Supplementary Material

Why is the winner the best? - Eisenmann *et al.*

A. Conferences

Table A. Overview of conferences included in this meta-study. The conferences link to the respective conference websites. The websites were last accessed on 2022-11-11.

#	ID	Conference	Conference date	Conference full name
1	I	IEEE ISBI 2021	2021-04-13 - 2021-04-16	18th International Symposium on Biomedical Imaging
2	M	MICCAI 2021	2021-09-27 - 2021-10-01	24th International Conference on Medical Image Computing and Computer Assisted Intervention

B. Challenges

Table B. Overview of biomedical challenges included in this meta-study. The challenge acronyms link to the respective challenge websites. The websites were last accessed on 2022-11-11.

#	ID	Conference	Challenge acronym	Challenge full name
1	I.1	IEEE ISBI 2021	CTC	6th ISBI Cell Tracking Challenge
2	I.2	IEEE ISBI 2021	MitoEM	Large-scale 3D Mitochondria Instance Segmentation Challenge
3	I.3	IEEE ISBI 2021	EndoCV2021	Addressing generalisability in polyp detection and segmentation challenge
4	I.4	IEEE ISBI 2021	RIADD	Retinal Image Analysis for multi-Disease Detection Challenge
5	I.5	IEEE ISBI 2021	SegPC-2021	Segmentation of Multiple Myeloma Plasma Cells in Microscopic Images Challenge
6	I.6	IEEE ISBI 2021	A-AFMA	Ultrasound Challenge: Automatic amniotic fluid measurement and analysis from ultrasound video
7	M.1	MICCAI 2021	KiTS21	2021 Kidney and Kidney Tumor Segmentation
8	M.2	MICCAI 2021	RealNoiseMRI	Brain MRI reconstruction challenge with realistic noise
9	M.3	MICCAI 2021	crossMoDA	Cross-Modality Domain Adaptation for Medical Image Segmentation
10	M.4	MICCAI 2021	AdaptOR 2021	Deep Generative Model Challenge for Domain Adaptation in Surgery 2021
11	M.5	MICCAI 2021	DFUC 2021	Diabetic Foot Ulcer Challenge 2021
12	M.6a	MICCAI 2021	HeiSurf	Endoscopic Vision Challenge 2021 - HeiChole Surgical Workflow Analysis and Full Scene

				Segmentation
13	M.6b	MICCAI 2021	GIANA	Endoscopic Vision Challenge 2021 - Gastrointestinal Image ANAlysis
14	M.6c	MICCAI 2021	CholecTriplet2021	Endoscopic Vision Challenge 2021 - Surgical Action Triplet Recognition
15	M.6d	MICCAI 2021	FetReg	Endoscopic Vision Challenge 2021 - Placental Vessel Segmentation and Registration in Fetoscopy
16	M.6e	MICCAI 2021	PETRAW	Endoscopic Vision Challenge 2021 - PEg TRAnsfer Workflow recognition by different modalities
17	M.6f	MICCAI 2021	SimSurgSkill	Endoscopic Vision Challenge 2021 - Objective Surgical Skill Assessment in VR Simulation
18	M.7	MICCAI 2021	DiSCo	Diffusion-Simulated Connectivity Challenge
19	M.8	MICCAI 2021	FLARE21	Fast and Low GPU Memory Abdominal Organ Segmentation in CT
20	M.9	MICCAI 2021	FeTS	Federated Tumor Segmentation Challenge
21	M.10	MICCAI 2021	FeTA	Fetal Brain Tissue Annotation and Segmentation Challenge
22	M.11	MICCAI 2021	HECKTOR	HEad and neCK TumOR segmentation and outcome prediction in PET/CT images
23	M.12	MICCAI 2021	LEARN2REG	Learn2Reg - The Challenge (2021)
24	M.13	MICCAI 2021	MOOD	Medical Out-of-Distribution Analysis Challenge 2021
25	M.14	MICCAI 2021	MIDOG	MItosis DOmain Generalization Challenge 2021
26	M.15	MICCAI 2021	M&Ms-2	Multi-Disease, Multi-View & Multi-Center Right Ventricular Segmentation in Cardiac MRI
27	M.16	MICCAI 2021	QUBIQ 2021	Quantification of Uncertainties in Biomedical Image Quantification 2021
28	M.17	MICCAI 2021	BraTS2021	RSNA/ASNR/MICCAI Brain Tumor Segmentation Challenge 2021
29	M.18	MICCAI 2021	SARAS-MESAD	SARAS challenge for Multi-domain Endoscopic Surgeon Action Detection
30	M.19	MICCAI 2021	AutoImplant 2021	Towards the Automatization of Cranial Implant Design in Cranioplasty: 2nd MICCAI Challenge on Automatic Cranial Implant Design
31	M.20	MICCAI 2021	VALDO	VAscular Lesions DetectiOn Challenge
32	M.21	MICCAI 2021	VWS	Carotid Artery Vessel Wall Segmentation Challenge
33	M.22	MICCAI 2021	FU-Seg	Foot Ulcer Segmentation Challenge 2021
34	M.23	MICCAI 2021	MSSEG-2	Multiple sclerosis new lesions segmentation challenge
35	M.24	MICCAI 2021	PAIP2021	Perineural Invasion in Multiple Organ Cancer (Colon, Prostate, and Pancreatobiliary tract)

