Medical Image Processing for Intuitive Navigation and Surgical Workflow Analysis

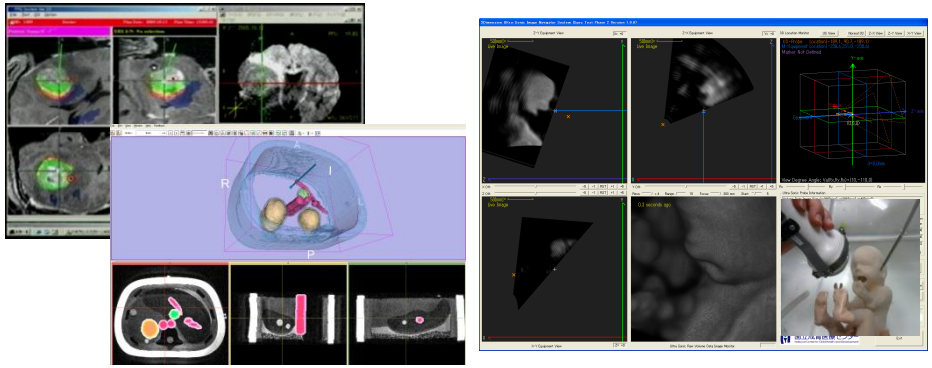
Ryoichi Nakamura, Ph.D

Laboratory of Innovative Therapeutic Engineering (LITE),
Department of Medical System Engineering, Graduate School & Faculty of Engineering
Chiba University

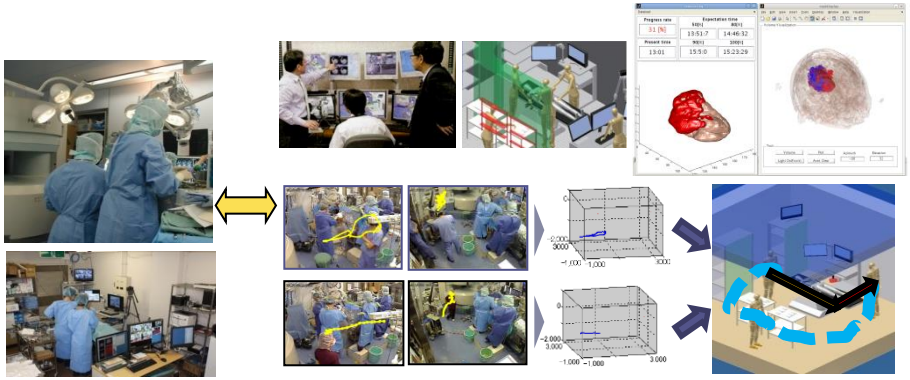
LITE: Laboratory of Innovative Therapeutic Engineering

Visualization and analysis of Intraoperative information & computer assisted surgical devices and robotics

Surgical Navigation and Informatics



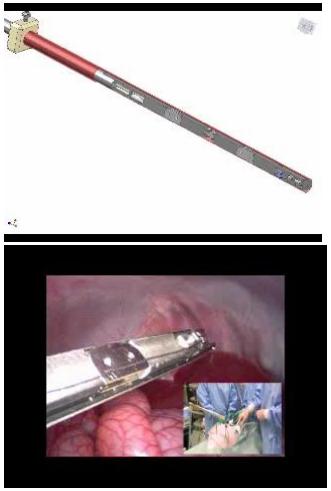
Surgical navigation system with “Distance Sensation” & real-time updated 4D ultrasound imaging



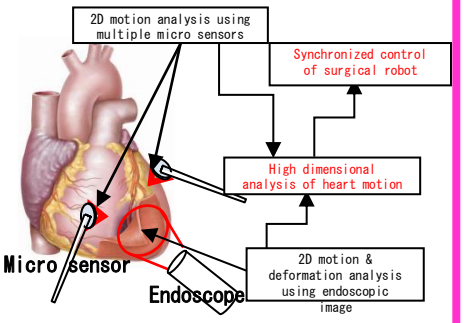
Surgical control platform using surgical workflow analysis & trajectory analysis inside OR

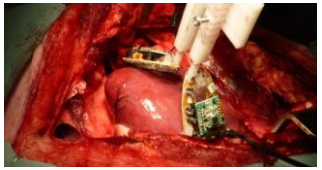
Surgical Instruments and Robotics

Advanced therapeutic device for endoscopic surgery and tissue regeneration therapy



LITE : Least Incision & Transformation Endoeffector





Non-contact analysis system for heart motion

Surgical Navigation

Realtime-updated Navigation System with intraoperative MRI can improve removal rate of malignant tumor and survival rate

(Courtesy：ABMES, Tokyo Women‘s Medical Univ.)

Computer Assisted Surgery based on Intraoperative Information and Navigation Technology

- Image-guided Surgery by Navigation Technology
  - Visualization of patient anatomy and surgical instruments
  - Navigation guidance for surgical procedure
  - Difficulties: Motion/deformation of organs

- Analysis of Surgery by Navigation Technology
  - Recording the information about patient and procedure
  - Evaluation of the performance of surgeons/device

Computer Assisted Surgery based on Intraoperative Information and Navigation Technology

- Today's topics
  - Real-time updated navigation system using intraoperative 3D ultrasound for endoscopic fetal surgery and Water-filled laparo-endoscopic surgery
  - Automatic surgical workflow analysis using navigation information

Real-time updated navigation system using intraoperative 3D ultrasound for endoscopic fetal surgery and Water-filled laparo-endoscopic surgery

Surgical Navigation

Realtime-updated Navigation System with intraoperative MRI can improve removal rate of malignant tumor and survival rate

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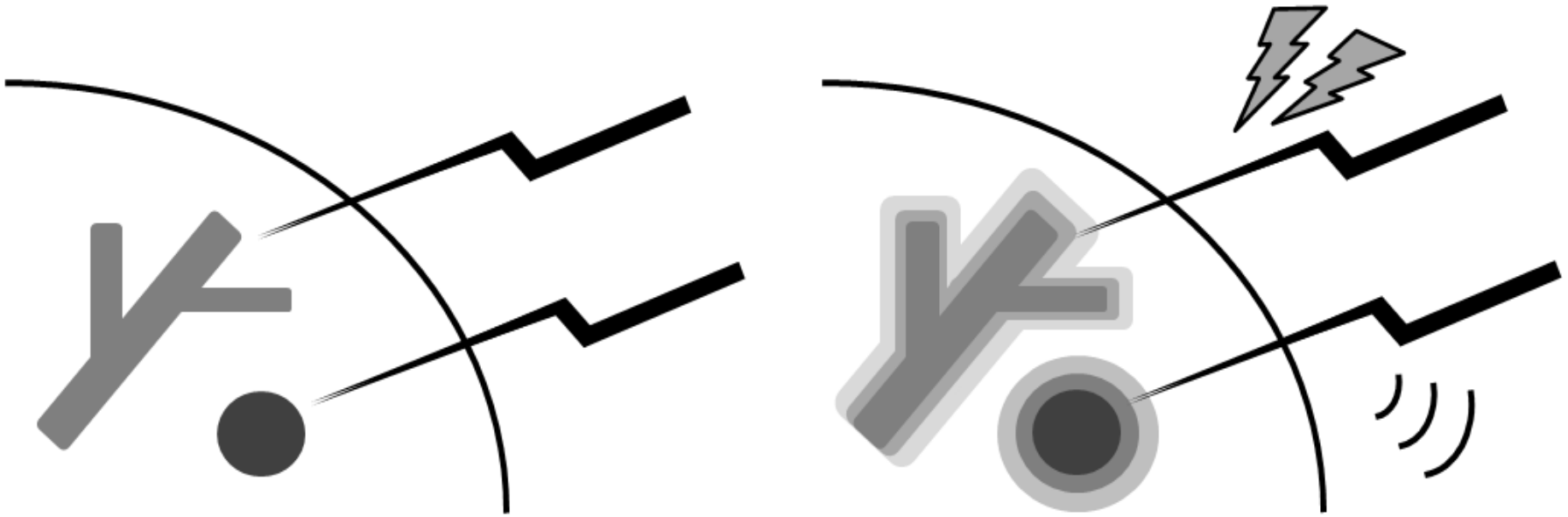
Surgical Navigation with Distance Sensation

- Provide the sensation of the distance of a given object
  - Guidance to treatment target / collision avoidance



Conventional navigation

navigation with Distance Sensation

(Nakamura, JJSCAS 14(2) 2012)

Surgical Navigation with Distance Sensation

- Provide the sensation of the distance of a given object
  - Guidance to treatment target / collision avoidance

Distance map for guidance to treatment target
(Nakamura, CARS2006)

Real-time updated Navigation

Need for Real-time Updated Navigation for abdominal organs (movable/deformable)

