포항공과대학교
산업경영공학과

Ergonomic Design Technology Lab

# Surgery Planning with Dr. Liver: Advanced Features and Functions

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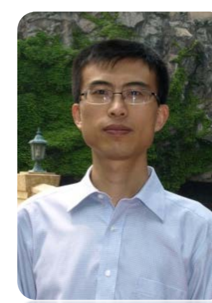
Baojian Wang

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  - Advanced Features of Dr. Liver
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- Future Work
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# Dr. Liver: a User-Centered Liver Surgery Planning System

- 3D **Reconstruction** of the liver, vessels, and tumor(s) from CT volume dataset
- Liver **anatomical segmentation**
- Virtual **resection simulation**

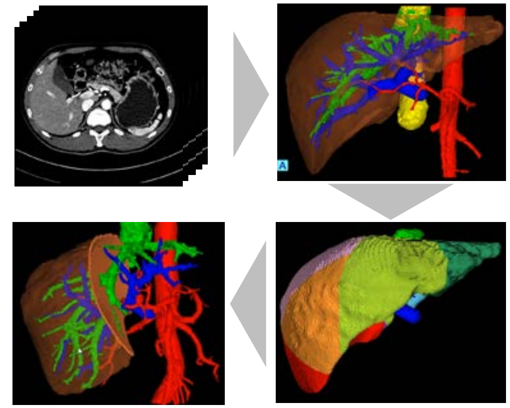


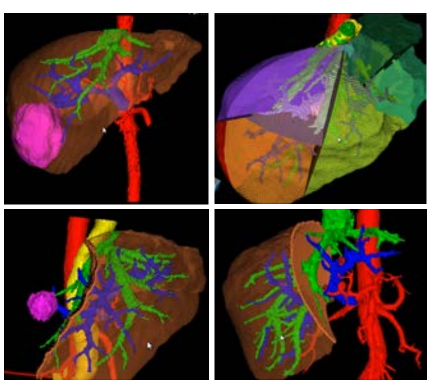
**Image Processing**

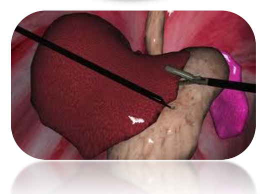
**Safe & Rational Surgery**

**Anatomical Visualization**

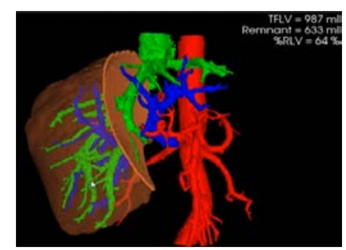
**Quantitative Analysis**

- **Location** & **size** of the tumor(s)
- **Vascular structure**
- Liver **segments**
- Location, orientation, and shape of the **Cutting plane**



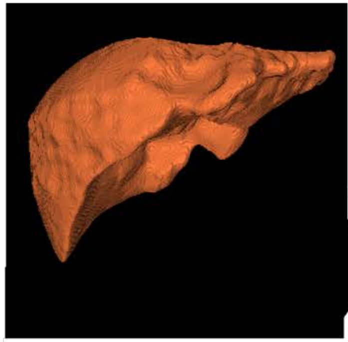


- **Volumetric measurement** of the liver, vessels, tumors, liver segments, the remnant, and/or graft



# Use Scenario: Overall

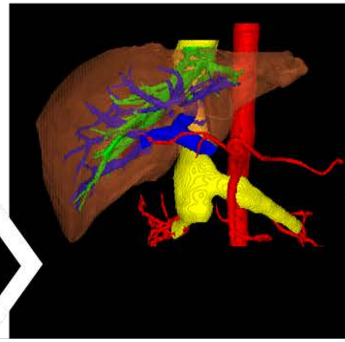
## S1. Liver extraction



5 min

S1.1. Seed point selection
S1.2. Liver extraction
S1.3. Contour editing
S1.4. Update & save

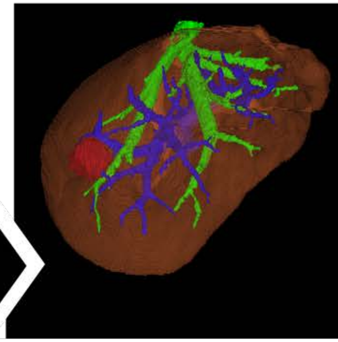
## S2. Vessel extraction



5 ~ 10 min

S2.1. Mask the liver
S2.2. Seed point selection
S2.3. Vessel extraction
S2.4. Contour editing
S2.5. Update & save

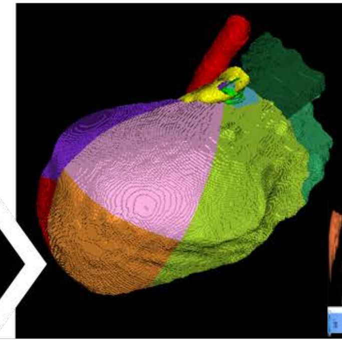
## S3. Tumor extraction



5 min

S3.1. Seed point selection
S3.2. Tumor extraction
S3.3. Contour editing
S3.4. Update & save

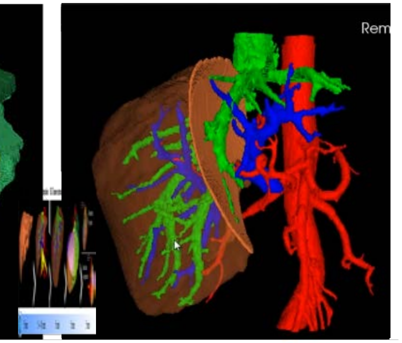
## S4. Liver segmentation



5 min

Plane-based
S4.1.1. Plane generation
S4.1.2. Confirm segmentation
S4.1.3. Segment management
Sphere-based
S4.2.1. Load the liver
S4.2.2. Remove segment
S4.2.3. Update & save
S4.2.4. Segment management

## S5. Surgery planning



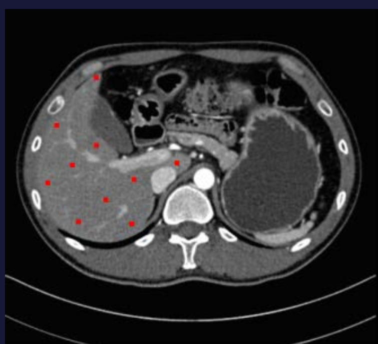
5 min

Plane-based
S5.1.1. Load files
S5.1.2. Point selection
S5.1.3. Plane generation
S5.1.4. Volume calculation
Segment-based
S5.2.1. Load segments
S5.2.2. Cut by segments
Sphere-based
S5.3.1. Load the liver
S5.3.2. Liver resection
S5.3.3. Update & save

