

Interest of Digital Twin in Liver Surgery

Eric Vibert, MD, PhD, IKO

Tribute to Irene Vignon Clementel
and Stephane Cotin from INRIA



Links of interest in my lab of Digital Innovation for OR

bopA
bloc opératoire augmenté

Institut Mines-Télécom
université PARIS-SACLAY

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INRIA CNAM

Startups

LETTRIA Xperteye™

TOYS FILMS aneo
the other solution

LYNX MOON SURGICAL

caresyntax® OPEN MIND
NEUROTECHNOLOGIES

Mecenes

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relyens orange Boston Scientific Foundation FUJIFILM Arthrex

GETINGE Medtronic Johnson & Johnson THALES MEDTECH

Disclosure – Co Founder of Startup

Twinical

Digital Twins for better outcomes in oncologic liver surgery
Augment vision. Reduce errors. Save lives.



Mario Aricò, CEO
Ph.D. in Surgical Robotics
BFC19 INSEAD graduate



Stéphane Cotin, CSO
Research Scientist
Head of MIMESIS @INRIA



Eric Vibert, CMO
HPB Surgeon @ AP-HP
France2030 Ambassador



CHAIRE INNOVATION BOPA: ORGANISATION EN BLOC



CHAIRE INNOVATION BOPA: ORGANISATION EN BLOC

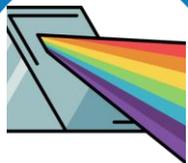
BLOC DATA



BLOC SCRUB



BLOC WAVE



BLOC HUMAN FACTORS



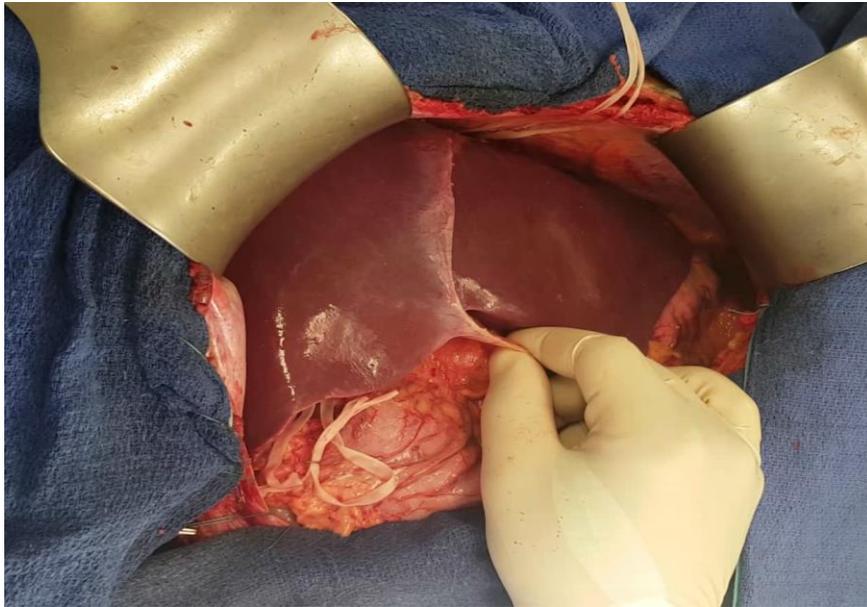
BLOC TWIN



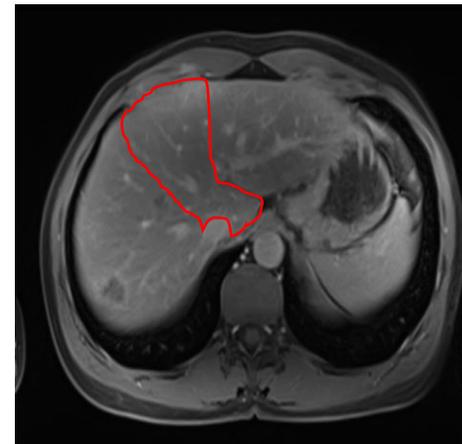
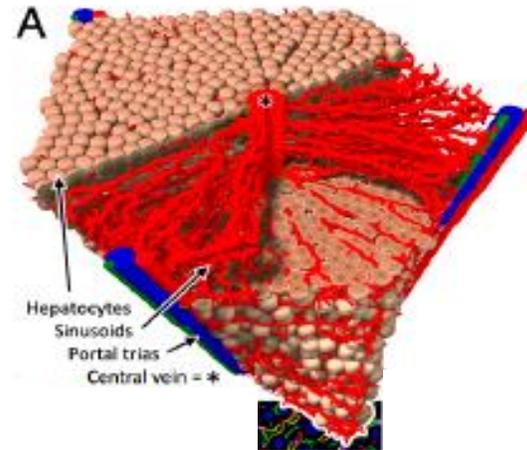
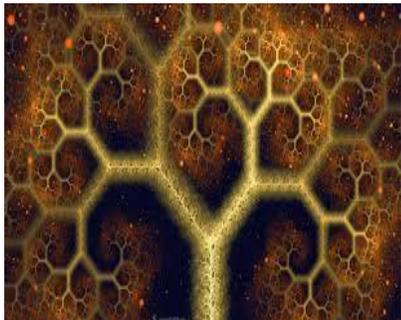
BOPA DANS SON ENVIRONNEMENT

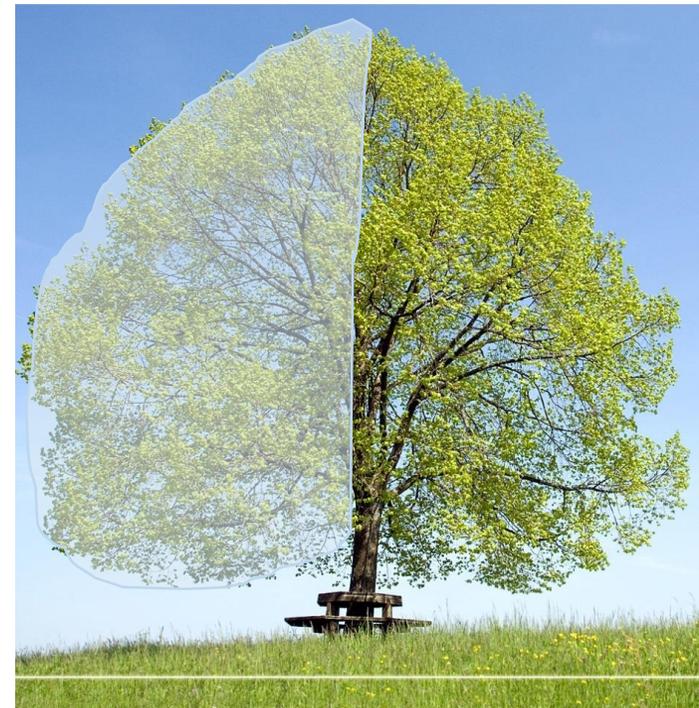
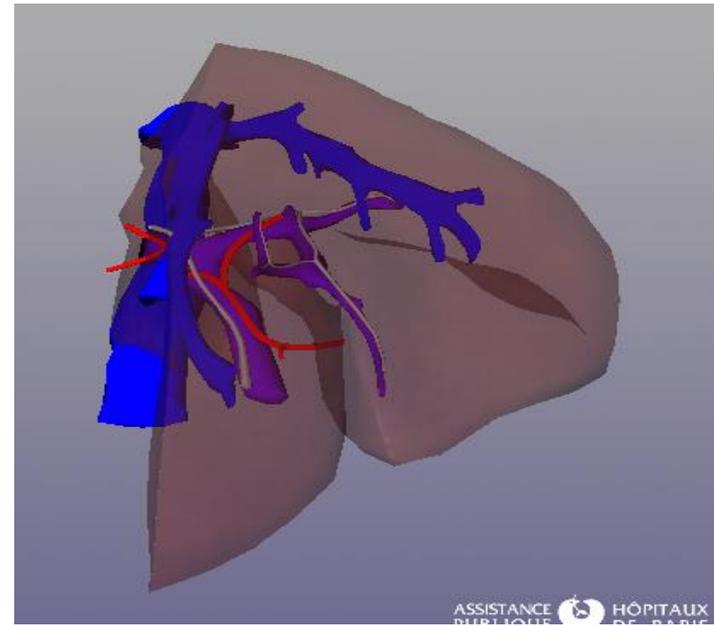
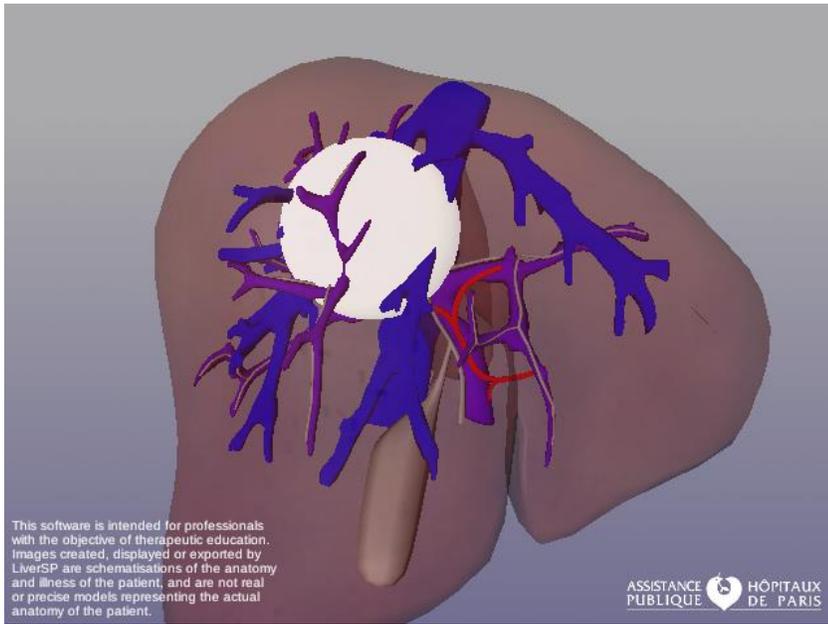


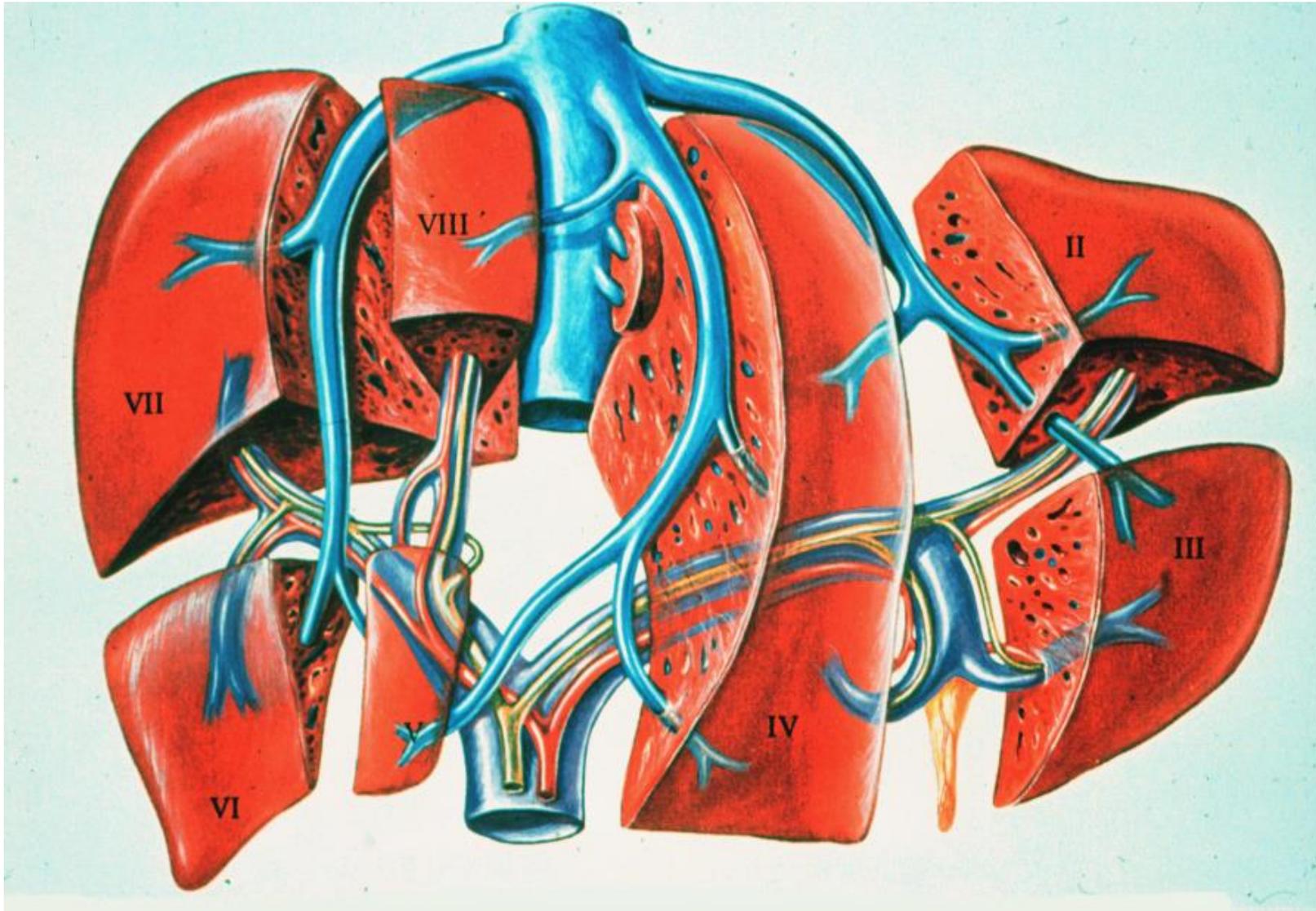
The Liver, a Well-Organized and Deformable Organ



A Soft Broccoli







Couinaud C. Le foie. Etudes anatomiques et Chirurgicale. Masson, 1957

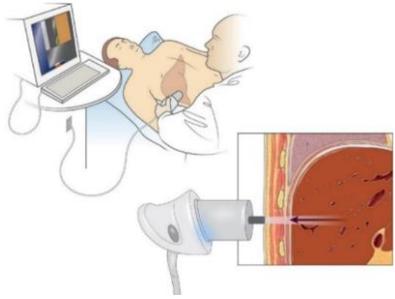
Bismuth H. Major and Minor segmentectomies "régliées" in liver surgery. World Journal Surgery 1982



The « Alphabet of the Liver »



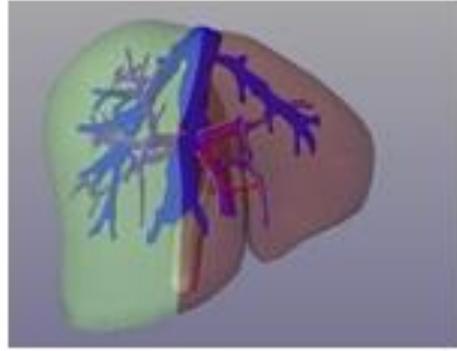
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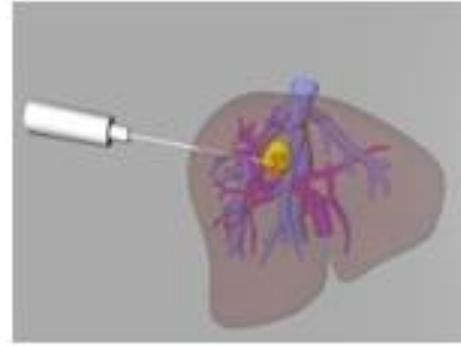
In absence of right large tumor



MELD < 9



MELD 9 à 12



MELD > 12



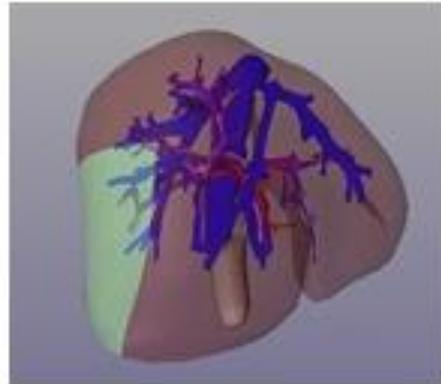
12 kPa

Spleen Vol > 400 ml ?

