ICRA2024
May 13-17, Yokohama, Japan

香港城市大學
City University of Hong Kong

Automated Non-invasive Analysis of Motile Sperms Using Cross-scale Guidance Network

Wei Dai, Zixuan Wu, Jiaqi Wang, Rui Liu, Min Wang, Tianyi Wu, Junxian Zhou, Zhuoran Zhang, and Jun Liu

(Anthony) Wei DAI

PhD Student

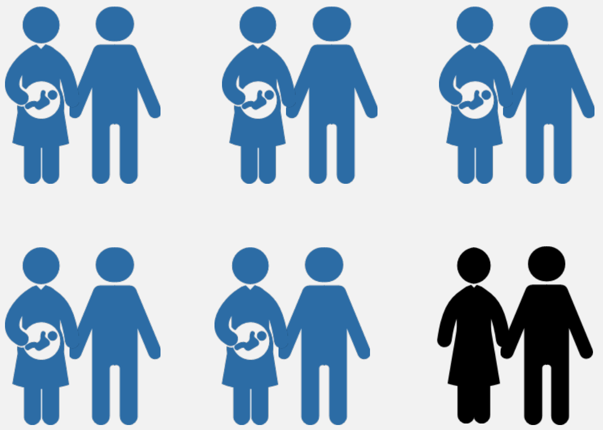
Centre for Robotics and Automation & Department of Mechanical Engineering, City University of Hong Kong

May 16, 2024

Multiscale Automation and Robotics Laboratory

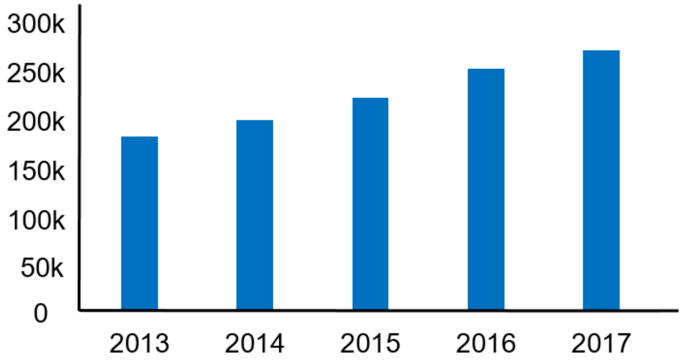
In vitro fertilization (IVF)

~15% couples are infertile



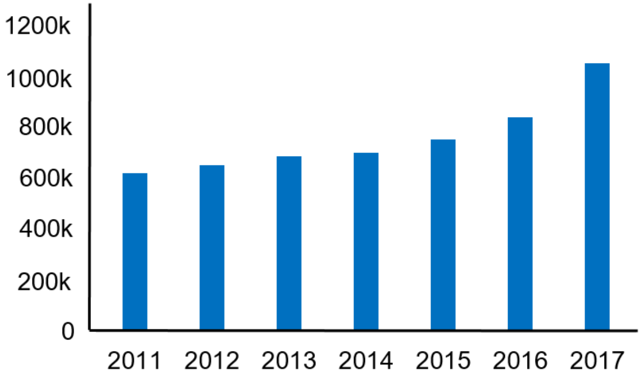
- ~113 million infertile population
  Lancet, 2016
- >8 million IVF children born
  ICMART, 2018
- $25 billion market – as 2019
- $41 billion market – by 2026
  www.economist.com/business/2019/08/08

US treatment cycles



CDC National Summary Report

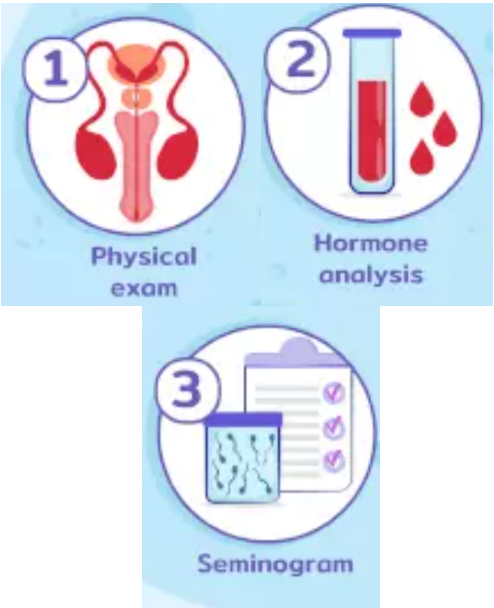
China treatment cycles



Forward Institute Summary Report

Male Infertility

- Male fertility problems contribute to 30% of infertility cases (You et al. 2021).
- The morphology and motility of sperm are critical for male fertility.