Entire processing time: **20 ~ 30 min**

# Use Scenario: Liver Extraction

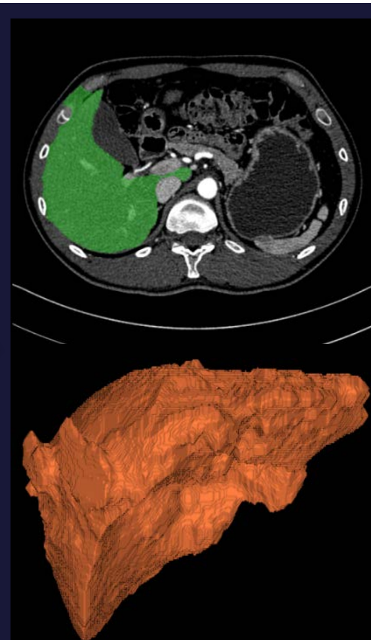
**S1(M). Seed point selection**



**< 1 min**

- **Multiple seed point selection** on liver using the mouse

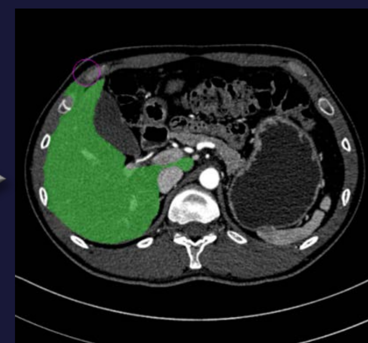
**S2(A). Liver extraction**



**< 2 min**

- **Liver extraction** using our hybrid method
- Liver contour **verification**

**S3(M). Contour editing**

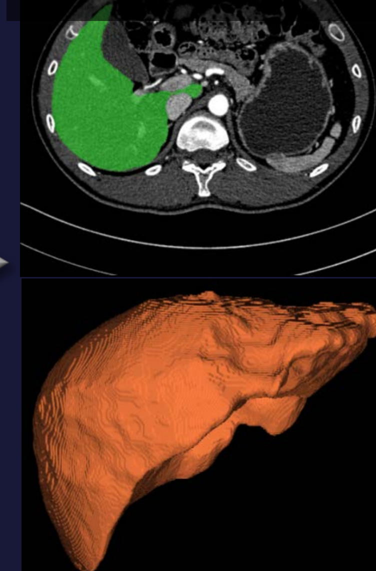


**< 2 min**

- **Liver contour editing** using a scalable editing sphere

**S4(A). Update & save**

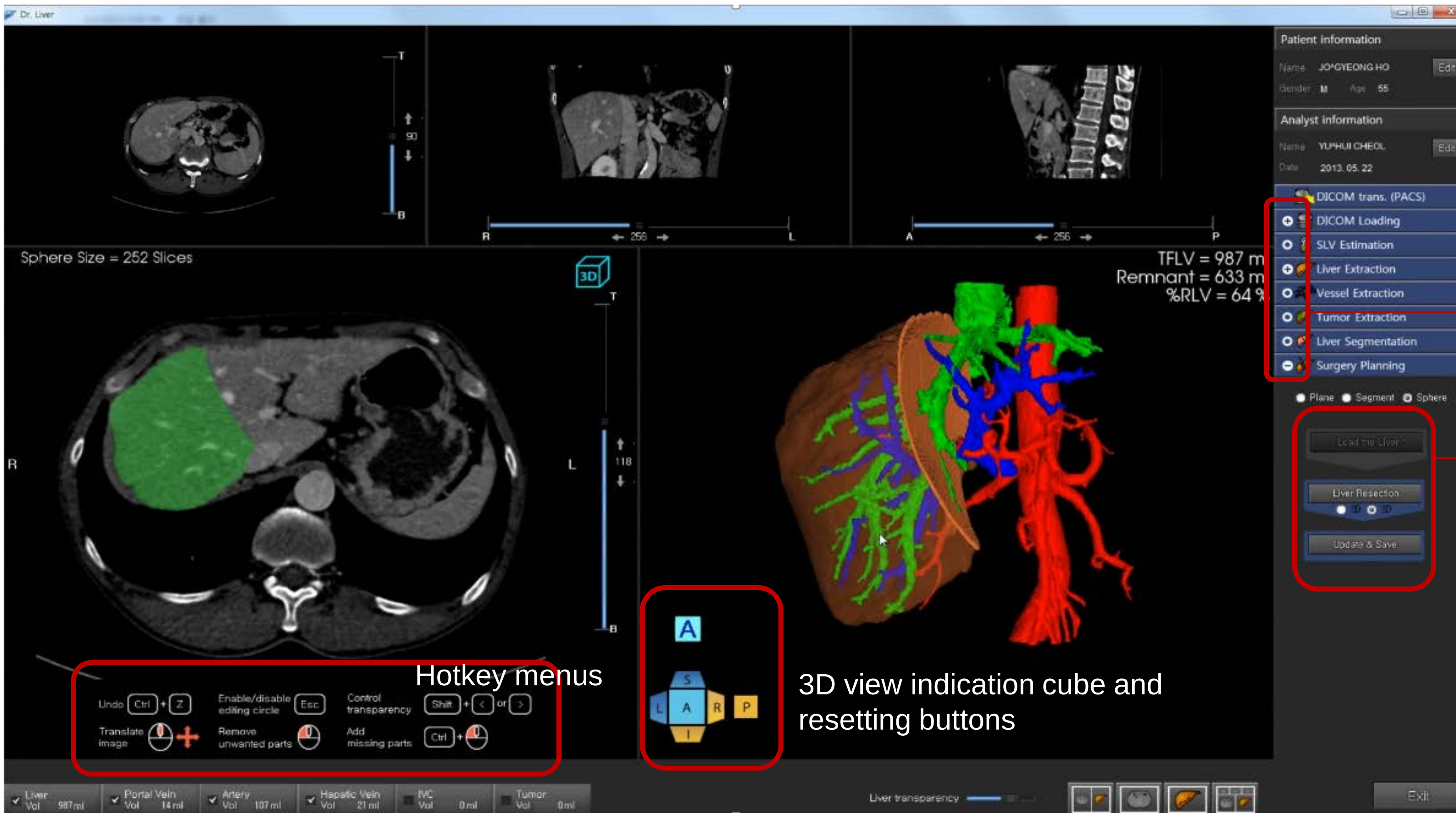
**Total 2 ~ 3 min**



**< 1 min**

- **Update** of the 3D liver
- Liver surface smoothing
- Liver extraction result saving

