A feasibility of image-guided minimally invasive robotic surgery using preoperative CT scan for gastric cancer patients.

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A feasibility of image-guided minimally invasive robotic surgery using preoperative CT scan for gastric cancer patients.

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The Master's Thesis
submitted to the Department of Medicine
the Graduate School of Yonsei University
in partial fulfillment of the requirements for the degree
of Master of Medical Science

YOO MIN KIM

June 2011

This certifies that the Master's Thesis of YOO MIN KIM is approved.

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June 2011

ACKNOWLEDGEMENTS

The authors would like to acknowledge the intellectual contribution of Yeo-Eun Kim to the work described herein. They would also like to thank Dong Su Jang for assistance with figure illustrations, and Song-ee Baik for assistance with data collection and system programming. This research followed protocols approved by relevant accredited ethical committees at Severance Hospital of Yonsei University

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ABSTRACT

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Purpose: This study was done to assess the feasibility of image-guided surgery in patients with gastric cancer using robotic surgery. We tried to make standardized protocol for vascular reconstruction technique to show images for gastrectomy during robotic gastrectomy in this study.

Method: CT angiography was performed preoperatively in 12 patients who underwent robotic gastrectomy in gastric cancer patients. Vessels encountered during gastrectomy are reconstructed during the operation using Aquarius program and transferred to the surgeon console using TilePro® program. Seven vascular structures encountered during were evaluated their anatomic variation and distances at each reference point with their 3D-reconstructed digital figure files made by radiologist. These findings were compared with operative findings of each vascular structure by surgeon during surgery.

Result: Intraoperatively provided vascular images depicted arterial and venous anatomy around the stomach and were able to identify important vascular variants. During the operation, the information concerning perigastric arteries and veins led us to the site of their branching and facilitated dissection of perigastric lymph nodes and enabled us to avoid accidental hemorrhage and ischemic liver damage. Presented 3D-recontructed CT images to the surgeon's console during the operation provide each patient's diverse information such as a vascular map which is critical for surgical guidance, and help to prevent the risks involved in minimal invasive surgery.

Conclusion: The image-guided minimally invasive robotic surgery using preoperative CT scan for gastric cancer patients is feasible and useful. Although more remedied and developed system is needed, Image-guided robotic surgery could support to surmount limitations of minimally invasive surgical approach and to apply image guided technology for deformable body structures.

Key words: Image-guided surgery, minimally invasive surgery, robot assisted gastrectomy, 3D-reconsdtructed computed tomography, Tile-Pro® vascular anatomy

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I. INTRODUCTION

Development of imaging tools provides new methods for diagnosis and treatment of disease to the medical and surgical practice. Using images of CT and MRI, not only disease extent but also patient-specific anatomy can be obtained. Diagnosis from virtual endoscopy and three-dimensional (3D) reconstruction of CT and MRI is replacing or supplementing invasive endoscopic and angiographic procedures. These imaging technologies are now rapidly applied to various types of complicated procedures in forms of pretreatment planning and simulation.[1]

The introduction of concepts of image-guided diagnosis, intervention planning and treatment has brought the application of image-guided surgery in accordance with the rapid propagation of minimally invasive surgery[2, 3, 4, 5, 6, 7, 8]. Image-guided surgery is the general term used for any surgical procedure where the surgeon uses indirect visualization to operate, i.e., by employing imaging instruments in real time, such as fiber optic guides, internal video cameras, flexible or rigid endoscopes, ultrasonography, etc. Most image-guided surgical procedures are minimally invasive.

The technology was originally developed for treatment of brain tumors[9], but has found widest application when applied to various types of surgery[3, 10, 11, 12, 13]. Previous studies regarding preoperative assessment vascular anatomy around stomach were informative and useful for successful surgery. [14, 15] However, application of image-guided surgery for minimally invasive gastric surgery is still far away to go.[16] We tried to make standardized protocol for vascular reconstruction technique to show images for gastrectomy during robotic gastrectomy in this study.

