Title: Novel navigation system by augmented reality technology using a tablet PC for hepatobiliary and pancreatic surgery

Jungo Yasuda[a], Tomoyoshi Okamoto[b], Shinji Onda[a], Yasuro Futagawa[b], Katsuhiko Yanaga[a], Naoki Suzuki[c], Asaki Hattori[c]

[a] Department of Surgery, The Jikei University School of Medicine, Tokyo, Japan

[b] Department of Surgery, The Jikei University Daisan Hospital, Tokyo, Japan

[c] Institute for High Dimensional Medical Imaging, The Jikei University School of Medicine, Tokyo, Japan

*Corresponding author

Jungo Yasuda

Department of Surgery, The Jikei University School of Medicine

3-25-8 Nishi-shimbashi, Minato-ku, Tokyo 105-8471, Japan

Tel: +81-3-3433-1111

E-mail: j.yasuda@jikei.ac.jp

FAX: +81-3-5472-4140

Keywords: navigation surgery, augmented reality, hepatobiliary, tablet PC

Abstract

Background: We previously developed an image-guided navigation system (IG-NS) using augmented reality technology for hepatobiliary and pancreatic (HBP) surgery. This system superimposed a 3D model onto a stereoscope-captured surgical field (i.e., scope method). Unfortunately, this method requires an expensive stereoscope, surgeons have to shift their eyesight away from the surgical field, and the method has poor controllability. Therefore, an IG-NS using a tablet PC (i.e., tablet method) was developed. The aim of the current study is to evaluate the efficiency of this novel method.

Methods : We studied nine patients, for whom a 3D model was created from CT images. After registration was performed, the 3D model was superimposed onto the surgical field, which was captured by the tablet PC's camera.

Results: IG-NS could be carried out with very little time lag. The visibility and controllability of the tablet method were superior to those of the scope method. The surgery for multiple metastatic liver carcinoma was especially useful due to easy localization of the position of the carcinomas and vessels.

Conclusions: We successfully developed the tablet method and tested it in a clinical setting. This system may contribute to surgical efficacy and improve the educational

effects.

Background:

Hepatobiliary and pancreatic (HBP) surgeries are characterized by complex anatomies and procedures. Therefore, accurate simulation using a 3D organ model was developed to improve the efficiency and to decrease the surgical risks involved[1-3]. A system wherein the organ model used for the simulation was superimposable onto the surgical field would aid in improving the quality of surgery. Thus, an image-guided navigation system (IG-NS) was developed, using augmented reality technology, and its usefulness in HBP surgery was reported [4-7]. In the aforementioned IG-NS, the surgical field was captured using a rigid stereoscope (i.e., scope method), and a 3D organ model was overlaid on the bedside monitor. However, the scope method has issues in terms of the cost of the rigid stereoscope and controllability due to the presence of multiple cables around the surgical field. In addition, the scope method requires surgeons to shift their eyesight away from the surgical field to observe a navigation image displayed on the bedside monitor.

To solve these problems, we developed a novel method of IG-NS using an inexpensive tablet PC (i.e., tablet method) that enables easy recognition of the navigation image intuitively on the surgical field without necessitating the shifting of the surgeon's eyesight away from the surgical field. A similar type of navigation surgery using a tablet PC has been reported in neurosurgery[8-11]; however, no report has been found in the field of abdominal surgery. Therefore, we report the usefulness of the tablet method that is suitable for HBP surgery.

Patients and methods:

Of the 48 patients who underwent HBP surgery with the use of IG-NS at The Jikei University Daisan Hospital, the tablet method was employed in nine patients (Table 1). Operative procedures consisted of hepatectomy in seven and pancreatectomy in two of these patients. Hepatectomy was undertaken for four patients with metastatic liver carcinoma, one patient with hilar cholangiocarcinoma, one patient with hepatocellular carcinoma, and one patient with gallbladder cancer. In addition, one patient with pancreatic carcinoma and one with carcinoma of the papilla of Vater underwent pancreatectomy.

This method involved preoperatively obtaining multi-detector computed tomography images or EOB-MRI in a Digital Imaging and Communications in Medicine (DICOM) format. The organs were then segmented in each image slice using the image analysis software Analyze® (Mayo Foundation, Rochester, MN, USA) [12-14] or VINCENT® (Fujifilm, Japan)[15,16]. Because a smaller amount of data was required for real-time navigation, this data converted the segmented images into surface-rendering models, which were also used for surgical planning and simulation. These models sent the data through the hospital information technology network to a special operating room for use in IG-NS [Fig. 1].

