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Image-Guided Uterine Fibroid Modelling, Surgery Planning, and Intervention

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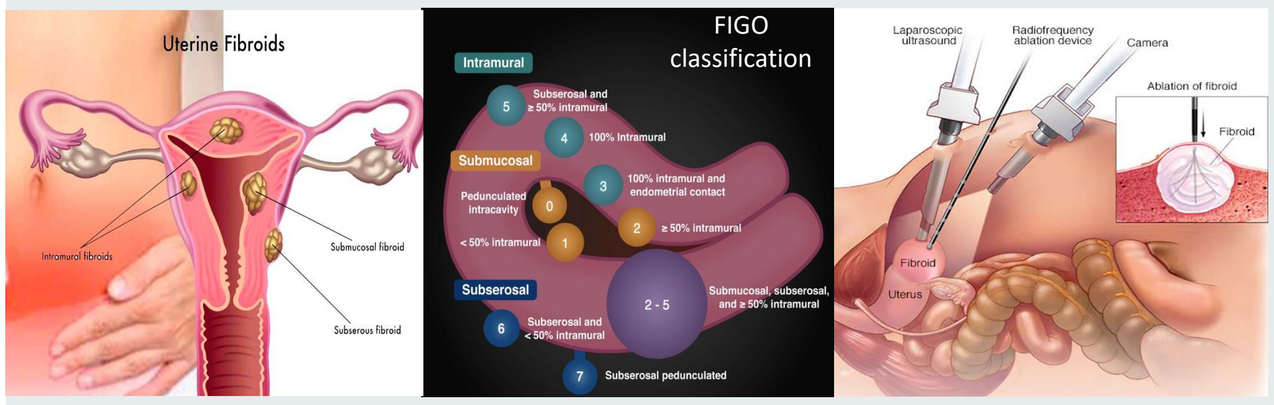
Background



Uterine fibroids, also known as uterine myomas, are the most common benign tumors in the female reproductive system, affecting approximately two-thirds of women at some stage in their lives. They often cause symptoms such as heavy menstrual bleeding and abdominal pain. Fibroids can develop in various parts of the uterus and vary in size and type. Based on the FIGO classification system, there are 9 types of uterine fibroids.

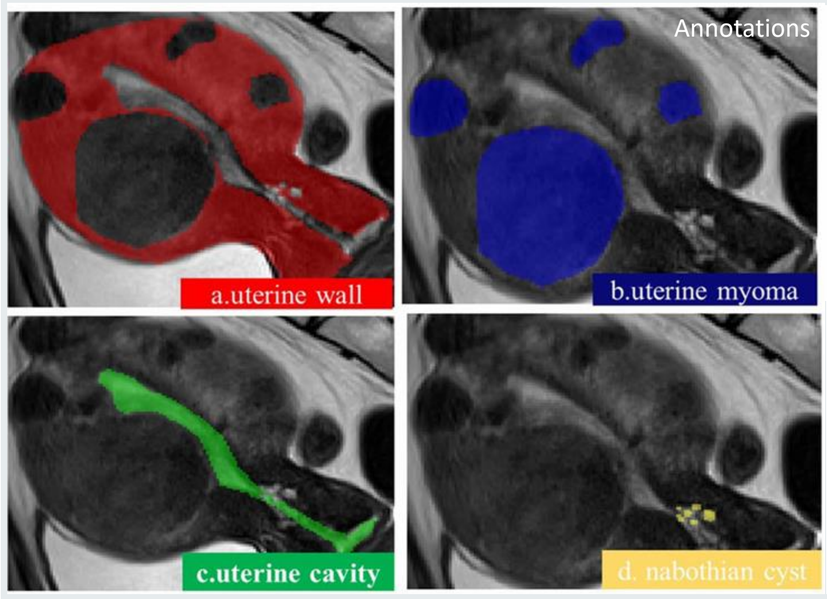
Laparoscopic myomectomy is one of the primary surgical treatments for fibroids, especially for treating types 3, 4, and 5. However, this procedure presents localization challenges due to the lack of effective intraoperative image guidance. This limitation, highlighted by gynecological surgeons, underscores the need for improved fibroid localization during surgery to improve surgical precision.