In this study, we assessed the usefulness and feasibility of image guided robotic gastrectomy with lymph node dissection and accuracy of radiologic findings (anatomical vascular structure) by comparing with surgical findings

II. MATERIALS AND METHODS

1. Patient

Between August 2009 and December 2009, 12 patients (10 men and 2 women, mean age 61.1±10.9 years old) scheduled for robot assisted gastrectomy for gastric cancer in Severance hospital underwent multidetector-row computed tomography(MDCT) as part of their routine preoperative assessment. To find out the failure rate, defined as conversion, less than 10%, 12 patients were enrolled. In our institute, robotic radical gastrectomy with lymph node dissection for gastric cancer is performed when the depth of tumor invasion is less than the muscularis propria. No patients had any comorbid condition that would make robotic radical gastrectomy and preoperative computed tomography with angiography unsafe, and all gave their written informed consent. The study protocol was approved by the institutional review board at Severance hospital. The selection and technique of robotic radical gastrectomy were described previously.[17] Single surgeon performed the procedures under the guidance of preoperative 3D-CT images. In all patients, vascular anatomy identified during operations was compared with 3D-CT images. The number of retrieved lymph nodes, operation time, blood loss, and the rate of conversion to laparotomy or laparoscopy assisted surgery because of uncontrollable surgical condition were evaluated.

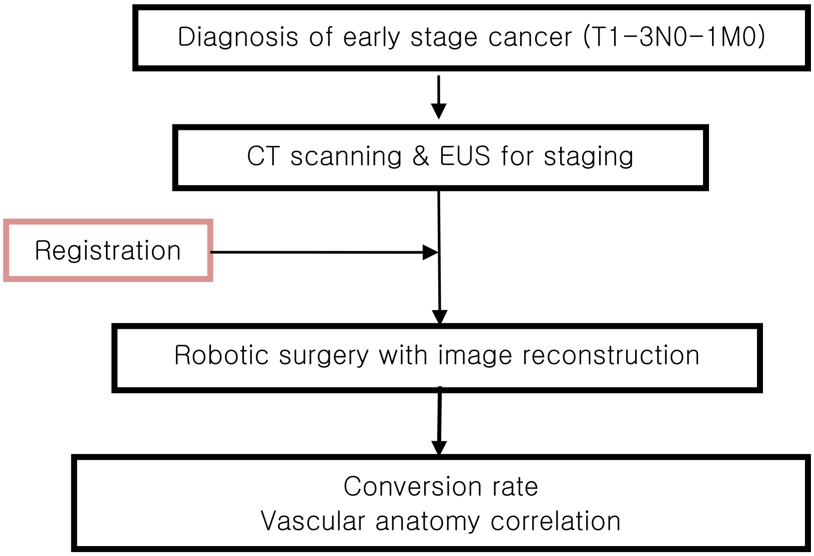

Figure 1. Study design and flow.

2. Computed Tomographic Technique

All of the patients included in the study underwent 64-detector row CT scanning (SOMATOM Sensation 64; Siemens Medical Solutions, Forchheim, Germany). Before CT scanning, all patients received 10 mg of butylscopolamine bromide (Buscopan; Boehringer Ingelheim, Ingelheim, Germany) intravenously through an antecubital vein to minimize bowel peristalsis and to facilitate hypotonia. One and half packs of gas-producing crystals (total, 6g) with a minimal amount of water (<10mL) were administered orally to each patient immediately prior to CT scanning to obtain gastric distention. All of the patients received 120-150 mL of contrast material (iopromide [Ultravist]; Schering and diatrizoate meglumine [Hypaque] or iohexol [Omnipaque 300]; Nycomed Amersham, Princeton, NJ) intravenously using an automatic power injector at a rate of 3-5 mL/s. Scans were acquired in a craniocaudal direction with the following parameters: a detector collimation of 64 rows x 0.6 mm; 0.5-second gentry rotation speed; a pitch of 1.0; and a tube current of 120 kilovolts (peak) and 160 mAs. An approximately 1-cm^2 region of interest was placed at the abdominal aorta, and the attenuation value was measured.

The CT scans were obtained at the early arterial phase (by adding after the attenuation value of the region of interest when it reached 100HU) and hepatic venous phase (by adding 35 seconds after the early arterial phase) in a supine position. The coronal images were reformatted with a section thickness of 3 mm with a 3-mm slice increment. Axial CT images were reconstructed with a 3-mm section thickness and a 3-mm reconstruction interval for clinical interpretation and with a 1-mm section thickness and a 1-mm interval for 3D reconstruction. In addition to axial images, coronal MPR (multiplanar reconstruction) images were also reconstructed with a 3-mm section thickness at a 3-mm interval.

