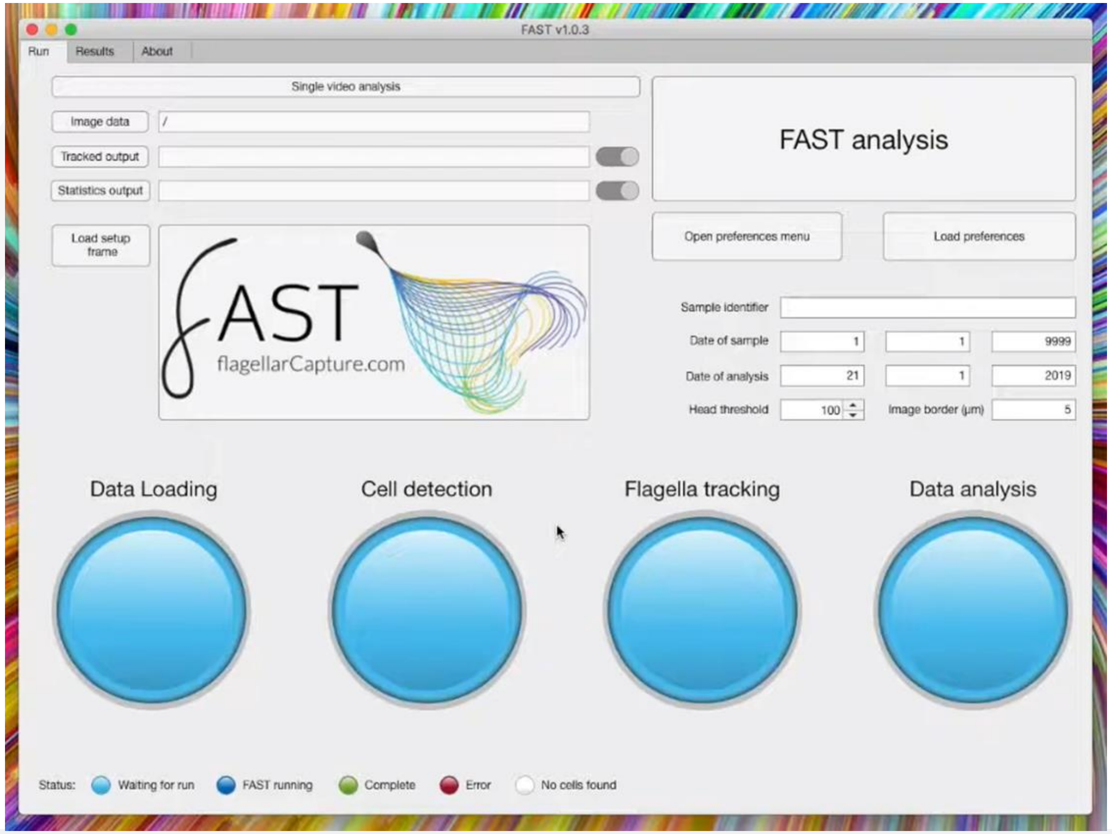
Sperm tail beat



Sperm flagellar movement, FAST (Flagellar Analysis and Sperm Tracking).

- Combining imaging, mathematics, fluid dynamics and computer science
- Better fertility diagnostics and improving treatment
- Vital to understand how the tail of sperm cells move and consume energy