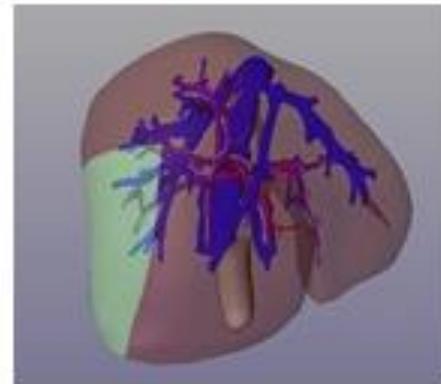
22 kPa

> 30 kPa

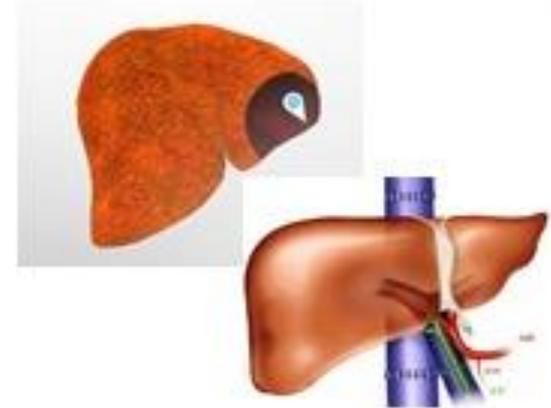
MELD < 12



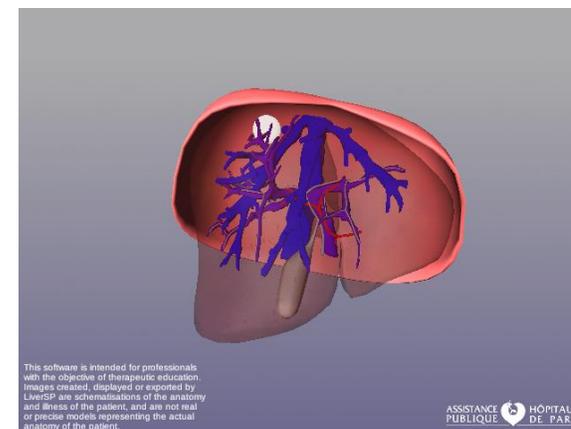
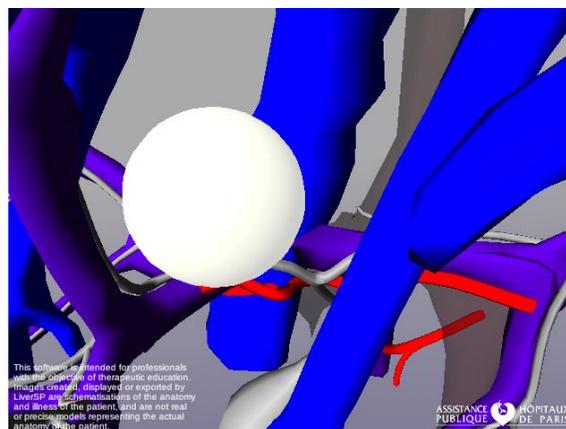
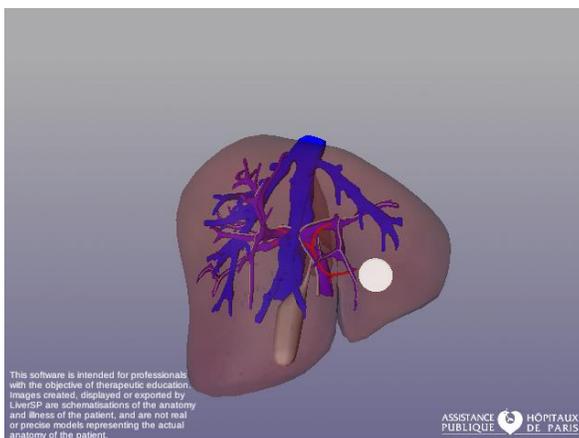
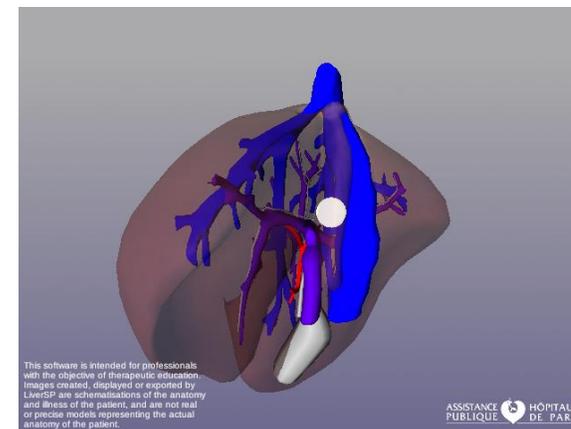
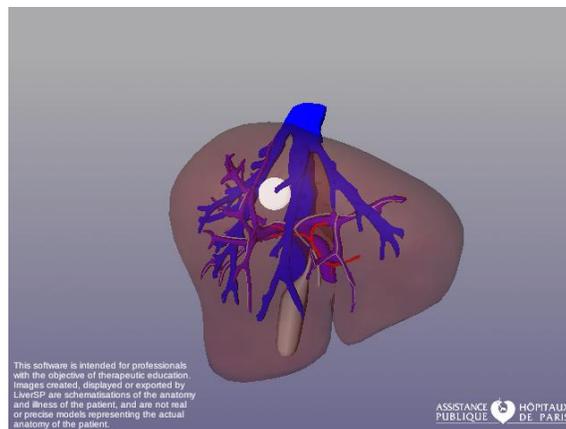
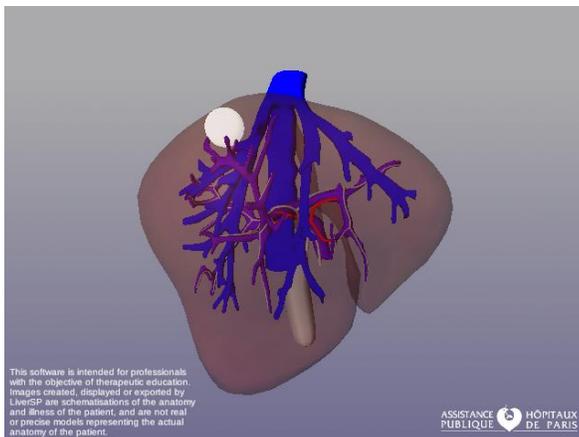
MELD < 12



MELD > 12



Tumor Location into the liver



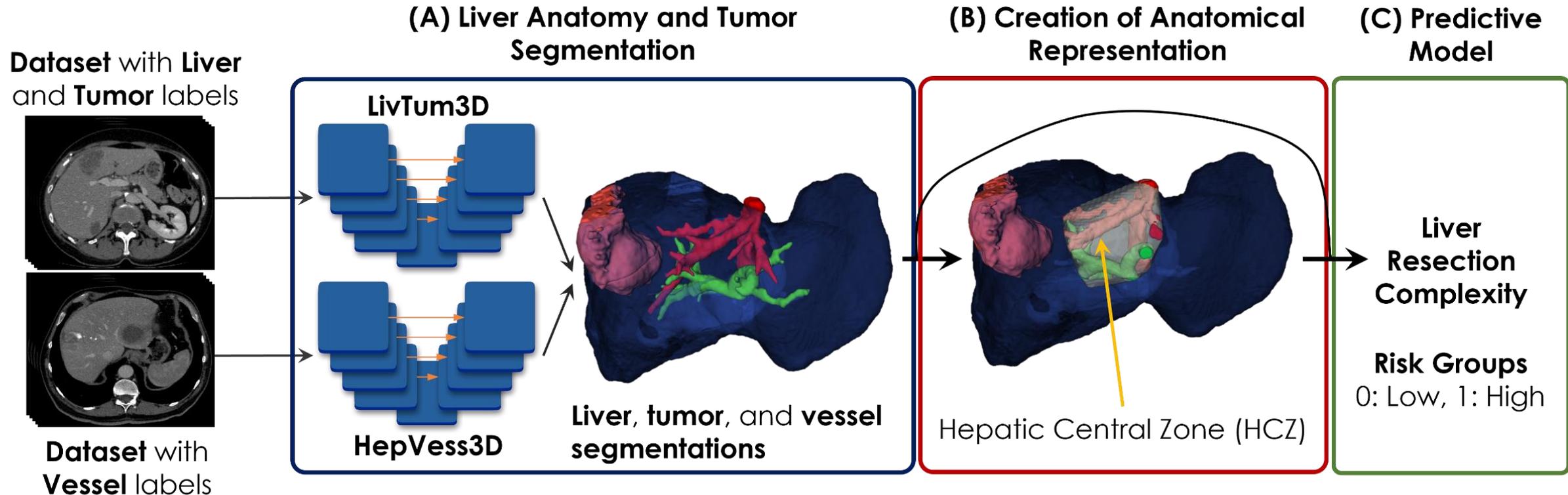
Digital Twin In Liver Surgery

Closer to the complexity of reality
to improve safety in surgery



1. A common digital reference to talk about the same thing to learn and identify complex cases to adapt the patient journey
2. Anticipate the anatomical and hemodynamic consequences of our treatment
3. Feed and Optimize the Model to grow the digital twin

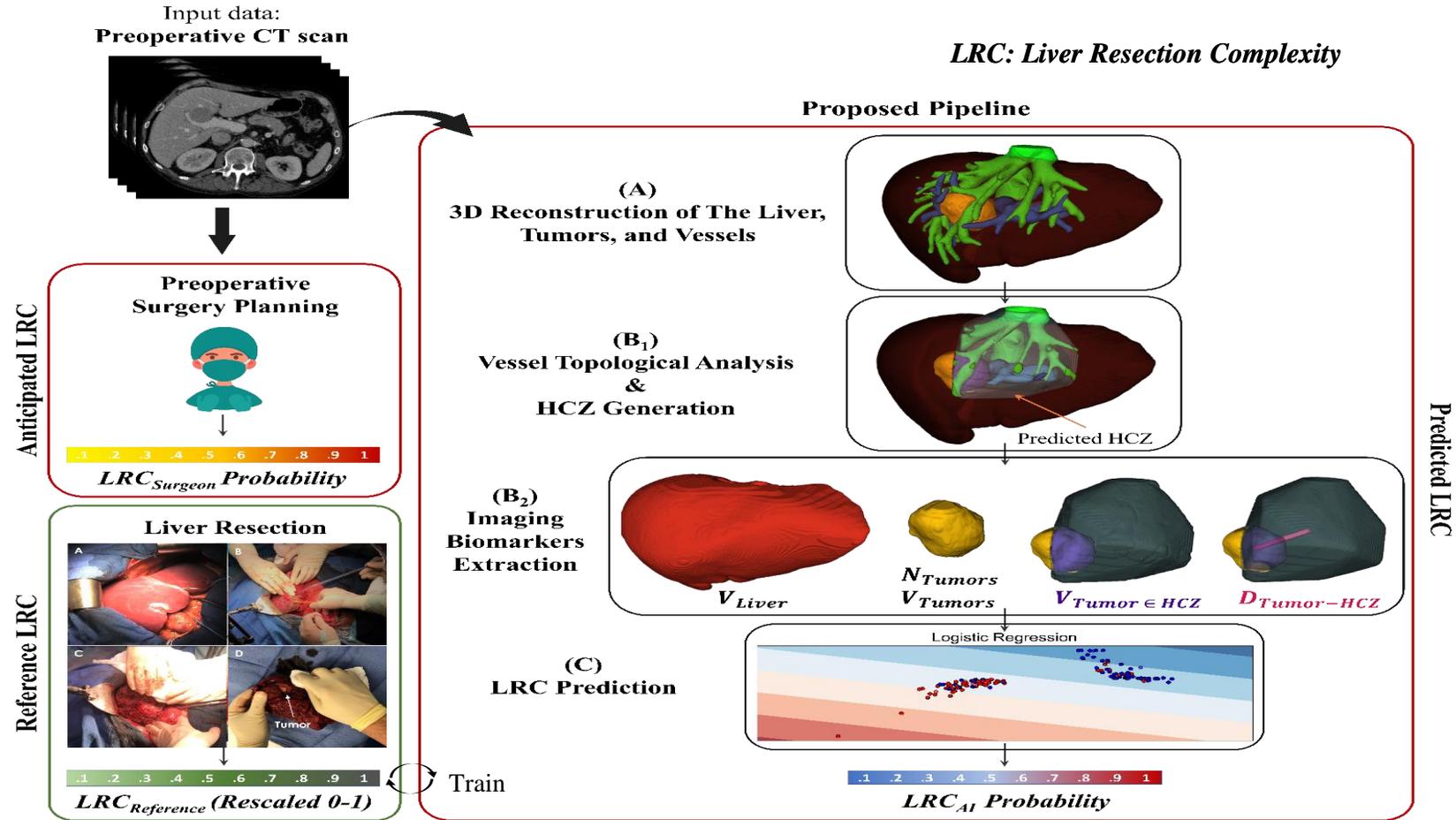
Digital “quantification” to identify complexity and help non “expert” surgeon