Before navigation, registration was performed for the paired-point method, which means that an anatomical landmark on an actual organ was matched to the corresponding point on the 3D organ model using a pointing device attached to an infrared position marker. The selection of registration sites was performed by the feature points of the organs and vessel bifurcations. A 3D positional measurement was obtained using the position sensor Optotrak® (Northern Digital, Waterloo, Ontario, Canada) installed in the special operating room. Using a Wi-Fi network, the results of this positional measurement during IG-NS were transmitted to a tablet PC. Registration accuracy was calculated as a fiducial registration error (FRE), which was the root mean square between corresponding fiducial points. FRE was recorded in 46 of 48 patients, and was subsequently compared between the scope method (n = 37) and the tablet method (n = 9) patients. A statistical analysis of FRE values was performed with an unpaired t-test with unequal variance using software “Stata/SE 13®”.

The surgical field was imaged using the back-facing camera of a tablet PC (NEC, Japan, CPU: Intel® Atom™ x7-Z8700, memory: 4GB) with an infrared position marker [Fig. 2]. This tablet PC was sterilized using ethylene oxide gas on the day prior to surgery. The 3D organ model was then superimposed onto the tablet PC display, which captured the surgical field images in real time.

The operator could choose the arbitrary organs by himself on the touch panel [Fig. 3]. A zoom function was also developed for observing the details of the navigation images in a manner similar to that of an ordinary touch panel.

The navigation image was also transmitted to the bedside monitor via an ad hoc wireless communication system using a Miracast adapter (Actiontec Electronics, CA, USA) to ensure that the navigation image could be shared with staff, residents, and students in the operating room [Fig. 4].

In addition, the tablet PC was equipped with an annotation function that allowed characters and figures to be drawn freehand using the touch panel.

Results:

FRE was 7.4 mm for the tablet method, which was not statistically different from that of the scope method (7.6 mm, P = 0.58). Like surgical cases reported previously by our team, all patients underwent safe and margin-free operations with only a few registration errors [6,7].

The time required for navigation, including segmentation and registration, was comparable to that of the scope method. Even when utilizing the Wi-Fi network, IG-NS could be employed with very little time lag capable of interfering with the surgery.

Arbitrary selection of necessary organs on the touch panel of the tablet PC reduced the functioning time. In the scope method, there were multiple cables (one light source cable, one infrared position marker cable, and two video cables). In contrast, the tablet method requires only a single, thin cable for the infrared positional marker, which allows for smooth navigation from various angles [Fig. 5] [Movie 1]. Thus, the intuitive visibility of the tablet display became more vivid than that of the scope method.

For patient 4, who underwent pancreaticoduodenectomy due to carcinoma of the papilla of Vater, IG-NS contributed to the identification of the inferior pancreaticoduodenal artery for ligation early in the procedure. In addition, we could successfully perform pancreatectomy along the resection line that was preoperatively planned [Fig. 6].

Patient 7 underwent surgery for metastatic liver carcinoma. Confirmation of the location of the carcinomas and vessels was especially useful for multiple and peripheral metastatic liver carcinomas because the surgeons could easily grasp the positional relationship between a tumor and the vessels to facilitate margin-free surgery [Fig. 7].

Discussion:

The clinical application of the real-time navigation surgery using a rigid stereoscope has been established. However, there are problems with the scope method in terms of eye movement, controllability, and cost.

The scope method requires surgeons to alternately observe the bedside monitor and the surgical field, which necessitates reorientation to each visual field during the procedure. In contrast, surgeons can now observe the navigation image through the tablet PC directly. IG-NS has become more practical as a result of this modification.

Controllability is important for the widespread use of IG-NS. In this regard, a tablet PC that unites a camera, display, and computer has high controllability that is suitable for use in our system. In particular, when observing overlaid images from any angle, the overlaid images can respond well and follow the movements of the tablet PC to facilitate intuitive understanding of the anatomy.

In the scope method, selection of the target organs for the operation is performed by an engineer outside the surgical field. In contrast, the operator can choose the required organs directly using the touch panel interface of the tablet PC. Thus, organ selection can be easily and frequently made during surgery.

In the tablet method, the operator or assistant needs to hold the tablet PC directly to control it. Therefore, the sterilization of the tablet PC is an issue. Covering the tablet PC with a sterilized plastic bag makes it difficult to manipulate the touch panel directly when the operator is wearing sterilized gloves[8]. To solve this issue, the entire tablet PC body was sterilized with ethylene oxide gas, which can be used for appliances that are vulnerable to heat or moisture[17]. In the near future, in order to free both hands of operator, an articulating sterile mechanical arm may be needed to hold the tablet PC.