Free download: https://www.flagellarcapture.com

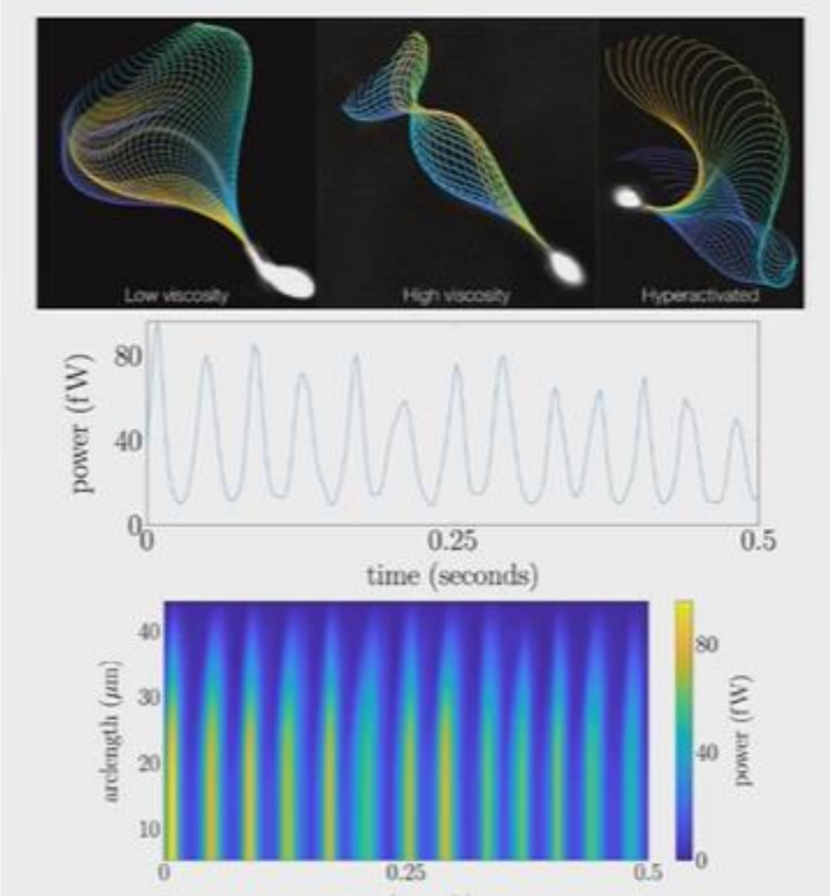


Sperm tail beat

Image analysis (FAST) gives flagellar waveforms

- Hyperactivation can be analysed

Calculates the **metabolic health of the sperm**



Advanced selection techniques

Automatic SpermSearch

JOURNAL ARTICLE

O-136 Artificial intelligence to assist in surgical sperm detection and isolation FREE

D Goss, S Vasilescu, P Vasilescu, G Sacks, D Gardner, M Warkiani

Human Reproduction, Volume 38, Issue Supplement_1, June 2023, dead093.163,
https://doi.org/10.1093/humrep/dead093.163
Published: 29 June 2023

Study question

Can an artificial intelligence (AI) improve the speed and accuracy of identifying sperm in complex testicular tissue samples?

Automatic SpermSearch

This AI tool can find sperm in infertile men 1,000 times faster than a human

Metric	AI Model	Trained Embryologist	P-Value
Time per Field of View	$0.019 \pm 1.4 \times 10^{-4}$ s	22.87 ± 0.98 s	$P < 0.0001$
Accuracy (%)	89.88 ± 1.56	83.22 ± 2.02	$P = 0.017$
Precision (%)	91.27 ± 1.27	100 (considered baseline)	NA
Sperm Identified (out of 688)	611	560	NA

Summary answer: Trained AI can identify sperm in real-time instantly with higher accuracy, not only reducing strain on embryologists but increasing sample coverage in a shorter time.

Automatic SpermSearch

Proof of concept

RBMO

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ARTICLE

CrossMark

Evaluation of an artificial intelligence-facilitated sperm detection tool in azoospermic samples for use in ICSI

BIOGRAPHY

Dale Goss is a PhD student at the University of Technology Sydney and a graduate of Stellenbosch University and Monash University. He is a clinical embryologist at IVFAustralia and as a scientific advisor for NeoGenix Biosciences. His research focuses on human embryology, male infertility, and technology in assisted reproduction.

Dale M. Goss[1,2,3,†], Steven A. Vasilescu[1,2,†], Phillip A. Vasilescu[2], Simon Cooke[3], Shannon HK. Kim[3,4], Gavin P. Sacks[1,3,4], David K. Gardner[2,5], Majid E. Warkiani[1,2,6,*]