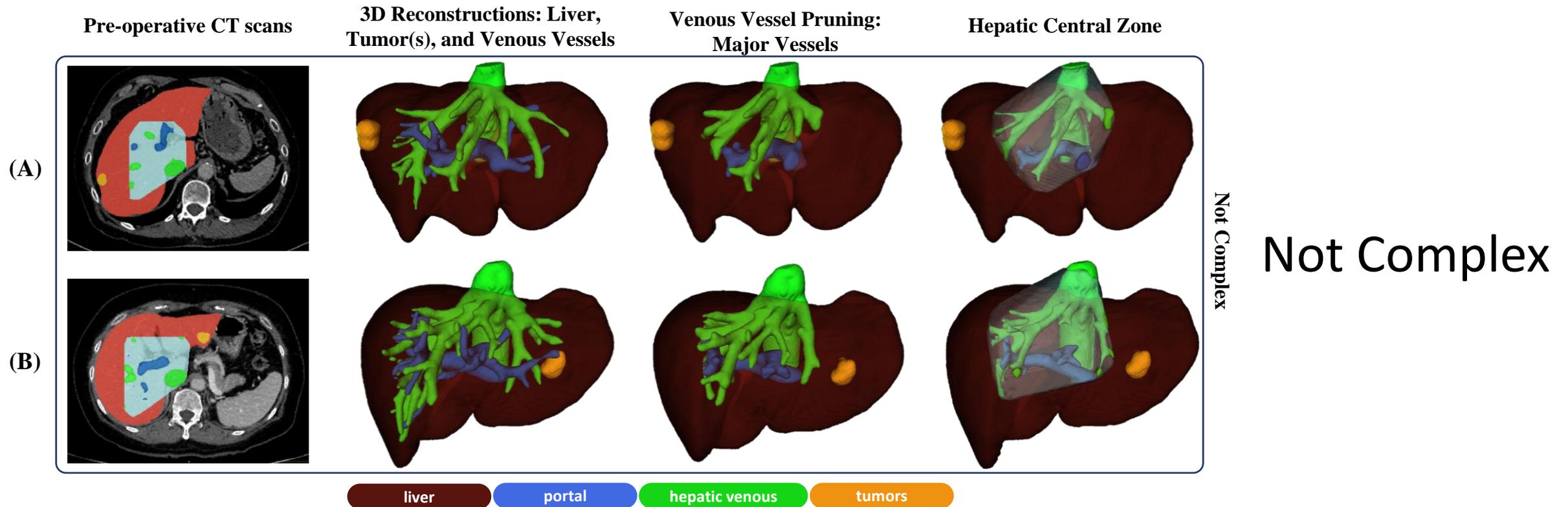
N=145 Pts with HCC

Quantifier Numérique les Rapports entre une anatomie ET une tumeur

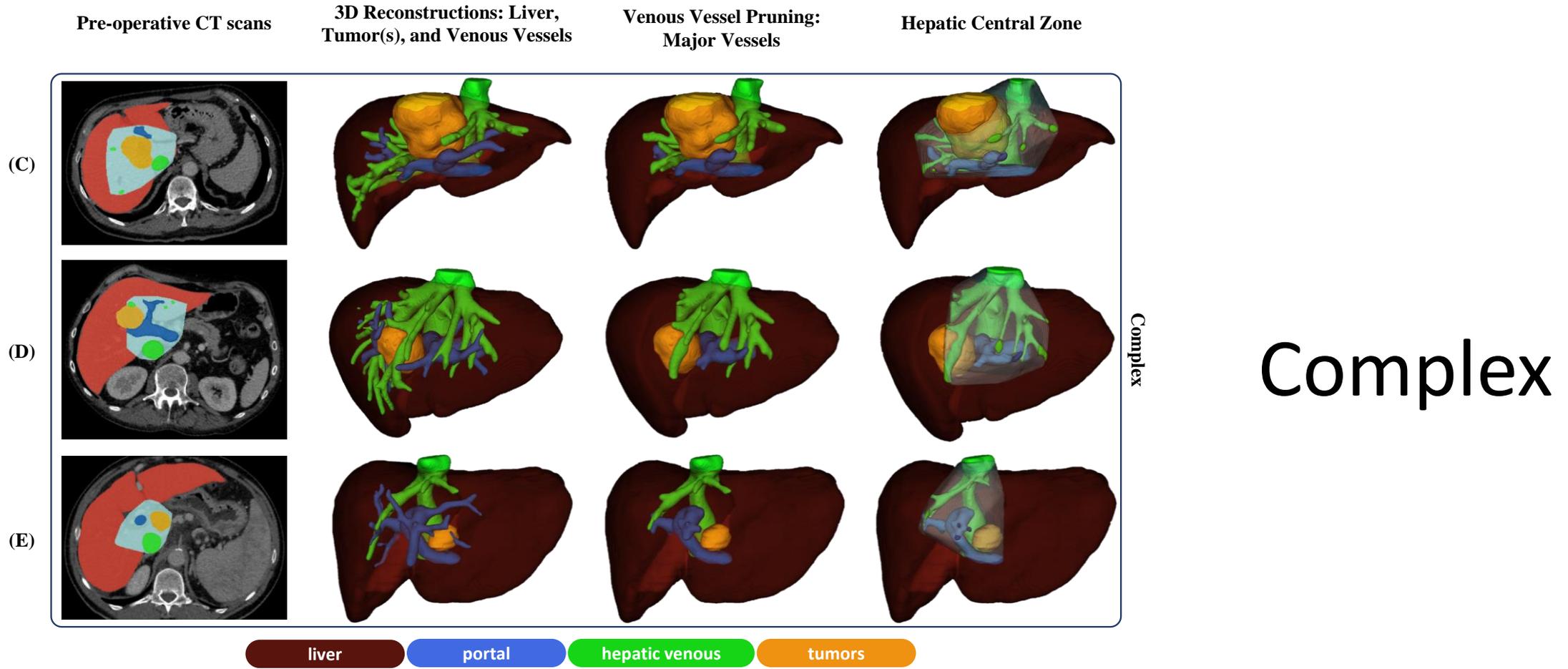
Digital Liver Resection Complexity Prediction



Automatic Prediction of Liver Resection Complexity



Automatic Prediction of Liver Resection Complexity

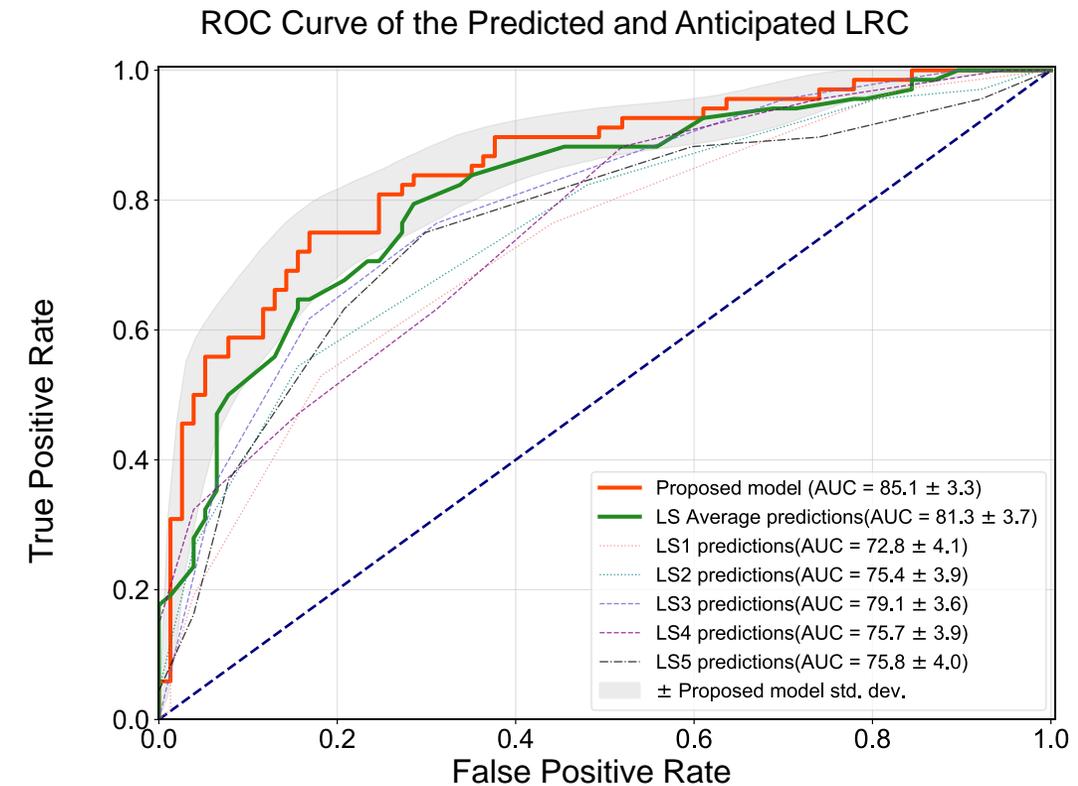
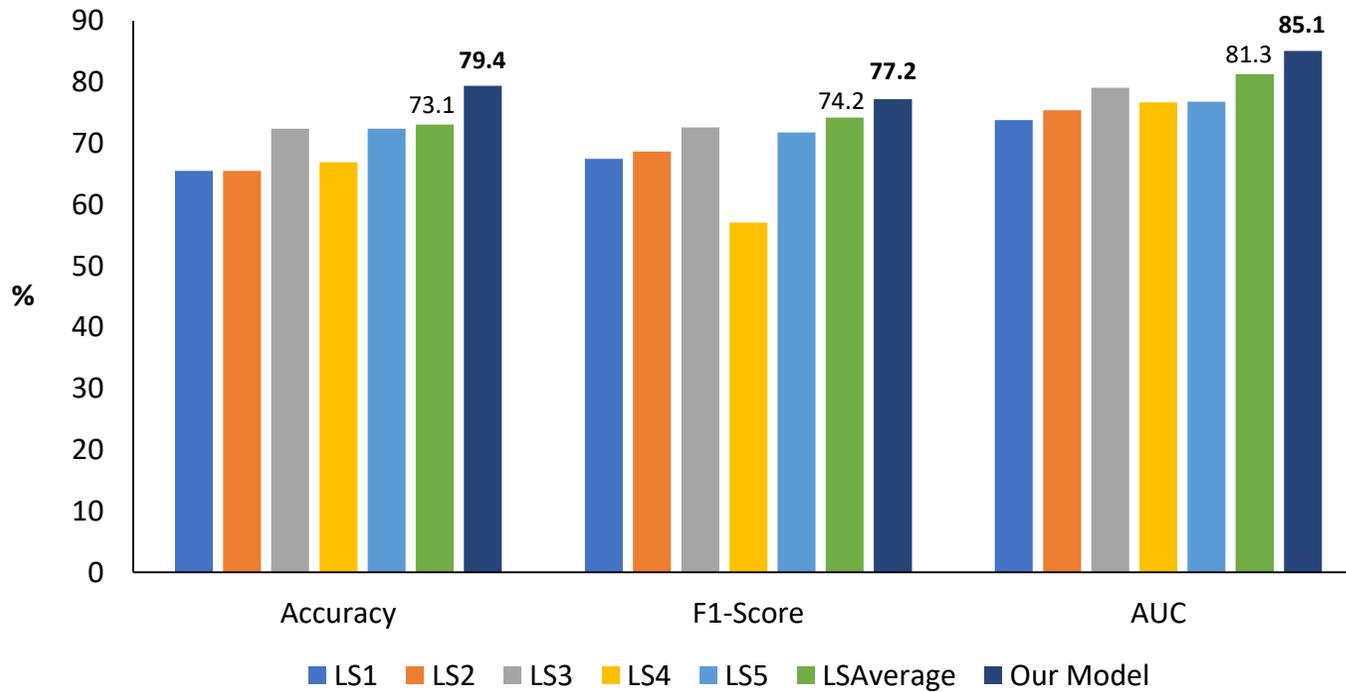


Complex

Liver Resection Complexity Prediction

■ Liver Resection Complexity: Quantitative Results

□ Proposed model surpasses individual and combined predictions of the five liver surgeons

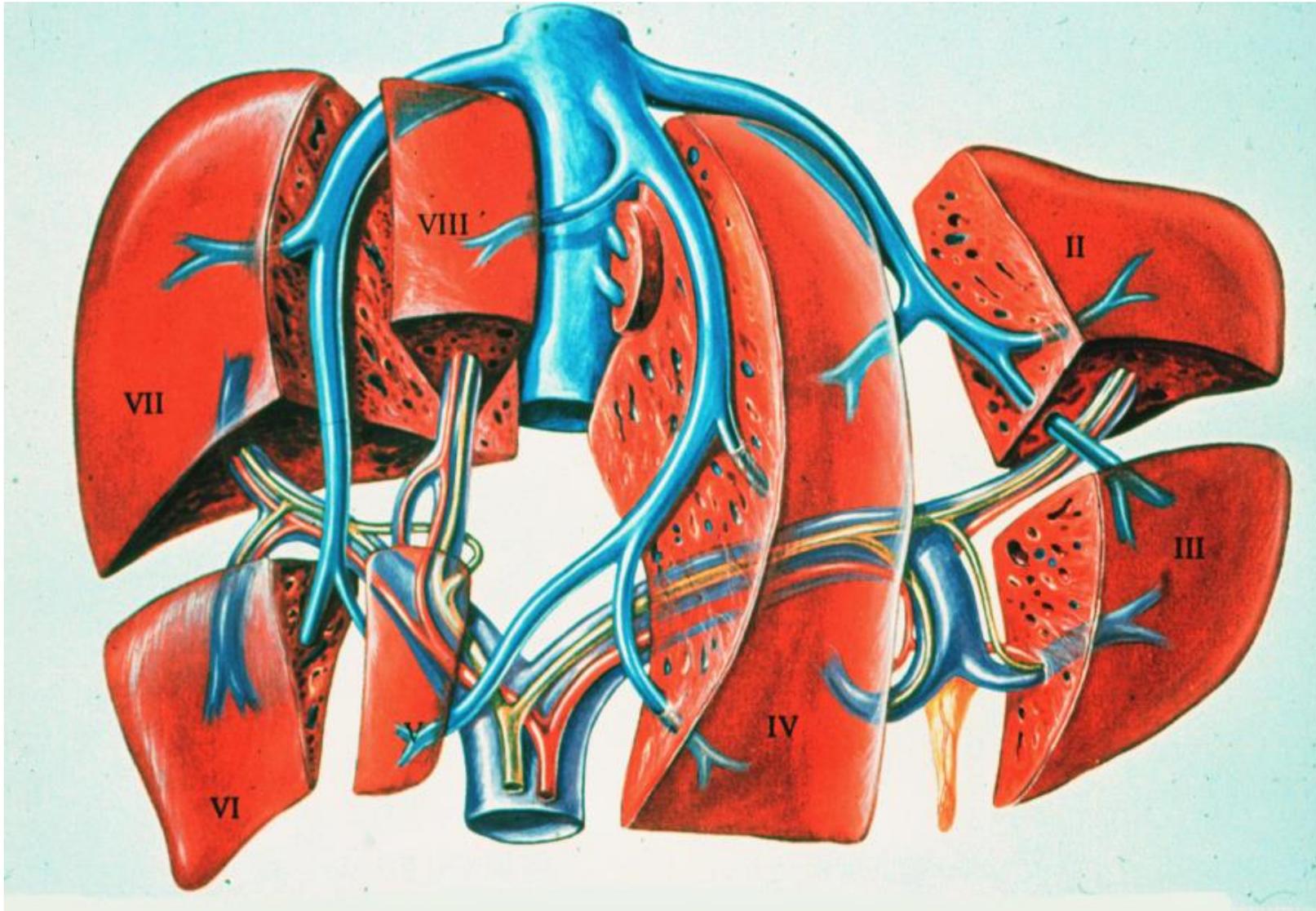


Digital Twin In Liver Surgery

Closer to the complexity of reality
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- 2. Anticipate the anatomical and hemodynamic consequences of our treatment**
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Couinaud C. Le foie. Etudes anatomiques et Chirurgicale. Masson, 1957