C. Competitions

Table C. Overview of competitions included in this meta-study.

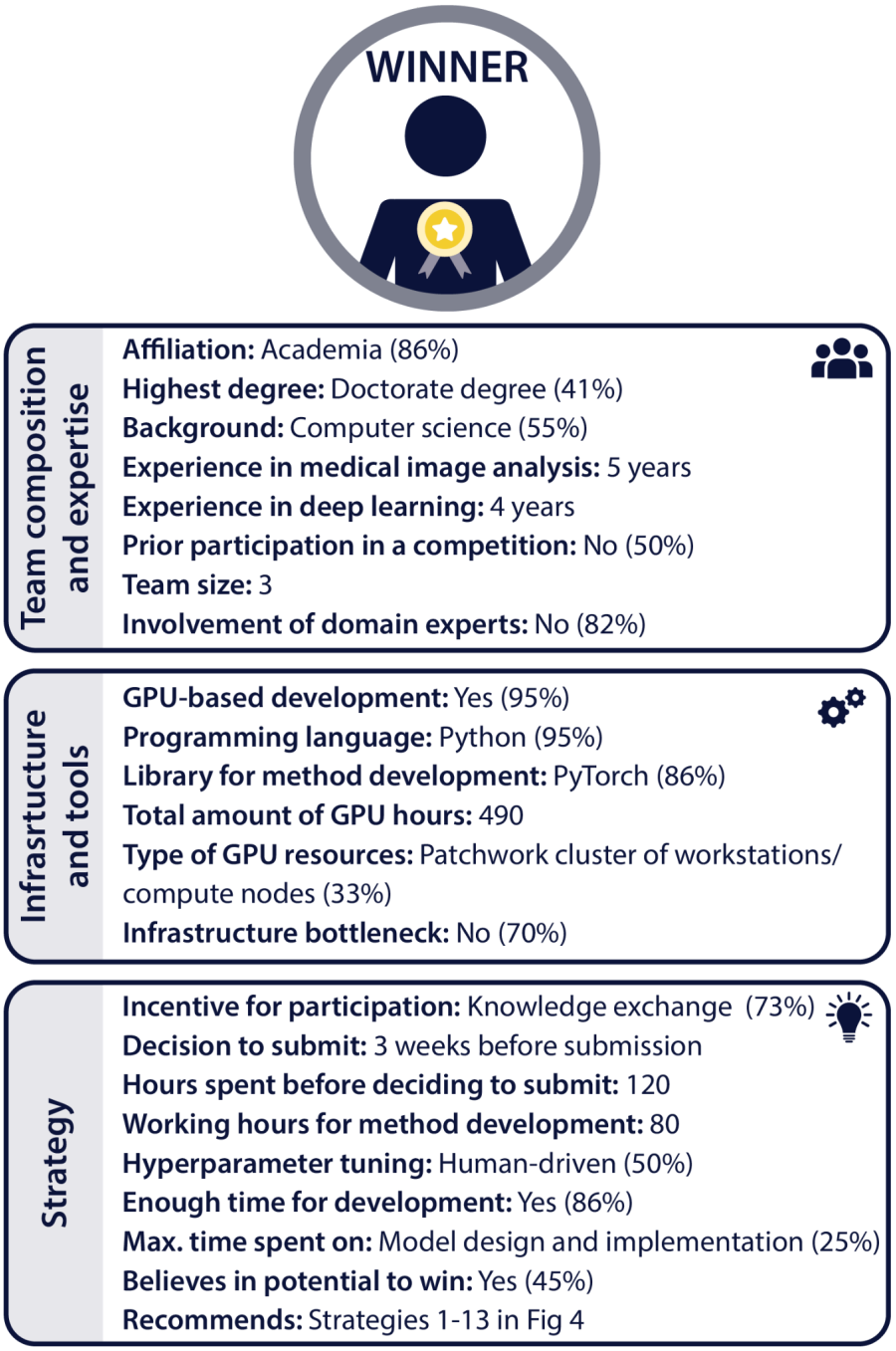
#	ID	Conference	Challenge	Competition
1	I.1.1	IEEE ISBI 2021	CTC	Primary Track (evaluation across 13 datasets)
2	I.1.2	IEEE ISBI 2021	CTC	Secondary Track - Dataset "DIC-C2DH-HeLa"
3	I.1.3	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-C2DL-MSC"
4	I.1.4	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-C3DH-H157"
5	I.1.5	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-C3DL-MDA231"
6	I.1.6	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-N2DH-GOWT1"
7	I.1.7	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-N2DL-HeLa"
8	I.1.8	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-N3DH-CE"
9	I.1.9	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-N3DH-CHO"
10	I.1.10	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-N3DL-DRO"
11	I.1.11	IEEE ISBI 2021	CTC	Secondary Track - Dataset "PhC-C2DH-U373"
12	I.1.12	IEEE ISBI 2021	CTC	Secondary Track - Dataset "PhC-C2DL-PSC"
13	I.1.13	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-N2DH-SIM+"