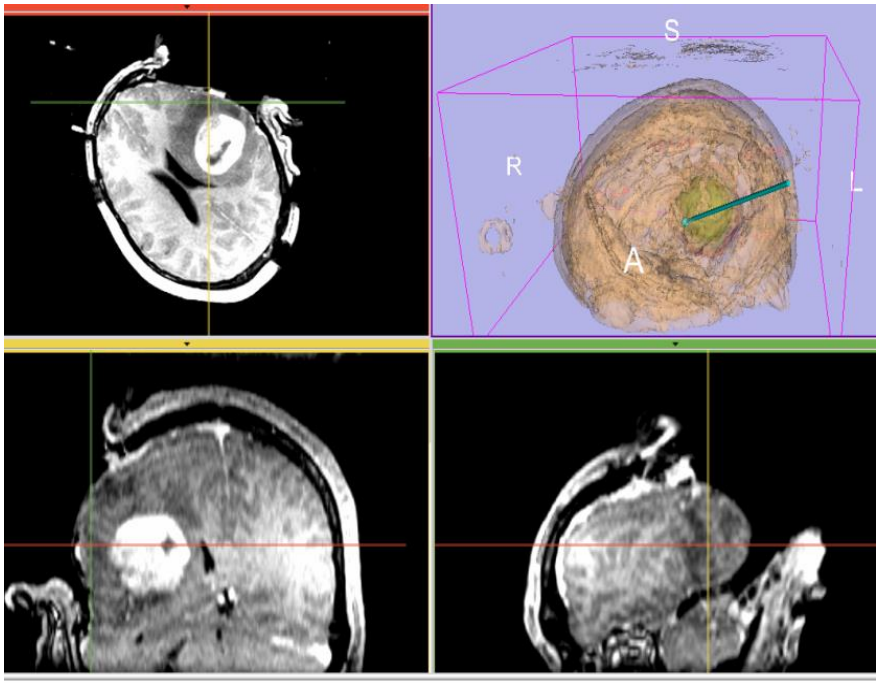
Surgical Navigation with intraoperative imaging

Intraoperative CT/MRI

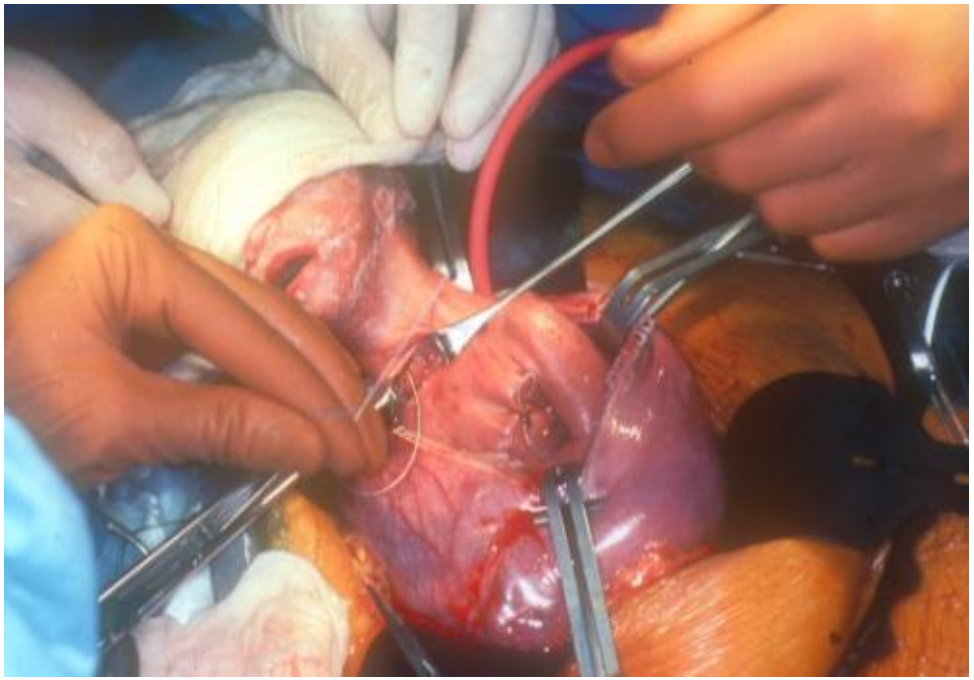
- ○High-quality, track movable organ
- ×Big equipment, Long scanning time
  Not applicable for high speed change

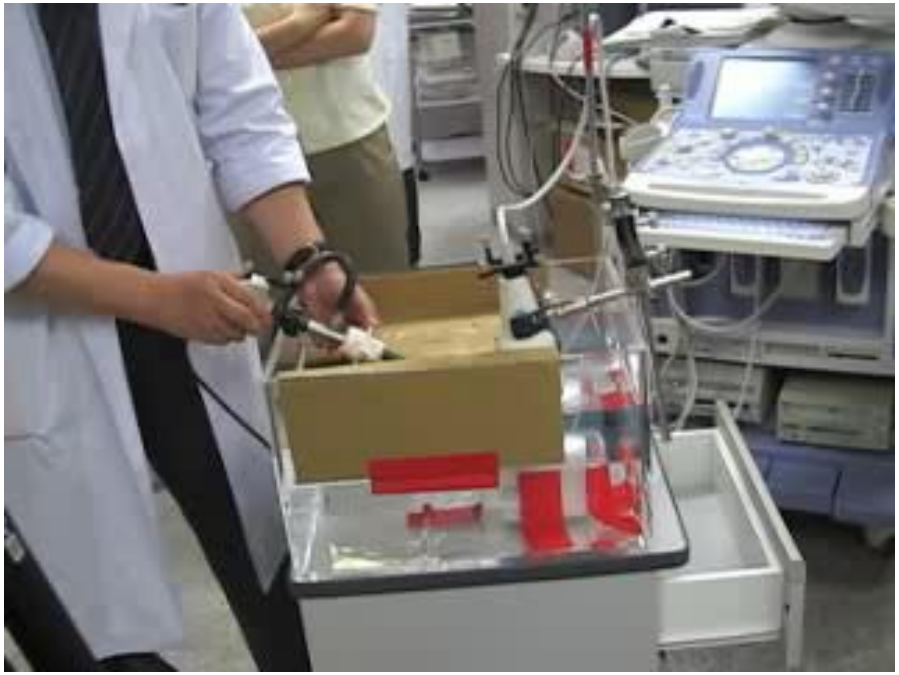
Intraoperative Ultrasound

- ○High speed scanning
- ×Limitation on target (no bone, no air)
  Low quality



Navigation for endoscopic fetal surgery





- Real-time Navigation with 3D view outside endoscopic view field
- Ultrasound Imaging is most suitable for fetal surgery

(courtesy：NICHD, Innoventure-C, Hitachi Aloka Medical)

Configuration of the navigation system

3D/4D
ultrasound
(Prosound α7)

Position
marker

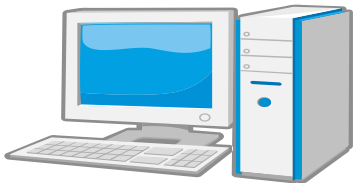
Surgical instrument

3D US
probe

Position sensor
(Polaris)

Intraoperative
3D ultrasound Image

Direct data transfer
USB2.0 interface

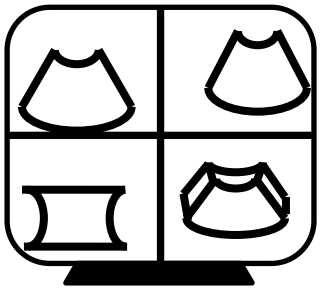


Navigation PC

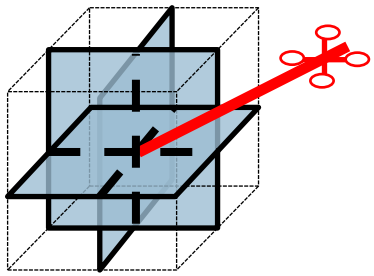
Data processing
with GPGPU
- Registration
- Reslice
- Volume rendering