Automatic SpermSearch

Study question

Can artificial intelligence (AI) improve sperm searches

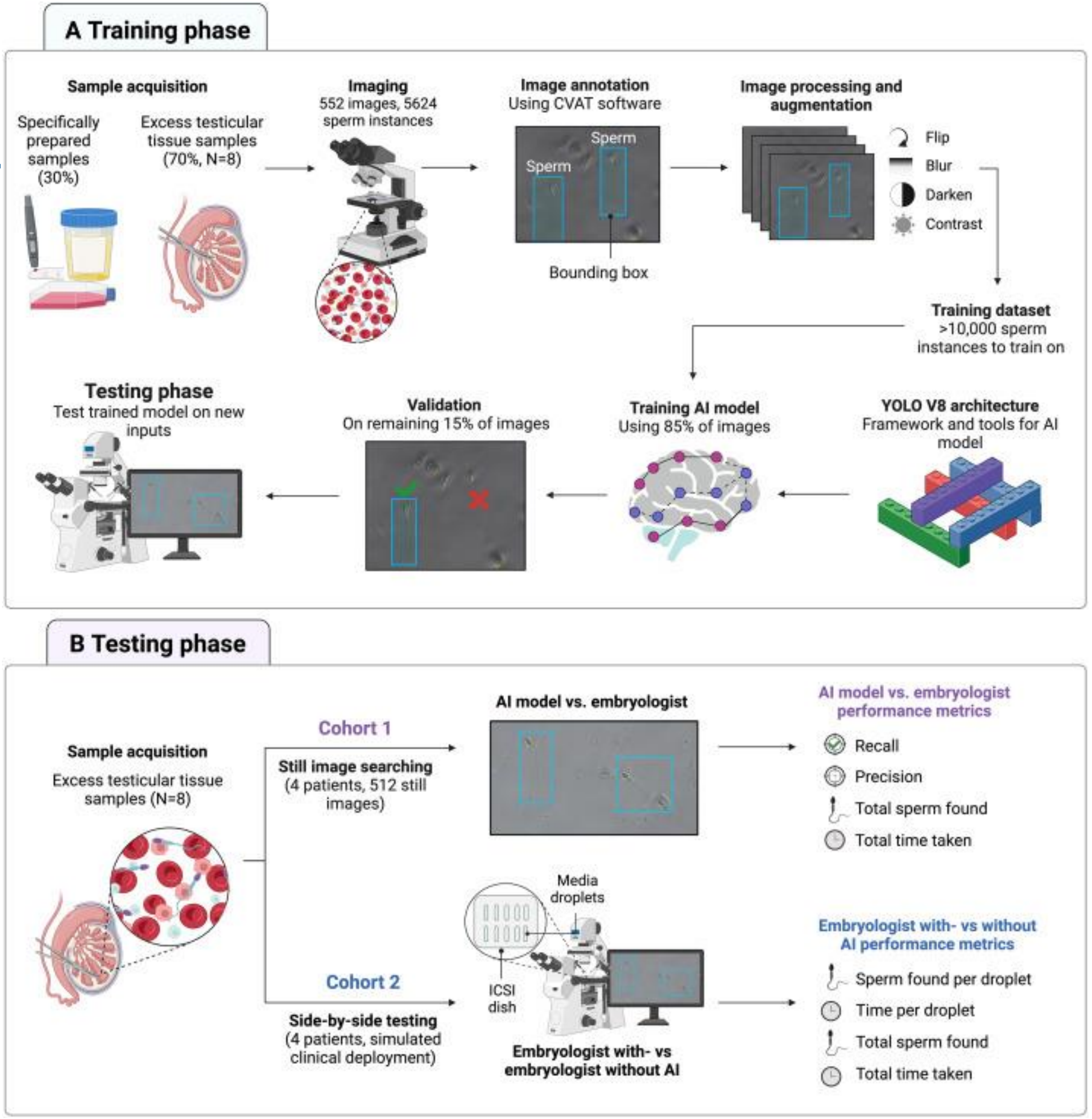
in azoospermic samples?