Bismuth H. Major and Minor segmentectomies "régliées" in liver surgery. World Journal Surgery 1982



The « Alphabet of the Liver »

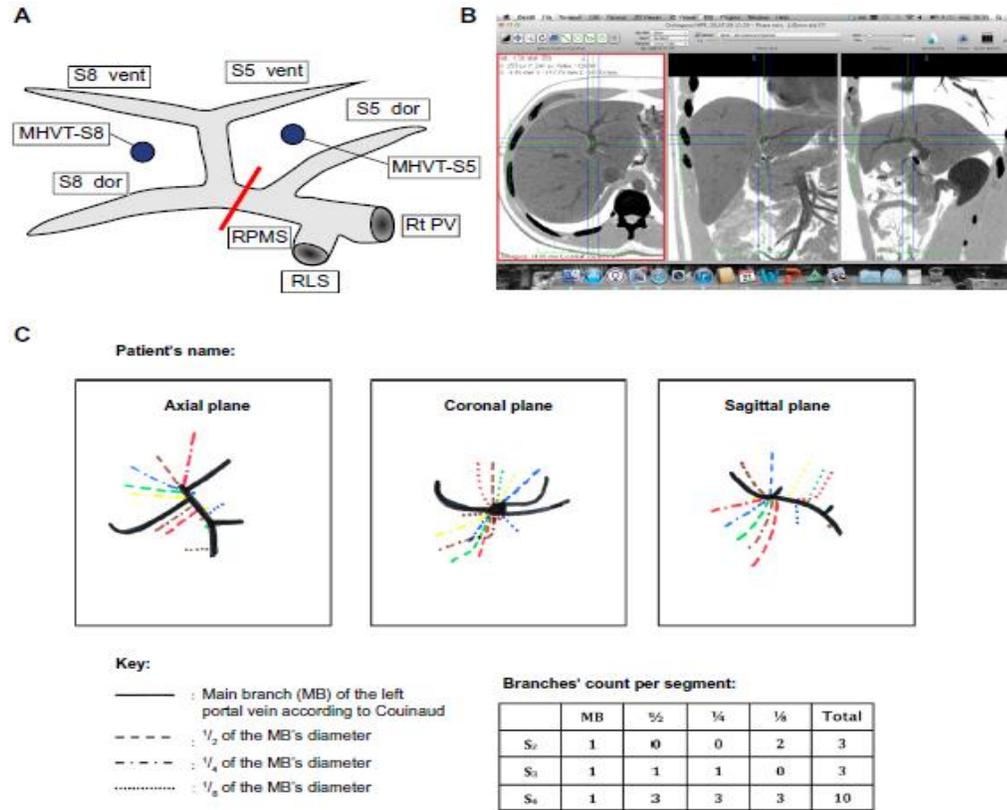


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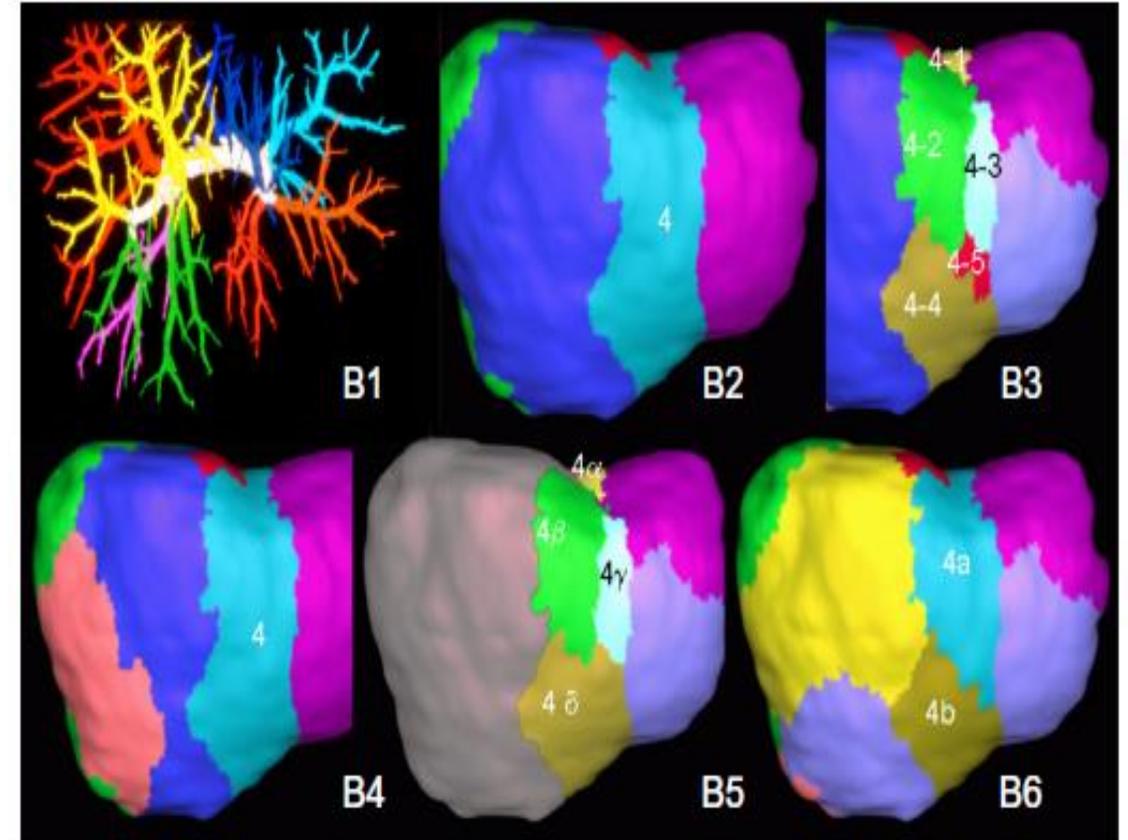
Anatomy of the liver: An outline with three levels of complexity – A further step towards tailored territorial liver resections

Pietro Majno^{1,*}, Gilles Mentha¹, Christian Toso¹, Philippe Morel¹, Heinz O. Peitgen²,
Jean H.D. Fasel³

¹Hepatobiliary Center, Digestive Surgery and Transplantation Units, Department of Surgery, University Hospitals of Geneva, Switzerland; ²Fraunhofer Institute for Medical Image Computing, Bremen, Germany; ³Anatomy Sector, Department of Cellular Physiology and Metabolism, Faculty of Medicine, University of Geneva, Switzerland

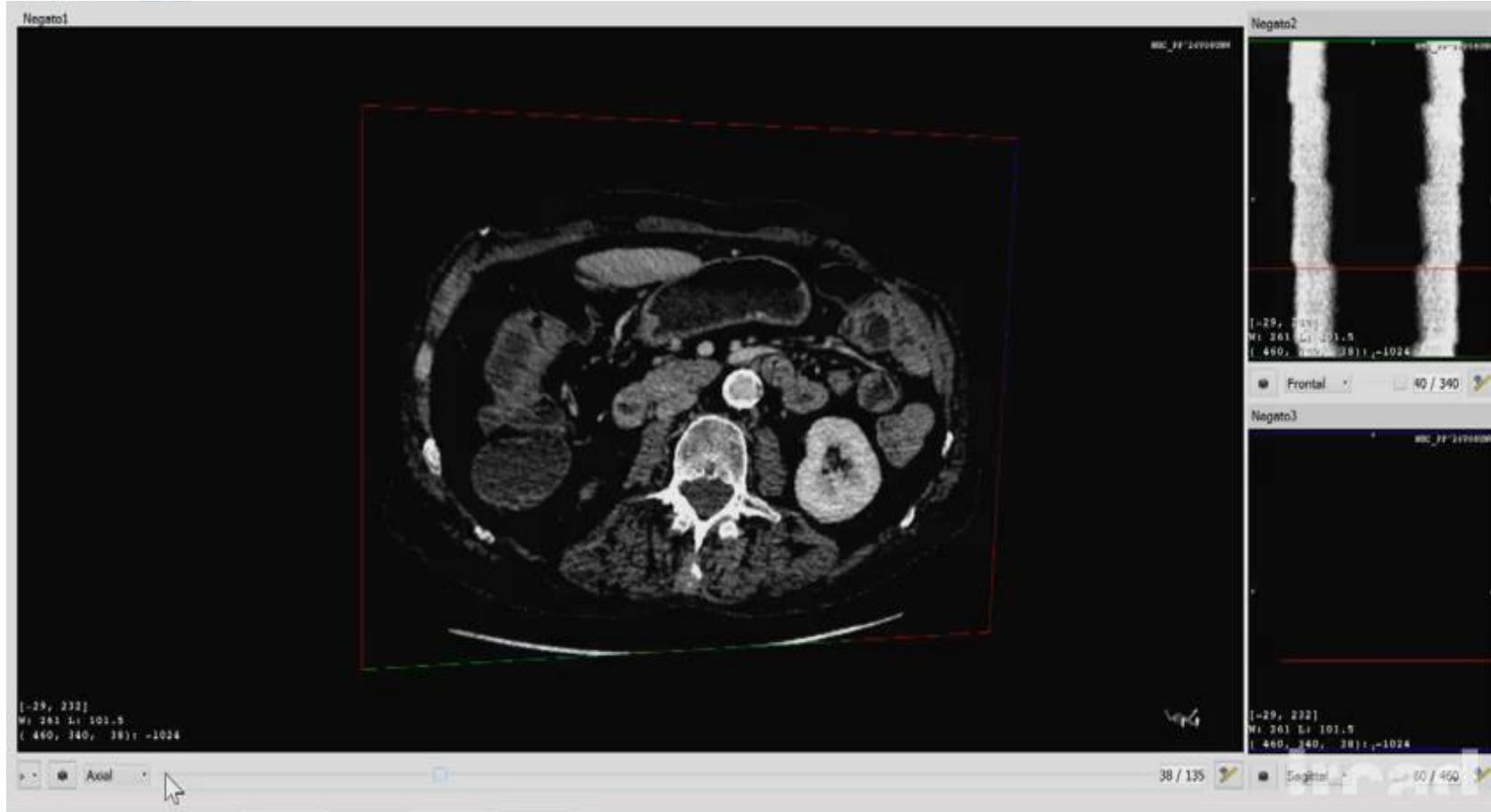


Adapt the level of anatomical complexity to the objective...



Couinaud Schema is correct for the staff meeting but not always for the surgery...