The operator or assistants wearing sterilized gloves could hold and control the interface on the touch panel with a degree of sensitivity similar to that without gloves. The tablet PC did not malfunction as a result of sterilization. Additionally, due to the adverse effects, such as surgical site infection, did not result from the sterilization. However, an increase in the rate of infection could occur if the same technique were tested using a bigger sample size. Therefore, it may be better to change gloves after touching the tablet PC.

When comparing the cost, the stereoscope costs USD 30,000, while the tablet PC can be bought for approximately USD 600. In addition, the tablet PC can be easily purchased commercially.

A limitation of this method is that no one except for the operator and assistants can view the navigation image on the tablet display. Therefore, the navigation image was transmitted from the tablet screen to the bedside monitor through an ad hoc connection. All co-medical staff and students in the operating room could now see the navigation image using this interface. Information sharing due to the annotation function also improved the educational effects.

Another drawback of the tablet method is that stereopsis could not be acquired. Further improvement of navigation surgery is needed for a tablet PC with stereoscopic vision. However, the high controllability in terms of being able to observe the navigation images from various angles seems to fully compensate for this lack of stereopsis.

The assessment of the surgical outcome after using IG-NS is very complicated, and it remains difficult to identify objective parameters. The FRE accuracy seemed to be the only objective method for appreciating the superiority or inferiority of each system. Therefore, novel assessment tools should be developed to evaluate the utility of the surgical modality.

Since this study included only a small sample size, this technique needs to be tested in future studies that involve case-control trials.

Conclusion:

IG-NS using the tablet method as surgical-assistance equipment appears to be a superior and more effective tool for HBP surgery compared to the scope method.

Disclosure Statement:

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics:

This study has been approved be the Ethics Committee of The Jikei University School of Medicine for Biomedical Research (Registration Number: 17-167 [4588]).

References

1. Hallet J, Gayet B, Tsung A, Wakabayashi G, Pessaux P. Systematic review of the use of pre-operative simulation and navigation for hepatectomy: current status and future perspectives; 2nd International Consensus Conference on Laparoscopic Liver Resection Group. J Hepatobiliary Pancreat Sci. 2015 May;22(5):353-62.

2. Abe Y, Itano O, Kitago M, Shinoda M, Yagi H, Hibi T, et al. Computer assisted surgery, preoperative planning and navigation for pancreatic cancer. J Hepatobiliary Pancreat Sci. 2014 Apr;21(4):251-5.

3. Morita Y, Takanishi K, Matsumoto J. A new simple navigation for anatomic liver resection under intraoperative real-time ultrasound guidance. Hepatogastroenterology. 2014 Sep;61(134):1734-8.

4. Okamoto T, Onda S, Matsumoto M, Gocho T, Futagawa Y, Fujioka S, et al. Utility of augmented reality system in hepatobiliary surgery. J Hepatobiliary Pancreat Sci. 2013; 20: 249–53

5. Onda S, Okamoto T, Kanehira M, Fujioka S, Suzuki N, Hattori A, et al. Short rigid scope and stereo scope designed specifically for open abdominal navigation surgery: clinical application for hepatobiliary and pancreatic surgery. J Hepatobiliary Pancreat Sci. 2013; 20: 448-453

6. Onda S, Okamoto T, Kanehira M, Suzuki F, Ito R, Fujioka S, et al. Identification of inferior pancreaticoduodenal artery during pancreaticoduodenal artery during pancreaticoduodenectomy using augmented reality-based navigation system. Hepatobiliary Pancreat Sci. 2014; 21: 281-287

7. Okamoto T, Onda S, Yasuda J, Yanaga K, Suzuki N, Hattori A. Navigation surgery using an augmented reality for pancreatectomy. Dig Surg. 2015; 32: 117-123

8. Morrison MA, Tam F, Garavaglia MM, Golestanirad L, Hare GM, Cusimano MD, et al. A novel tablet computer platform for advanced language mapping during awake craniotomy procedures. J Neurosurg. 2016 Apr;124(4):938-44.

9. Deng W, Li F, Wang M. Song Z. Multi-mode navigation in image-guided neurosurgery using a wireless tablet PC. Australas Phys Eng Sci Med (2014) 37: 583-9.

10. Deng W, Li F, Wang M, Song Z. Easy-to-use augmented reality neuronavigation using a wireless tablet PC. Stereotact Funct Neurosurg. 2014;92(1):17-24.

11. Watanabe E, Satoh M, Konno T, Hirai M, Yamaguchi T. The trans-visible navigator: a see-through neuronavigation system using augmented reality. World Neurosurg. 2016 Mar; 87:399-405.