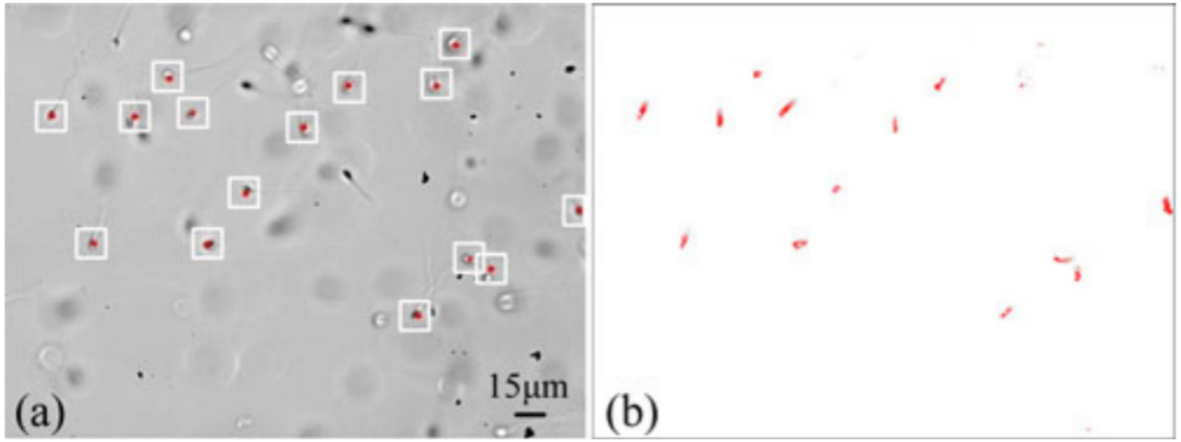
Manual Inspection

- Manual inspection and selection are laborious.

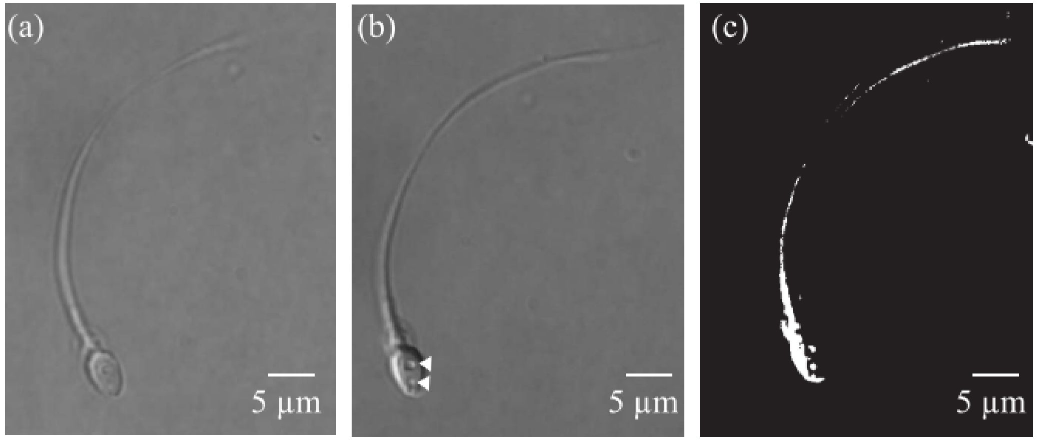
Automated sperm analysis

Conventional computer vision:

- Kalman filter, track sperm head [1]
- Differential interference contrast (DIC), identify sperm mophology [2]



(Liu et al., TBME, 2012).

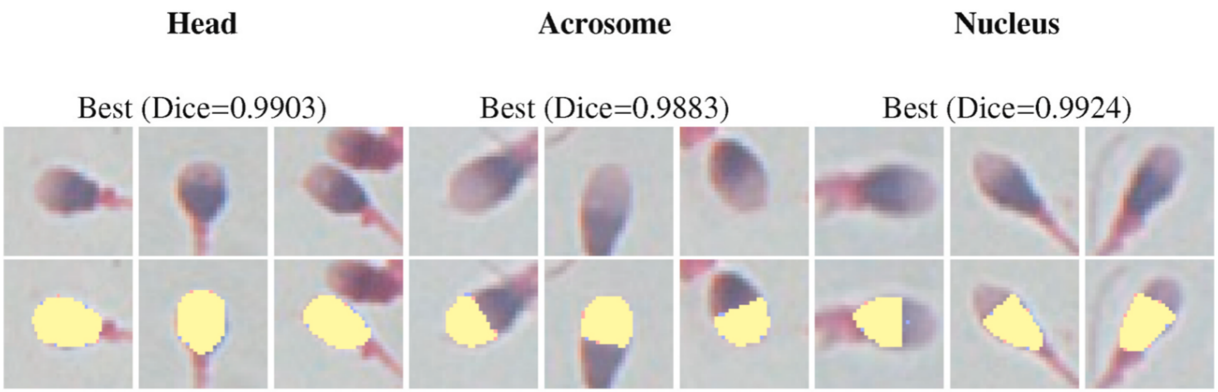


(Dai et al., TMI, 2018).