14	I.1.14	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-N3DH-SIM+"
15	I.1.15	IEEE ISBI 2021	CTC	Secondary Track - Dataset "BF-C2DL-HSC"
16	I.1.16	IEEE ISBI 2021	CTC	Secondary Track - Dataset "BF-C2DL-MuSC"
17	I.1.17	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-C2DL-Huh7"
18	I.1.18	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-C3DH-A549"
19	I.1.19	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-N3DL-TRIC"
20	I.1.20	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-N3DL-TRIF"
21	I.1.21	IEEE ISBI 2021	CTC	Secondary Track - Dataset "Fluo-C3Dh-A549-SIM"
22	I.2.1	IEEE ISBI 2021	MitoEM	3D Mitochondria Instance Segmentation
23	I.3.1	IEEE ISBI 2021	EndoCV2021	Assessing generalisability in polyp detection
24	I.3.2	IEEE ISBI 2021	EndoCV2021	Assessing generalisability in polyp segmentation
25	I.4.1	IEEE ISBI 2021	RIADD	Disease Screening
26	I.4.2	IEEE ISBI 2021	RIADD	Disease Classification
27	I.5.1	IEEE ISBI 2021	SegPC-2021	Segmentation of Multiple Myeloma Plasma Cells in Microscopic Images Challenge
28	I.6.1	IEEE ISBI 2021	A-AFMA	Detection: Automatic amniotic fluid detection from