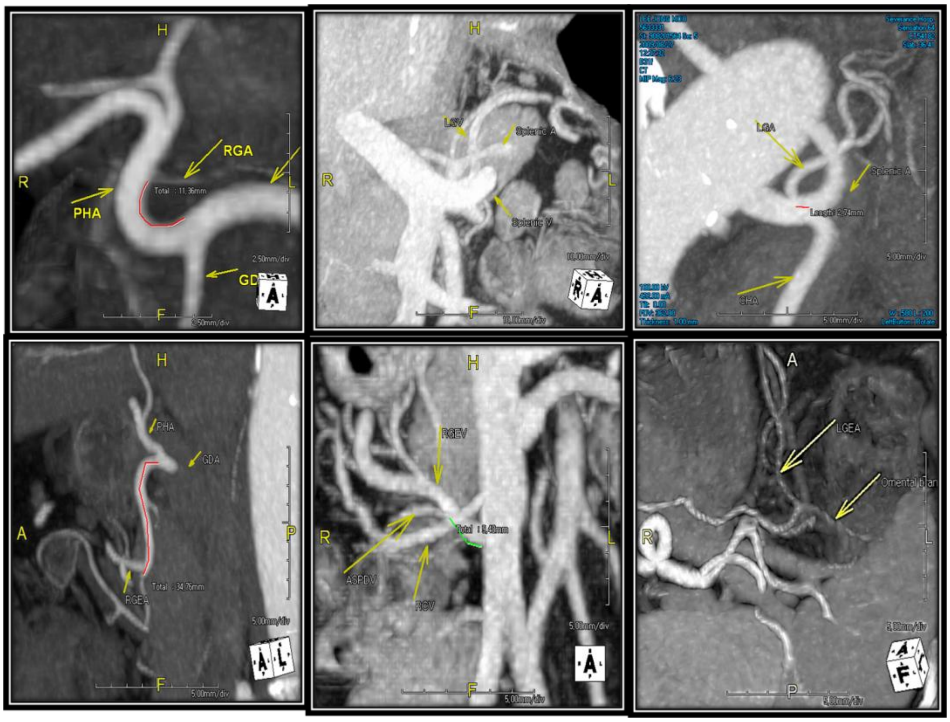

Figure2. Maximum Intensity Projection (MIP) images of vascular structures around stomach.

3. Image analysis and intraoperative technique

(A) 3D reconstruction of CT images during operation

For the 3D rendering and display, the 1-mm section thickness CT datasets were transferred to a workstation (Aquaris WS, TeraRecon, San Mateo, Ca, USA). Perigastric vessels encountered during gastrectomy are reconstructed and displayed by a radiologist during the operation using 3D software (AquariusNET thin-client viewer, TeraRecon, San Mateo, Ca, USA) in the operating room. The 3D volume set was manipulated using different orientation and cut planes and by adjusting window level, center, brightness and opacity to best demonstrate the celiac artery, gastric artery and to identify as many of the branches as possible. Volume rendering and maximum intensity projection images were also used.

(B) Image-guided robotic gastrectomy using Tile-pro® program.

The reconstructing process will be transferred to the surgeon console in which surgeon will be presented reconstructed images integrated into the da Vinci Robot system using TilePro® program. Robotic surgery will be performed as routine robotic gastrectomy at the same with reconstruction of vascular images. TilePro® is a multi-image video display mode of the da Vinci S surgical system that allows the surgeon to simultaneously view up to two additional images, such as intraoperative ultrasonography and preoperative CT images, as a picture-on picture on the 3D console screen and assistant monitors. TilePro® was used during robot assisted gastrectomy to identify vessels encountered during gastrectomy and to help surgeon navigate lymph node dissection.