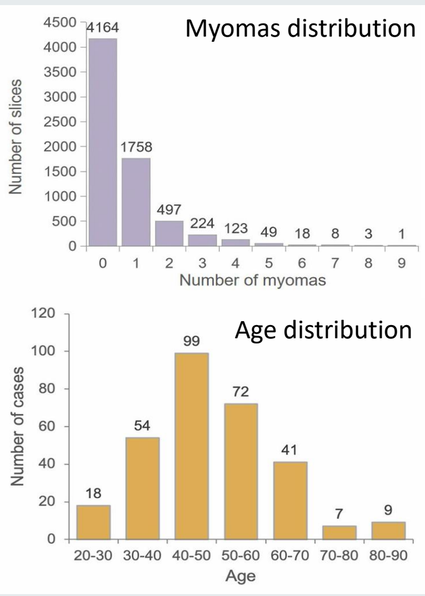
This project focuses on addressing these challenges in laparoscopic myomectomy by utilizing the open-source Uterine Myoma MRI Dataset (UMD) to train an automatic segmentation and 3D reconstruction model for fibroids. Additionally, it explores surgical path planning based on clinical guidelines and surgical expertise to optimize incision sites and reviews ultrasound-guided intervention to improve intraoperative fibroid localization.

Methods I – 3D Reconstruction

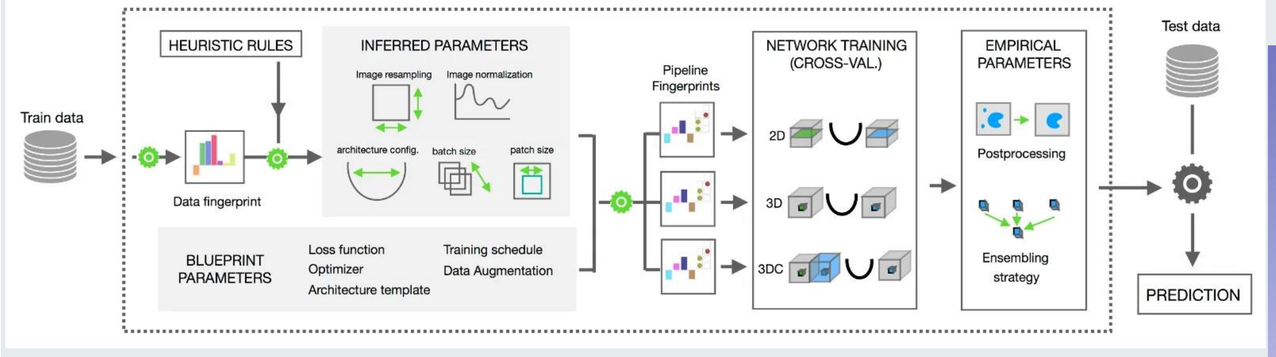
UMD - Summary of Patient Demographics, Annotations, and Myoma Distribution

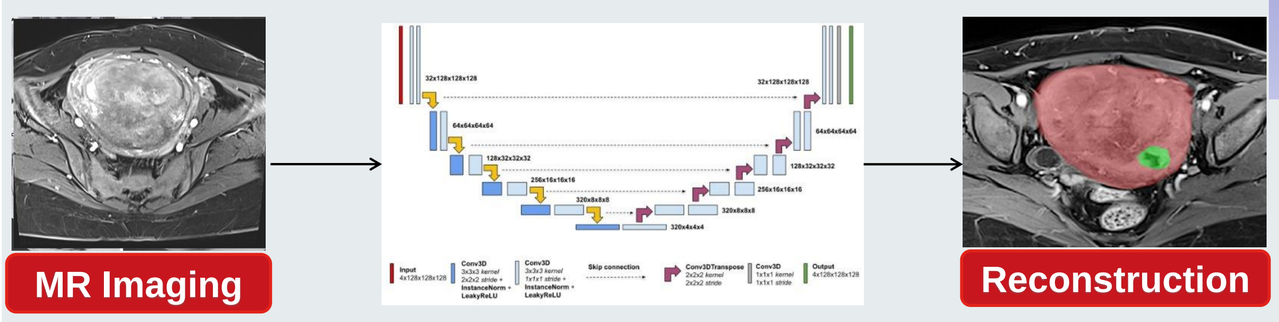
Number of cases	Number of slices	Age	Modalities	Category
300	6845	49.73±12.96	T2W	uterine wall, uterine cavity, uterine myoma, nabothian cyst