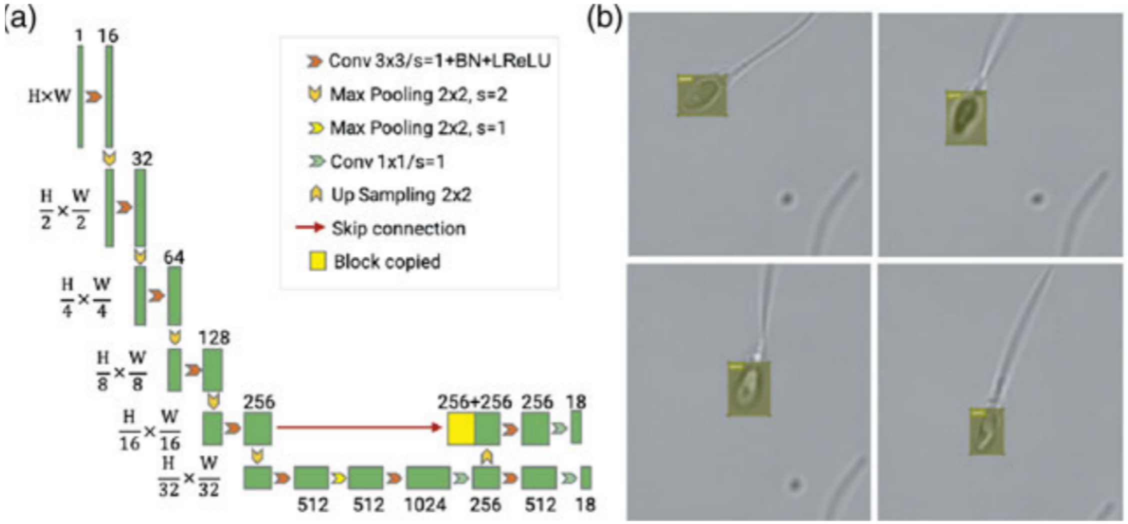
Automated sperm analysis

Machine-learning-based computer vision:

- UNet , sperm head segmentation.
- YOLO, track sperm head.



(Mar´ın et al., Computers in Biology and Medicine, 2021)



(Liu et al., Microscopy and Microanalysis, 2022)

Challenges and Contributions

Problems and Challenges

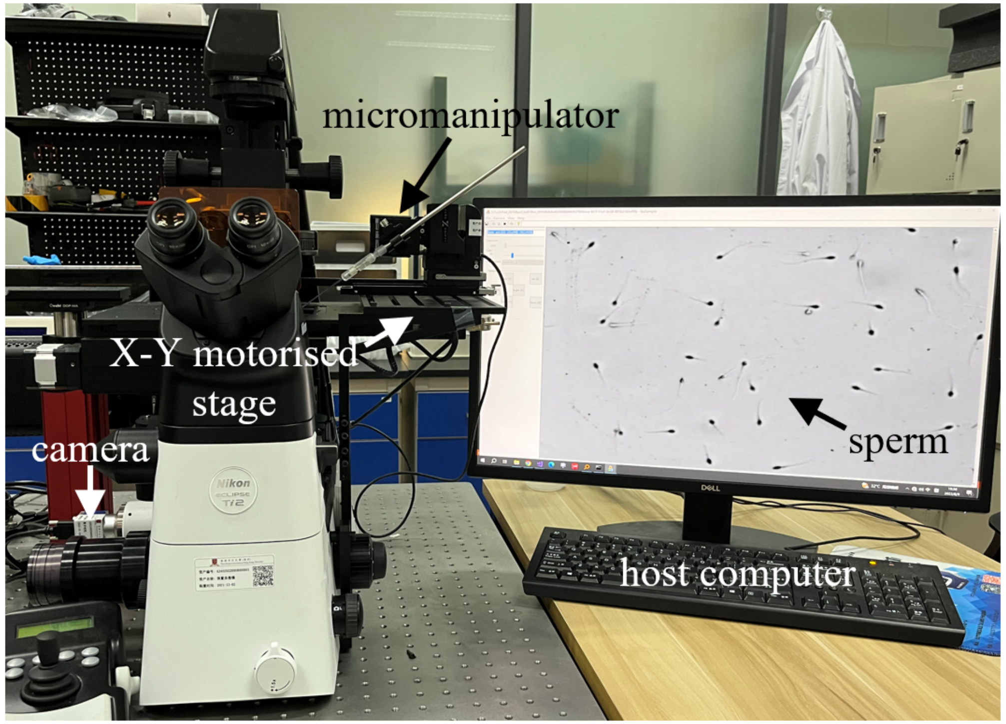
- Morphology and motility are not analyzed simultaneously.
- Averaged sperms per image are less as magnification increases.
- Dyes and fluorescences make sperms clinically unavailable.
- Too small to be detected. Less than 1% area ratio of a petri dish under 20× objective lens.