- compare AI with embryologists on static images

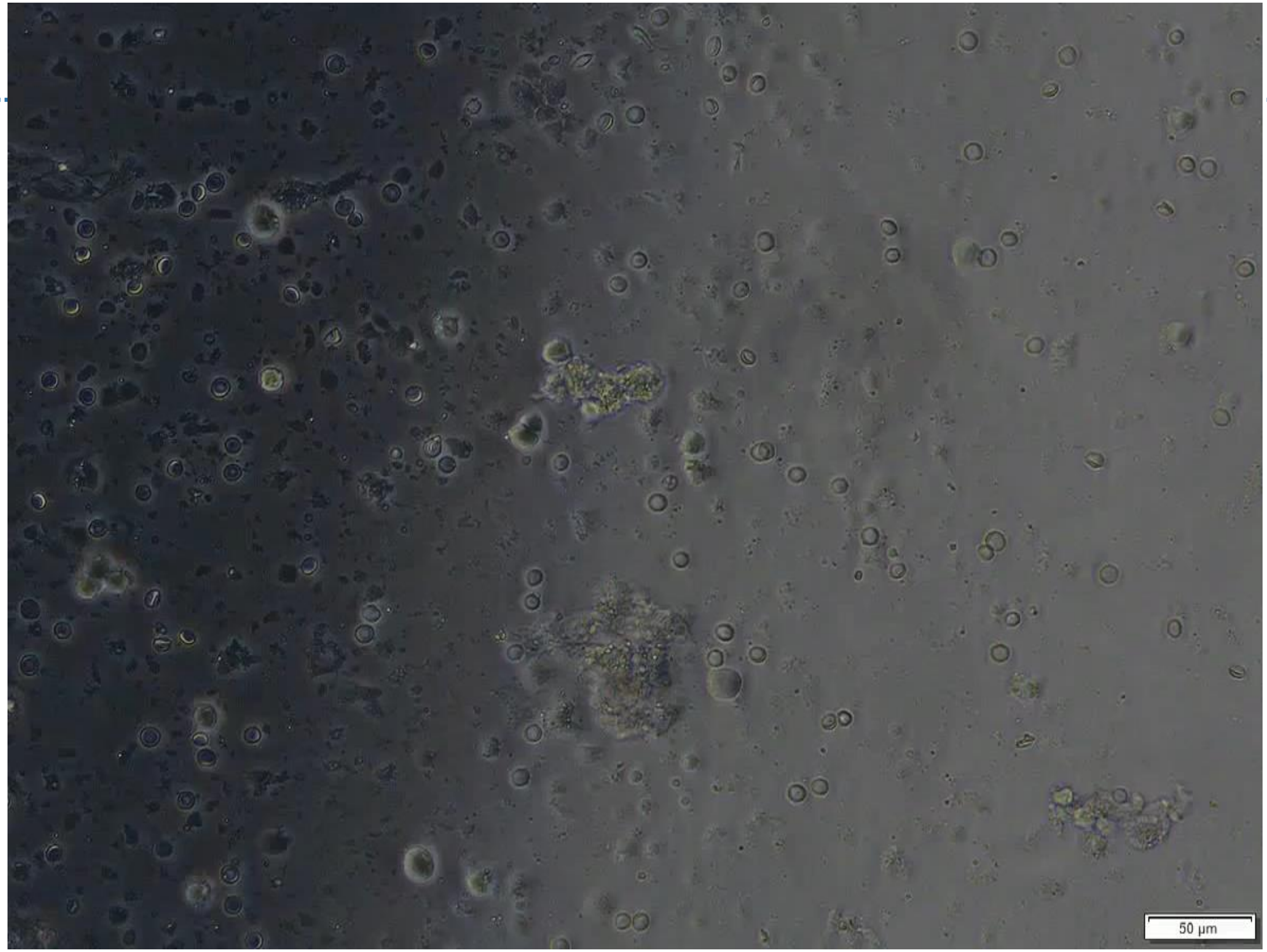
  (time, recall and number of spermatozoa)

- sperm search with AI integrated into an ICSI microscope

  embryologist using with or without AI



Automatic SpermSearch



Evaluation of an artificial intelligence-facilitated sperm detection tool in azoospermic samples for use in ICSI

Author: Dale M. Goss,Steven A. Vasilescu,Phillip A. Vasilescu,Simon Cooke,Shannon HK. Kim,Gavin P. Sacks,David K. Gardner,Majid E. Warkiani
Publication: Reproductive BioMedicine Online
Publisher: Elsevier
Date: July 2024

Automatic SpermSearch

Results

RBMO

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ARTICLE

Evaluation of an artificial intelligence-facilitated sperm detection tool in azoospermic samples for use in ICSI