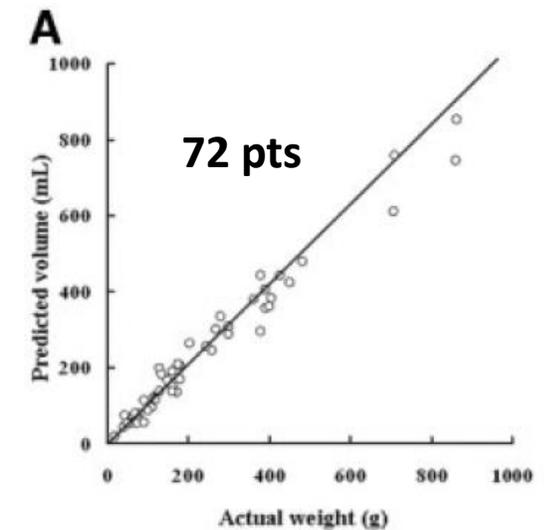
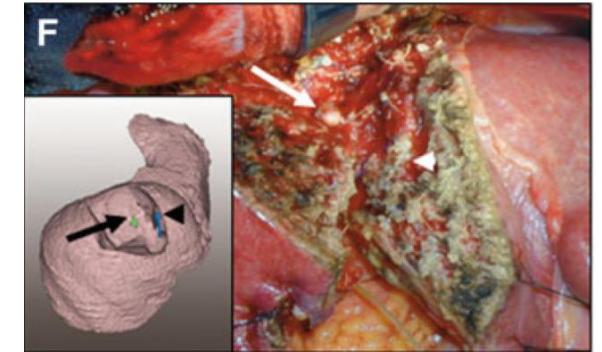
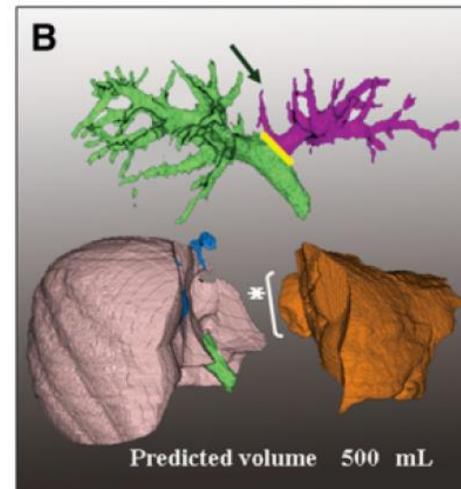
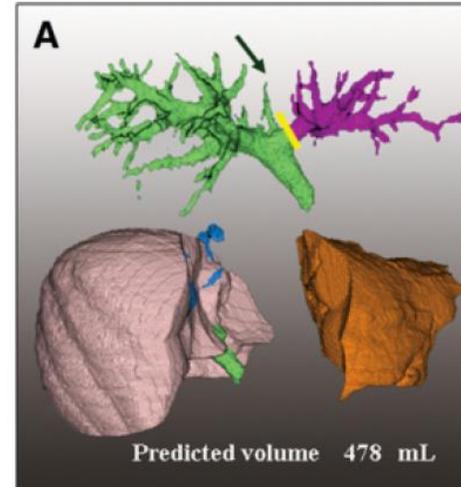
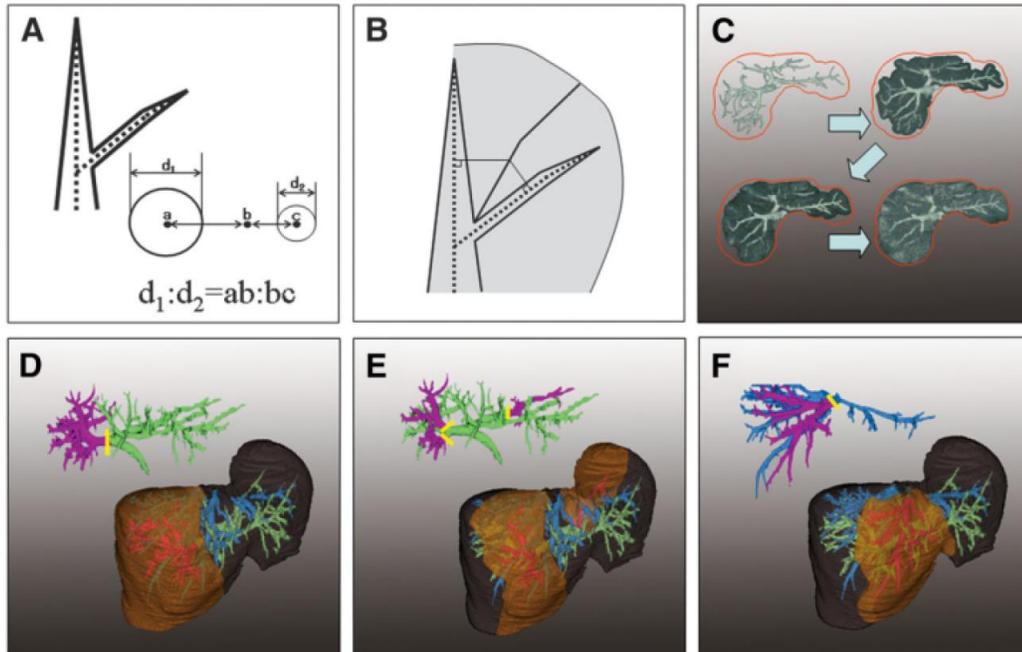
From Standard Anatomy to Personalized



An « old » Japanese Surgical Tradition of PRECISION

A Novel 3D Hepatectomy Simulation Based on Liver Circulation: Application to Liver Resection and Transplantation

Shinichi Saito,¹ Junichi Yamanaka,¹ Koui Miura,² Norio Nakao,² Tomohiro Nagao,³ Takaaki Sugimoto,¹
Tadamichi Hirano,¹ Nobukazu Kuroda,¹ Yuji Iimuro,¹ and Jiro Fujimoto¹

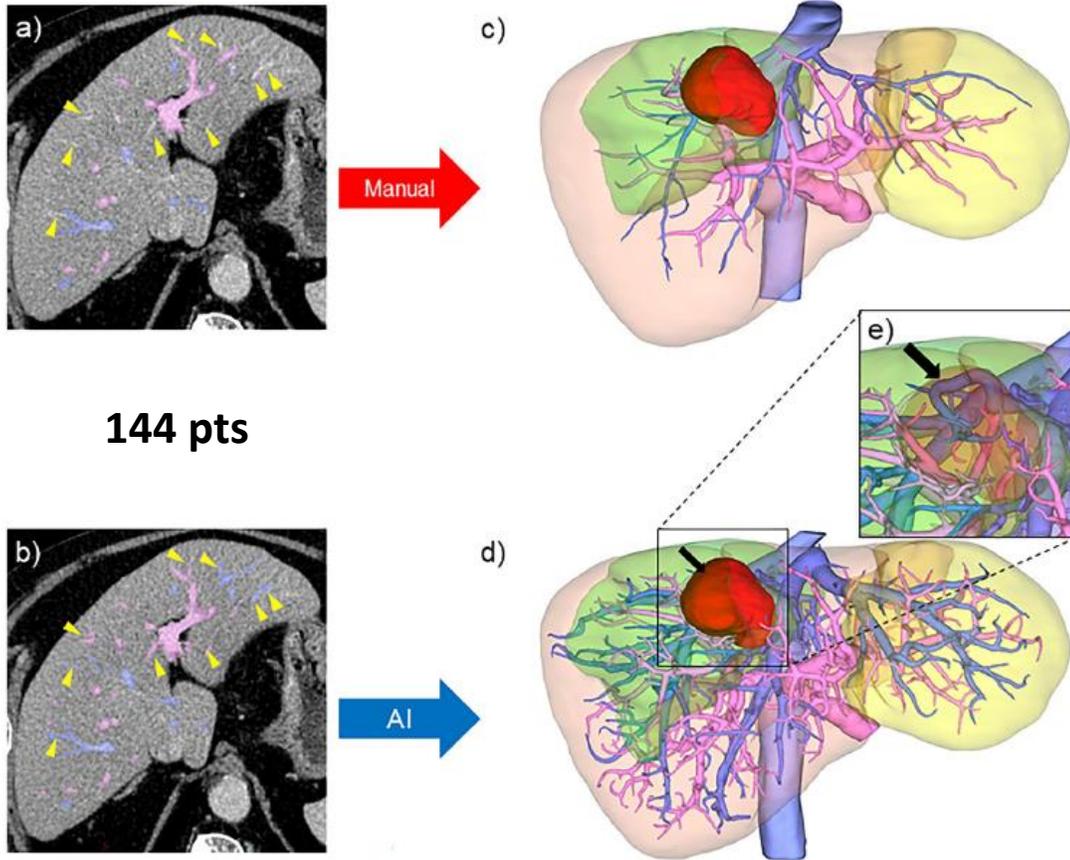


PVE or Not ?

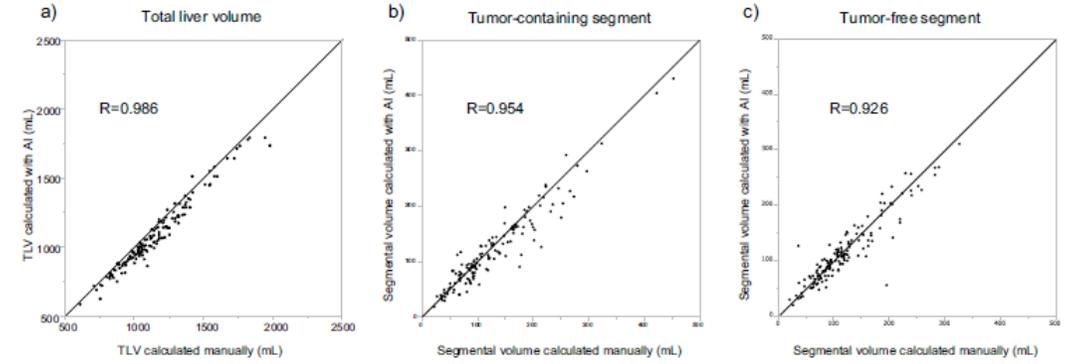
Hepatology 2005

Automated Three-Dimensional Liver Reconstruction with Artificial Intelligence for Virtual Hepatectomy

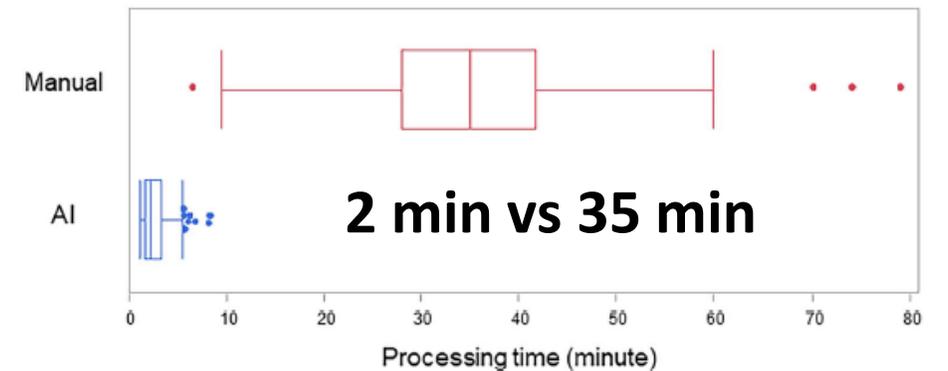
Takeshi Takamoto¹ · Daisuke Ban¹ · Satoshi Nara¹ · Takahiro Mizui¹ · Daisuke Nagashima¹ · Minoru Esaki¹ · Kazuaki Shimada¹



144 pts



More Precise, Reliable and Very Rapid



Less Post Operatives Complications with 3D...

A meta-analysis of the three-dimensional reconstruction visualization technology for hepatectomy



Yu Liu, Qing Wang, Bo Du, XuZhi Wang, Qian Xue, WeiFeng Gao*

Department of Hepatobiliary Surgery, People's Hospital of Leshan, Sichuan Leshan, 614000, China

12 Retrospectives studies that evaluated some intraoperatives and postoperatives data with or without preoperative virtual hepatectomy : 2053 Patients

Studies	Year	Country	Disease types	Age(years) ^a	3D reconstruction system	Sample Size			NOS
						Total	3D-RVT	N3D-RVT	
Fang et al	2013	China	NLT	50.6 ± 11.5/53.5 ± 12.6	MI-3DVS ^b	98	56	42	8
Wei et al	2015	China	LT	50 ± 10.6/48 ± 10.0	3D Plus Body Visible System, Yorktal Medical, ShenZhen, China	74	31	43	7
Fang et al	2015	China	LT	47.5 ± 13.8/46.5 ± 13.3	MI-3DVS ^b	116	60	56	8
He et al	2015	China	NLT	41.4 ± 13.1/42.5 ± 13.2	IQQA Liver, EDDA Technology, Princeton, NJ, United States	106	59	47	6
Okuda et al	2015	Japan	LT	64 ± 11/66 ± 9	IAP ^c	118	49	69	7
Su et al	2016	China	LT	NA	Hisense CAS system	26	16	10	6
Guan et al	2016	China	NLT	52.9 ± 11.6/53.3 ± 11.9	MI-3DVS ^b	148	74	74	7
Mise et al	2017	Japan	LT	68 (22–85)/68 (19–88)	Surgical Planning Software	802	297	505	7
Nakayama et al	2017	Japan	LT	67 (17–81)/65 (22–80)	Synapse Vincent, FUJIFILM Medical Co., Ltd., Tokyo, Japan	240	120	120	7
Yang et al	2018	China	LT	NA	Transparent VeroClear™ and RGD720	30	15	15	6
Zhang et al	2021	China	NLT	NA	NA	200	100	100	6
Zhu et al	2022	China	LT	57.6 ± 9.2/60.2 ± 9.2	TM-MIS 1.0, Tuomeng Science and Technology Ltd, Heilongjiang, China	95	37	58	7

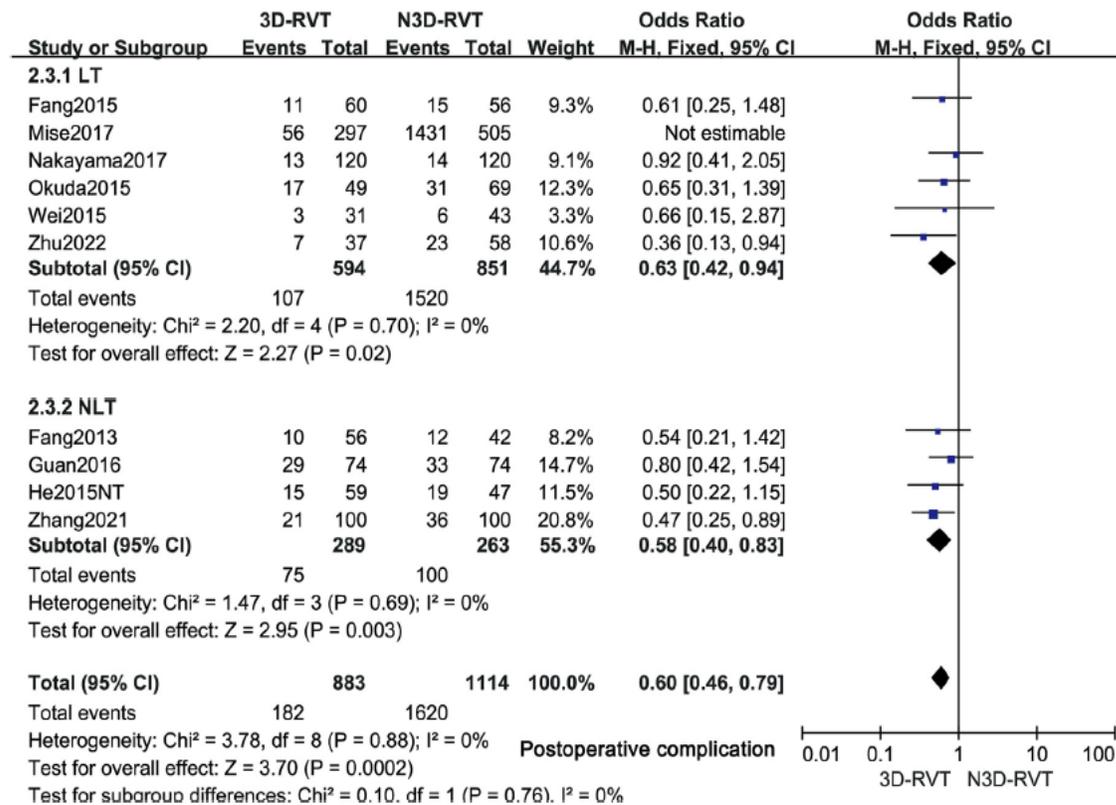
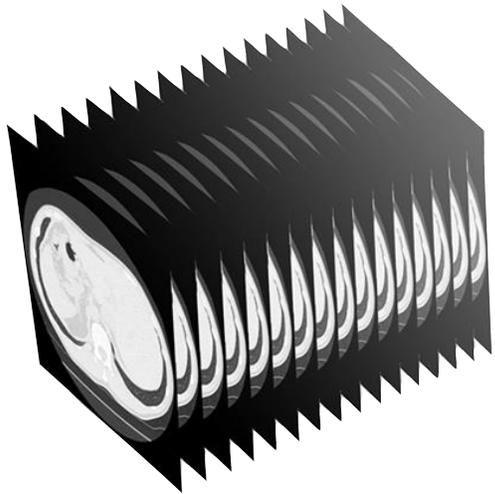


Fig. 7. Forest plot of overall postoperative complications in combined and subgroup analysis.