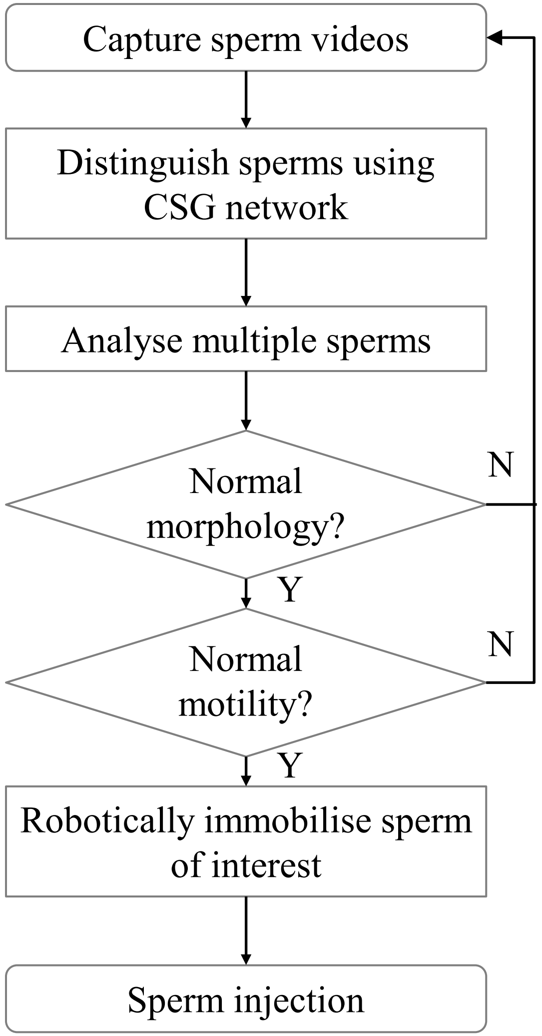
Main Contributions

- Introduce a novel architecture that alleviate compression artifacts.
- Measure sperm’s morphology and motility simultaneously.
- Analyze sperm in a non-invasive manner at 20x objectives.

Mcirorobotic cell manipulation System

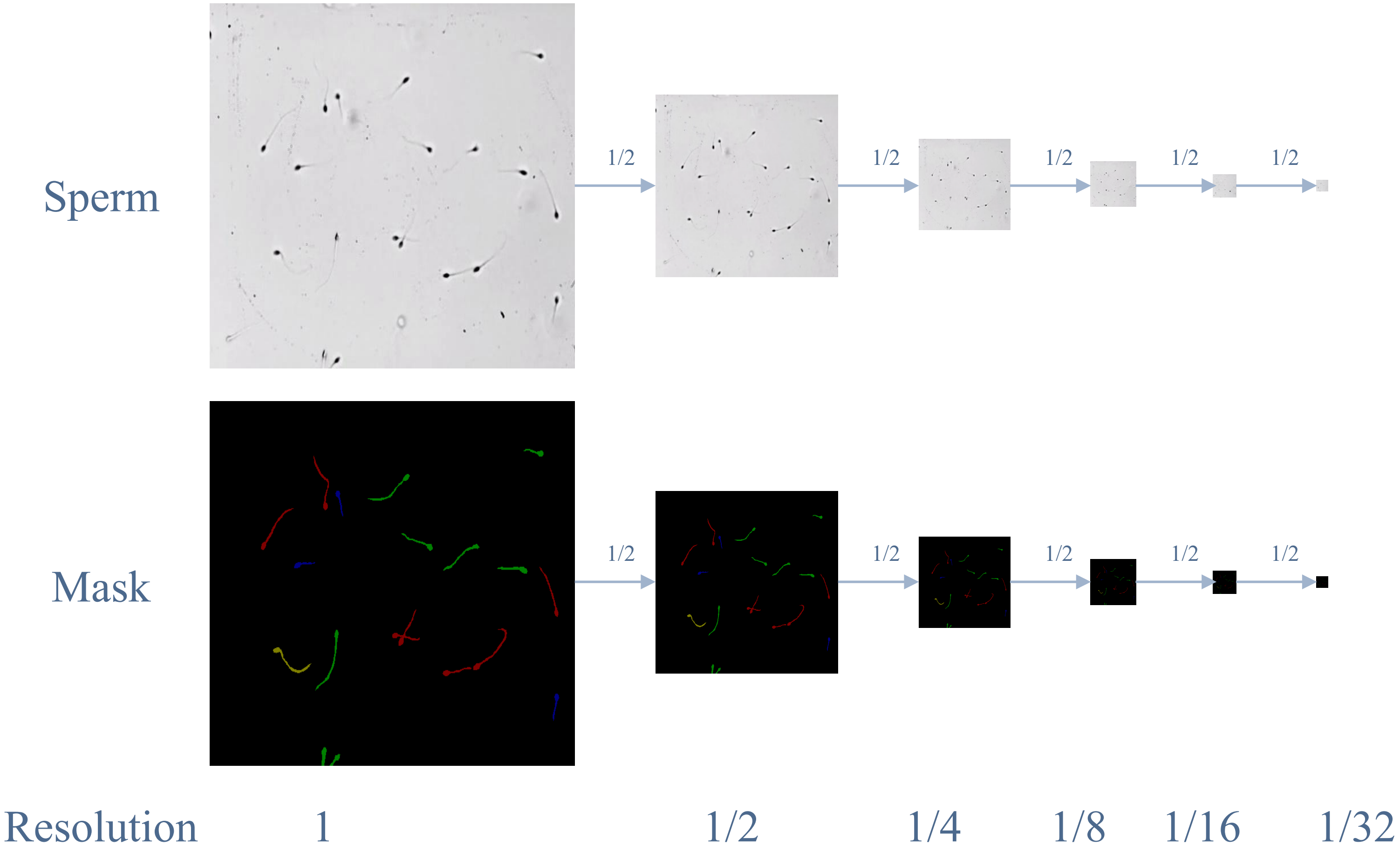
Nikon microscope with 20× objective lens, CMOS camera, 3-DOF micromanipulator (MP-285).





