Multimodal Intraoperative Imaging Research

Multimodal intraoperative imaging is the integration of two or more imaging techniques during surgery to improve anatomical visualization, functional mapping, and decision-making in real time.

Definition

Multimodal intraoperative imaging combines different **real-time imaging modalities** during surgery to provide **complementary anatomical, functional, or metabolic information** about the surgical field.

Common Modalities in Neurosurgery

Imaging Modality	Function
Intraoperative MRI (iMRI)	High-resolution anatomical images; detects residual tumor.
Intraoperative Ultrasound (iUS)	Real-time, dynamic visualization; guides resection.
Neuronavigation	GPS-like surgical guidance using pre-op MRI/CT data.
Fluorescence Imaging (5-ALA, ICG)	Highlights tumor tissue or vasculature.
Intraoperative CT (iCT)	Useful for bone, hemorrhage, and spinal alignment.
Hyperspectral Imaging (HSI)	Spectral differentiation of tissue types.
Electrophysiological Monitoring (MEP, SSEP, ECoG)	Functional mapping and safety during resection.
Optical Coherence Tomography (OCT)	High-resolution imaging for microstructures.

Objectives

- Maximize tumor resection while preserving function
- Compensate for brain shift
- Detect residual tumor in real time
- Prevent complications (e.g. vascular injury)
- Enable functional preservation (e.g. motor, language)

Research Areas

- Integration platforms (coregistration of MRI + US, etc.)
- AI-based segmentation and intraoperative decision support
- Data fusion and visualization systems
- Hardware miniaturization for OR use
- Clinical outcome studies (extent of resection, survival)

Example Projects

- **SLIMBRAIN database** – includes hyperspectral, RGB, depth images from brain surgeries
- **Project HYPER-MRI** – fusion of HSI with intraoperative MRI in glioma surgery
- **MIT-MGH iUS Fusion Lab** – AI segmentation of iUS with MRI-based navigation

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The SLIMBRAIN database fills a crucial gap in multimodal intraoperative imaging research and sets a new benchmark for open-access datasets in neurosurgery. It is well-positioned to:

Foster the development of real-time ML-based surgical guidance tools.

Enable transfer learning and domain adaptation studies using rich spectral and geometric features.

Serve as a validation benchmark for new HSI sensors and fusion algorithms.

Future work should emphasize:

Cross-validation with postoperative histopathology.

Standardization of acquisition protocols and interoperability with hospital systems.

Expansion to include longitudinal follow-up and outcome-based annotations.

Conclusion

The SLIMBRAIN database is a landmark contribution to the field of surgical imaging and AI in neuro-oncology. Despite certain methodological limitations—chiefly regarding labeling consistency and histopathological correlation—its scale, multimodal depth, and open availability make it a transformative resource. Its full potential will be realized when integrated into prospective, outcome-linked ML workflows and subjected to external clinical validation.