1/ Images

- Reduce the time
- Better recall

2/ Side by side

- Reducing the time using the AI
- No difference in number of sperm found

TABLE 1 COMPARISON OF AI AND EMBRYOLOGIST SPERM SEARCH PERFORMANCE METRICS

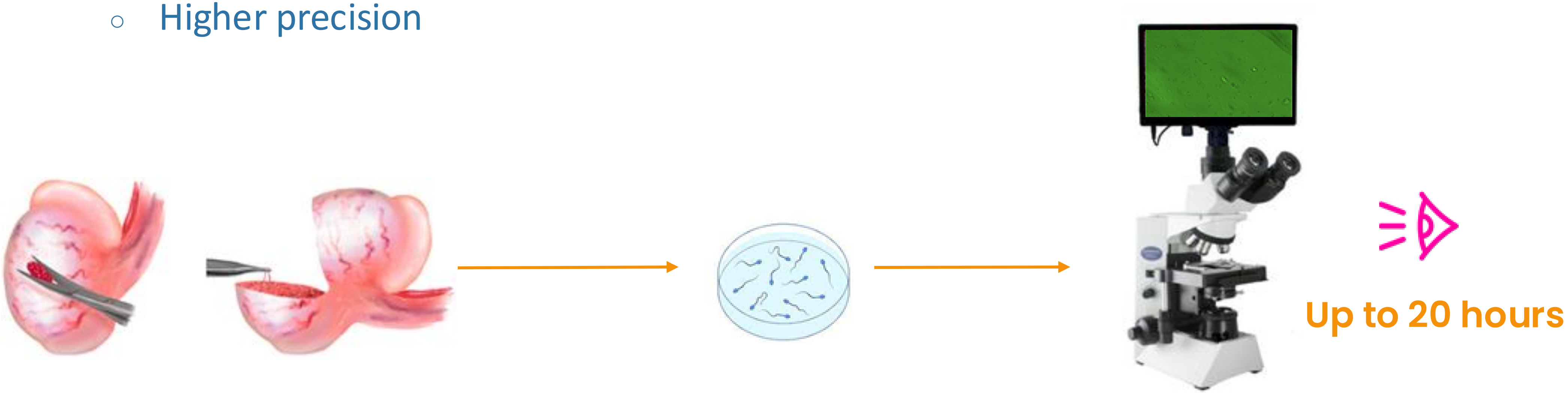
Parameter	Embryologist	AI	P-value
Cohort 1 (still images)			
Time per FOV (s)	36.10 ± 1.18	$0.02 \pm 0.3 \times 10^{-5}$	<0.0001[a]
Recall (%)	86.52 ± 1.34	91.95 ± 0.81	0.0006[a]
Precision (%)	98.18 ± 0.38	89.58 ± 0.87	<0.0001[a]
No. of sperm found (from 2660)	1937	1997	N/A
Cohort 2 (side-by-side deployment)			
Time taken per drop (s)	168.7 ± 7.84	98.9 ± 3.19	<0.0001[b]
Total time taken (s)	6749.71	3955.89	N/A
Sperm found per drop	31.85 ± 3.09	34.9 ± 3.43	0.3843[b]
Total no. of sperm found	1274	1396	N/A

Data are presented as the mean ± SEM or total. Between-group differences were tested using a Mann–Whitney *U*-test[a], and variance effects between groups were assessed using two-way analysis of variance.[b]

AI, artificial intelligence; FOV, field of view; N/A, not applicable.

Brussels IVF use case

- Problem
  - Time consuming (manual) sperm search
  - Special skill required
  - Fatigue – losing focus
- Solution
  - Fully automated solution
  - Higher precision



T’Easy

Making TESE easy…

- Fully automated tool for sperm search
  - Lower the risk of false negatives
  - To help with objective decision making
    - When to stop, very important question!!
  - Decision impacts genetically own children

ARAB JOURNAL OF UROLOGY
2021, VOL. 19, NO. 3, 247–254
https://doi.org/10.1080/2090598X.2021.1932303
Taylor & Francis

REVIEW ARTICLE

OPEN ACCESS Check for updates

Fresh vs frozen testicular sperm for assisted reproductive technology in patients with non-obstructive azoospermia: A systematic review

Medhat Amer[a,b] and Emad Fakhry[a]

Table 3. A comparison between the different policies while dealing with a NOA case.

Policy	Indications	Advantages	Disadvantages	Special counselling
A. TESE on the day of oocyte retrieval OPU (with sperm cryopreservation of the remaining samples)	1. Expected positive cases: previous positive TESE, cryptozoospermic ejaculate or virtual azoospermia (pervious presence of spermatozoa in the ejaculate), favourable previous histopathological diagnosis such as hypospermatogenesis, maturation arrest at spermatid, mixed patterns with normal spermatogenesis. 2. Expected difficulty with limited possibility to repeat TESE in the future: severe gonadal failure, e.g. previous genetic or histopathological diagnosis of Klinefelter syndrome or small testes where repeating biopsy seems improbable. 3. Expected low sperm number with difficulty in freezing (redo-patients and patients with documented deletions of the AZFb region) if the couple accept the high possibility of sperm retrieval failure [3].	1. The use of fresh testicular sperm sample with no fear of losing sperm motility after freezing. 2. Avoidance of repeating the TESE procedure if no motile spermatozoa were found in the frozen-thawed sample on the day of ICSI in a small testicular size male. 3. The possibility of use of very limited number of sperms with poor or no motility that are not suitable for freezing.	1. Pointless ovarian stimulation, risk of hyperstimulation, financial burden if no spermatozoa were retrieved. 2. The TESE procedure must be scheduled on the day of OPU, which is not practical in a busy IVF laboratory or for the surgeon. 3. Risk of *in vitro* post maturity of oocytes associated with low fertilisation rate and poor embryo quality after ICSI in difficult prolonged sperm search [45].	Risk of finding no sperms is great, so the couple should accept this fact and according to their preference, oocyte retrieval can be cancelled or the oocytes are collected and vitrified for future hope: Possibility of finding sperm in the future in a redo TESE, spontaneously in extended ejaculated sperm pellet analysis, hormonal treatment or future advances in NOA management (spermatid injection, *in vitro* maturation). TESE before oocyte retrieval for expected difficult cases should preferably be scheduled 4–8 h before ovum pick-up to allow more time to extract and collect sufficient normal motile testicular sperm for injection of all available oocytes [45].