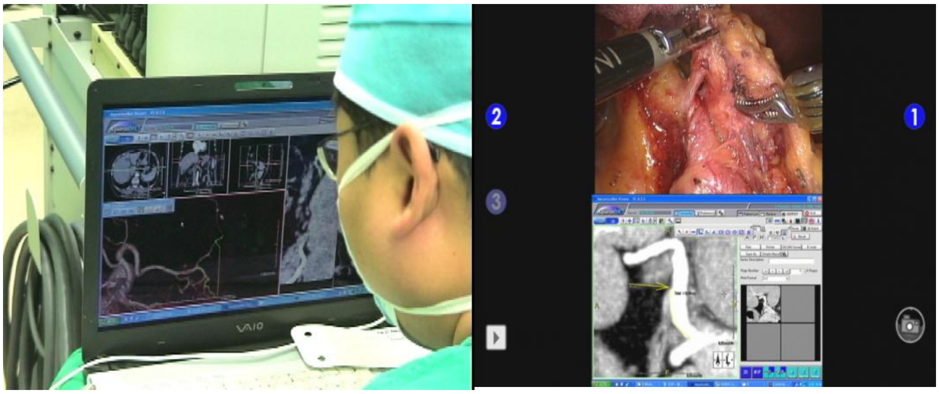

Figure3. Image-guided robot assisted gastrectomy using Tile-pro®. The radiologist reconstructs 3D-CT images during operation (Right). The real operation field on the top and reconstructed CT image on the bottom (Left)

(C) Correlation of vascular anatomy

Seven vascular structures usually encountered during gastrectomy (left gastroepiploic artery (LGEA) & vein (LGEV), right gastroepiploic artery (RGEA) & vein (RGEV), right gastric artery(RGA), left gastric artery (LGA) & vein (LGV)) were recorded their anatomic variations and distances at each reference point (Figure 4-5). For further evaluation, 3D reconstruction images of each vascular structure were saved as digital figure files. All of the operations have been recorded and operative findings of each vascular structure have been also saved as digital figure files.

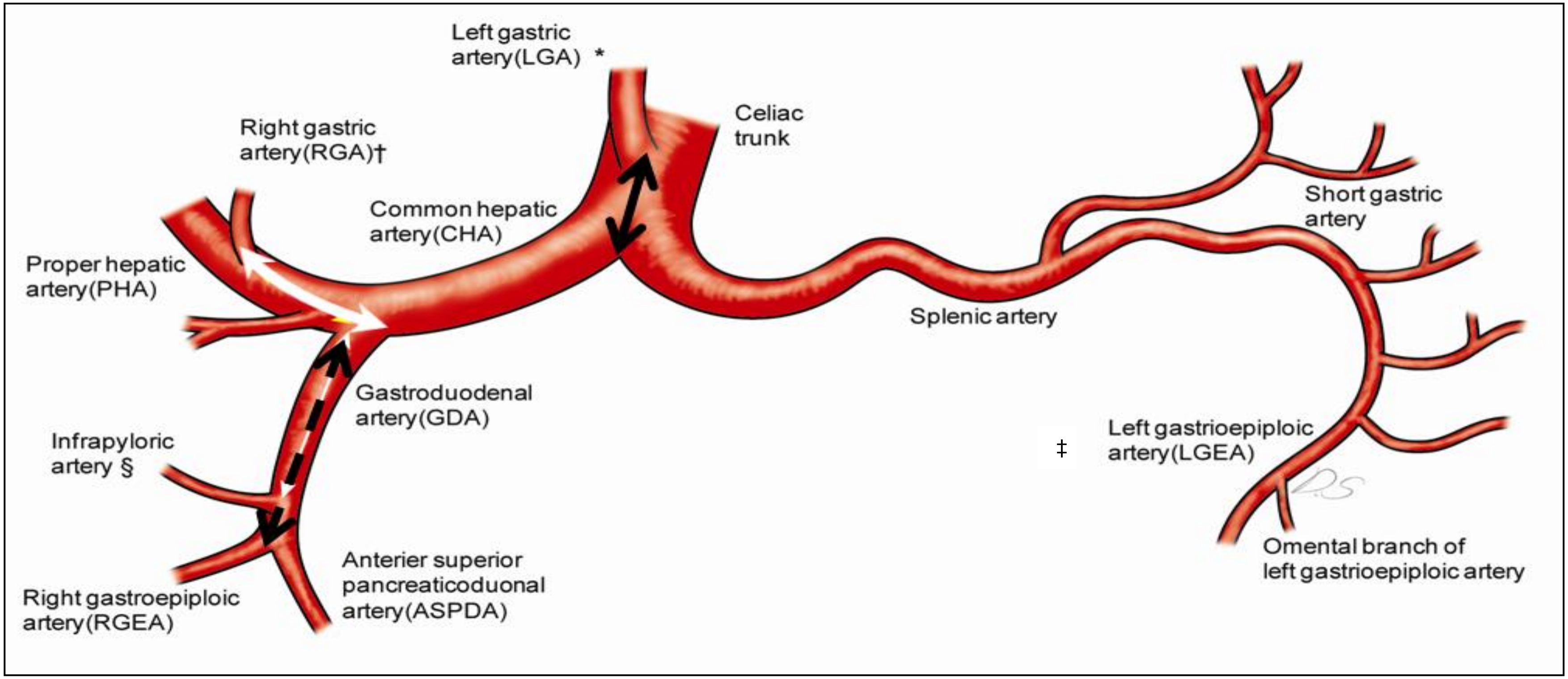

Figure4. Arterial Components Estimated.