12. Robb RA. The biomedical imaging resource at Mayo Clinic. Guest Edition. IEEE Trans Med Imaging. 2001; 20(9):854-867

13. Robb RA, Barillot CC. Interactive display and analysis of 3-D medical images. IEEE Trans Med Imaging. 1989; 8(3):217-226

14. Robb RA, Hanson DP, Karwoski RA, Larson AG, Workman EL, Stacy MC. ANALYZE: a comprehensive, operator-interactive software package for multidimensional medical image display and analysis. Comput Med Imaging and Graph. 1989; 13: 433-454

15. Ohshima S. Volume analyzer SYNAPSE VINCENT for liver analysis.
J Hepatobiliary Pancreat Sci. 2014 Apr;21(4):235-8.

16. Ogawa C, Minami Y, Morita M, Noda T, Arasawa S, Izuta M, et al. Prediction of embolization area after conventional transcatheter arterial chemoembolization for hepatocellular carcinoma using SYNAPSE VINCENT.
Dig Dis. 2016;34(6):696-701.

17. Sabnis RB, Bhattu A, Vijaykumar M. Sterilization of endoscopic instruments. Curr Opin Urol. 2014 Mar;24(2):195-202.

18. Meola A, Cutolo F, Carbone M, Cagnazzo F, Ferrari M, Ferrari V. Augmented reality in neurosurgery: a systematic review. Neurosurg Rev. 2016 May 7. [Epub ahead of print]

Table 1: Characteristics of patients

	Age (years)	SEX	Diagnosis	Operative procedure	FRE (mm)	TNM classification Stage(UICC)
1	70	M	Metastatic liver carcinoma	Liver subsegmentectomy(S3)	10.25	Ⅳ
2	80	M	Metastatic liver carcinoma	Liver subsegmentectomy(S8)	3.51	Ⅳ
3	71	M	Pancreatic carcinoma	Distal pancreatectomy	7.81	ⅡB
4	70	F	Carcinoma of the papilla of Vater	Pancreaticoduodenectomy	1.1	ⅡB
5	82	F	Gallbladder carcinoma	Liver subsegmentectomy (S4a+5)	8.64	Ⅳ
6	58	M	Hilar cholangiocarcinoma	Left hepatic lobectomy	7.77	ⅡB
7	78	M	Metastatic liver carcinoma	Partial liver resection	10.51	Ⅳ
8	73	M	Hapatocellular carcinoma	Right hepatic lobectomy	7.04	ⅢA
9	76	F	Metastatic liver carcinoma	Extended posterior hepatectomy	9.94	Ⅳ

M: Male F: Female FRE: Fiducial Registration Error

Figure legends:

Fig. 1: Special operating room for IG-NS

This room is equipped with an optical location sensor and bedside monitors.

Fig. 2: Tablet PC with an infrared sensor marker

Fig. 3: The choice of organs displayed on the tablet PC

A surgeon can choose and display arbitrary organs for the operation using the swipe and touch function on the touch panel of the tablet PC.

a: All of the organ models are superimposed.

b: A doughnut editable chart-like selection interface is displayed.

c: The selective organ models are superimposed.

Fig. 4: Ad hoc connection between the tablet PC and bedside monitor

Since the tablet PC can only be viewed by the operator and assistants, the superimposed image was transferred from the tablet PC to a bedside monitor using a

Miracast adapter via an ad hoc connection. Annotation function (↑) of the tablet PC can also be used as an educational tool for staff, residents, and medical students.

Fig. 5: Displays from various directions in real-time

Since the position of the tablet is measured with the infrared position marker, the tablet PC can be moved freely to obtain optimal navigation images.

Fig. 6: Navigation image for patient 4

a: Preoperatively estimated transection line of the pancreas is indicated on the 3D organ model.

b: All of the segmented models are overlaid on the surgical field.

c: The tumor, pancreas, and transection line are displayed.

Fig. 7: Multiple metastatic liver carcinomas for patient 7

a: 3D organ model (red: tumors, green: hepatic veins, purple: portal vein, light yellow: hepatic artery).

b: 3D organ model overlaid on the surgical field (white arrow: tumors).