				ultrasound video
29	I.6.2	IEEE ISBI 2021	A-AFMA	Localization: Automatic amniotic fluid measurement from ultrasound video
30	M.1.1	MICCAI 2021	KiTS21	Segmentation of Kidney and Associated Structures
31	M.2.1	MICCAI 2021	RealNoiseMRI	Reconstruction of motion corrupted T1 weighted MRI data
32	M.2.2	MICCAI 2021	RealNoiseMRI	Reconstruction of motion corrupted T2 weighted MRI data
33	M.3.1	MICCAI 2021	crossMoDA	Vestibular Schwannoma and Cochlea Segmentation
34	M.4.1	MICCAI 2021	AdaptOR 2021	Domain Adaptation for Landmark Detection
35	M.5.1	MICCAI 2021	DFUC 2021	Analysis Towards Classification of Infection & Ischaemia of Diabetic Foot Ulcers
36	M.6a.1	MICCAI 2021	HeiSurf	Scene segmentation
37	M.6a.2	MICCAI 2021	HeiSurf	Phase segmentation
38	M.6a.3	MICCAI 2021	HeiSurf	Instrument presence
39	M.6a.4	MICCAI 2021	HeiSurf	Action recognition
40	M.6b.1	MICCAI 2021	GIANA	Polyp detection in colonoscopy images
41	M.6b.2	MICCAI 2021	GIANA	Polyp segmentation in colonoscopy images
42	M.6b.3	MICCAI 2021	GIANA	Histology prediction
43	M.6c.1	MICCAI 2021	CholecTriplet2021	Surgical Action Triplet Recognition
44	M.6d.1	MICCAI 2021	FetReg	Placental semantic segmentation
45	M.6d.2	MICCAI 2021	FetReg	Placental RGB frame registration for mosaicking
46	M.6e.1	MICCAI 2021	PETRAW	Video-based surgical workflow recognition
47	M.6e.2	MICCAI 2021	PETRAW	Kinematic-based surgical workflow recognition
48	M.6e.3	MICCAI 2021	PETRAW	Segmentation-based surgical workflow recognition
49	M.6e.4	MICCAI 2021	PETRAW	Video and kinematic-based surgical workflow recognition
50	M.6e.5	MICCAI 2021	PETRAW	Video, kinematic and segmentation-based surgical workflow recognition
51	M.6f.1	MICCAI 2021	SimSurgSkill	Surgical tool/needle detection
52	M.6f.2	MICCAI 2021	SimSurgSkill	Skill Assessment
53	M.7.1	MICCAI 2021	DiSCo	Quantitative connectivity estimation
54	M.8.1	MICCAI 2021	FLARE21	Abdominal Organ Segmentation in CT Images
55	M.9.1	MICCAI 2021	FeTS	Federated Training