# User Interface: User-Friendly Features




Hierarchical drop-down menus

Procedure status indication coding

Procedure status color coding

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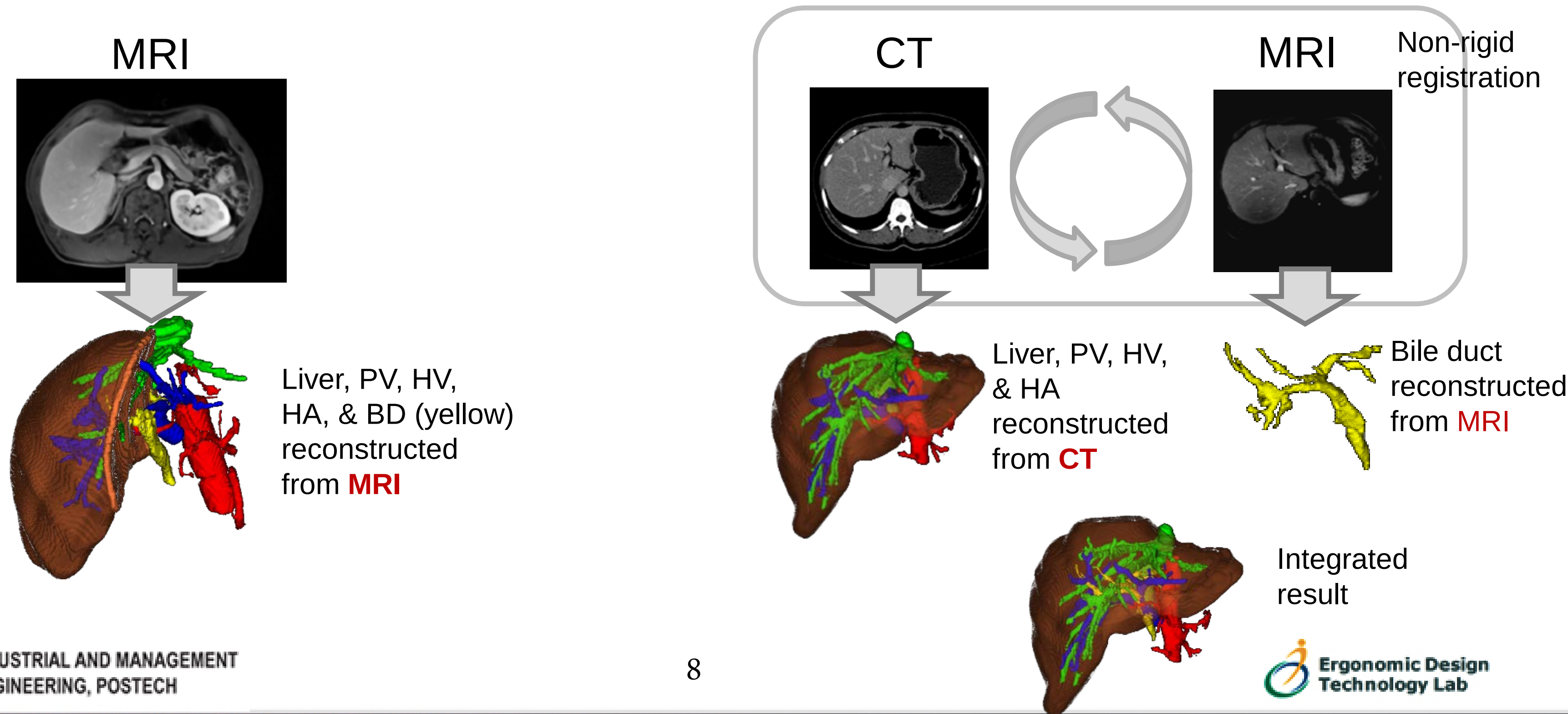
# Advanced Features: MRI Analysis (1/3)

- Developed especially for visualization and volumetric measurement of bile duct in liver surgery planning
  - Module 1: extraction of the liver, vessels, tumor(s) and bile duct from only MRI
  - Module 2: extraction of the liver, vessels, and tumor(s) from CT, extraction of the bile duct from MRI non-rigidly registered to CT