Fig.1

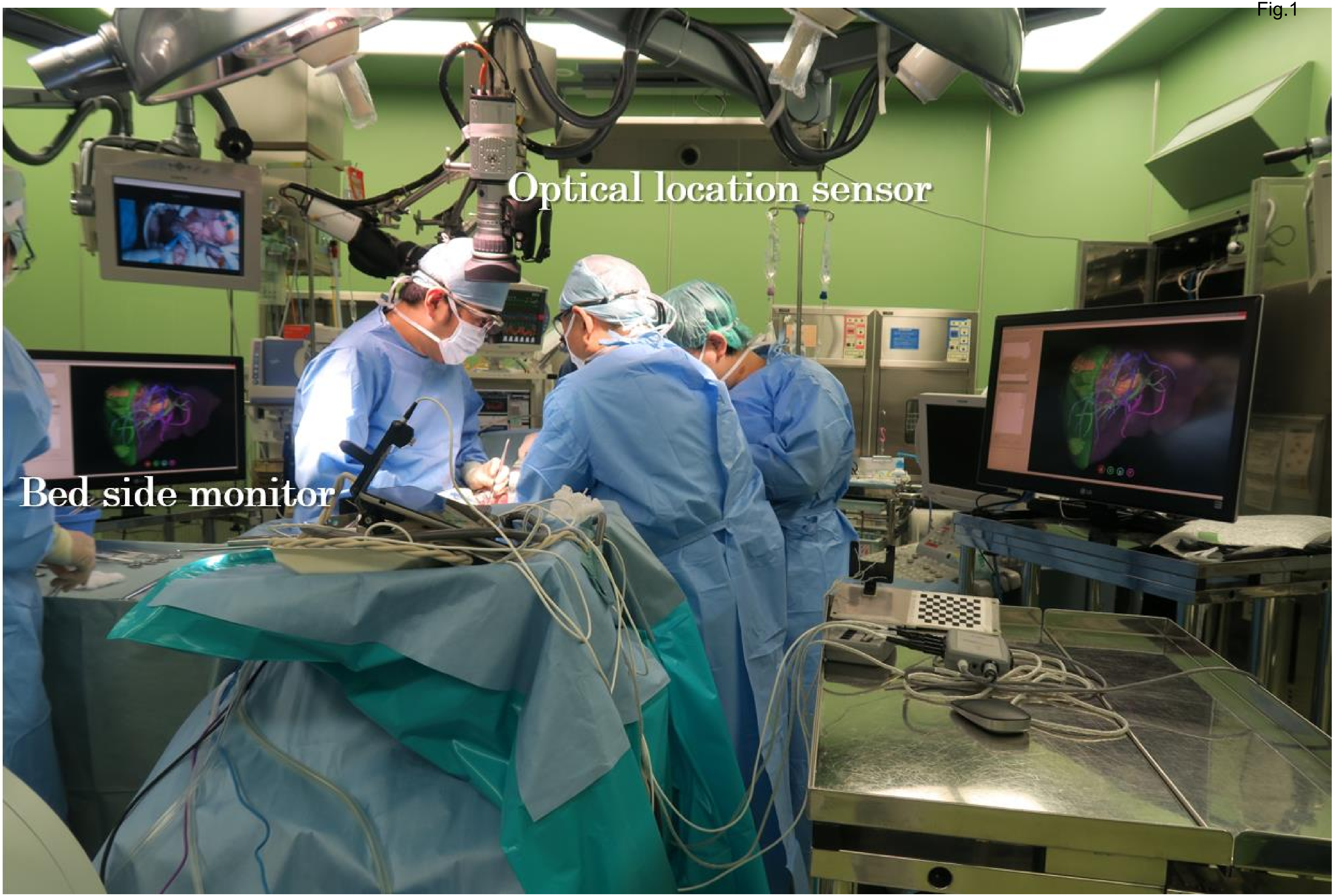

Fig.2