56	M.9.2	MICCAI 2021	FeTS	Federated Evaluation
57	M.10.1	MICCAI 2021	FeTA	Fetal Brain Tissue Segmentation
58	M.11.1	MICCAI 2021	HECKTOR	Tumor segmentation
59	M.11.2	MICCAI 2021	HECKTOR	Radiomics
60	M.11.3	MICCAI 2021	HECKTOR	Radiomics with ground truth contour
61	M.12.1	MICCAI 2021	LEARN2REG	Intra-patient multimodal abdominal MRI and CT registration
62	M.12.2	MICCAI 2021	LEARN2REG	Intra-patient large deformation lung CT registration
63	M.12.3	MICCAI 2021	LEARN2REG	Inter-patient large scale brain MRI registration
64	M.13.1	MICCAI 2021	MOOD	Sample-level
65	M.13.2	MICCAI 2021	MOOD	Pixel-level
66	M.14.1	MICCAI 2021	MIDOG	Mitotic figure detection
67	M.15.1	MICCAI 2021	M&Ms-2	Segmentation of the right ventricle (RV) in cardiac MRI
68	M.16.1	MICCAI 2021	QUBIQ 2021	Quantifying segmentation uncertainties
69	M.17.1	MICCAI 2021	BraTS2021	Segmentation of glioblastoma in mpMRI scans
70	M.18.1	MICCAI 2021	SARAS-MESAD	Multi-domain static action detection
71	M.19.1	MICCAI 2021	AutoImplant 2021	Cranial implant design for diverse synthetic defects on aligned skulls
72	M.19.2	MICCAI 2021	AutoImplant 2021	Cranial implant design for real patient defects
73	M.19.3	MICCAI 2021	AutoImplant 2021	Improving the model generalization ability for cranial implant design
74	M.20.1	MICCAI 2021	VALDO	Segmentation of enlarged PVS
75	M.20.2	MICCAI 2021	VALDO	Segmentation of cerebral microbleeds
76	M.20.3	MICCAI 2021	VALDO	Segmentation of lacunes
77	M.21.1	MICCAI 2021	VWS	Vessel wall segmentation
78	M.22.1	MICCAI 2021	FU-Seg	Foot Ulcer Segmentation
79	M.23.1	MICCAI 2021	MSSEG-2	New MS lesions segmentation
80	M.24.1	MICCAI 2021	PAIP2021	Detection of perineural invasion in three organ cancers

D. Profile of a competition winner

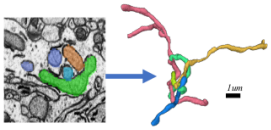
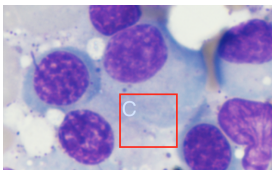
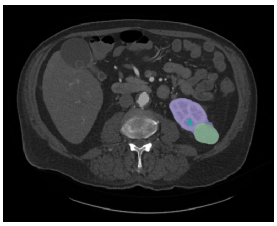
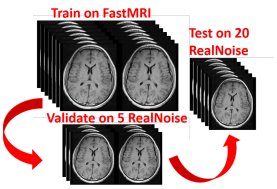
Figure D. Profile of a competition winner. In case of categorical values, the majority vote of all participants was used (note that “unsure" was also an option where appropriate). In case of continuous values, the median was taken.

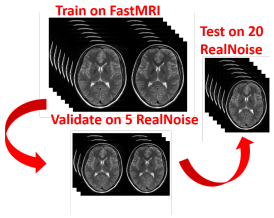
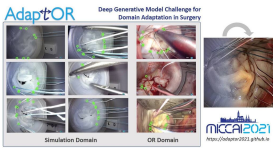
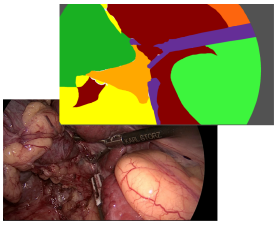
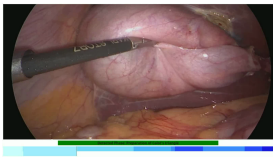
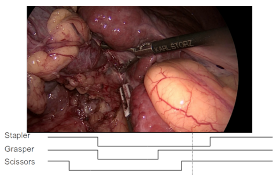
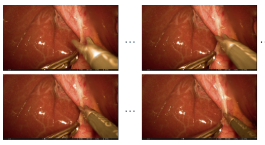
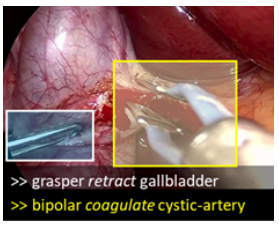