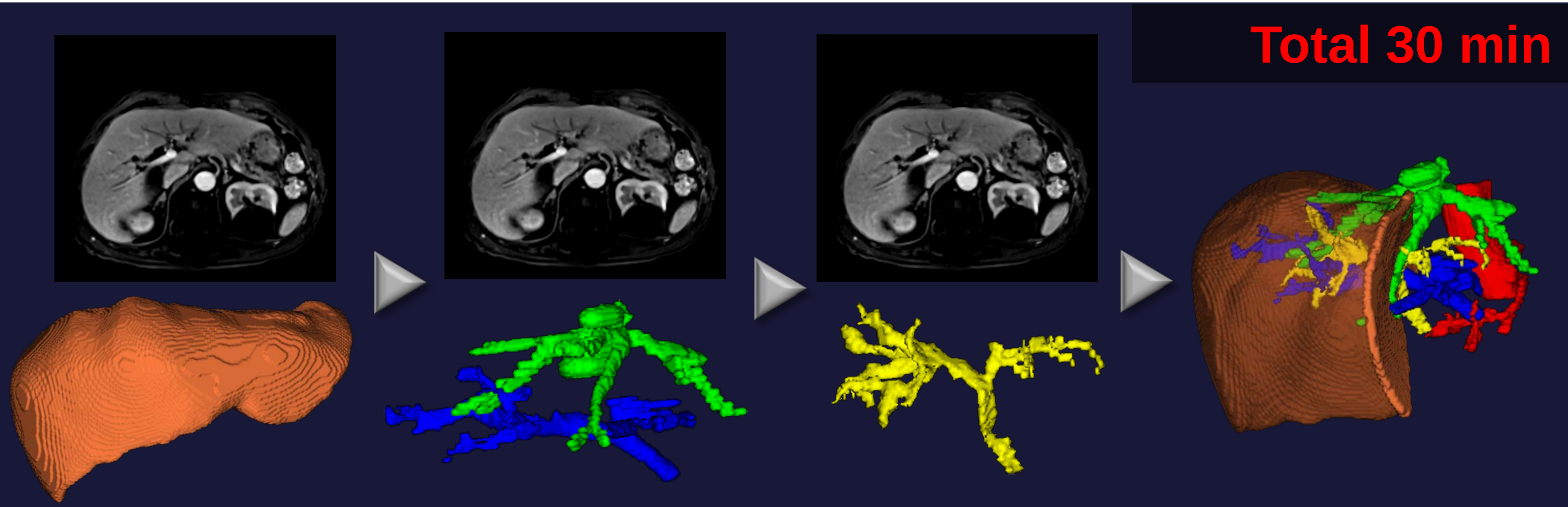
# Module 1: Analysis from Only MRI

**S1(SA). Liver extraction (MRI)**

**S2(SA). Vessel extraction (MRI)**

**S3(SA). BD extraction (MRI)**

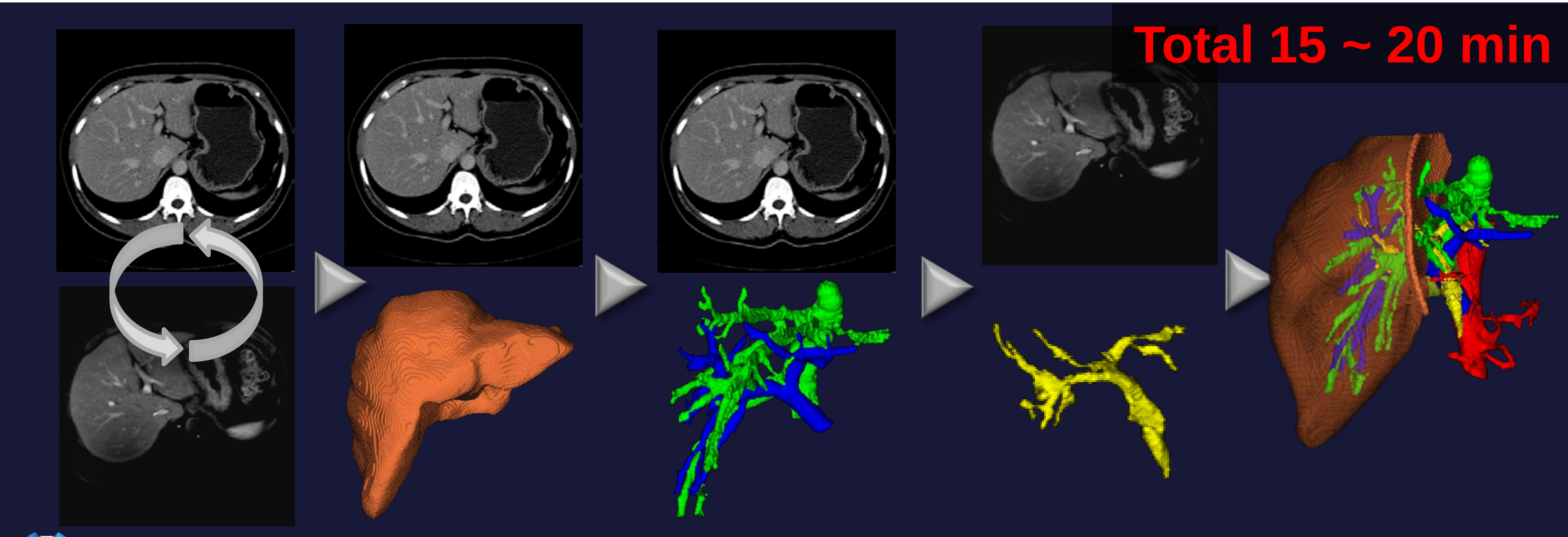
**S4(SA). Surgery Planning**




| 3 ~ 5 min | 15 ~ 20 min | 2 ~ 3 min | 1 ~ 2 min |
|---|---|---|---|
| • **Liver extraction** using our proposed hybrid method | • **Vessel extraction** using our proposed method (long editing time due to low contrast of MRI) | • **BD extraction** using the same method as vessels | • **Resection simulation**<br>• **Volumetric** measurement |

# Module 2: Non-Rigidly Registered CT & MRI

| S1(A). Registration | S2(SA). Liver extraction (CT) | S2(SA). Vessel extraction (CT) | S3(SA). BD extraction (MRI) | S4(SA). Surgery Planning |
|---|---|---|---|---|
| 6 min | 3 ~ 5 min | 2 ~ 3 min | 2 ~ 3 min | 1 ~ 2 min |



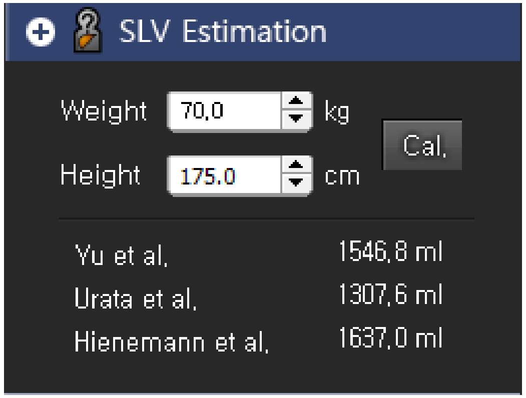

- **Non-rigid registration** between MRI & CT
- **Liver extraction** using our proposed hybrid method
- **Vessel extraction** using our proposed method
- **BD extraction** using the same method as vessels
- **Resection simulation**
- **Volumetric** measurement

# Advanced Features: Standard Liver Volume (SLV) Estimation

- Three regression equations used by Dr. Liver for SLV estimation

| Author | Regression models | Adjusted $R^2$ | Errors* | | | | Sample | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Median | SD | SE | Nation | Size | Age |
| Yu et al. (2004) | LV = $21.585 \times BW^{0.732} \times BH^{0.225}$ | 0.590 | -27.96 | -27.78 | 275.4 | 275.8 | Korea | 652 | 42.4 ± 16.5 |
| Urata et al. (1995) | LV = 2.4 + 706.2 × BSA | 0.962† | 226.90 | 213.31 | 289.4 | 289.6 | Japanese | 96 | 11.1 ± 8.8 |
| Heinemann et al. (1999) | LV = -345.7 + 1072.8 × BSA | 0.300† | -30.64 | -29.88 | 281.5 | 281.7 | Caucasian | 1332 | 50.6 ± 18.9 |

*Differences between actual LV data and corresponding regression estimates
†Values reported by Heinemann et al. and Urata et al.
BW: body weight, BH: body height, BSA: body surface area