From 3D Liver Reconstruction to Digital Liver Twin

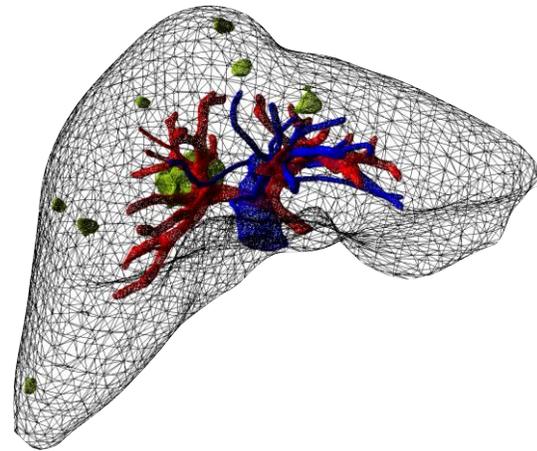
“Digital twins use data from sensors installed on physical objects to determine the objects’ real-time performance, operating conditions, and changes over time. Using this data, the digital twin evolves and continuously updates to reflect any change to the physical counterpart ... creating a closed-loop of feedback in a virtual environment.”

Stephane Cotin, Famous French Mathematician



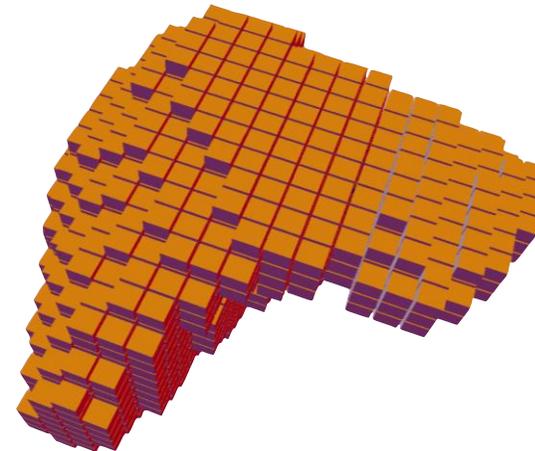
1

Automatic segmentation from medical images



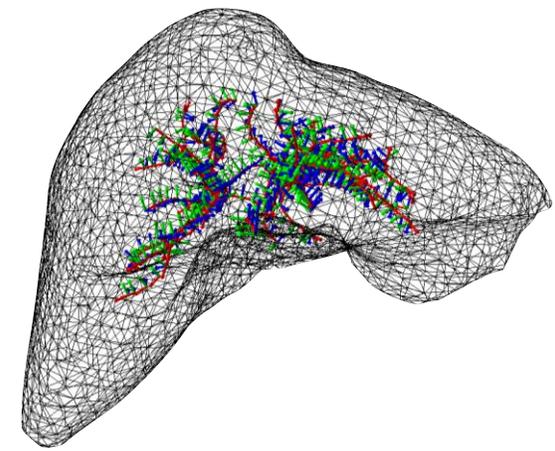
2

Automatic 3D reconstruction of anatomical structures



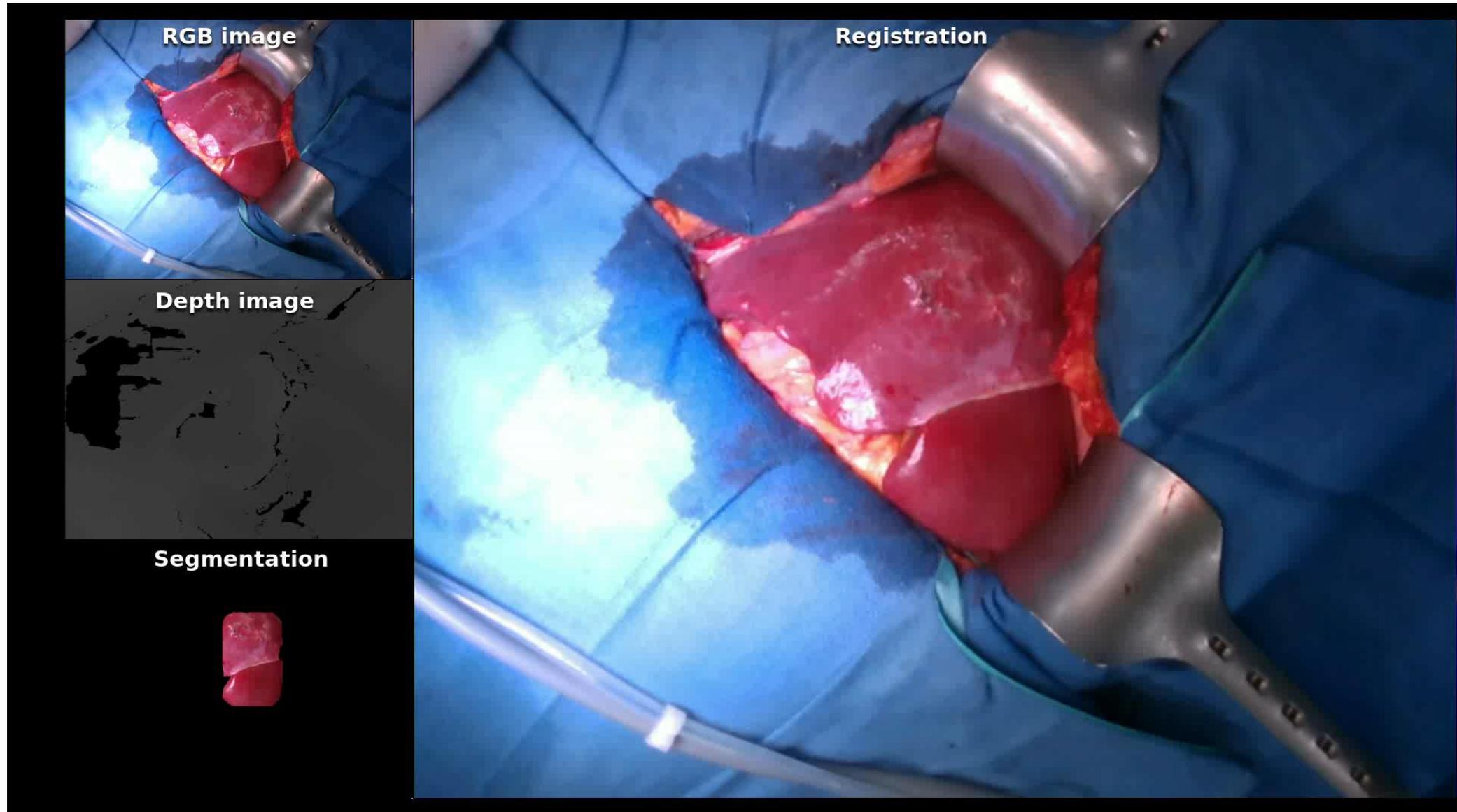
3

Stable and automatic FEM mesh generation using an immersed boundary approach

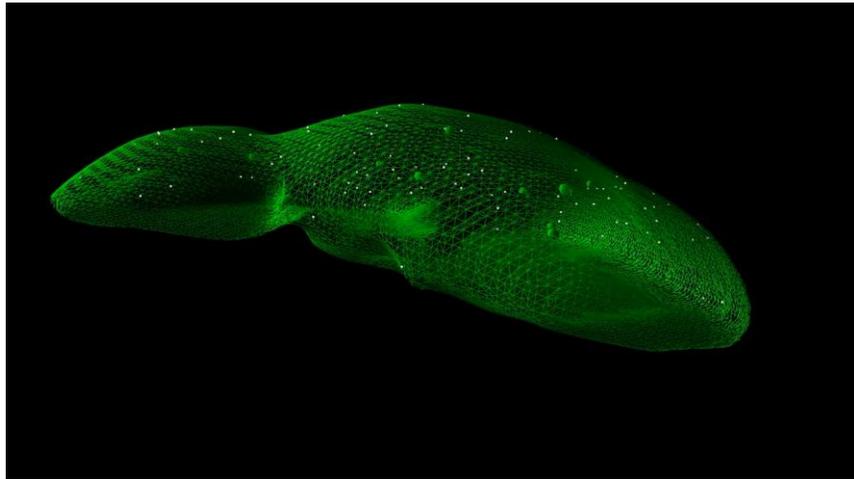


4

Integration of vessels as beam elements for improved simulation



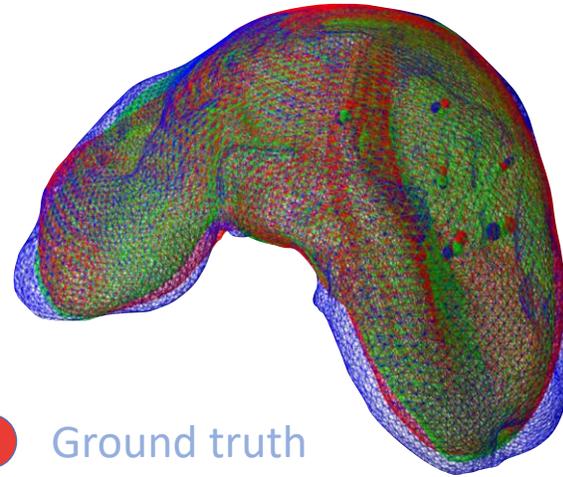
Deep Physics for elastic registration and validation



Our U-mesh method

Computation time 3 ms per time step

Accuracy mean TRE: 2.9 mm



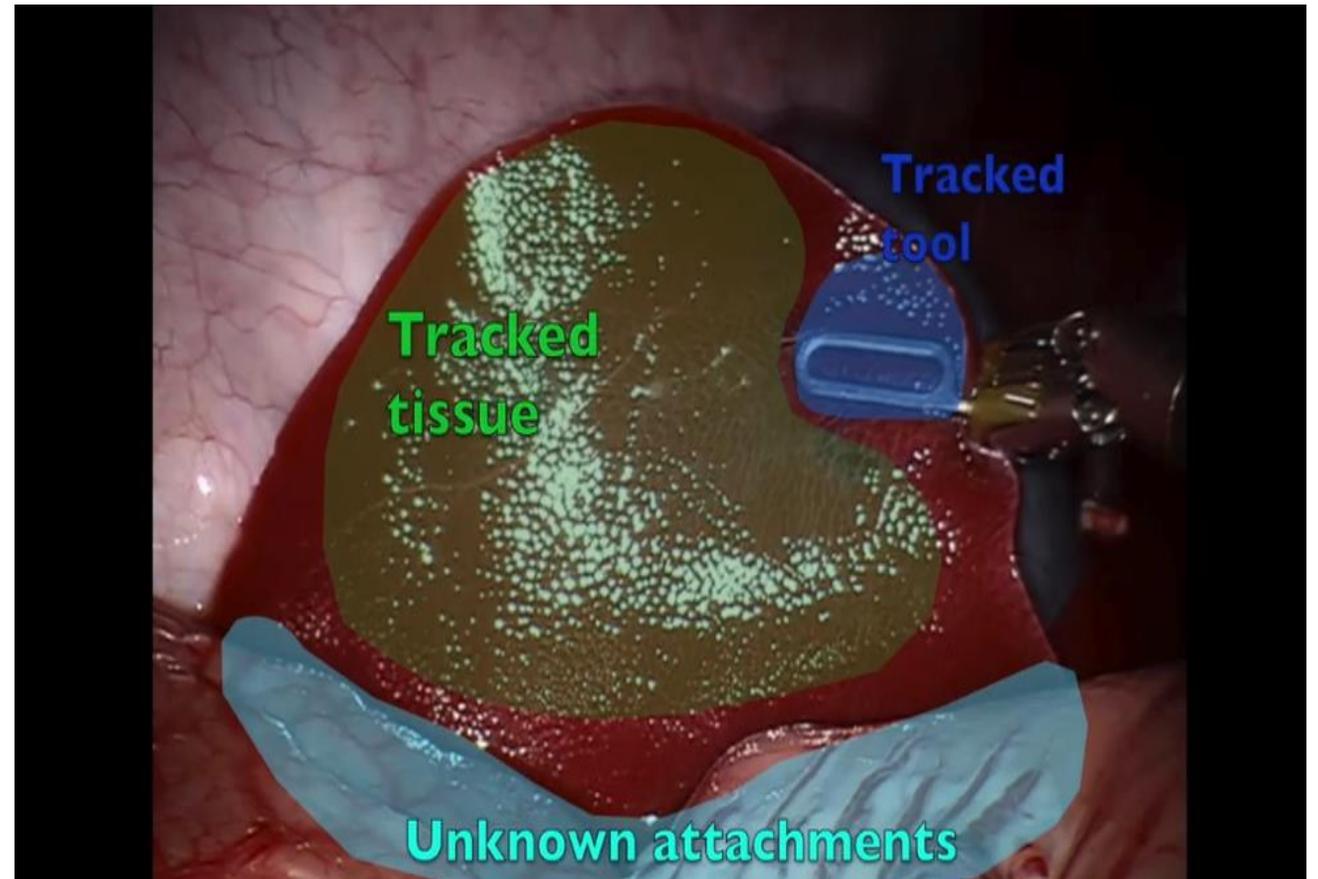
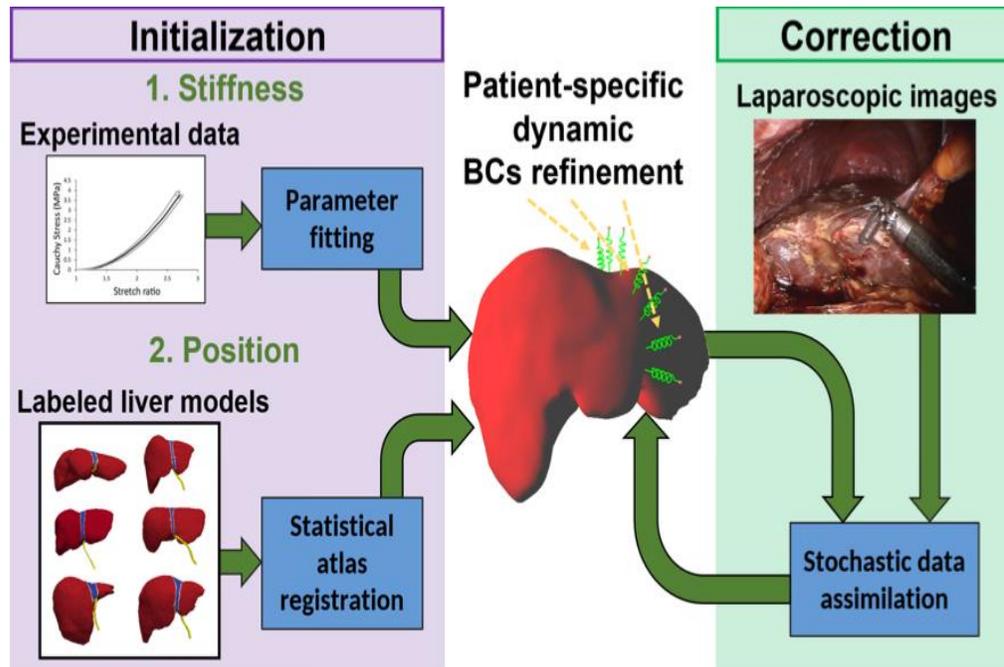
- Ground truth
- U-mesh prediction
- FEM model

Validation on ex vivo
explanted human
liver



Deformed under CT Scan
Including Cholangiography

Look what happen during surgery today to create very realistic models tomorrow...