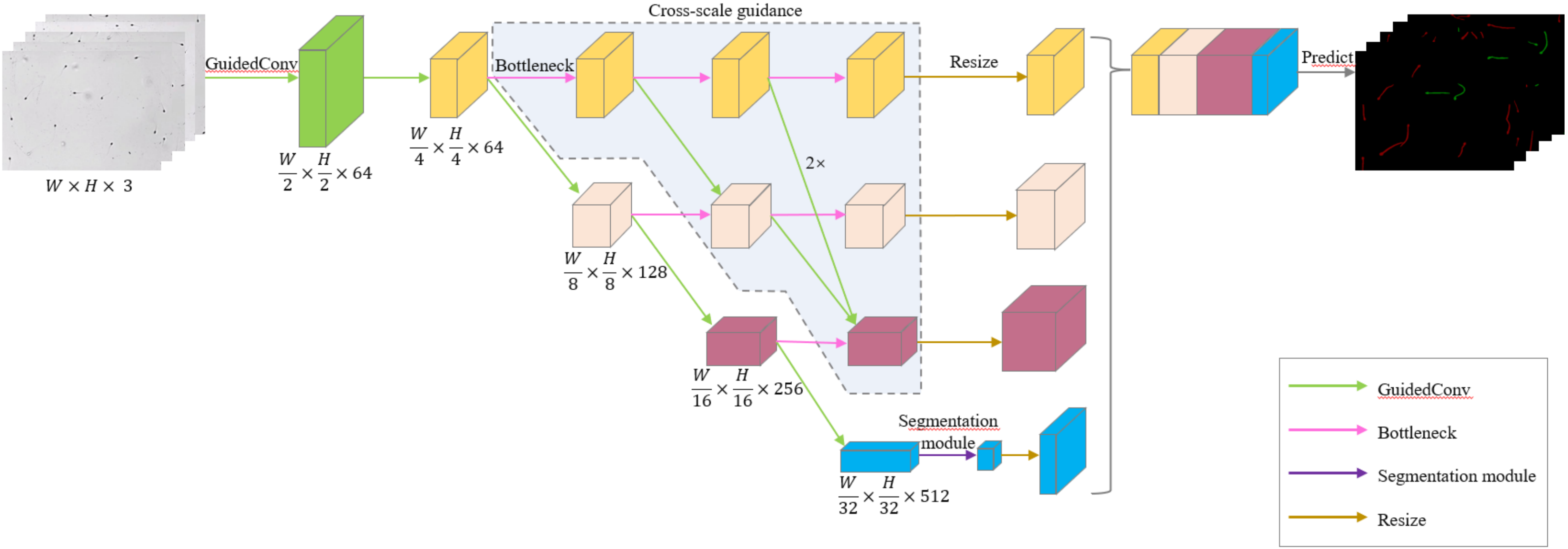
Motivation

Information loss during processing



Cross-scale Guidance Network (CSG Network)