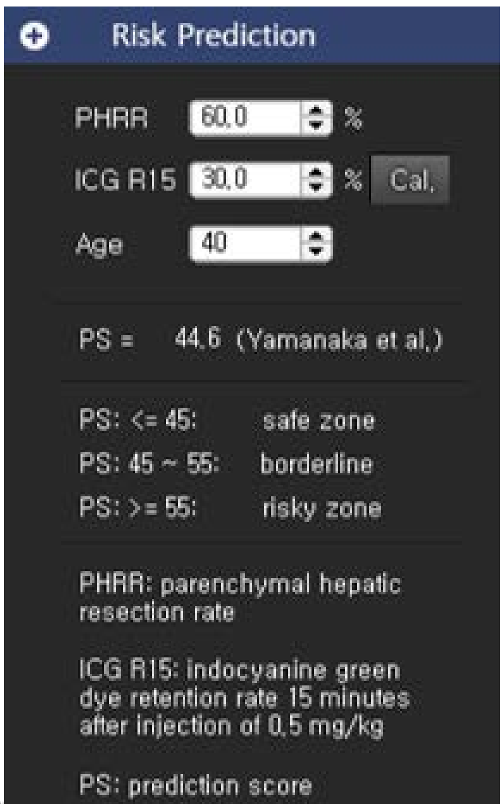


# Advanced Features: Risk Prediction

- Risk prediction equation added to Dr. Liver proposed by Yamanaka et al. (1994)

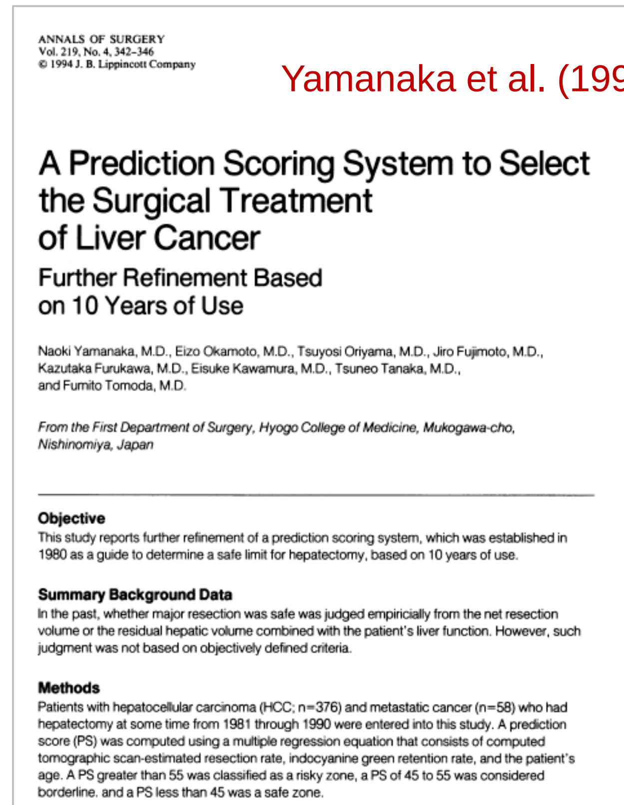
$$Y = -84.6 + 0.933\ \text{PHRR} + 1.11\ \text{ICG R15} + 0.999\ \text{age}$$

where: PHRR = parenchymal hepatic resection rate
ICG R15 = indocyanine green dye retention rate 15 minutes after injection of 0.5 mg/kg




Y > 55: risky
45 < Y < 55: borderline
Y < 45: safe

Yamanaka et al. (1994)



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A Prediction Scoring System to Select the Surgical Treatment of Liver Cancer

Further Refinement Based on 10 Years of Use

Naoki Yamanaka, M.D., Eizo Okamoto, M.D., Tsuyosi Oriyama, M.D., Jiro Fujimoto, M.D., Kazutaka Furukawa, M.D., Eisuke Kawamura, M.D., Tsuneo Tanaka, M.D., and Fumito Tomoda, M.D.

*From the First Department of Surgery, Hyogo College of Medicine, Mukogawa-cho, Nishinomiya, Japan*

**Objective**
This study reports further refinement of a prediction scoring system, which was established in 1980 as a guide to determine a safe limit for hepatectomy, based on 10 years of use.

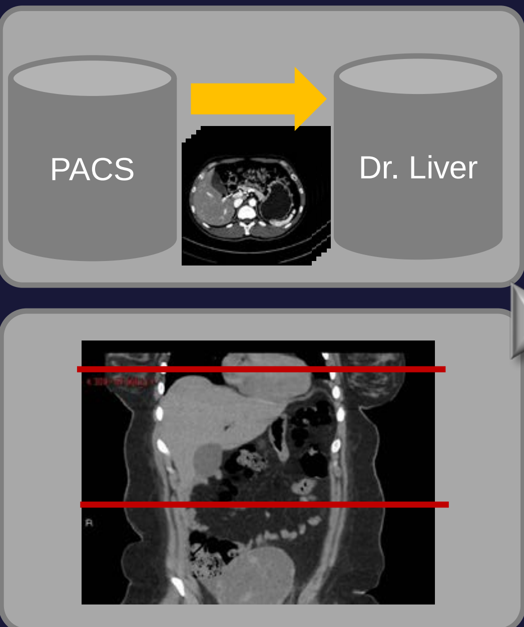
**Summary Background Data**
In the past, whether major resection was safe was judged empiricially from the net resection volume or the residual hepatic volume combined with the patient's liver function. However, such judgment was not based on objectively defined criteria.