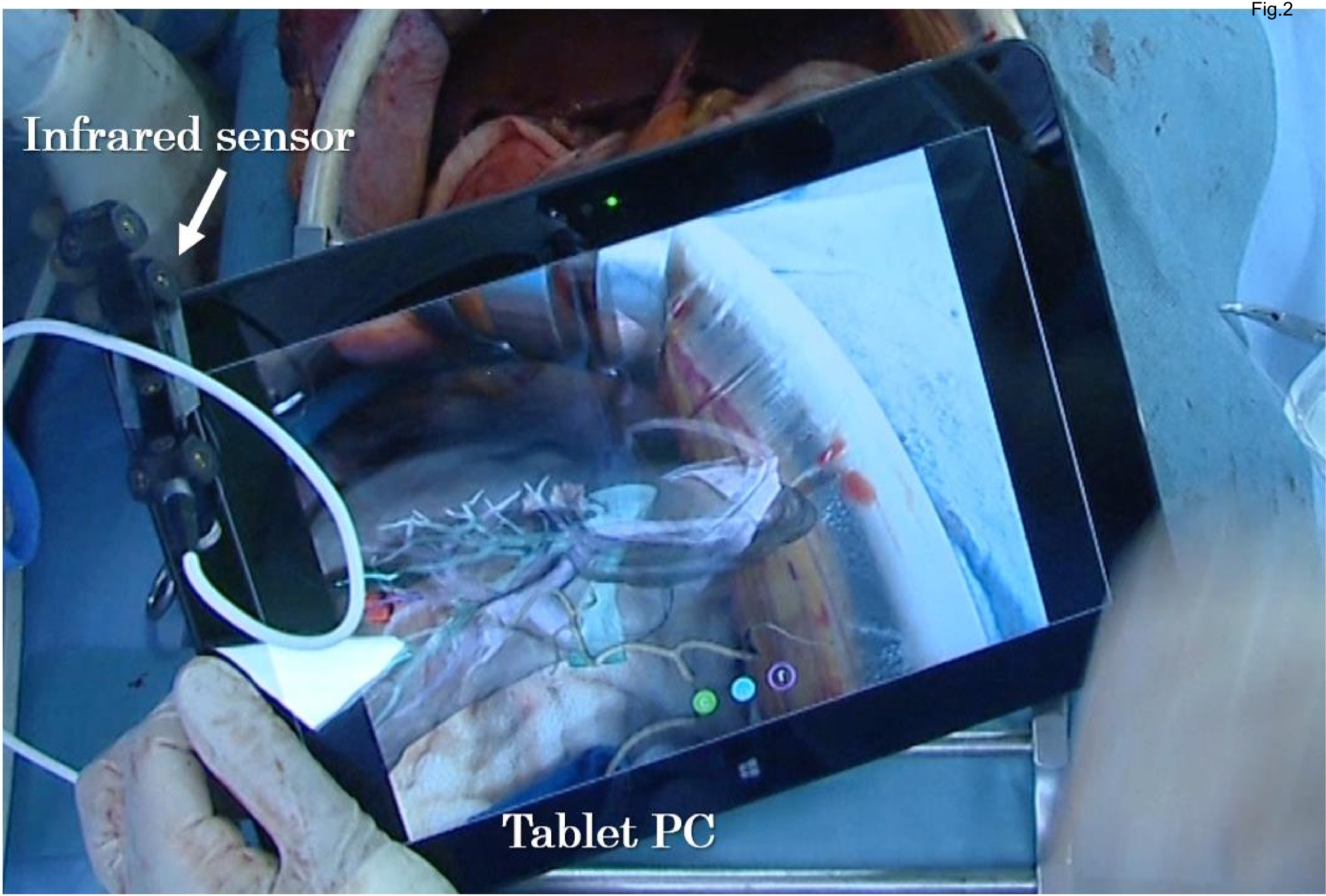

Fig.3

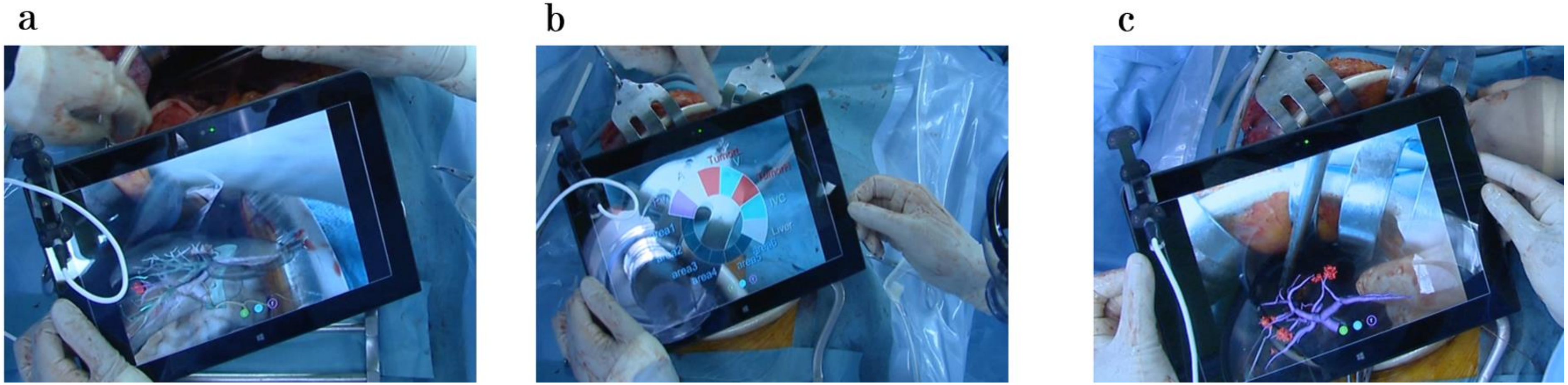