Automatic Medical 3D Segmentation and Reconstruction Workflow using nnU-Net

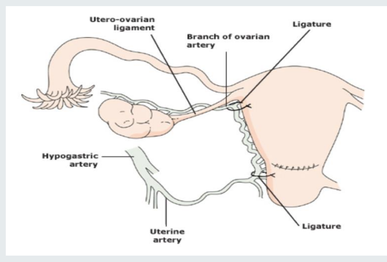




Methods II – Surgery Planning

Multi-objective Optimal Path Planning Based on Clinical Guidelines

- **Clinical surgical guidelines**
  - **Constraint conditions**
    - **Feasibility**: Surgical path length must not exceed needle length
    - **Angle**: Insertion angle should be greater than 20°
    - **Endometrium**: Avoid endometrial penetration
  - **Target conditions**
    - **Length** — Minimize total path length to reduce surgical risk
    - **Distance**
      - Greater distance from the endometrium reduces surgical complications
      - Path extension distance from the endometrium
    - **Angle**
      - Incisional approach with skin
      - Incisional approach with uterine fibroids



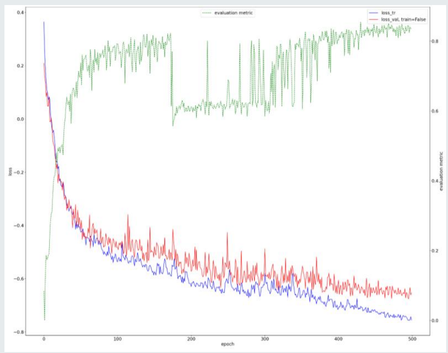
Surgical Guidelines Provided by Surgeons:

- Minimize the number of incisions.
- Avoid damaging important structures (ligaments, blood vessels, fallopian tubes, etc.).
- Consider the difficulty of removal and suturing.
- Ensure optimal postoperative recovery.