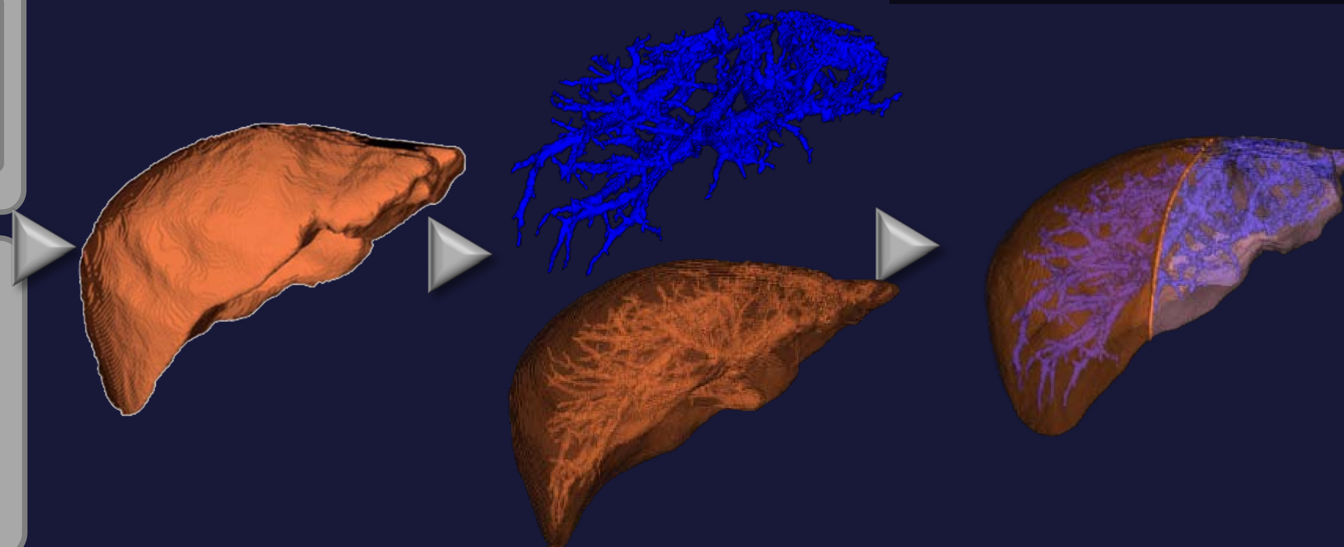
**Methods**
Patients with hepatocellular carcinoma (HCC; n=376) and metastatic cancer (n=58) who had hepatectomy at some time from 1981 through 1990 were entered into this study. A prediction score (PS) was computed using a multiple regression equation that consists of computed tomographic scan-estimated resection rate, indocyanine green retention rate, and the patient's age. A PS greater than 55 was classified as a risky zone, a PS of 45 to 55 was considered borderline. and a PS less than 45 was a safe zone.

# Surgery Planning for LDLT

| S1(M). Data Preparation | S2(SA). Liver extraction | S3(SA). PV & HV extraction | S4(SA). Surgery Planning |
|---|---|---|---|

**Total 5 ~ 7 min**



| 1 ~ 2 min | 2 ~ 3 min | 2 ~ 3 min | 1 ~ 2 min |
|---|---|---|---|

**S1(M). Data Preparation**
- **Data transfer** from PACS
- **Data cut**

**S2(SA). Liver extraction**
- **Liver extraction** using our proposed hybrid method

**S3(SA). PV & HV extraction**
- **Vessel extraction** using our proposed method
- **Exclude vessels** from the liver

**S4(SA). Surgery Planning**
- **Resection simulation**
- **Volumetric** measurement
- **Print** the liver surgery planning results

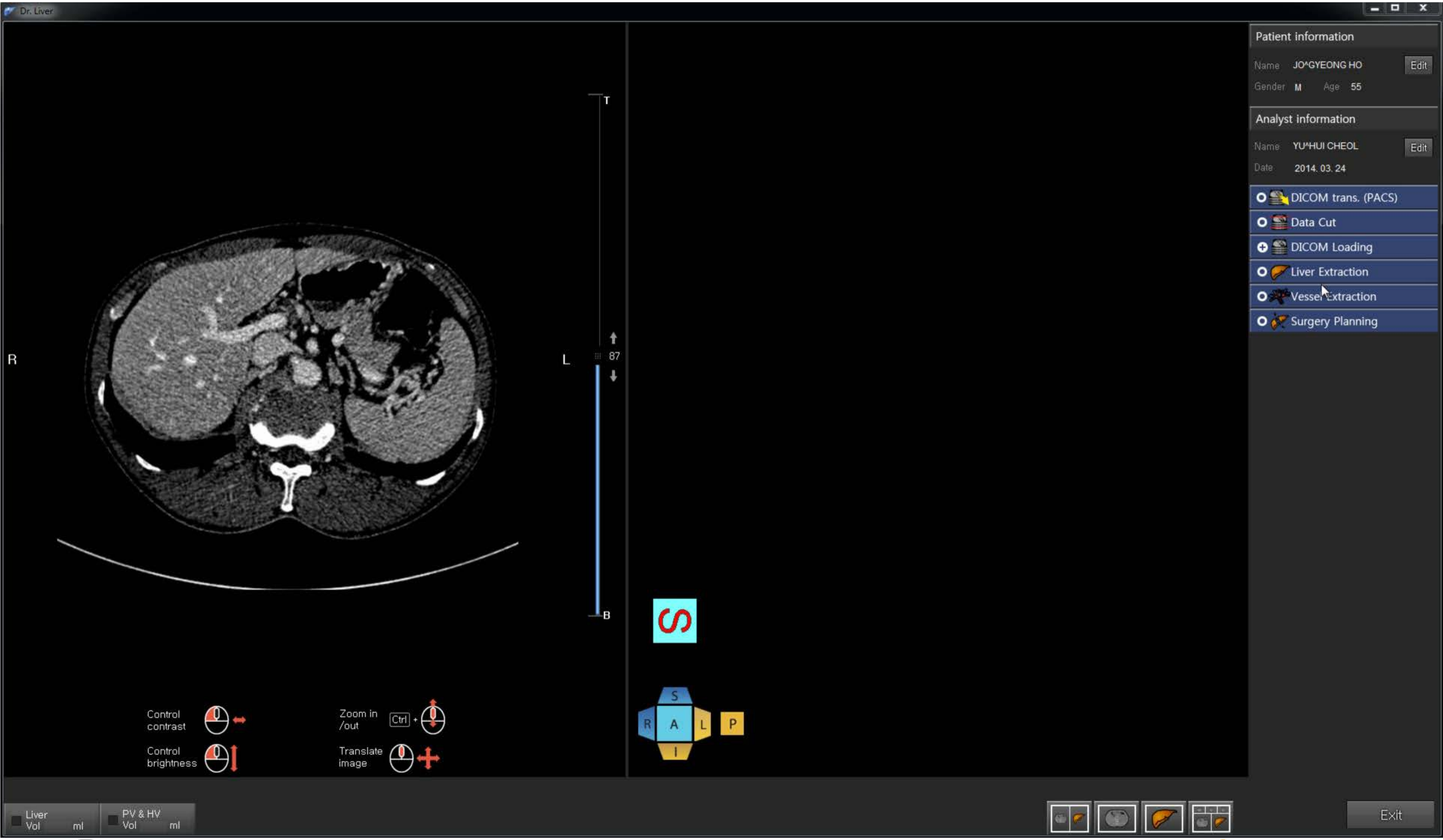
# Graft Weight Estimation by Dr. Liver

- Proposed a regression model for graft weight estimation from preoperative vein free graft volume