Position data

Display

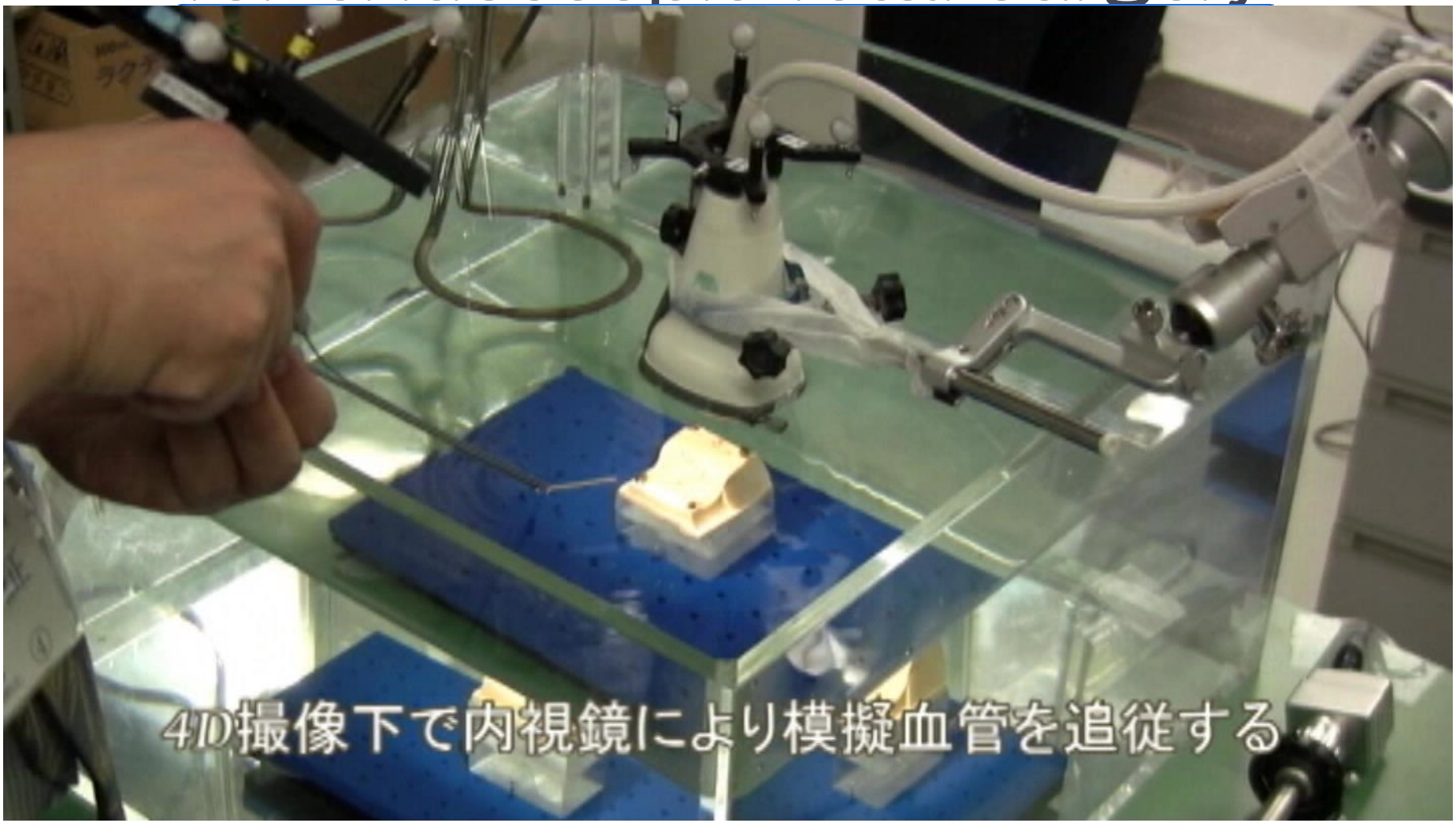


2D cross sections
and
3D view



Surgical instrument

Real-time 3D Ultrasound Navigation for endoscopic fetal surgery

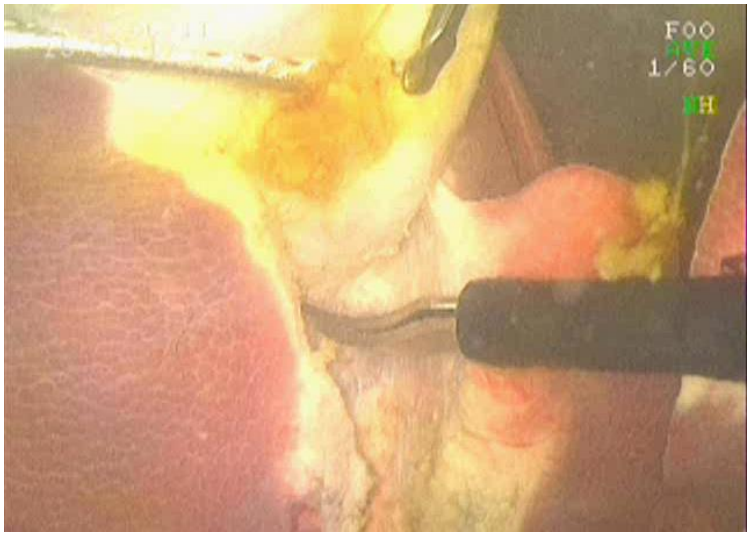


Nakamura et al JJSCAS 2011 13(2):87-95

WaFLES

Water filled Laparo-Endoscopic Surgery

- Replace carbon dioxide gas with isotonic liquid in laparoscopic surgery
- Pro
  - Control venous bleeding by water pressure
  - Set organs in warm condition during surgery
  - Acquire ultrasound images

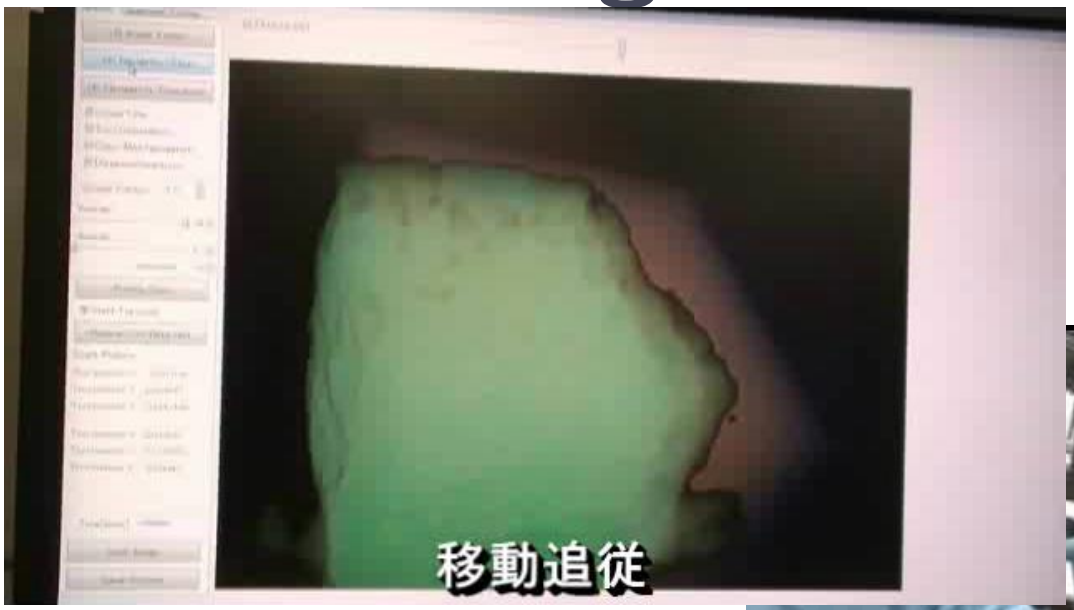


Laparoscopic cholecystectomy in WaFLES condition (porcine model)

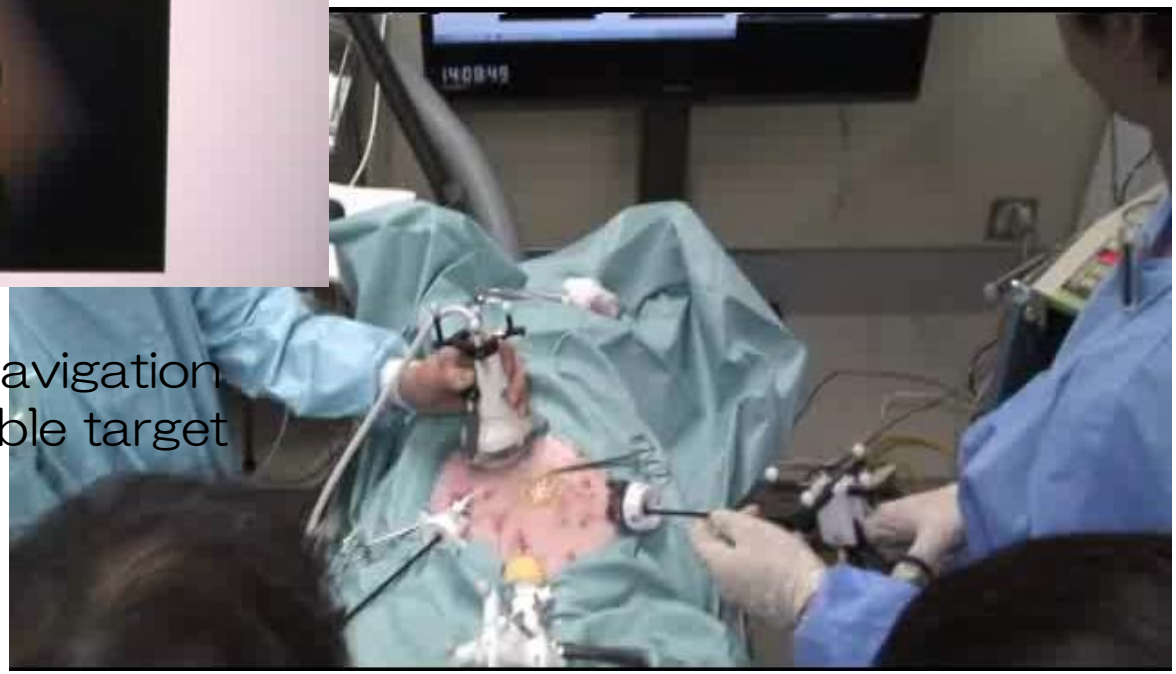
Ultrasound-based Navigation System is applicable for laparoscopic surgery