Main component: **cross-scale feature map guide**

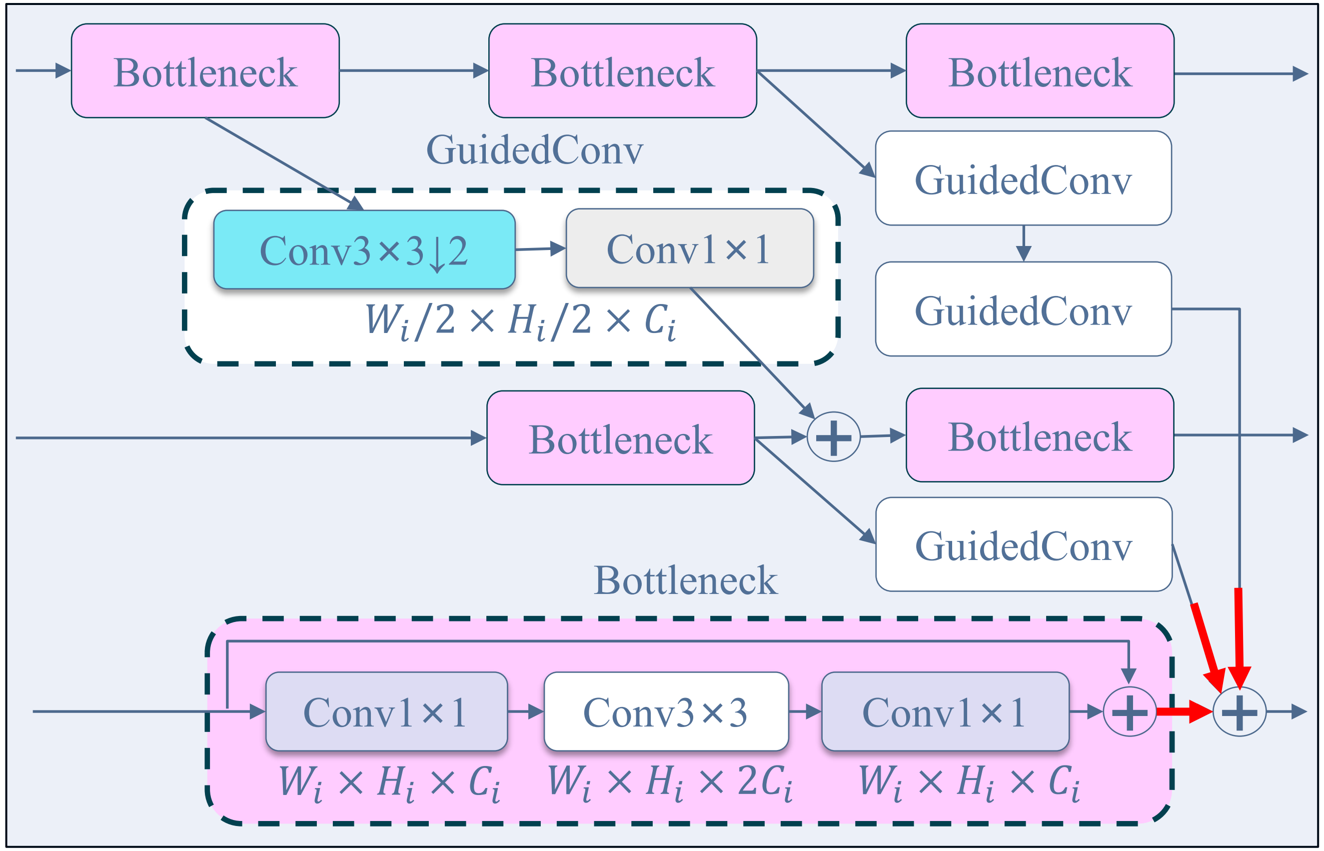


Cross-scale feature map guide

R_x: input tensor

$f_{xr}(R_x)$: (r-x) 3 × 3 strided convolution

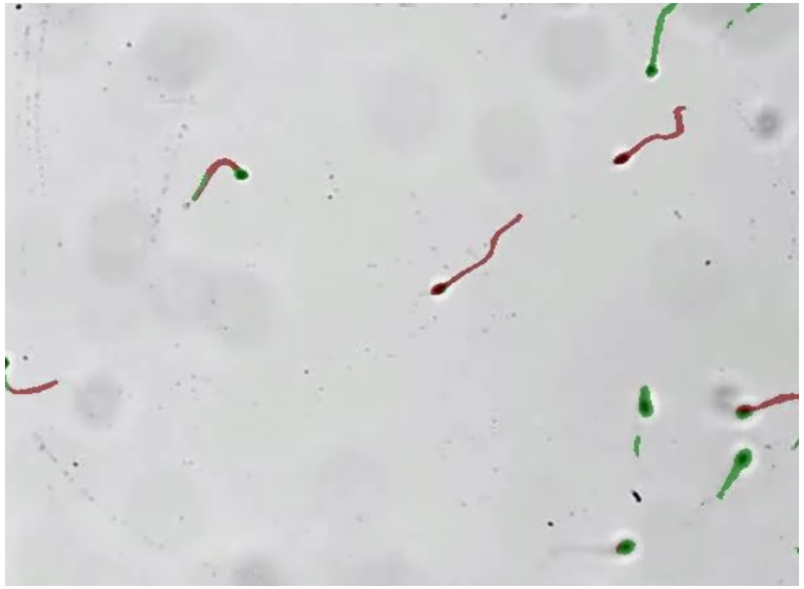
$$R' = f_{1r}(R_1) + f_{2r}(R_2) + f_{3r}(R_3)$$