Twinical

Digital Twins for better outcomes in oncologic liver surgery

Augment vision. Reduce errors. Save lives.



Mario Aricò, CEO
Ph.D. in Surgical Robotics
BFC19 INSEAD graduate



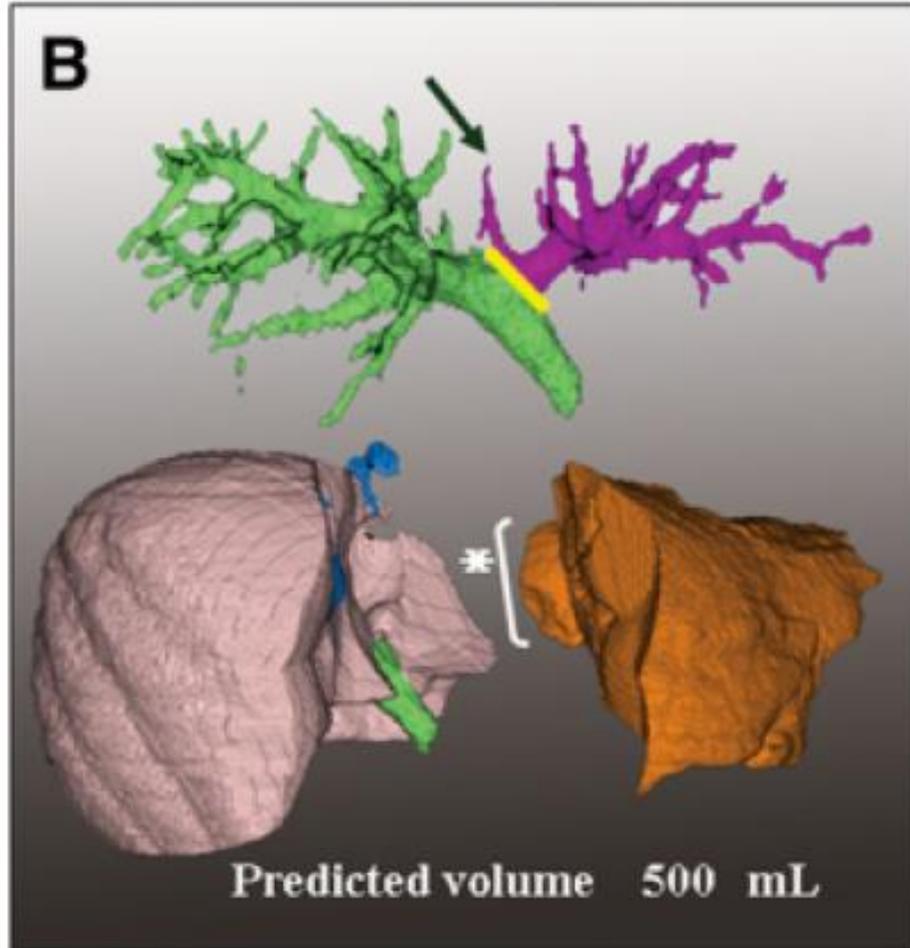
Stéphane Cotin, CSO
Research Scientist
Head of MIMESIS @INRIA



Eric Vibert, CMO
HPB Surgeon @ AP-HP
France2030 Ambassador



To operate after the limit defined by liver volume



ORIGINAL ARTICLES FROM THE ESA PROCEEDINGS

Posthepatectomy Portal Vein Pressure Predicts Liver Failure and Mortality after Major Liver Resection on Noncirrhotic Liver

Marc-Antoine Allard, MD,† René Adam, MD, PhD,*†§ Pétru-Octav Bucur, MD,*†‡ Salah Termos, MD,*† Antonio Sa Cunha, MD,*†‡ Henri Bismuth, MD, PhD, Denis Castaing, MD,*†‡ and Eric Vibert, MD, PhD*†‡*

Hepatic venous pressure gradient in the preoperative assessment of patients with resectable hepatocellular carcinoma

Alessandro Cucchetti*, Matteo Cescon, Rita Golfieri, Fabio Piscaglia, Matteo Renzulli, Flavia Neri, Alberta Cappelli, Federico Mazzotti, Cristina Mosconi, Antonio Colecchia, Giorgio Ercolani, Antonio Daniele Pinna

The Portal Caval Gradient < 12 mmHg at the end of surgery is the key to avoid post-operative death

RESEARCH ARTICLE | ARTICLES IN PRESS

Predicting the risk of post-hepatectomy portal hypertension using a digital twin: A clinical proof of concept

Nicolas Golse • Florian Joly • Prisca Combari • ... René Adam • Eric Vibert •

Irene E. Correspondence information about the author Nicolas Golse

Published: November 15, 2020 • DOI: <https://doi.org/10.1016/j.jhep.2020.10.036>

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PlumX Metrics

Highlights

Graphical abstract

Keywords

References

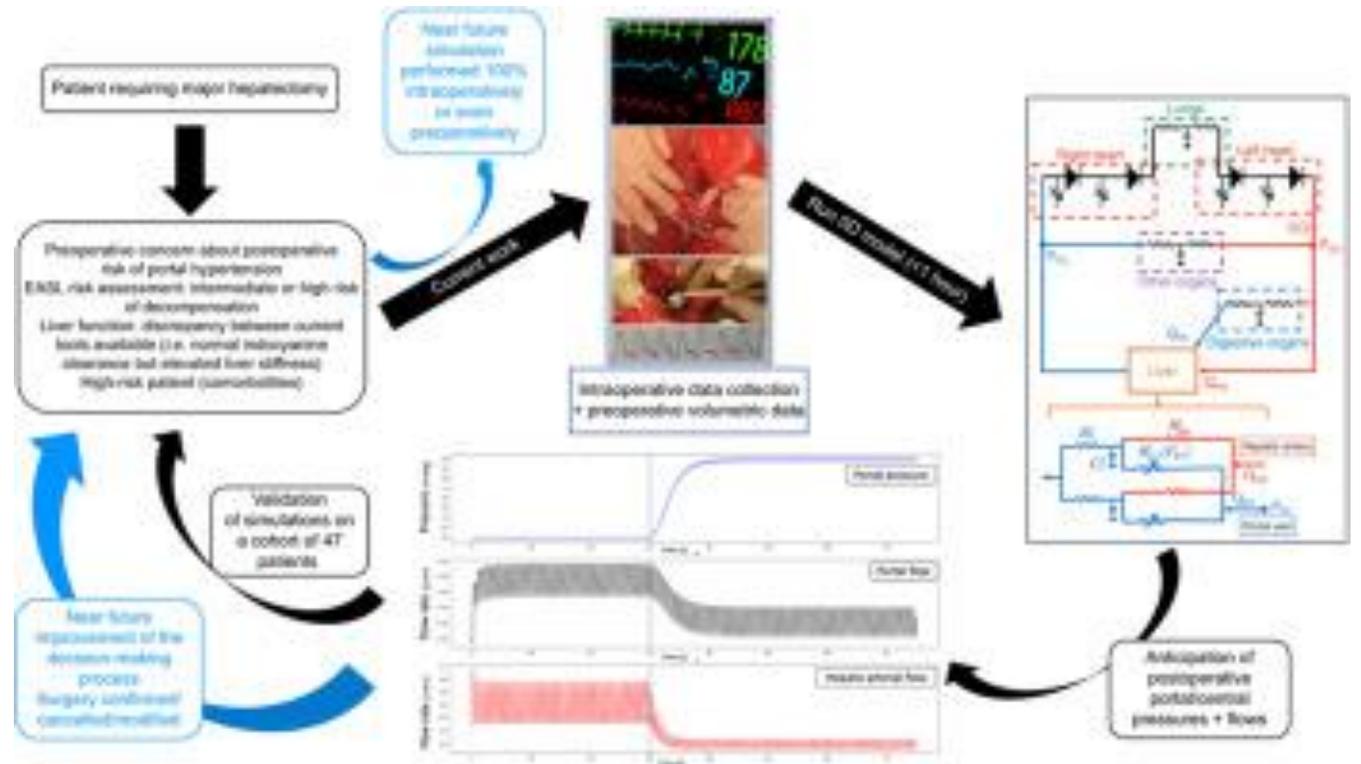
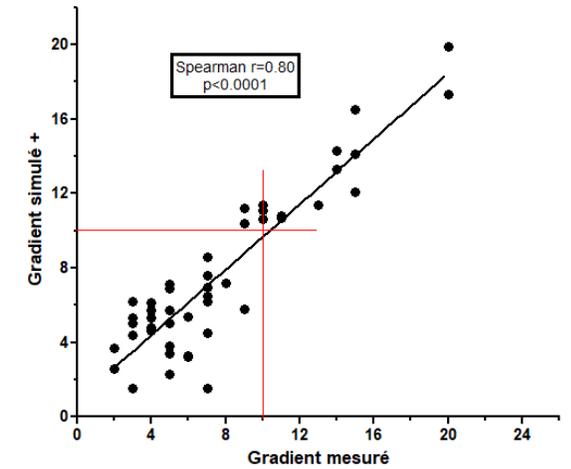
Article Info

Highlights

- Personalized predictors of postoperative portal hypertension level are still lacking.
- We developed a mathematical model to anticipate postoperative hemodynamics.
- This patient specific numerical tool is accurate in major hepatectomy setting.
- It can be applied for cirrhotic or non-cirrhotic patients.
- In the near future, it could be used in the clinical decision-making process.

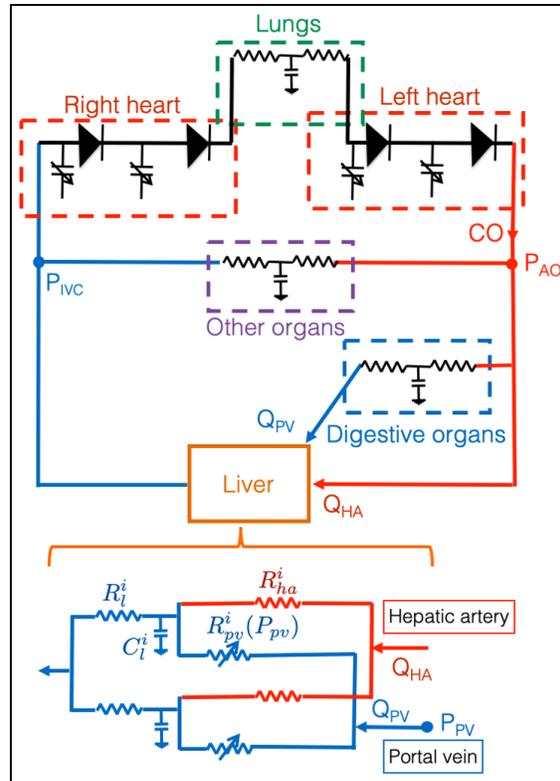
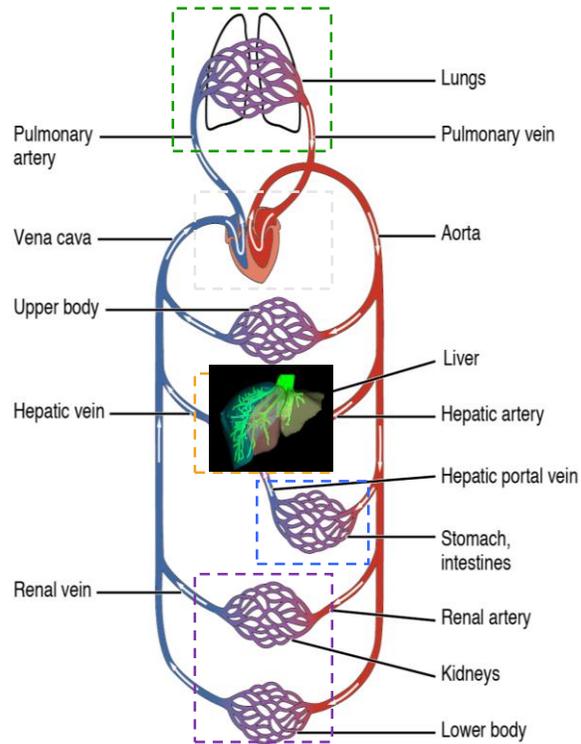
How anticipate ACCURATELY the hemodynamic consequence of our surgery according to the futur liver remnant volume ?