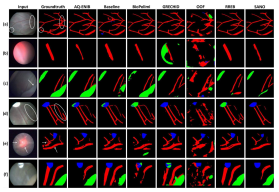
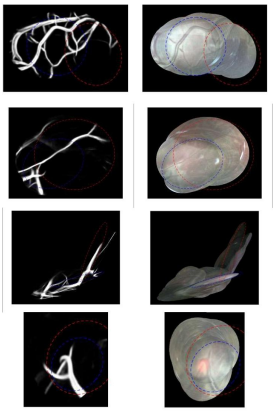
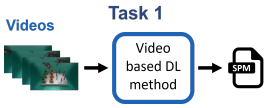
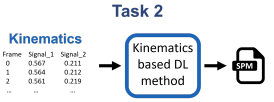
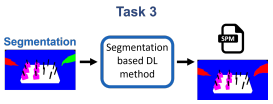
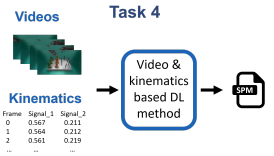
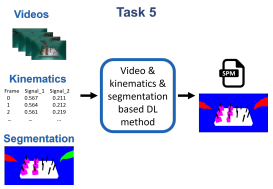
E. Remaining challenges

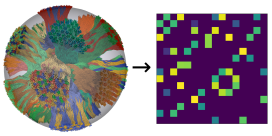
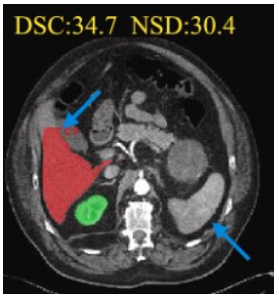
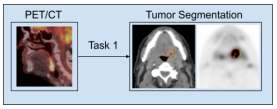
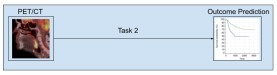
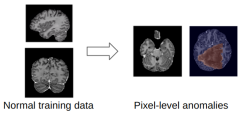
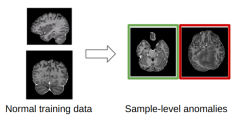
The amount of tasks that were “not solved at all”/“completely solved” differed substantially across medical disciplines ranging from 0%/33% for pathology, 0%/8% for radiology, to 16%/12% for surgery, thus suggesting that specifically surgical video analysis is an open grand challenge. Some overarching open research questions extracted from our work are provided in Tab. F. We have further obtained permission from the challenge organizers to de-anonymize their answers in order to explicitly list the gaps in the literature for tasks that have not been solved (Tab. E).

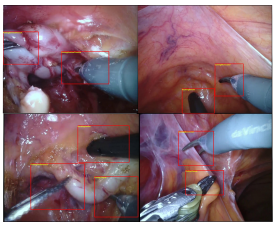
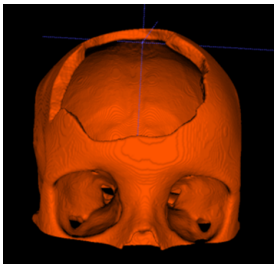
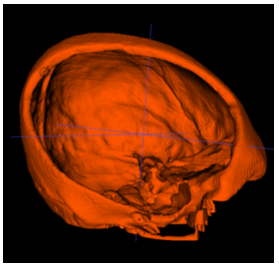
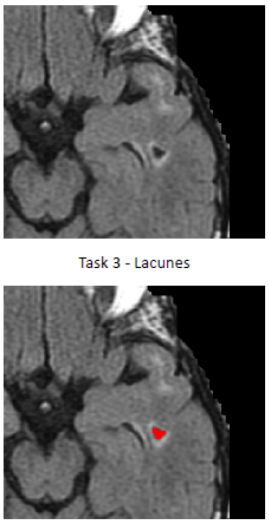
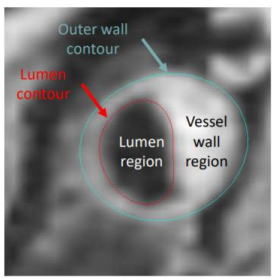
Table E. Remaining challenges related to unsolved biomedical imaging tasks according to challenge organizers. The task IDs given in brackets refer to Suppl. C.