***Water-Filled Laparoendoscopic Surgery (WAFLES): Feasibility Study in Porcine Model**
Tatsuo Igarashi et al. Journal of Laparoendoscopic & Advanced Surgical Techniques Volume: 22 Issue 1, 2012

Real-time updated 3D ultrasound Navigation for WaFLES



Experiment for real-time navigation for movable and deformable target



In vivo experiment
on WaFLES Model (animal)

Automatic surgical workflow analysis using navigation information

Case1: iMRI-guided Glioma Surgery

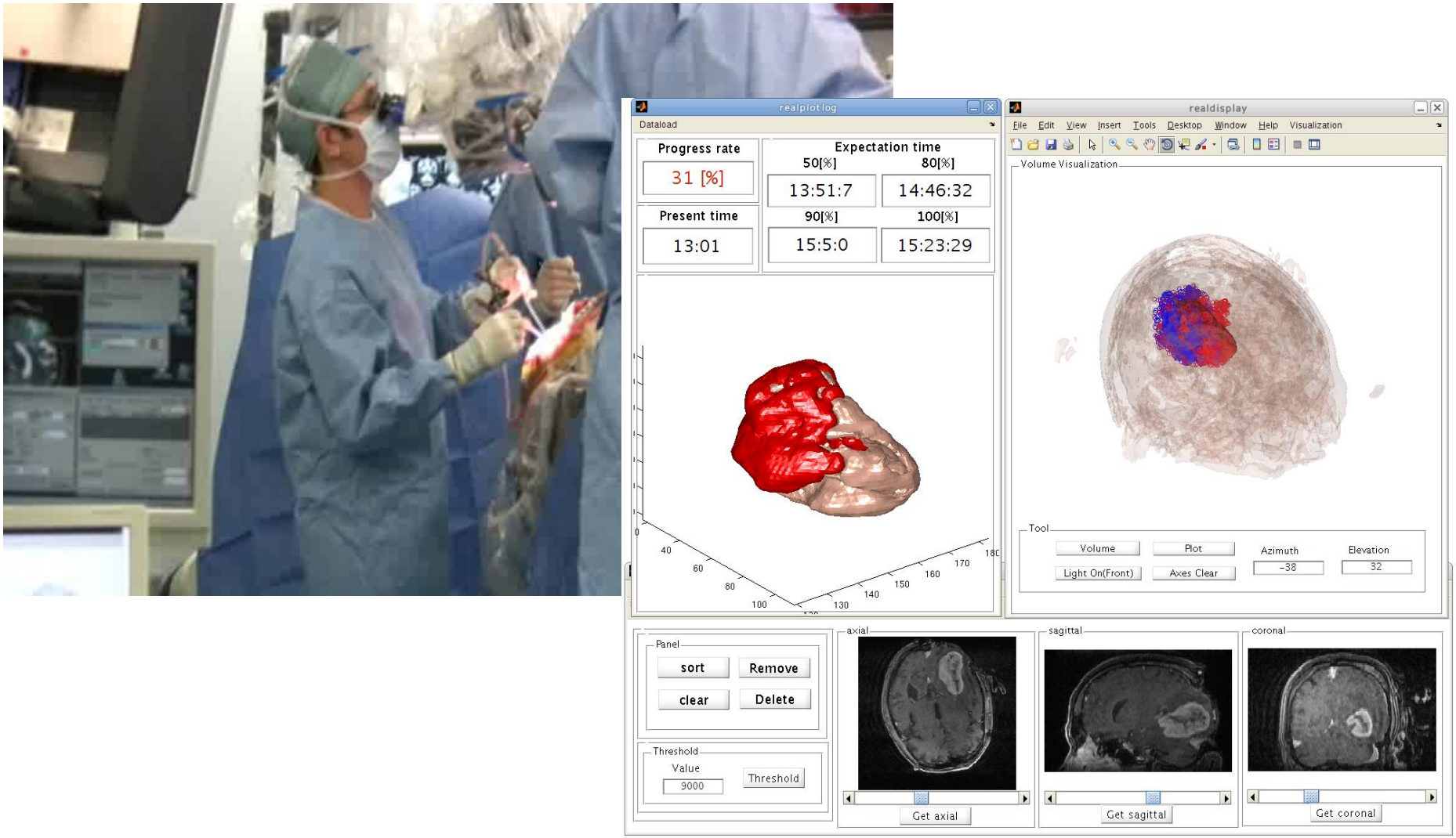
Computer Assisted Surgery based on Intraoperative Information and Navigation Technology

- Evaluation of performance of surgeon/procedure/device
  - Record, Analyze, Visualize
  - By human: hard task, long time, high cost, error
  - By new device: Do not disturb surgical procedure

- Demand for Automatic Recording/Analysis/Visualization
  - Quantitative digital data for computer processing
  - No effect on surgical procedure and environment

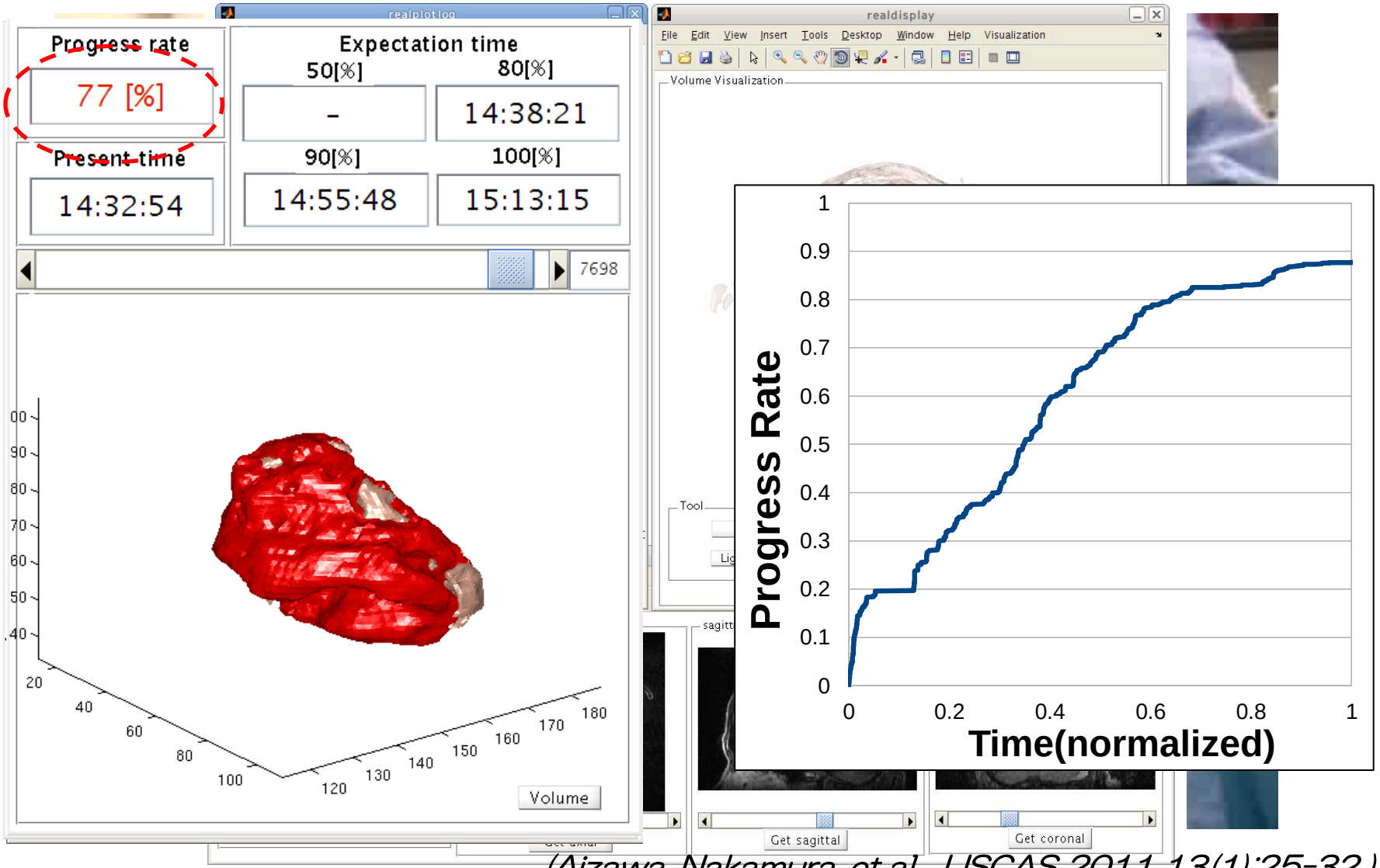
Automatic analysis using navigation information

Process analysis system using surgical navigation 1: Visualization of Progress Rate P(t)