Corrélation Grad. porto-cave mesuré vs simulé+ débits estimés, calibrat° auto (n=47)



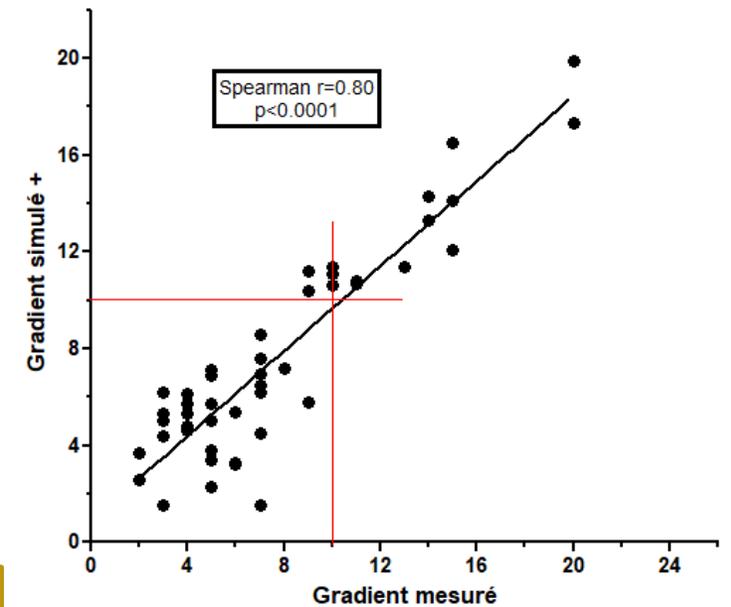
Digital twin concept to predict porto-caval gradient

OD Model

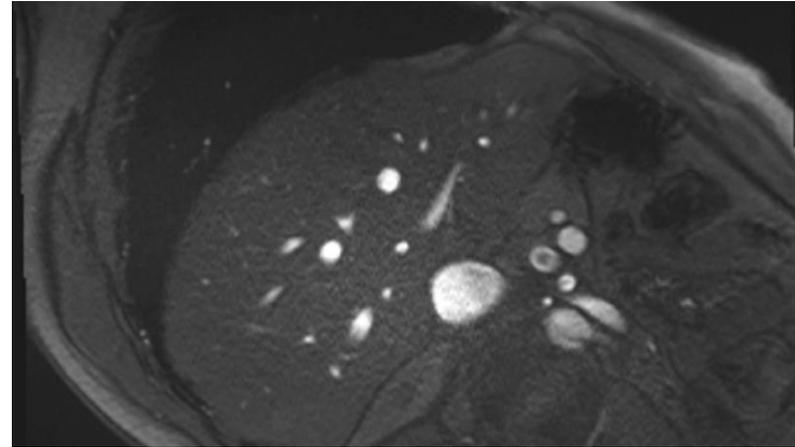
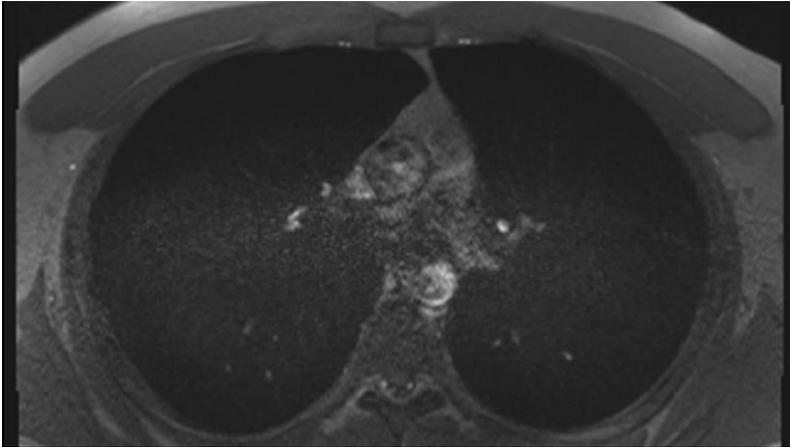


Intraoperative data collection + preoperative volumetric data

Corrélation Grad. porto-cave mesuré vs simulé+ débits estimés, calibrat° auto (n=47)

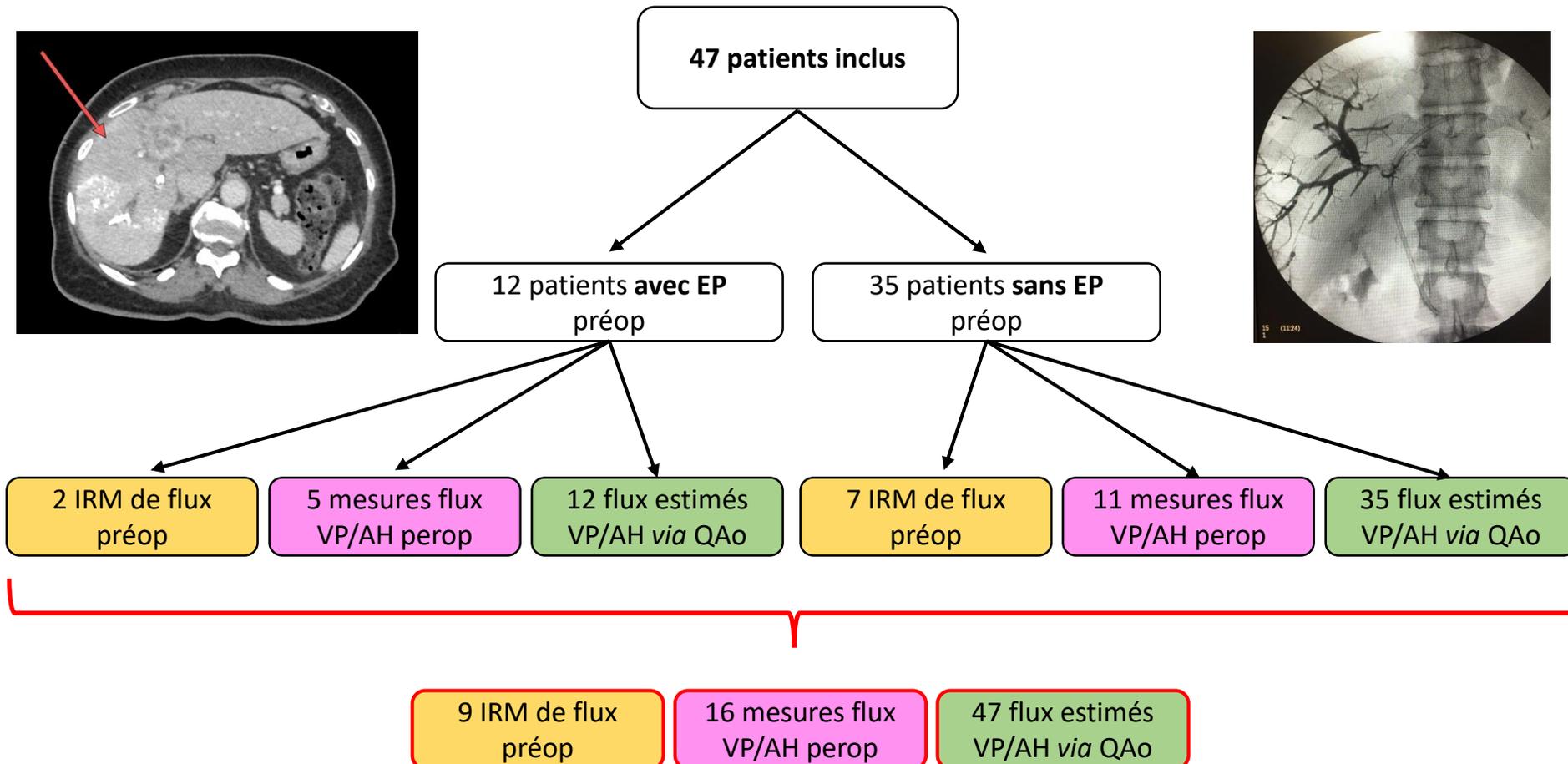


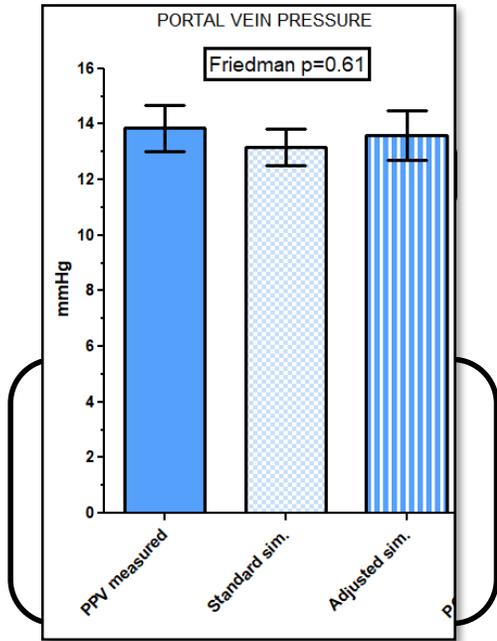
Flow MRI Preoperatively to measure Aortic and Portal Flow...



« Estimated data » for hepatic arterial flow : 5% of the measure aortic flow (Vilgrain et al. J Radiol 2002)

Prospective Evaluation of OD model in human in Paul Brousse



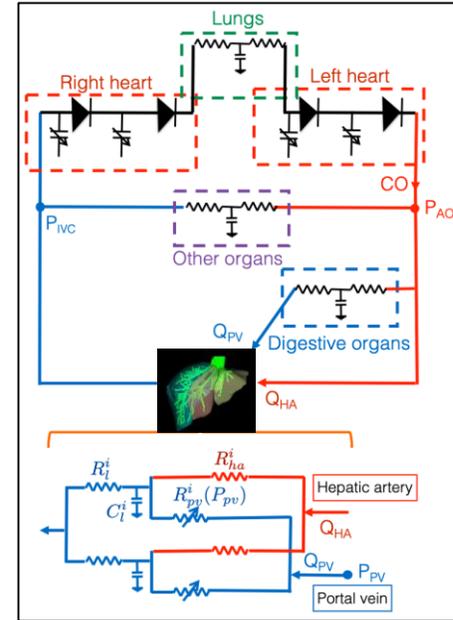


Current work

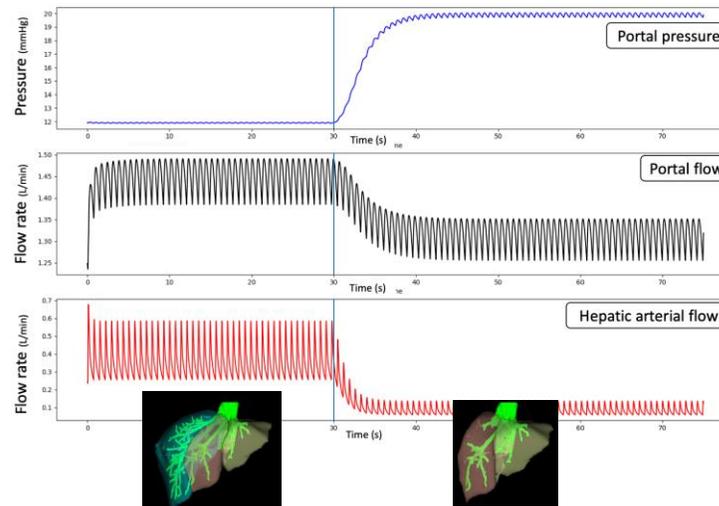


Intraoperative data collection + preoperative volumetric data

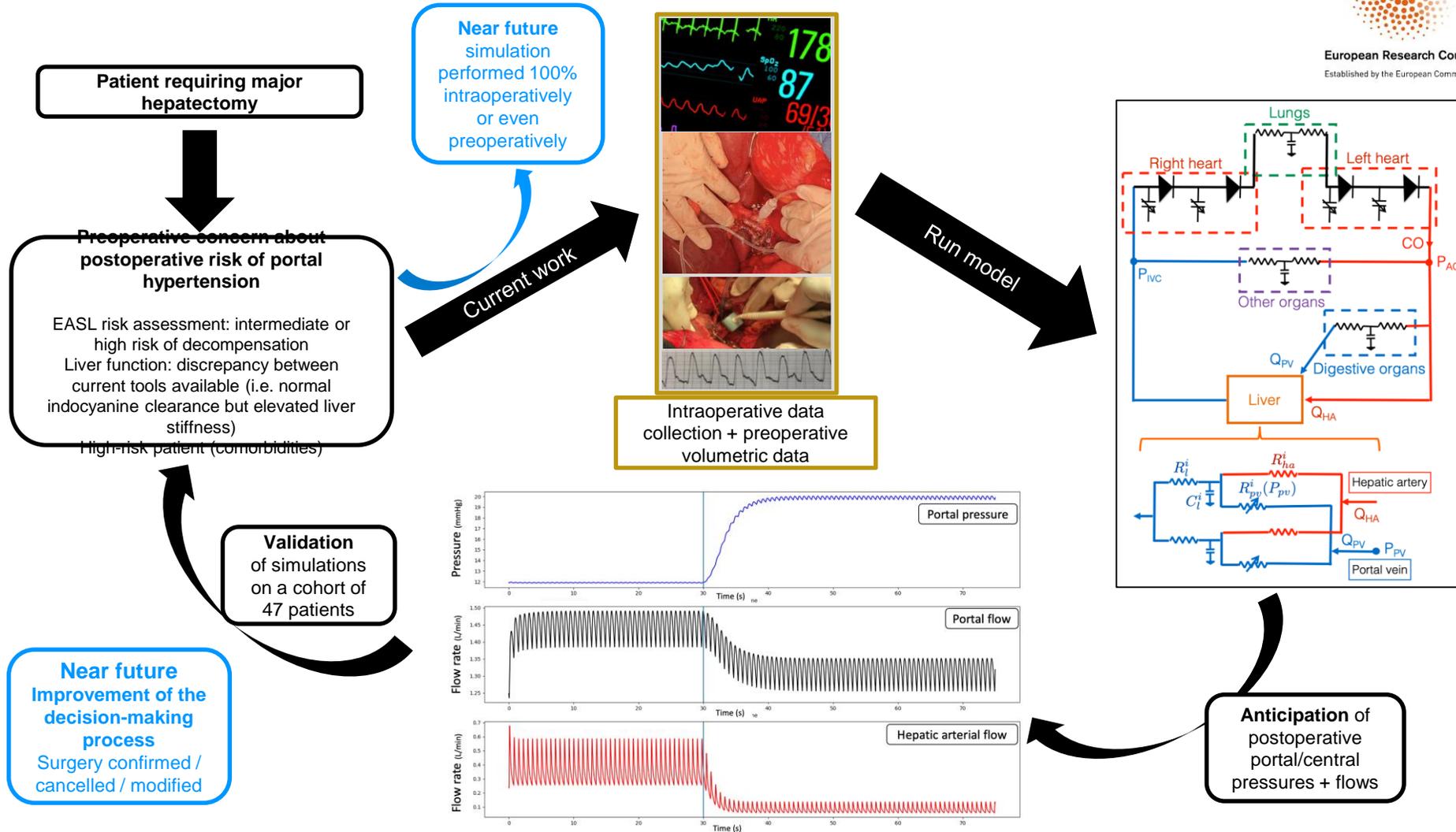
Hemodyn. model



Validation of simulations on a cohort of 47 patients



Anticipation of postoperative portal/central pressures + flows



Finally, Paul Valery is more and more wrong !

« Ce qui est simple est faux mais ce qui est juste est inexploitable »

This was no more totally true with digital twin so we need to use it (and feed it...) to improve the safety of liver surgery