$$GW = 29.1 + 0.943 \times GV_{w/o\_vein} \text{ (Adj. } R^2 = 0.94)$$

| Methods | PNUYH Data ($n$ = 20) | | | | | CBNUH Data ($n$ =23) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Absolute Error (AE; g) | | Percentage of AE (PAE) | | Percentage of PAE > 10% | AE (g) | | PAE | | Percentage of PAE > 10% |
| | Mean (SD) | SE | Mean (SD) | SE | | Mean (SD) | SE | Mean (SD) | SE | |
| Lemke et al. (2006) by $GV_{w\_vein}$ | 36.6 (22.5) | 5.0 | 5.8% (4.1%) | 0.9% | 15.0% | 45.5 (32.9) | 6.9 | 6.1% (4.1%) | 0.9% | 17.4% |
| Yoneyama et al. (2011) by $GV_{w\_vein}$ | 34.2 (26.4) | 5.9 | 5.0% (3.5%) | 0.8% | 10.0% | 42.0 (36.8) | 7.7 | 5.7% (4.9%) | 1.0% | 13.0% |
| SyngoVia | 52.5 (49.7) | 12.4 | 8.3% (7.1%) | 1.8% | 31.3% | - | - | - | - | - |
| Proposed by $GV_{w/o\_vein}$ | 16.3 (12.6) | 2.8 | 2.6% (2.2%) | 0.5% | 0.0% | 21.5 (16.5) | 3.4 | 3.0% (2.3%) | 0.5% | 0.0% |

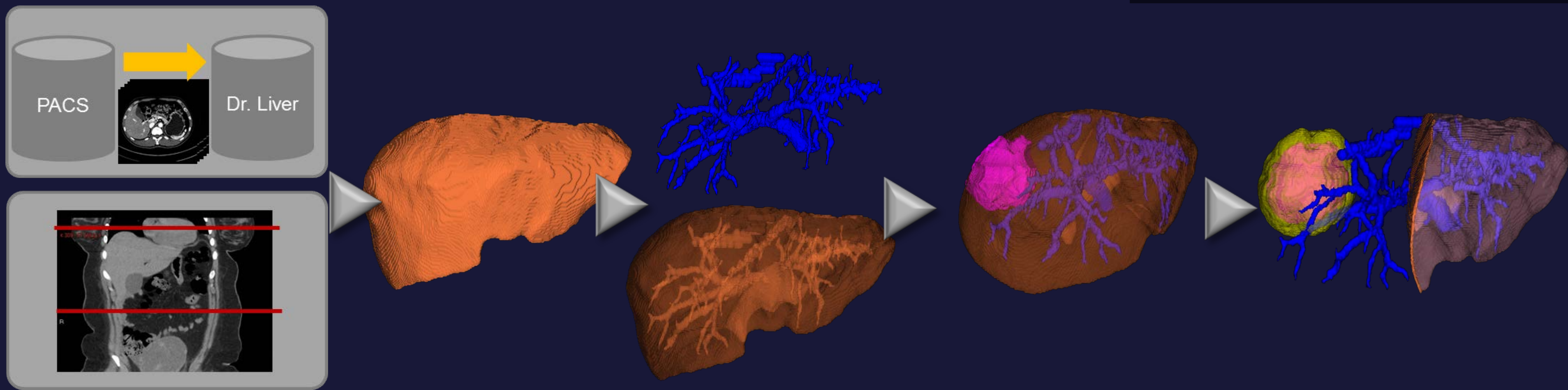
# Demo: Surgery Planning for LDLT



# Surgery Planning for Tumor Resection

S1(M). Data Preparation | S2(SA). Liver extraction | S3(SA). PV & HV extraction | S4(SA). Tumor extraction | S5(SA). Surgery Planning

**Total 8 ~ 13 min**



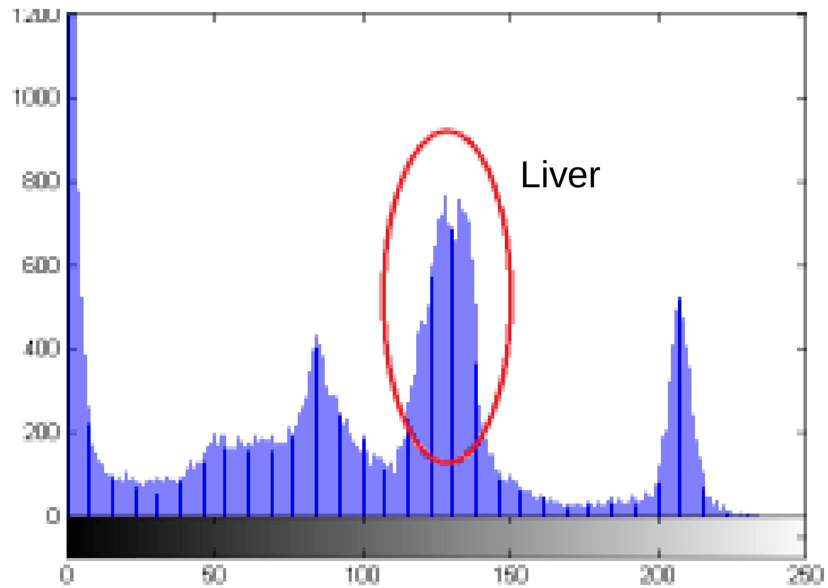

| < 1 min | 2 ~ 3 min | 2 ~ 3min | 2 ~ 3min | 1 ~ 2 min |
|---|---|---|---|---|
| • **Data transfer** from PACS<br>• **Data cut** | • **Liver extraction** using our proposed hybrid method | • **Vessel extraction** using our proposed method<br>• **Exclude vessels** from the liver | • **Tumor extraction using the same method as liver extraction** | • **Resection simulation**<br>• **Volumetric** measurement<br>• **Print** the liver surgery planning results |

# Demo: Surgery Planning for Tumor Resection

# Future Work: Automatic Liver Reconstruction

- Currently, user interaction such as seed point selection is needed for liver extraction ⇒ Surgeons don't like it.
- Through histogram analysis of CT images, ROI can be automatically detected and used as seed for extraction of the liver, vessels, and tumors.