Video Outputs

Speed × 1.5

Coarse

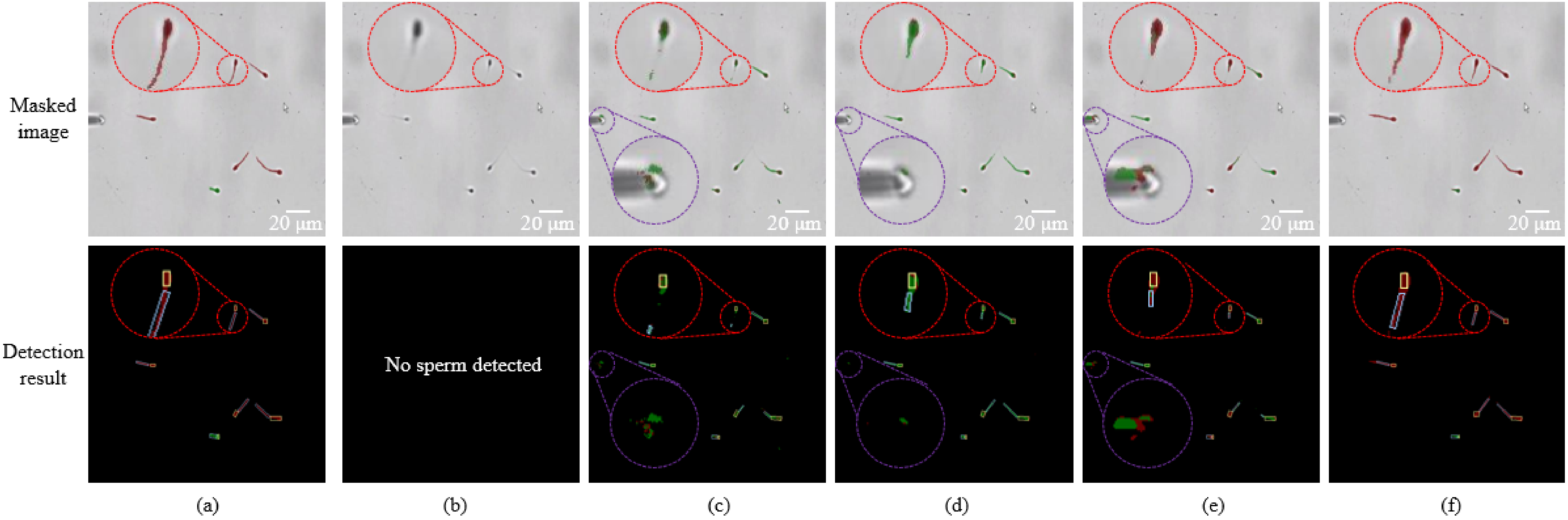


Medium

Dense

Error Analysis

Visualisation of segmentation ground truth (a) and segmentation results using (b) ResNet50 + DeepLabV3, (c) SegNet, (d) UNet,(e) UNet++, and **(f) CSG Network + DeepLabV3**.



Segmentation quantity results

- Achieved highest mIoU of 51.89%.
- Exceeding 21% and 32% for normal and abnormal sperm segmentation

Segmentation IoU and mIoU (Unit:%) for various methods.
IoU = TP / (TP + FP + FN).

Method	Module	Background	Normal	Abnormal	mIoU
SegNet	-	99.11	7.11	24.93	42.41
UNet	-	99.30	13.82	34.06	48.25
UNet++	-	99.29	18.29	33.29	48.40
ResNet50	OCR	98.86	0.00	0.00	33.98
	LR-ASPP	98.87	1.36	5.14	35.19
	DeepLabV3	98.86	0.00	0.02	33.27
CSG Network (ours)	OCR	**99.31**	21.23	32.77	51.45
	LR-ASPP	99.30	**22.41**	33.36	51.64
	DeepLabV3	**99.31**	21.61	**34.60**	**51.89**

Dai *et al.*, *Automated Non-invasive Analysis of Motile Sperms Using Cross-scale Guidance Network*, ICRA 2024

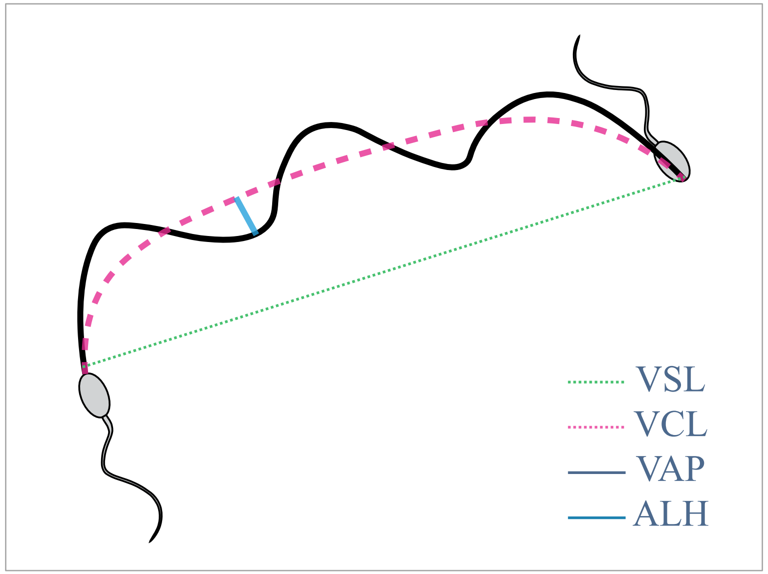
Case Studies

Sperm No.3 is the only healthy sperm

TABLE II: AUTOMATED QUANTIFICATION OF FIVE SPERM SAMPLES (AU: ARBITRARY UNIT).