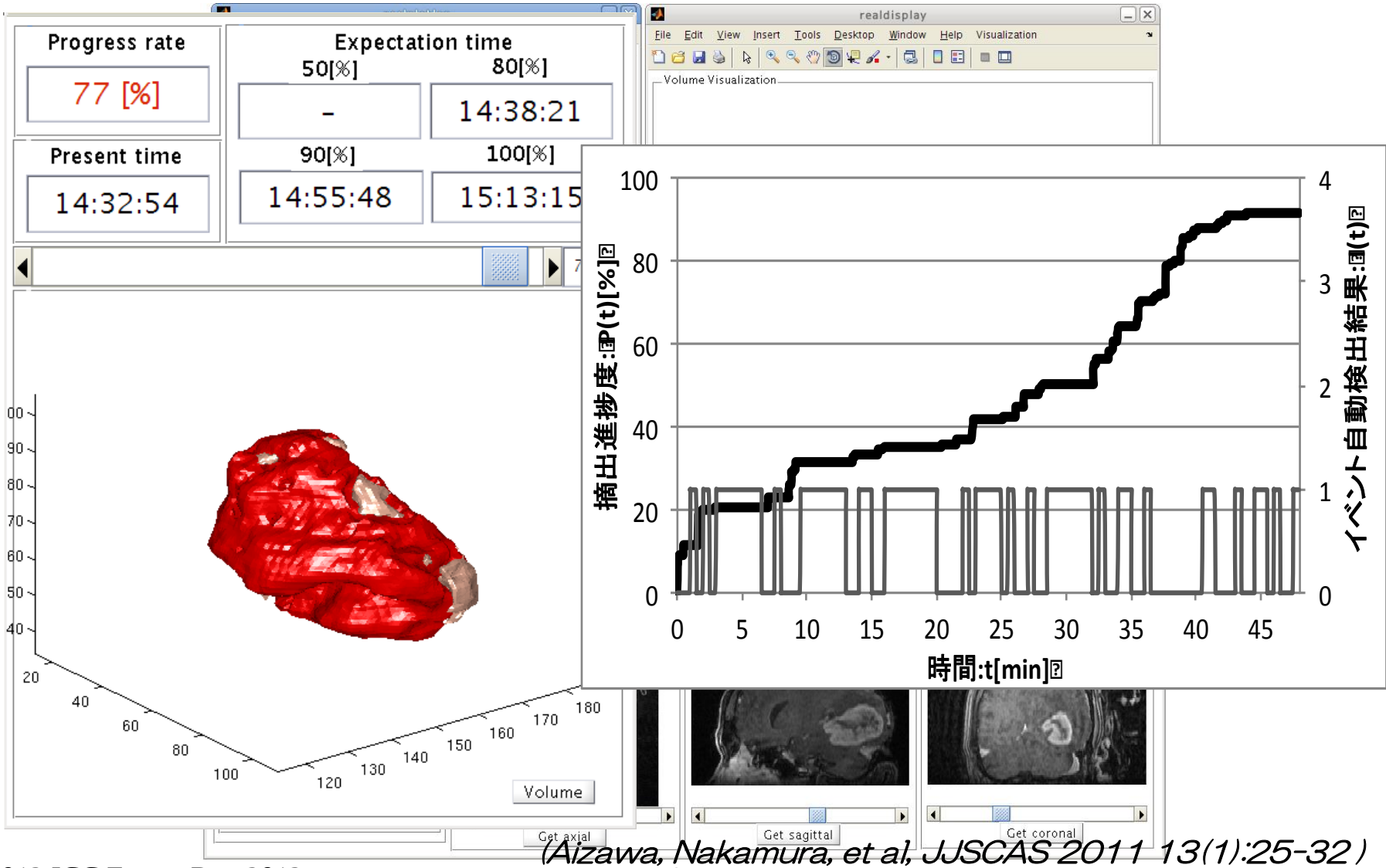
(Aizawa, Nakamura, et al, JJSCAS 2011 13(1):25-32)

Process analysis system using surgical navigation
1: Visualization of Progress Rate P(t)



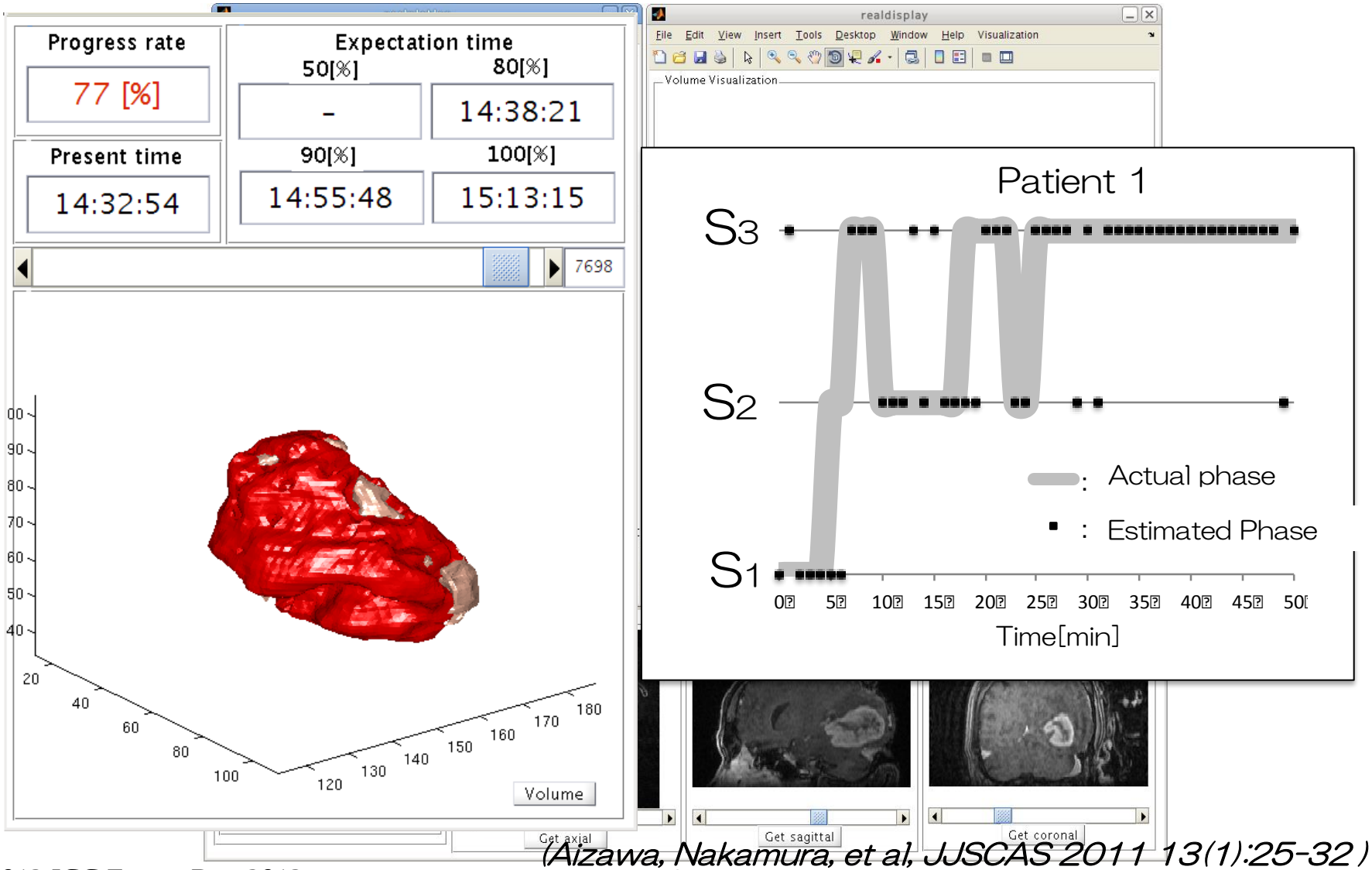
(Aizawa, Nakamura, et al, JJSCAS 2011 13(1):25-32)

Process analysis system using surgical navigation 2: Automatic detection of intraoperative events