Fig.4

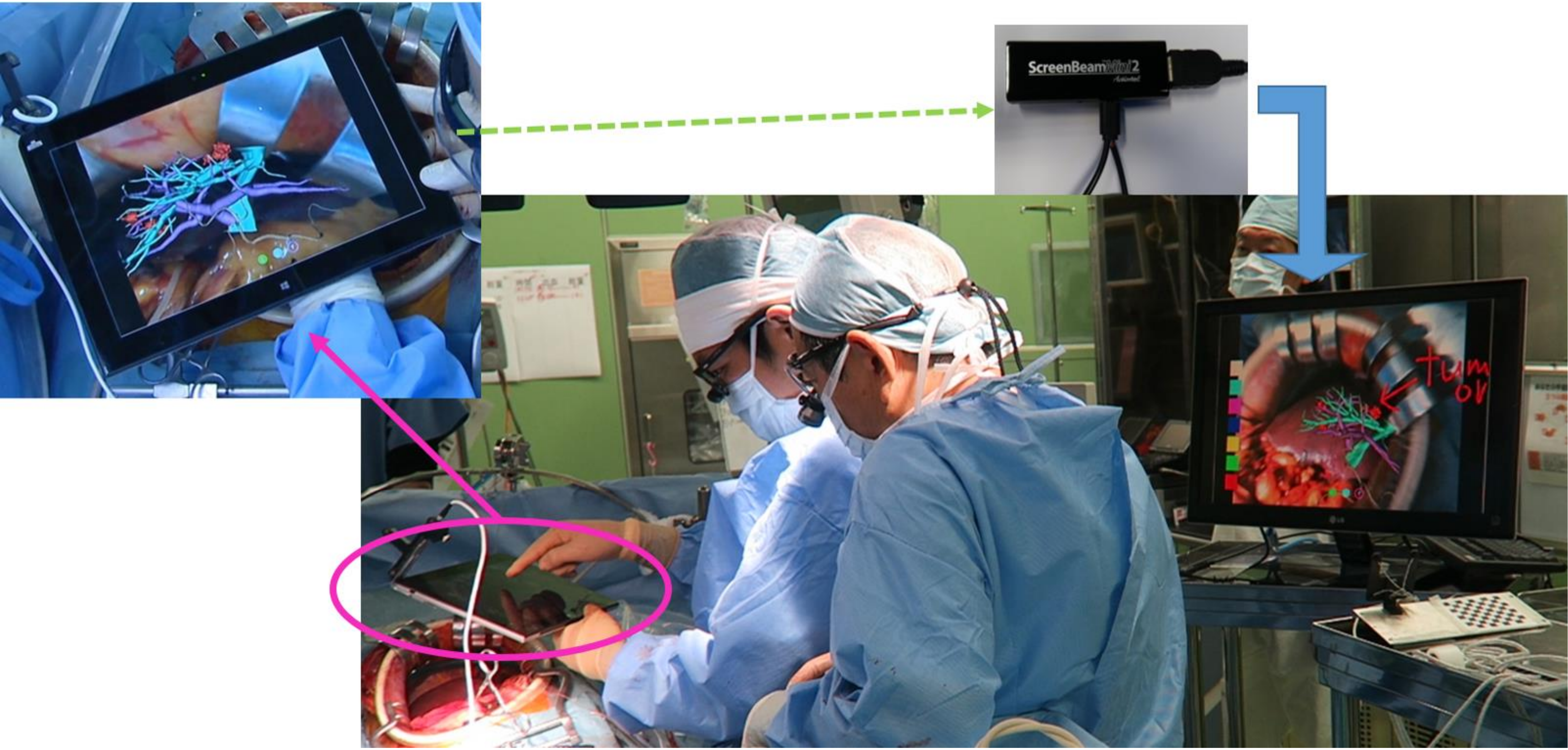

Fig.5

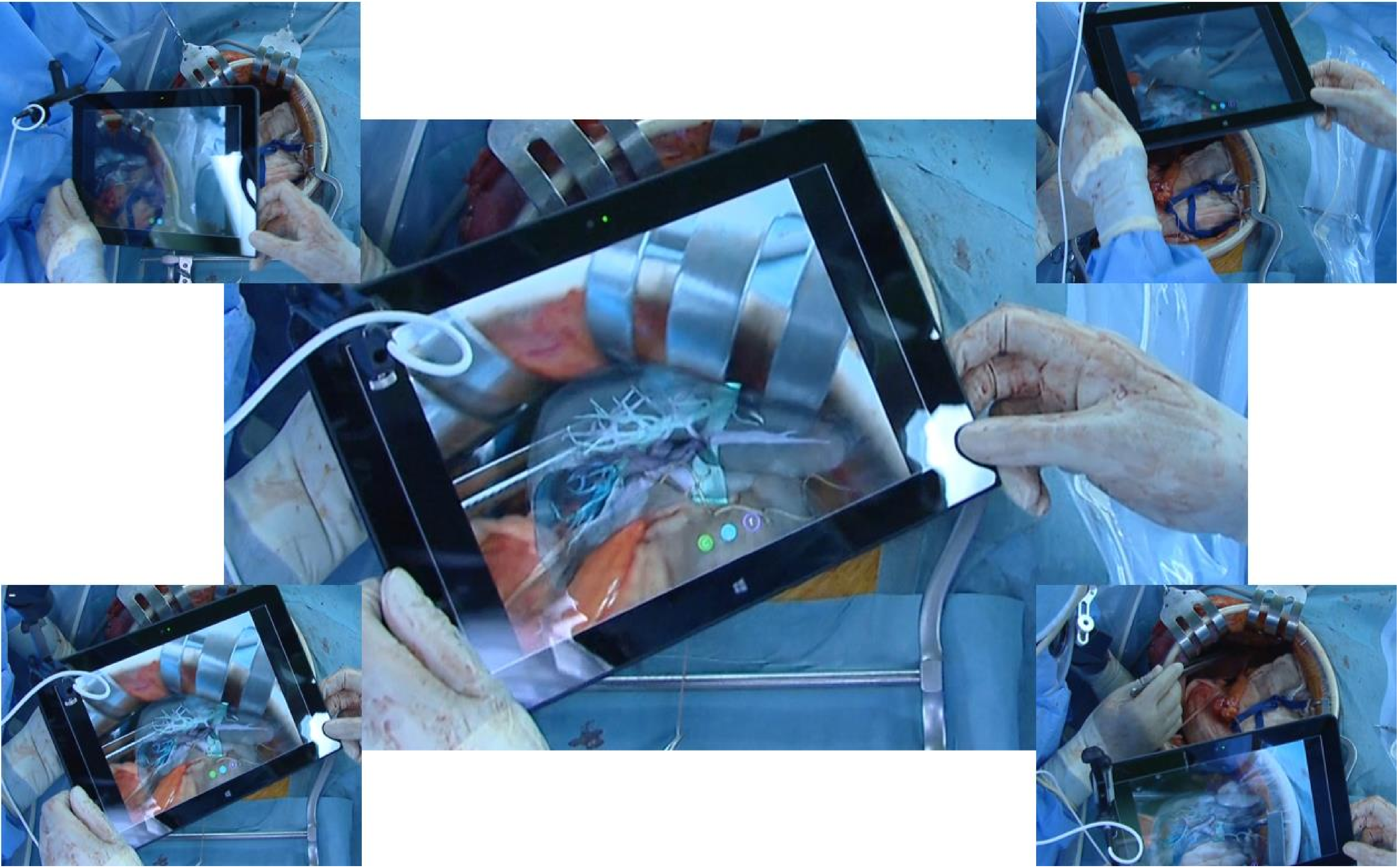