Evolution-Driven Universal REward Kit for Agent for Planning

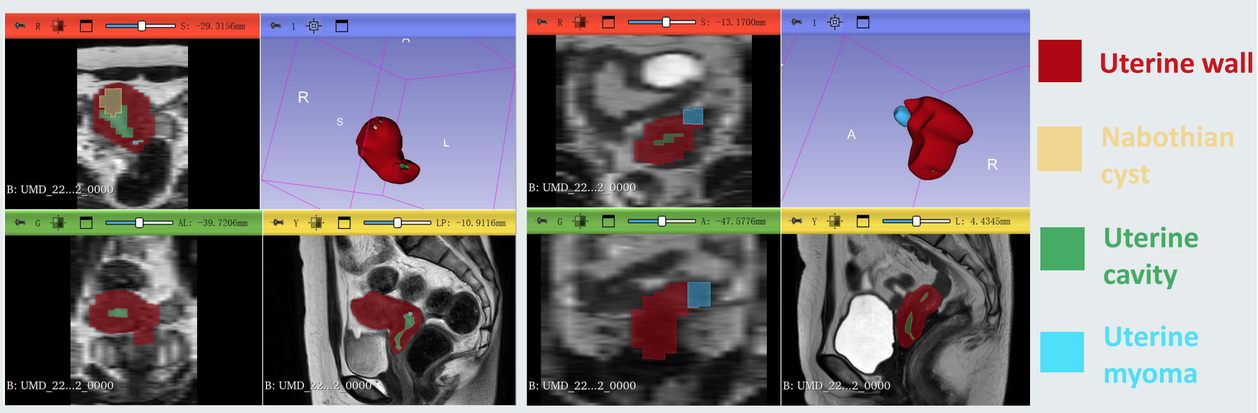
Results

Training Performance and Reconstruction Results

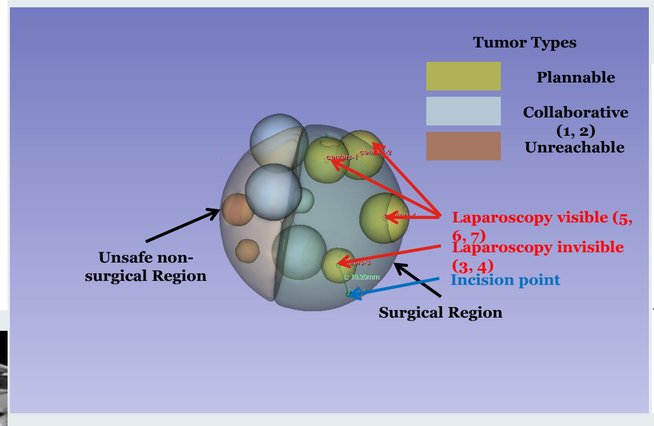


Training Settings		
GPU		NVIDIA GeForce RTX3070 (8.0 GB)
Epoch		500
Dataset (266/300)	Train & Val	204
	Test	62
Training Time (h)		20.8

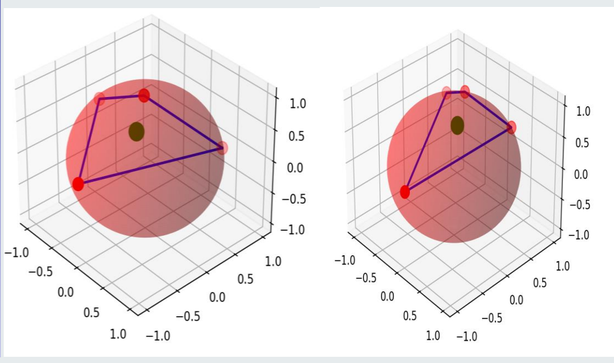
Test	Dice
Uterine Wall	0.8674
Uterine Myoma	0.8426
Uterine Cavity	0.8854
Nabothian Cyst	0.8394



Geometric Model Demo for Surgery Planning using Clinical Guidelines



Result Sample Demo



Conclusion

The nnU-net model achieved a robust performance with a dice exceeding 87%, demonstrating its effectiveness in the automatic segmentation and 3D reconstruction of uterine fibroids. By integrating clinical guidelines and surgical expertise, this approach addresses the challenge of fibroid localization during laparoscopic myomectomy. The project has provided a solid foundation for improving patient outcomes and advancing future developments in image-guided surgical interventions.

References

1. Indian Interventional Radiology, Uterine fibroid treatment non-surgically by embolization (UFE/UAE), Available at: https://indianinterventionalradiology.com.
2. Knipe, H., FIGO classification system for uterine leiomyoma, _Radiopaedia.org_, Available at: https://radiopaedia.org/articles/figo-classification-system-for-uterine-leiomyoma.
3. Mayo Clinic, Laparoscopic radiofrequency ablation, Available at: https://www.mayoclinic.org/zh-hans/diseases-conditions/uterine-fibroids/multimedia/img-20473999.
4. Pan, H., Chen, M., Bai, W. et al. (2024). Large-scale uterine myoma MRI dataset covering all FIGO types with pixel-level annotations, Scientific Data 11, 410. Available at: https://doi.org/10.1038/s41597-024-03170-x.
5. Isensee, F., Jaeger, P.F., Kohl, S.A.A. et al. (2021). nnU-Net: a self-configuring method for deep learning-based biomedical image segmentation, Nature Methods, 18, 203–211. Available at: https://doi.org/10.1038/s41592-020-01008-z.
6. OSS Online, CS Uterus Extend 450, Available at: https://oss-online.ca/knowledge-base/cs-uterus-extend-450/.

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