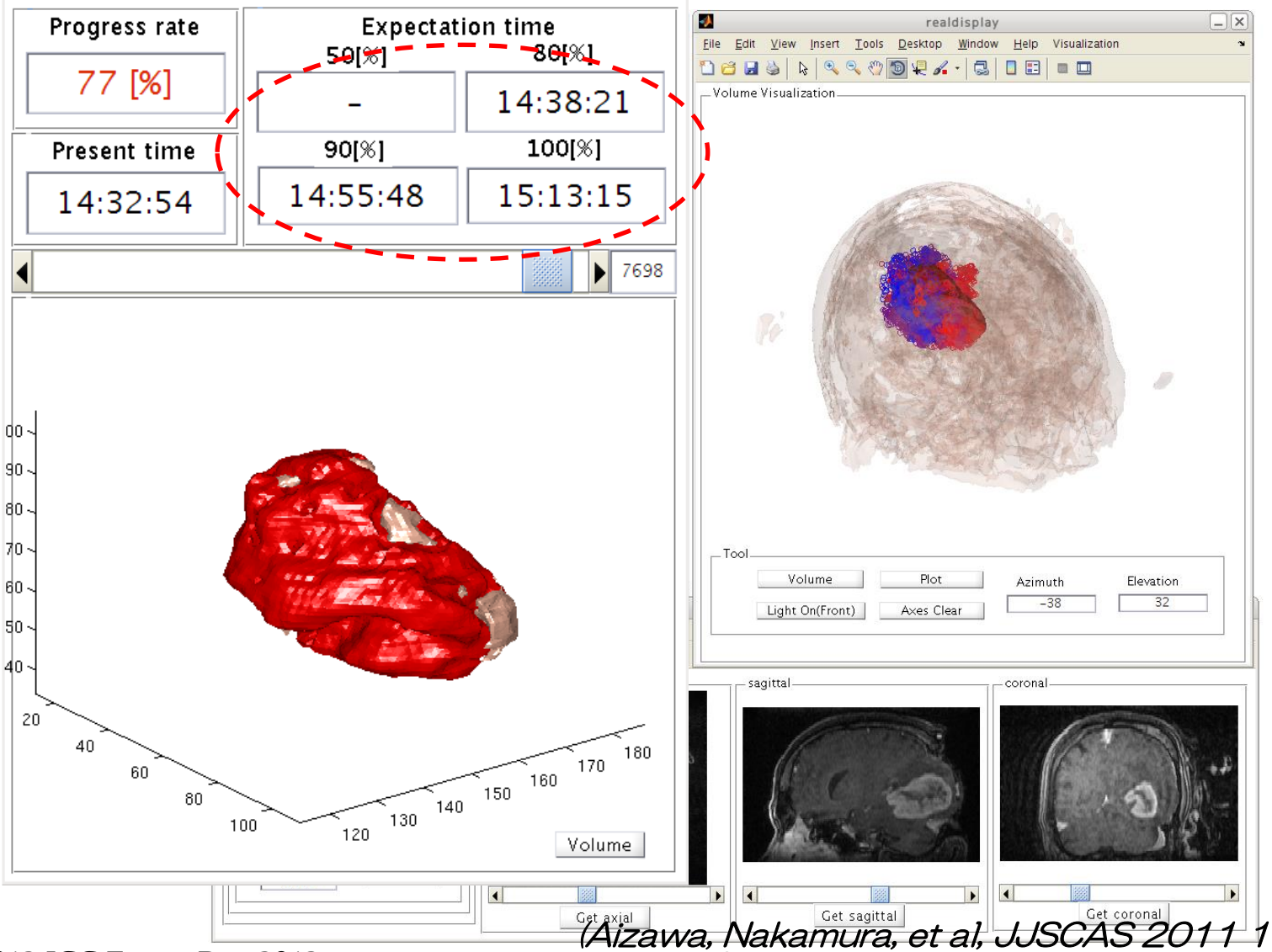
(Aizawa, Nakamura, et al, JJSCAS 2011 13(1):25-32)

Process analysis system using surgical navigation
3: Automatic detection of stage of procedure



(Aizawa, Nakamura, et al, JJSCAS 2011 13(1):25-32)

Process analysis system using surgical navigation
4: Prediction of the end time of treatment



(Aizawa, Nakamura, et al, JJSCAS 2011 13(1):25-32)

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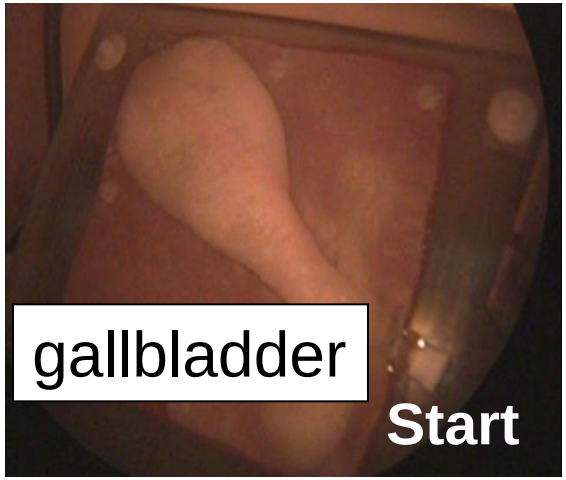
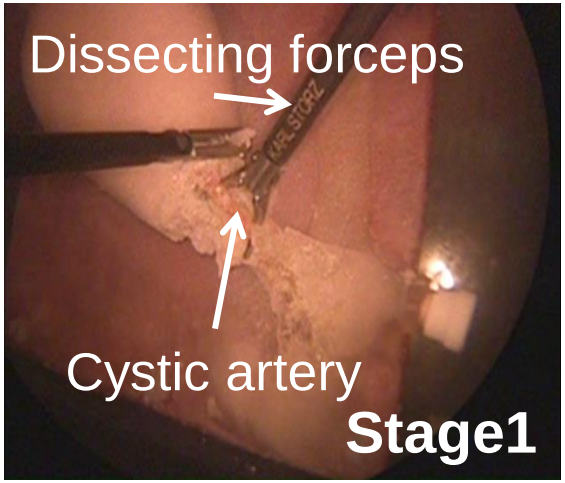
Automatic surgical workflow analysis using navigation information

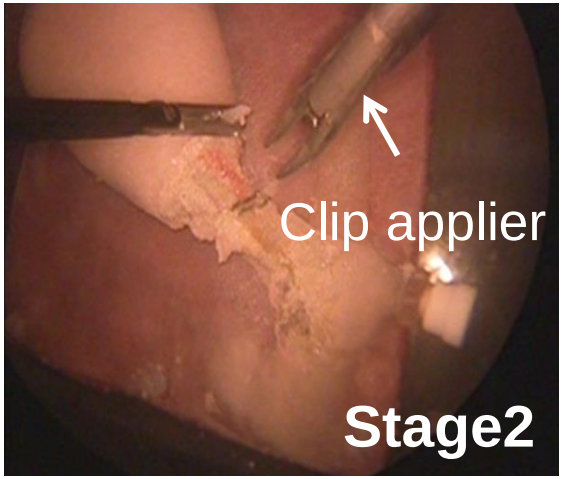
Case2: Laparoscopic cholecystectomy

(Sugino, JSES2012)

Workflow of laparoscopic cholecystectomy

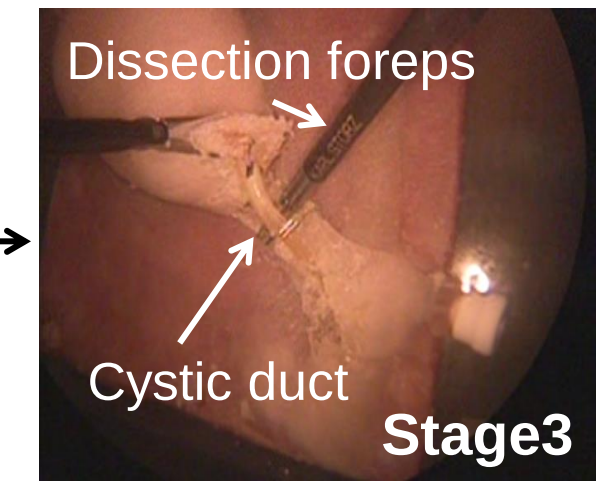


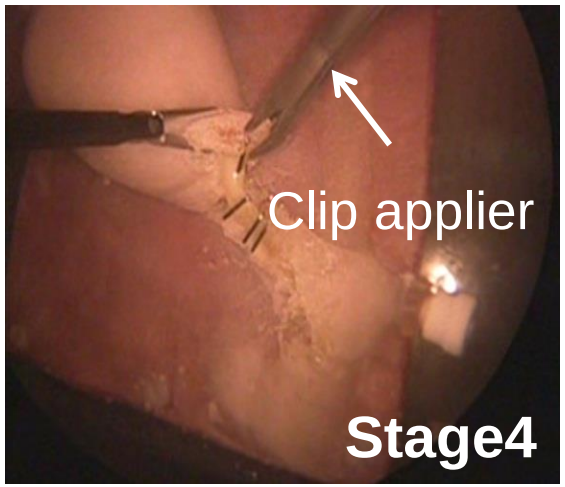


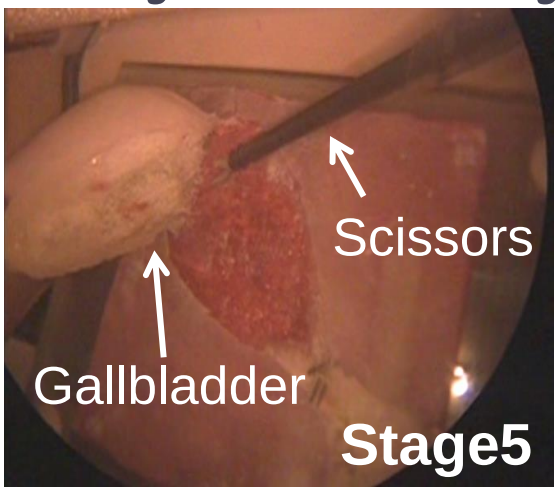


Stage	Operation	Tools
Stage1	Dissection of Cystic duct or artery	Scissors, dissecting forceps
Stage2	Clipping of Cystic duct or artery	Clip applier
Stage3	Cutting clipped duct/artery, dissection the rest of them	Scissors, dissecting forceps
Stage4	Clipping of the duct/artery	Clip applier
Stage5	Cutting clipped duct/artery, dissection of gallbladder	Scissors, dissecting forceps