‡ **Left gastroepiploic artery(LGEA);** whether omental branch is or not.

§ **Right gastroepiploic artery (RGEA);** whether infrapyloric artery is or not. If there is infrapyloric artery, it is examined whether the infrapyloric artery is the branch of RGEA or GDA branches off the infrapyloric artery separately. And we measure the distance from the starting point of gastroduodenal artery to the starting point of RGEA (black dotted line).

† **Right gastric artery(RGA);** measuring the distance from the starting point of proper hepatic artery to branch point of right gastric artery(white arrow) and observing in which direction it is pointing

* **Left gastric artery(LGA);** measuring the distance from dividing point of common hepatic artery and splenic artery to branch point of left gastric artery(black arrow) and observing whether the left aberrant hepatic artery is or not. If the left aberrant hepatic artery is existed, we evaluate it is replaced LHA or accessory LHA.

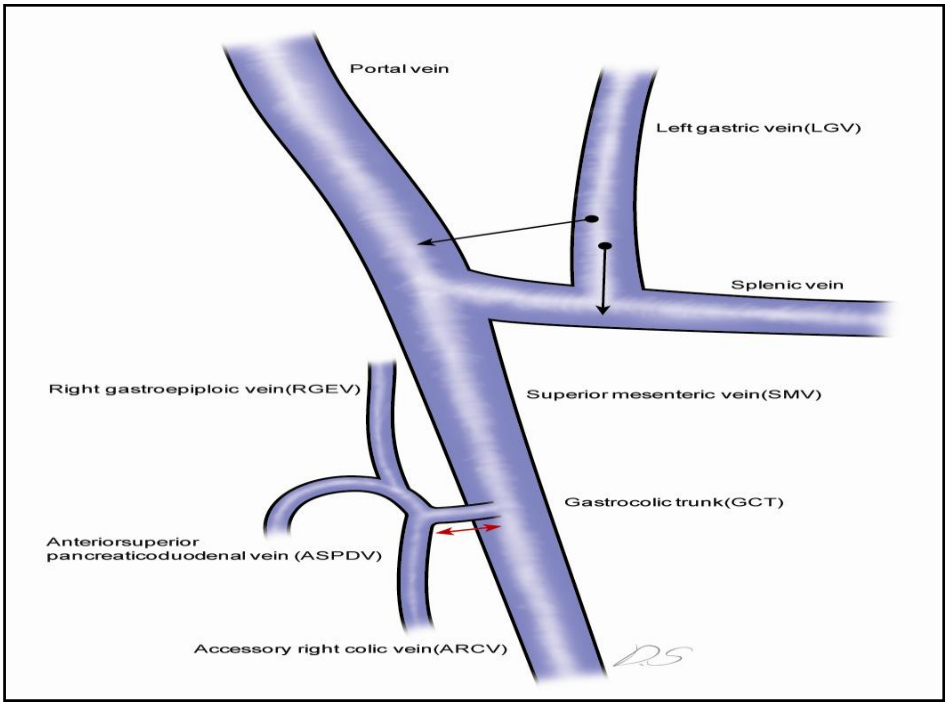

Figure5. Venous Components Estimated.

† **Gastro-colic trunk(GCT);** we examine whether GCT is existed or the venous flow of RGEV drains into SMV(superior mesenteric vein) as distinct from ARCV(accessory right colic vein). If there is GCT, we measure the distance from starting point of GCT (the point of ARCV meets RGEV) to SMV.

‡ **Left gastric(coronary) vein(LGV or LCV);** It is evaluated whether the venous flow of LGV drains into portal vein(PV) or splenic vein(SV) by measuring the distance from starting point of PV to point which the LGV meets PV or SV. And it is discovered whether the LGV drains through the dorsal part of CHA (common hepatic artery) or SA (splenic artery) or drains through the ventral part of CHA or SA.