Task	Illustration	Solved?	Core remaining challenges
ISBI / MitoEM (I.2.1): 3D mitochondria instance segmentation		No; substantial progress	Segmentation of a specific type of mitochondria (mitochondria-on-a-string); imaging artifacts such as knife marks and lighting variations.
ISBI / SegPC-2021 (I.5.1): Segmentation of multiple myeloma plasma cells in microscopic images		No; minor progress	Cytoplasm boundaries, which provide a poor contrast relative to background.
ISBI / A-AFMA (I.6.1): Automatic amniotic fluid detection from ultrasound video		No; first baseline	Lack of use of temporal context; lack of incorporation of clinical context knowledge; poor imaging conditions (e.g., artifacts).
ISBI / A-AFMA (I.6.2): Automatic amniotic fluid measurement from ultrasound video	N/A	No; minor progress	Ultrasound image artifacts, e.g., acoustic shadow, unclear boundaries.
MICCAI / KiTS21 (M.1.1): Segmentation of kidney and associated structures		No; substantial progress	Small cysts and tumors.
MICCAI / RealNoiseMRI (M.2.1): Reconstruction of motion corrupted T1 weighted MRI data		No; minor progress	The challenge was focused on providing realistically degraded brain MRI to evaluate reconstruction algorithms on, and it showed that current algorithms still cannot handle this.

MICCAI / RealNoiseMRI (M.2.2): Reconstruction of motion corrupted T2 weighted MRI data		No; minor progress	The challenge was focused on providing realistically degraded brain MRI to evaluate reconstruction algorithms on, and it showed that current algorithms still cannot handle this.
MICCAI / AdaptOR 2021 (M.4.1): Domain Adaptation for landmark detection		Not at all	Varying light conditions and non-standardized views.
MICCAI / DFUC 2021 (M.5.1): Analysis towards classification of infection & ischaemia of diabetic foot ulcers		No; substantial progress	Data imbalance (the majority of the images are of type infection and control).
MICCAI / HeiSurf (M.6a.1): Scene segmentation		No; substantial progress	Smoke and motion blur, high brightness/darkness.
MICCAI / HeiSurf (M.6a.2): Phase segmentation		No; substantial progress	Complex surgeries, out-of-body frames.
MICCAI / HeiSurf (M.6a.3): Instrument presence		No; substantial progress	Occlusions, and motion blur.
MICCAI / HeiSurf (M.6a.4): Action recognition		No; minor progress	Poor performance on some classes.
MICCAI / GIANA (M.6b.3): Histology prediction	N/A	No; substantial progress	Poor performance on the rare class (adenomatous).
MICCAI / EndoVis / CholecTriplet (M.6c.1): Surgical action recognition		No; minor progress	Non-intuitive data augmentation; poor performance on rare triplets and difficult imaging conditions.

MICCAI / FetReg (M.6d.1): Placental semantic segmentation		No; minor progress	High variability across different centers/devices; poor visibility, varying illumination, artifacts, occlusions.
MICCAI / FetReg (M.6d.2): Placental RGB frame registration for mosaicking		Not at all	Poor vessel visibility, artifacts, texture paucity, occlusions, non-planar views, non-rigid deformations (i.e., maternal breathing).
MICCAI / PETRAW (M.6e.1): Video-based surgical workflow recognition		No; minor progress	Non-standardized workflows; the data set is highly unbalanced with respect to the action verb (some prevalences < 5%).
MICCAI / PETRAW (M.6e.2): Kinematic-based surgical workflow recognition		No; minor progress	Non-standardized workflows; the data set is highly unbalanced with respect to the action verb (some prevalences < 5%).
MICCAI / PETRAW (M.6e.3): Segmentation-based surgical workflow recognition		Not at all	Non-standardized workflows; the data set is highly unbalanced with respect to the action verb (some prevalences < 5%).
MICCAI / PETRAW (M.6e.4): Video and kinematic-based surgical workflow recognition		No; minor progress	The data set is highly unbalanced with respect to the action verb (some prevalences < 5%).
MICCAI / PETRAW (M.6e.5): Video, kinematic and segmentation-based surgical workflow recognition		No; minor progress	Non-standardized workflows; the data set is highly unbalanced with respect to the action verb (some prevalences < 5%).
MICCAI / SimSurgSkill (M.6f.1): Skill Assessment	N/A	No; minor progress	Change of background.
MICCAI / SimSurgSkill (M.6f.2): Surgical tool/needle detection	N/A	No; substantial progress	Domain shifts (i.e., different background but same tools).