Workflow of laparoscopic cholecystectomy







Stage	Operation	Tools
Stage1	Dissection of Cystic duct or artery	Scissors, dissection forceps
	↓	
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	↓	
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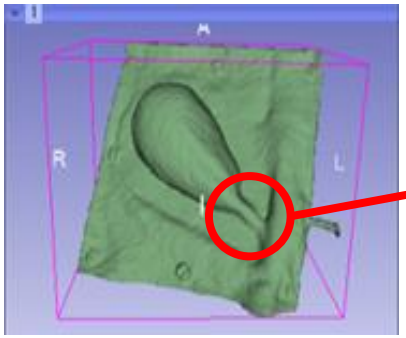
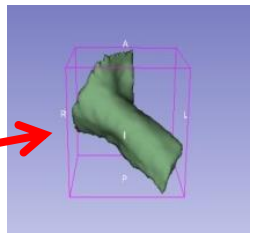
	↓	
Stage4	Clipping of the duct/artrey	Clip applier
	↓	
Stage5	Cutting clipped duct/artery, dissection of gallbladder	Scissors, dissection forceps

Automatic Assessment of Task Progress on Each Stage

Step1 Segmentation

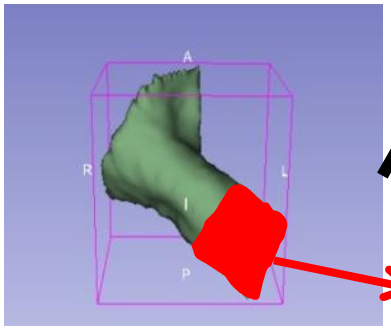


Organ Model



Segmentation of task target region

Step2 Task analysis



Segmented region

Contact with Instrument region by instrument

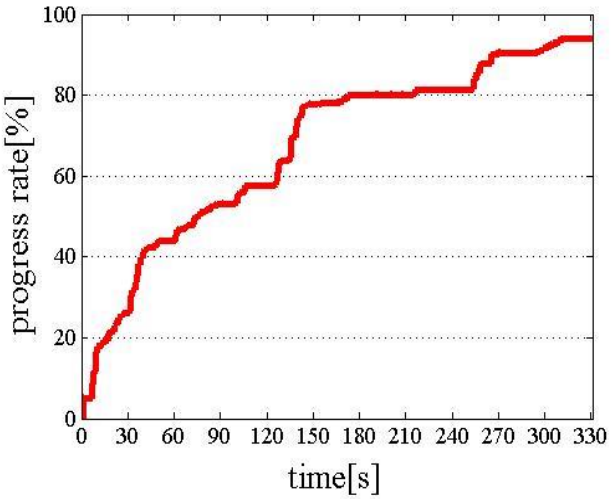
||

Task Completed

Step3 Progress Rate

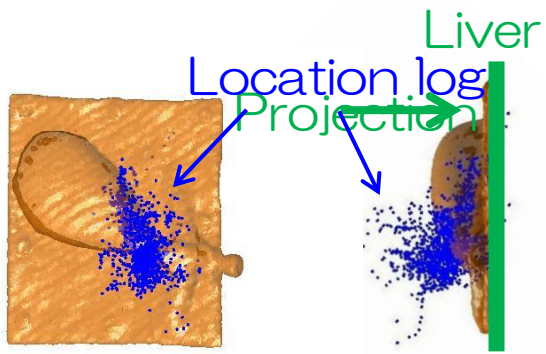
Progress rate of Stage N (N=1,3,5)

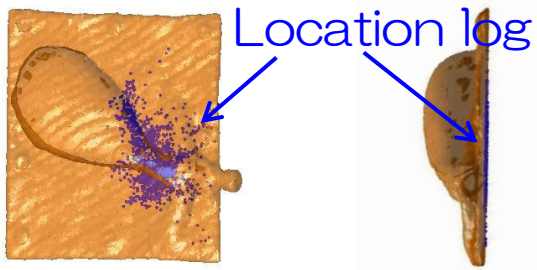
$P_N(t)[\%]$ =
Task Completed Volume/Total Volume×100



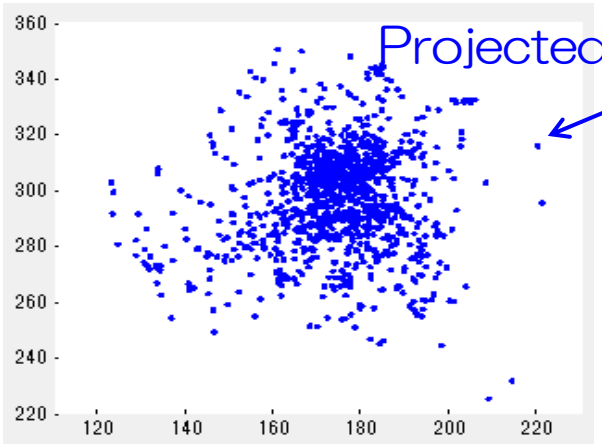
Automatic Analysis of Procedure Distribution