Special counselling
Risk of finding no sperms is great, so the couple should accept this fact and

3. Risk of *in vitro* post maturity of oocytes associated with low fertilisation rate and poor embryo quality after ICSI in difficult prolonged sperm search [45].

Funding

Belcoo – transregional R&D project

Collaboration

Brussels IVF

ROBOVISION

EVIDENT
OLYMPUS

Human versus Machine

Proof of concept

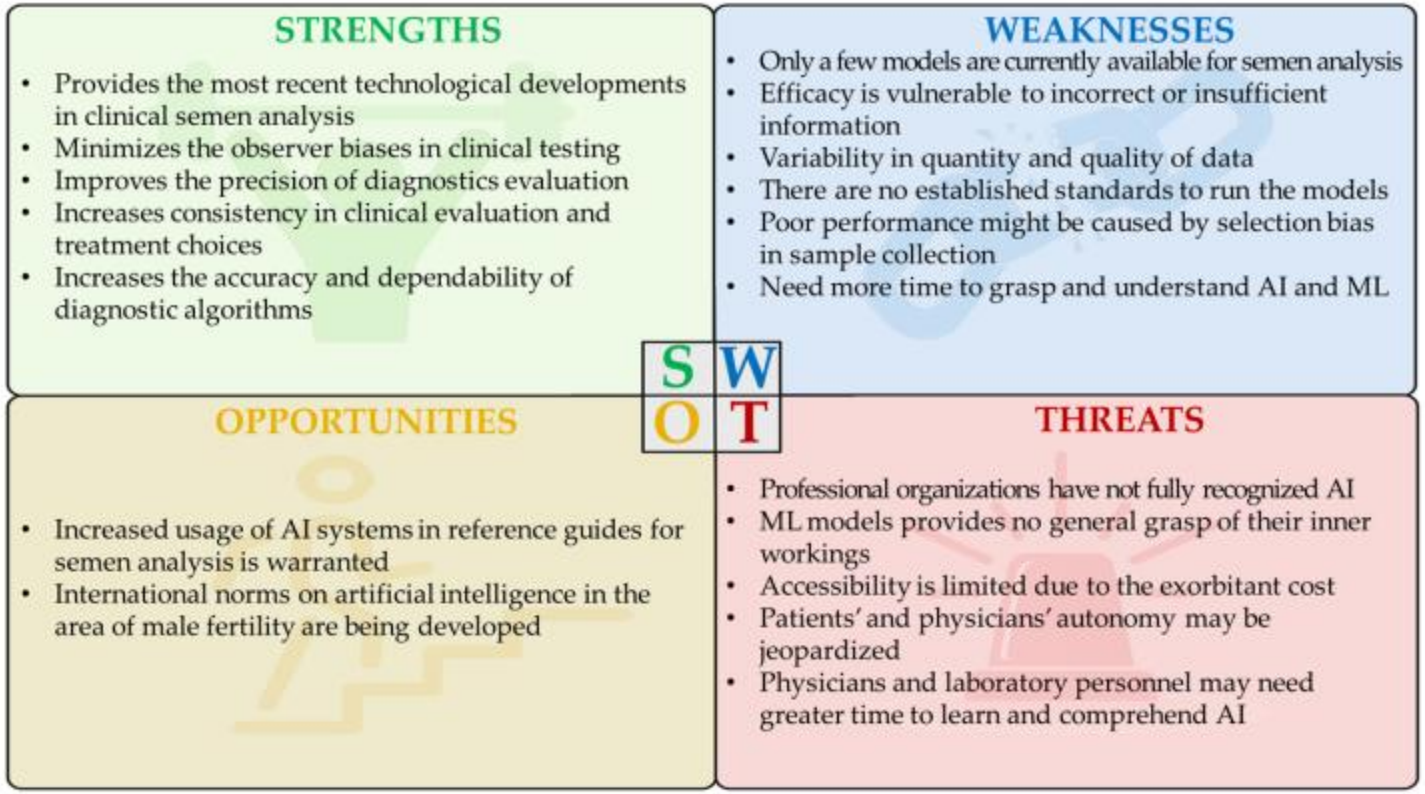
	T'Easy	Confirmed	Human	False positives	Missed detection	Precision	Recall
Sample 1	309	304	340	5	36	98,4%	89,4%
Sample 2	227	223	240	4	17	98,2%	92,9%