MICCAI / DiSCo (M.7.1): Quantitative connectivity estimation		No; substantial progress	Estimation of connectivity in more complex microstructural environments; coping with various MRI noise sources and artifacts.
MICCAI / FLARE21 (M.8.1): Abdominal organ segmentation in CT images		No; substantial progress	The top algorithms tend to fail in the regions with low contrast, pathological changes, and fuzzy boundaries.
MICCAI / FeTS (M.9.2): Federated evaluation		No; minor progress	Reference segmentations with empty enhancing tumor regions lead to extreme metric values. Analysis of failure cases is limited by the federated setup.
MICCAI / FeTA (M.10.1): Fetal brain tissue segmentation	N/A	No; substantial progress	Consistent performance across all five classes.
MICCAI / HECKTOR (M.11.1): Tumor segmentation		No; substantial progress	Corner cases, such as large metastatic lymph nodes incorrectly segmented as a primary tumor.
MICCAI / HECKTOR (M.11.2): Radiomics		No; substantial progress	Stratifications of patient populations in terms of treatment and imaging protocols, HPV status, and age are needed.
MICCAI / HECKTOR (M.11.3): Radiomics with ground truth contours		No; substantial progress	Stratifications of patient populations in terms of treatment and imaging protocols, HPV status, and age are needed.
MICCAI / LEARN2REG (M.12.1): Intra-patient multimodal abdominal MRI and CT registration	N/A	No; substantial progress	Large deformations, large variations in voxel-size (before pre-processing), and contrast.
MICCAI / MOOD (M.13.1): Pixel-level		No; minor progress	Medically relevant but less obvious anomalies.
MICCAI / MOOD (M.13.2): Sample-level		No; minor progress	Medically relevant but less obvious anomalies.

MICCAI / SARAS-MESAD (M.18.1): Multi-domain static action detection		Not at all	Domain shifts (i.e., large shifts in the characteristics of scenes, such as change in lighting conditions, properties of the tools, change in endoscopic camera).
MICCAI / AutoImplant 2021 (M.19.1): Cranial implant design for diverse synthetic defects on aligned skulls		No; substantial progress	Complex shapes in the "frontal" group of implant cases.
MICCAI / AutoImplant 2021 (M.19.2): Cranial implant design for real patient defects		No; minor progress	Big cranial defects. The given training data was strictly shape completion, but the predicted implants were evaluated against real cranial implants. This led to a mismatch in the shape of the predicted implant designs.
MICCAI / Where is VALDO (M.20.3): Segmentation of lacunes		No; minor progress	Dataset representativeness, e.g., sparsity of small elements of interest with potentially large variability in shape and intensity signature.
MICCAI / VWS (M.21.1): Vessel wall segmentation		No; substantial progress	Vessel wall segmentation at the carotid bifurcation, in the presence of flow artifacts or low SNR; complex plaque.

F. Open research questions

Table F. Overarching general open research questions extracted from this work.

Research question
How can we better integrate clinical context data in neural network solutions?
How can we effectively leverage temporal information in endoscopic video analysis?
How to do data augmentation in endoscopic video analysis?
How can we achieve generalization across biomedical devices, protocols, and caregivers involved in image acquisition?
How can we arrive at performance metrics that better address the biomedical domain interest?

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