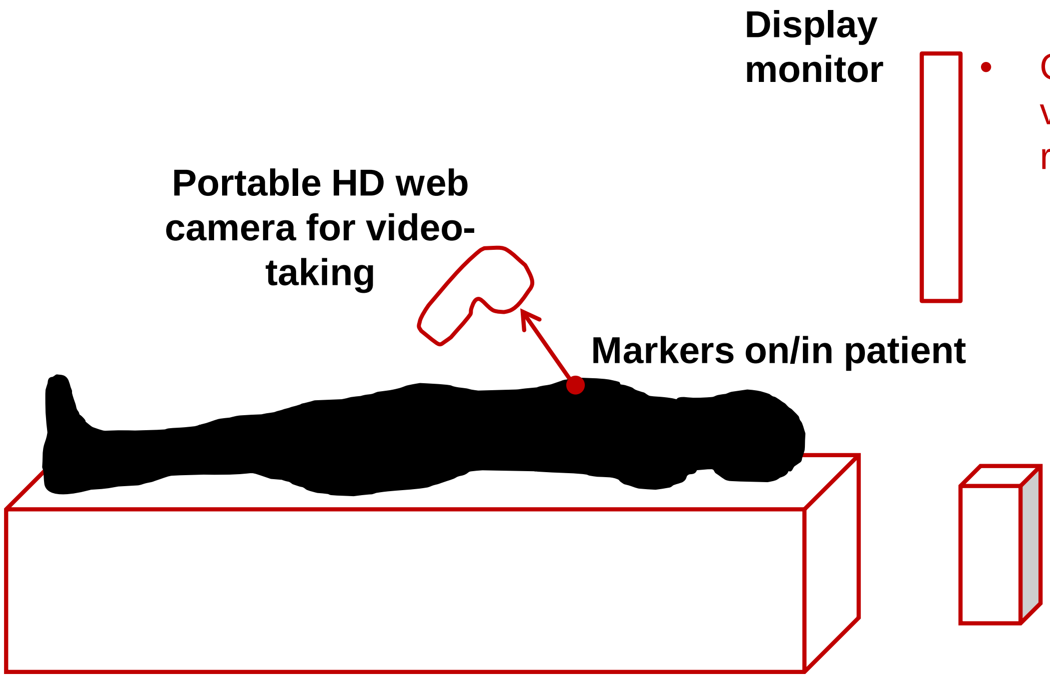
Abdominal CT Histogram



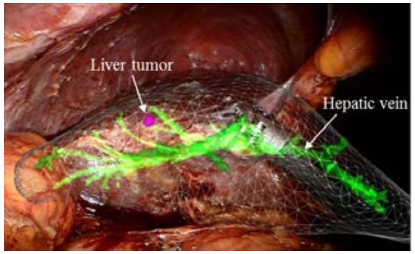

Kumar & Moni, 2010

# Future Work: Intraoperative Navigation

- Develop higher accuracy registration algorithms to synchronize preoperative surgery planning results (from Dr. Liver) with the real liver during surgery
  - Visualize vital structures such as vessels and tumors invisible during surgery
  - Support more safe and accurate liver surgery




- Overlaid view of virtual structure with real liver




- Preoperative surgery planning results from Dr. Liver
- Registration of virtual structure to real liver

# Future Work: 3D Printing of the Liver

- Develop a module to support 3D printing of the liver, vessels, tumor(s) and surgery planning results obtained from Dr. Liver
  - Intuitive visual inspection of the liver, vasculature structures, tumor location and size, and cutting plane

# Q & A

# Research Work Conducted by Dr. Liver

1) Prediction of Postoperative Liver Function After Tumor Resection by RLV/TFLV and RLV/SLV
2) Graft Weight Estimation

# Prediction of Postoperative Liver Function After Tumor Resection by RLV/TFLV and RLV/SLV

Korean J Hepatobiliary Pancreat Surg 2013;17:143-151

**Original Article**

## Comparison of remnant to total functional liver volume ratio and remnant to standard liver volume ratio as a predictor of postoperative liver function after liver resection

Hee Joon Kim, Choong Young Kim, Young Hoe Hur, Yang Seok Koh, Jung Chul Kim, Chol Kyoon Cho, and Hyun Jong Kim

*Department of Surgery, Chonnam National University College of Medicine, Gwangju, Korea*

**Backgrounds/Aims:** The future liver remnant (FLR) is usually calculated as a ratio of the remnant liver volume (RLV) to the total functional liver volume (RLV/TFLV). In liver transplantation, it is generally accepted that the ratio of the graft volume to standard liver volume (SLV) needs to be at least 30% to 40% to fit the hepatic metabolic demands of the recipient. The aim of this study was to compare RLV/TFLV versus RLV/SLV as a predictor of postoperative liver function and liver failure. **Methods:** CT volumetric measurements of RLV were obtained retrospectively in 74 patients who underwent right hemihepatectomy for a malignant tumor from January 2010 to May 2013. RLV and TFLV were obtained using CT volumetry, and SLV was calculated using Yu's formula: SLV (ml)=21.585×body weight $(kg)^{0.732}$×height $(cm)^{0.225}$. The RLV/SLV ratio was compared with the RLV/TFLV as a predictor of postoperative hepatic function. **Results:** Postheptectomy liver failure (PHLF), morbidity, and serum total bilirubin level at postoperative day 5 (POD 5) were increased significantly in the group with the RLV/SLV ≤30% compared with the group with the RLV/SLV >30% ($p$=0.002, $p$=0.004, and $p$<0.001, respectively). But RLV/TFLV was not correlated with PHLF and morbidity ($p$=1.000 and 0.798, respectively). RLV/SLV showed a stronger correlation with serum total bilirubin level than RLV/TFLV (RLV/SLV vs. RLV/TFLV, R=0.706 vs. 0.499, $R^2$=0.499 vs. 0.239). **Conclusions:** RLV/SLV was more specific than RLV/TFLV in predicting the postoperative course after right hemihepatectomy. To determine the safe limit of hepatic resection, a larger-scaled prospective study is needed. **(Korean J Hepatobiliary Pancreat Surg 2013;17: 143-151)**

**Key Words:** Liver volumetry; Future liver remnant; Liver resection; Liver failure

### Volumetric liver analysis using Dr. Liver

All patient underwent contrast-enhanced computed tomography (CT) as part of the routine preoperative assessment. Arterial, portal, and venous phase series of images from the preoperative CT scans were used for the CT volumetry. Volumetric analysis using Dr. Liver (Humanopia co., Ltd, Pohang, Gyungbuk, Korea) was performed by two surgeons (HJ Kim and CY Kim). The liver