Fig.6

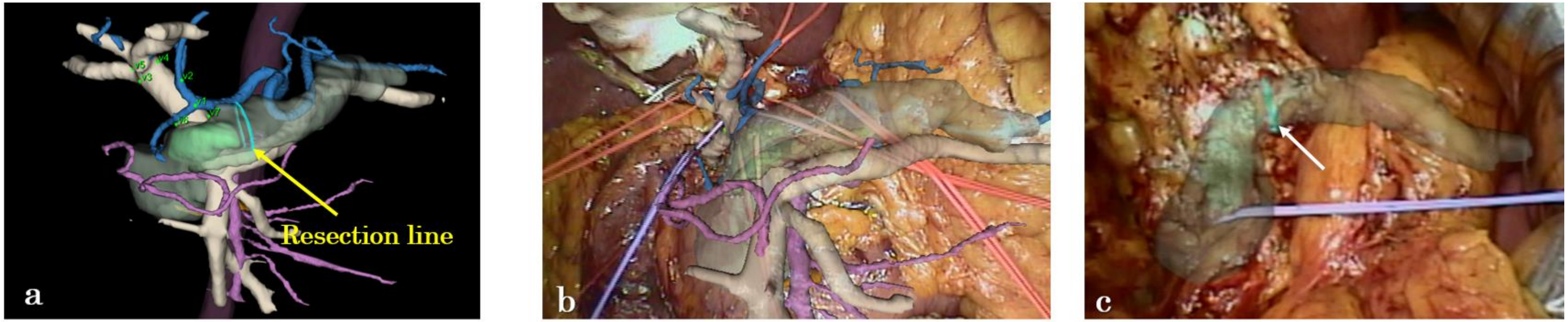

Fig.7