Advantages of AI in Sperm Selection

- More objective and consistent
- Faster and more efficient analysis
- Make better-informed decisions for patients

Limitations and Challenges

- High setup costs
- Need for robust training datasets
- Watch out for BIAS!
- Ethical concerns
- Patient data privacy



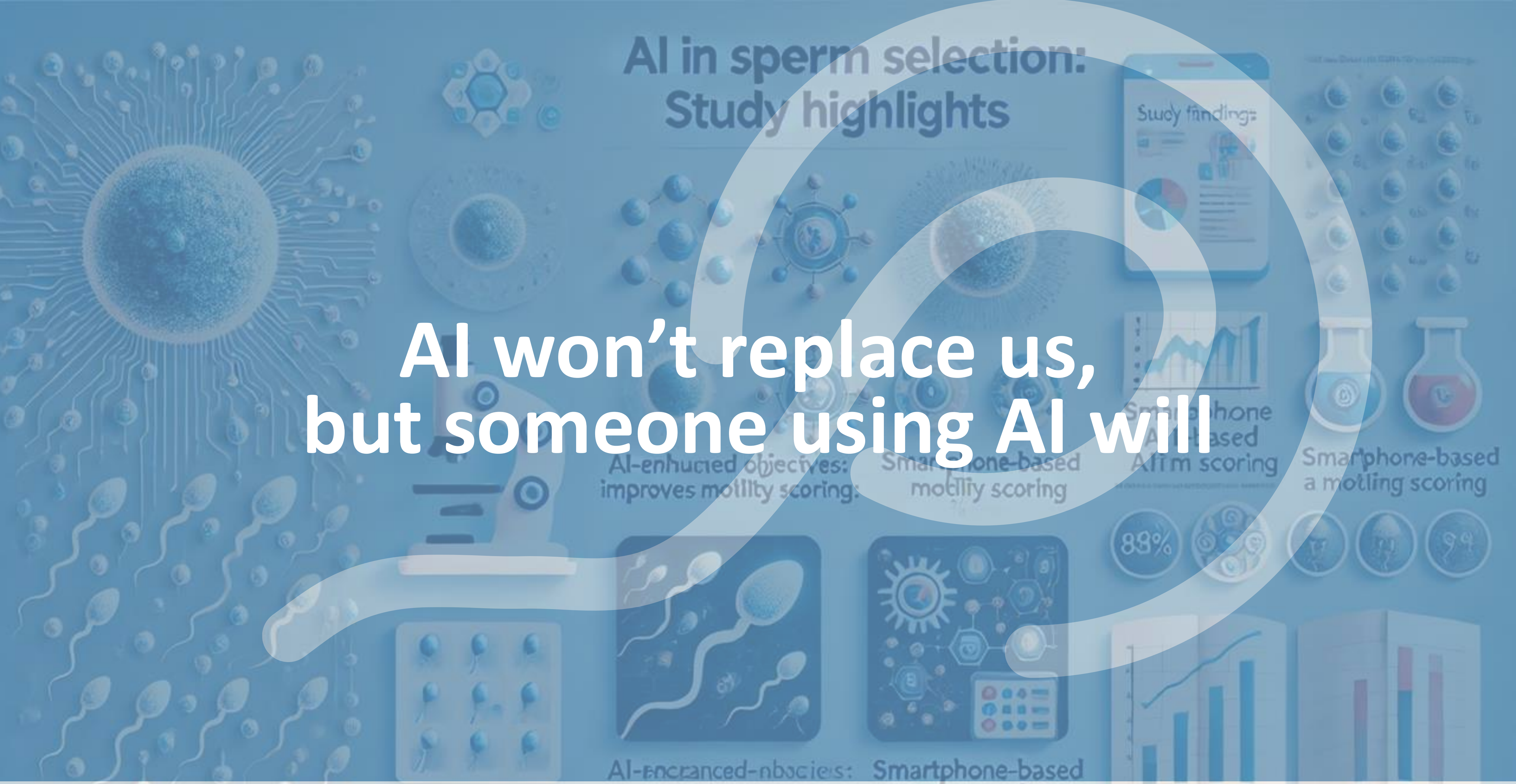
Panner Selvam et al, 2024
Strengths, weaknesses, opportunities, and threats (SWOT) analysis of AI and ML in andrology