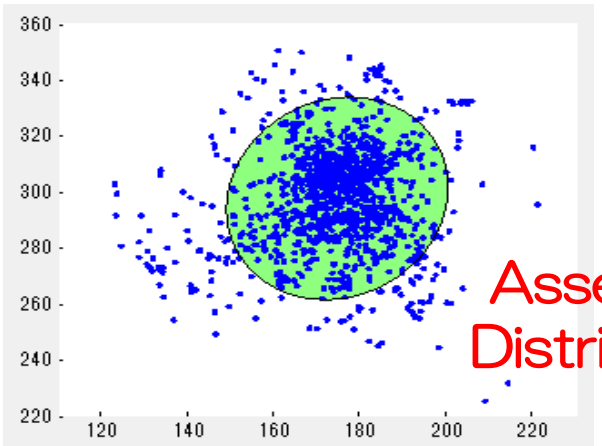
Step1
3D → 2D Distribution





Step2 Distribution Analysis



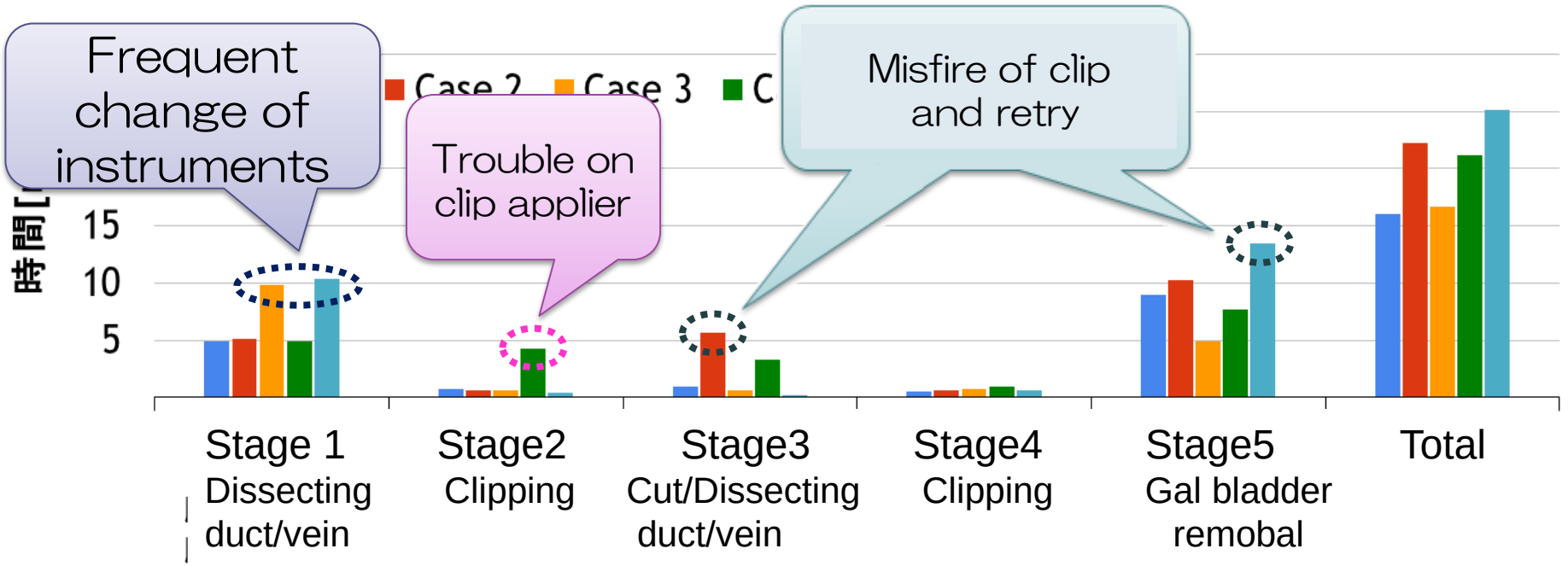


Result: Procedure time on each stage

- Comparison with several cases by one surgeon

→

Find some incident from the change of procedure time



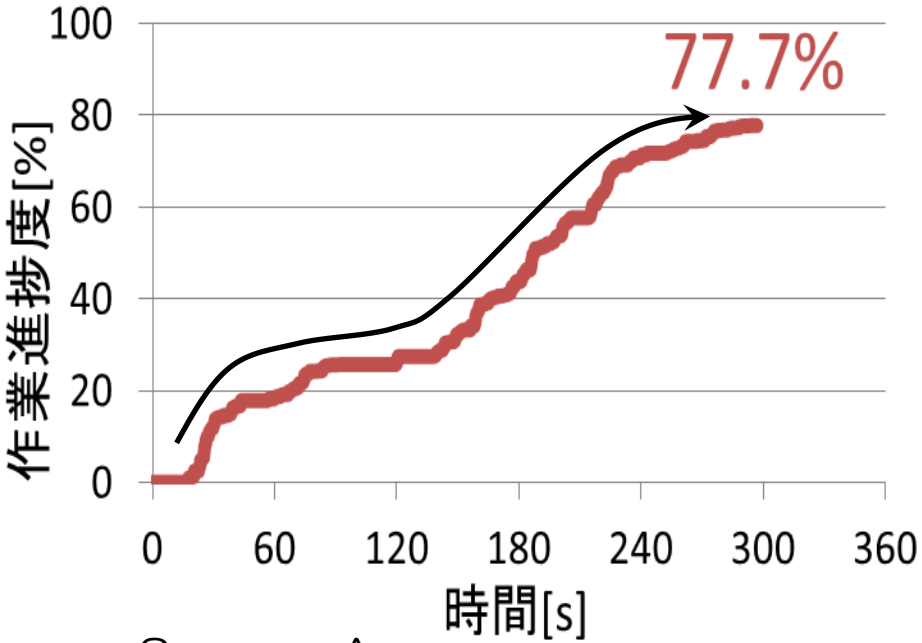
Procedure time on each stage by one surgeon (N=5)

Result: Task Progress Assessment

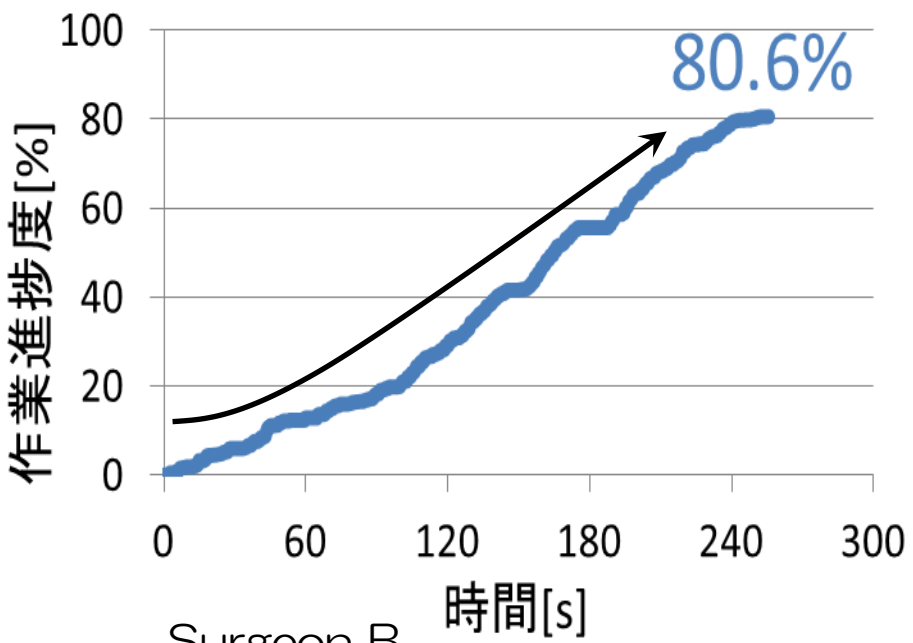
- Difference between surgeons

→

Progress rate data shows
the difference of ability/method/environment



Surgeon A,
Stage5(Removal of Galbladder)

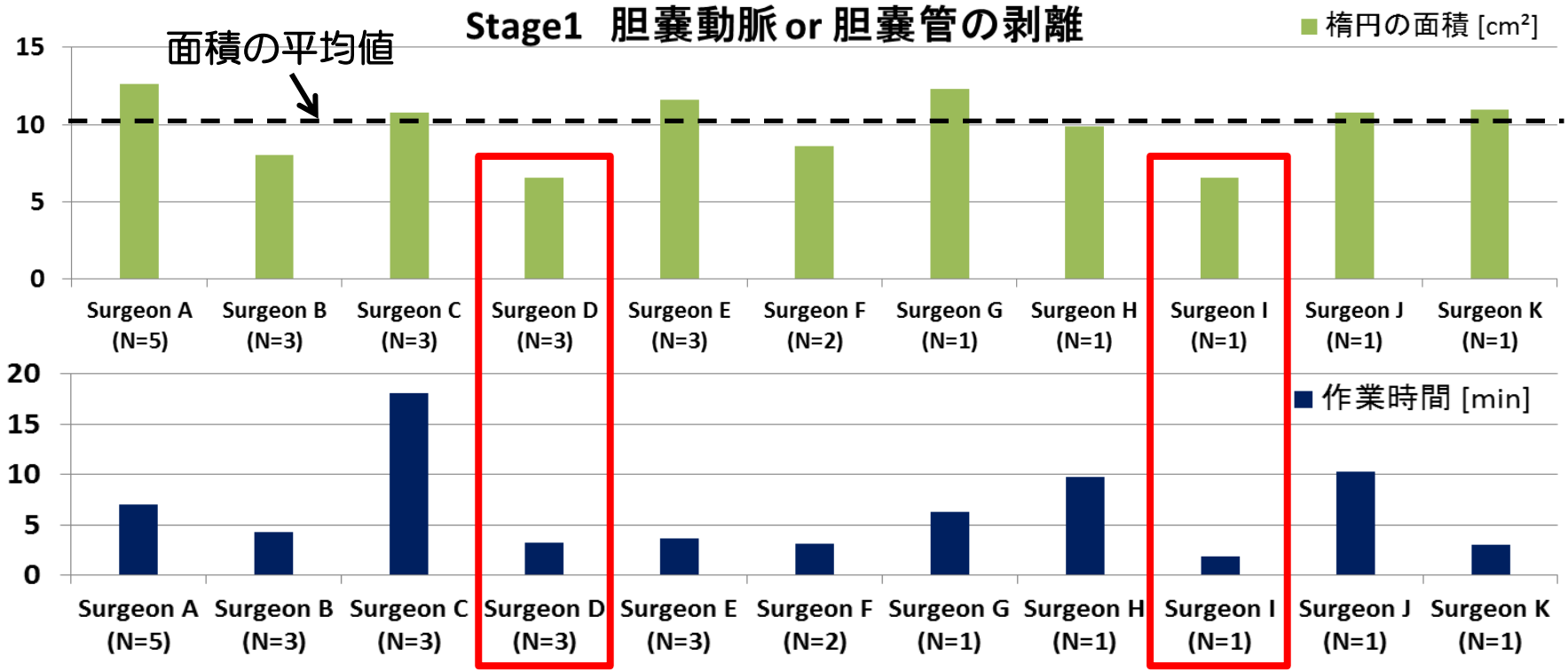


Surgeon B
Stage5(Removal of Galbladder)

Result: Task Distribution Assessment

- Comparison with the size of distribution
  - → Short procedure time in small size case

Distribution may reflect the task efficiency



Distribution Size and Task Time on Stage 1

Summary

- Navigation system in next generation is

Precision guidance system for surgeon with real-time updated information of target condition

- Need for high-speed and portable
  - Intraoperative imaging
  - Intraoperative processing

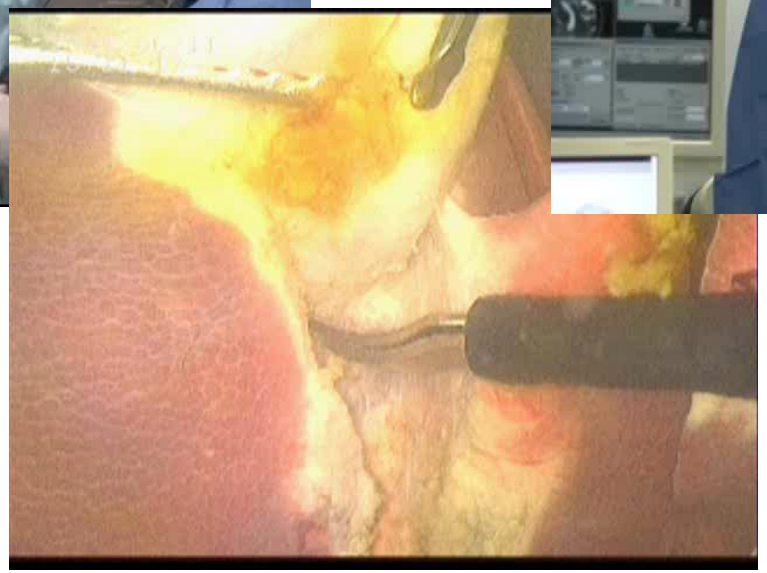
Summary

- Navigation system in next generation is

Digital recorder/analyzer for surgical procedure

  - Automatic recording and computing in OR
  - Protect individual personal information

- Future Application
  - Digital Reference Data: General procedure of surgery
  - Quantitative evaluation of performance



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Laboratory of Innovative Therapeutic Engineering,

Department of Medical System Engineering,
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