Sperm No.	Morphology							Motility									Healthy
	Head area (μm^2)	Head length (μm)	Head width (μm)	Head ellipticity (AU)	Head angle (°)	Tail length (μm)	Normal	VSL ($\mu m/s$)	VCL ($\mu m/s$)	VAP ($\mu m/s$)	ALH ($\mu m/s$)	MAD (°)	LIN (AU)	WOB (AU)	STR (AU)	Normal	
1	14.50	5.62	3.00	1.88	90.00	15.74	✗	12.64	12.64	12.65	0.66	0.62	1.00	1.00	1.00	✓	✗
2	14.50	5.00	3.00	1.67	0.00	38.93	✓	0.68	0.80	0.98	0.82	0.97	0.85	1.22	0.70	✗	✗
3	17.50	5.74	3.50	1.64	2.73	40.45	✓	11.97	12.01	12.01	0.99	0.22	1.00	1.00	1.00	✓	✓
4	19.56	6.25	2.00	3.13	72.25	33.83	✗	0.20	0.20	0.21	0.29	0.47	0.98	1.01	0.98	✗	✗
5	25.31	4.75	3.75	1.27	0.00	33.03	✓	0.76	0.76	0.76	0.10	3.19	1.00	1.00	1.00	✗	✗

Morphology	Motility
Head area	Straight-line velocity (VSL)
Head length	Curvilinear velocity (VCL)
Head width	Average-path velocity (VAP)
Head ellipticity	Lateral head displacement (ALH)
Head angle	Mean angular displacement (MAD)
Tail length	Linearity (LIN)
	Wobble (WOB)
	Straightness (STR)

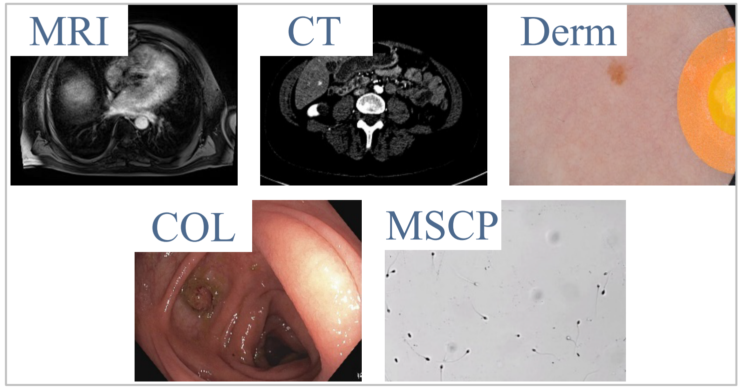


Conclusion and Future Work

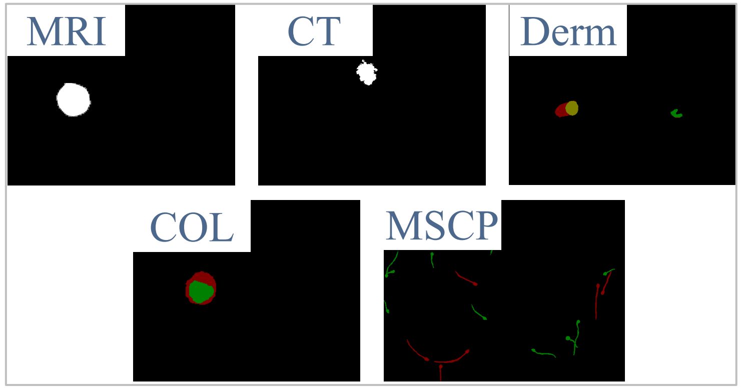
Conclusion

- Outperformed other SOTA methods by over **3.59%** mIoU.
- Selected the healthy sperm among samples non-invasively.

General small medical object detection



Images of
Small Medical Objects



Segmentation
Results

Acknowledgment

CReATe Research Program

- Clifford Librach
- Iryna Kuznyetsova
- Khaled Abdalla
- Sergey Moskovtsev
- Sahar Jahangiri
- Cheryl Ethier
- Zenon Ibarrientos
- Viola Kajendrakumar
- Sadrosadat Zeinab
- Julia Louis

Mount Sinai Fertility
Sinai Health

- Keith Jarvi
- Susan Law
- Brendan Mullen
- Farid Abolhassani

SickKids®

- Xi Huang
- Xin Chen
- Xian Wang

威爾斯親王醫院
Prince of Wales Hospital

UGC 大學教育資助委員會
University Grants Committee

广东省基础与应用基础研究基金委员会

香港城市大學
City University of Hong Kong

深圳市科技创新委员会
深圳市国家自主创新示范区管理委员会
深圳市高新技术产业园区管理委员会
深圳市外国专家局