Clinical Implications

- Potential to increase fertilization and pregnancy rates
- Can support subjective human assessments
- Role in personalized medicine

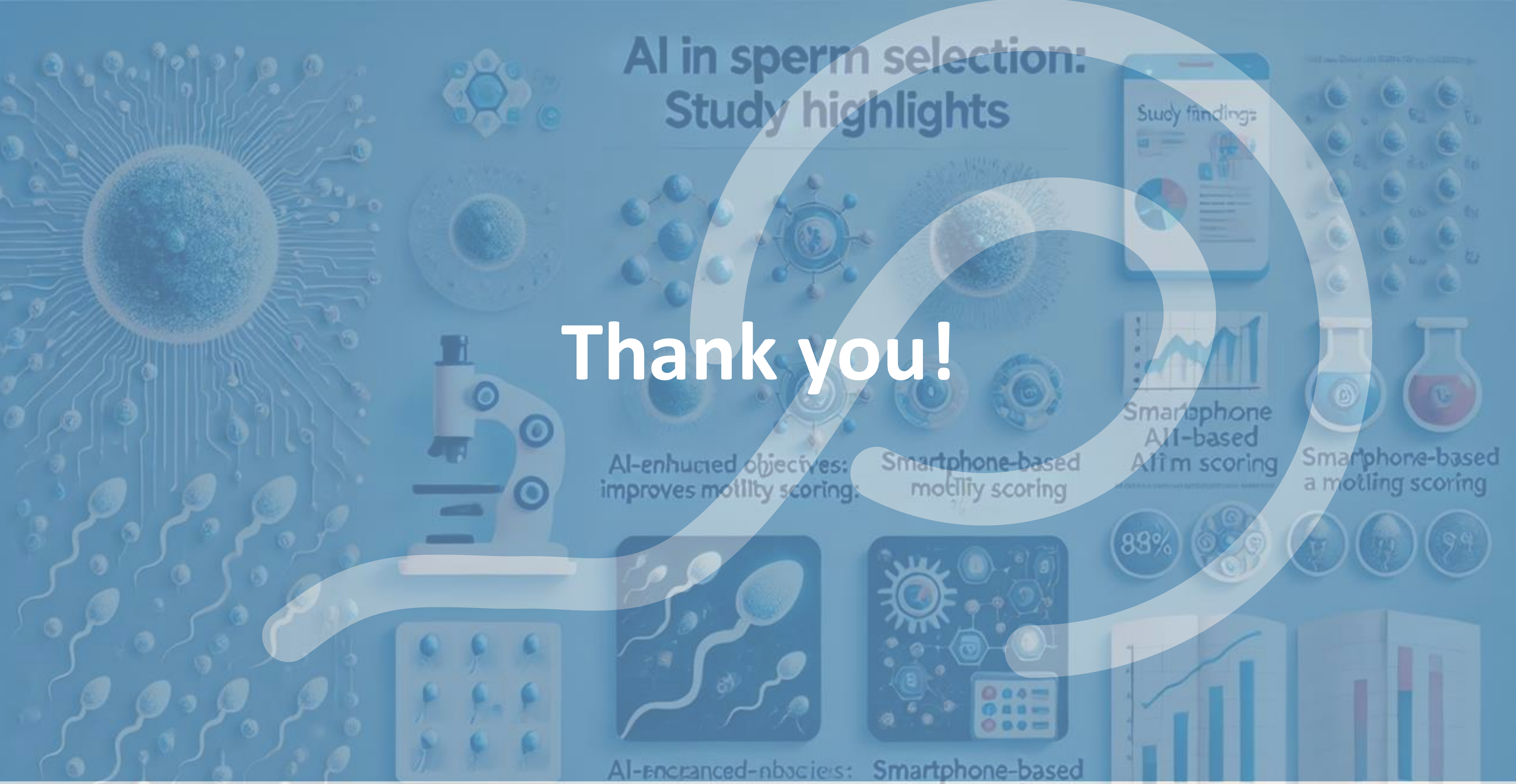
Future Directions

- Development of real-time AI-assisted sperm selection systems
- Integration with other ART technologies
- Ongoing research and collaboration between AI developers and fertility clinics



AI won't replace us, but someone using AI will

Thank you!


AI in sperm selection:
Study highlights
Study findings
Smartphone-based
motility scoring
88.5% accuracy