III. RESULTS

All 12 examinations were successful. In all patients, the stereoscopic vascular anatomy relating to the stomach was correctly identified and accurately rendered when compared with operative findings. There was no open or laparoscopic conversion and no postoperative mortality occurred.

Table 1. Patients Clinicopathologic Characteristics(N†=12)

Characteristics	N†(%)	Mean±SD‡	Range
Age(years)		61.1±10.9	43-75
Gender(Male:Female)	10:2		
BMI§(kg/m²)		23.6.2±1.8	19.2-26.2
Co-morbidity	5 (41)		
Cardiovascular disease	1 (8.3)		
Diabetes Mellitus	0 (0)		
Pulmonary disease	2 (16.7)		
Renal disease	1 (8.3)		
Hepatic disease	1 (8.3)		
Cerebrovascular accident	0 (0)		
Previous abdominal surgery	2 (11.8) *		
Tumor location in stomach			
Middle	3 (25)		
Lower	9 (75)		
Number of retrieved lymph nodes		42.4±12.6	26-72
Resection margin(mm)			
Proximal		46.6±26.5	12-100
Distal		50.9±26.5	28-120
Stage(7th AJCC)			
Ia	8 (66.7)		
Ib	3 (25)		
III(c)	1 (8.3)		

N†: Number, SD‡:standard deviation, BMI§: body mass index

* 1 peritonitis,1 appendectomy

Sex, age, BMI, comorbidity and tumor characteristics of patients in this study are shown in Table 1. Mean number of harvested lymph nodes was 42±12.6 (range 26-72). Resection margins were negative in all cases. Operative data and short term outcomes are shown in Table 2.

Table 2. Operative Data and Early Outcomes

Variables	N† (%)	Mean±SD‡	Range
Extent of lymph node dissection			
D1+β	2 (16.7)		
D2	10 (83.3)		
Operation Time(minutes)		234.7±28.2	194-296
Estimated Blood Loss(mL)		46.4±12.6	23-84
Postoperative Hospital Stay(days)		6.0±2.0	5-11
Discharge at POD #5	8 (66.7)		
Discharge at POD #6	2 (16.7)		
Discharge at POD #9	1 (8.3)		
Discharge at POD #11	1 (8.3)		
Postoperative Complications	1 (8.3)		
Wound Infection	0		
Fluid collection/ abscess	0		
Postoperative bleeding	0		
Anastomosis leakage	0		
Pancreatitis	1 (8.3)		

N†: number SD‡: standard deviation

Mean operative time was 234.7±28.2 (range, 194-296) minutes. Estimated blood loss (EBL) was 46.4±12.6 mL (range, 23-84). There was no combined resection or operation of other organs and all of patients underwent curative R0 resection. Mode of hospital stay was postoperative 5th day (range, 5-11) and eight of twelve patients in this study were discharged from the hospital. Surgery-related morbidity was one of twelve patients (8.3%, postoperative pancreatitis) and there was no surgery-related mortality.

In all cases, the omental branch of left gastroepiploic artery (LGEA), infrapyloric artery, right gastric artery (RGA), left gastric artery (LGA), gastrocolic trunk (GCT), and left gastric vein (LGV) were precisely identified. In 2 cases, the accessory left hepatic artery from LGA was correctly identified and the replaced left hepatic artery from LGA was found out in 1 case. The variations of the veins included the left gastric vein flowing into the splenic vein in 7 cases: the portal vein in 3, the confluence of the portal and splenic veins in 1 and the left portal vein in 1 case. The gastrocolic trunk, which is formed by joining the accessory right colic vein (ARCV) with the right gastroepiploic vein (RGPV), flows in to the superior mesenteric vein (SMV), we measured the distance from joining point to SMV to make lymph node dissection easier. In 2 cases, ARCV and RGEV are not joined together; they flow to the SMV separately. (Table 3)

Table 3. Observed data on 12 patients who underwent image-guided robot assisted gastrectomy for gastric cancer in this study

Patient No	Sex	Age	Omental Branch of LGEA	Infrapyloric artery from	Distance from GDA to RGEV	RGEV drains into	Length of GCT	RGA * (mm)	RGA-direction**	LCV drains into	Distance from PV to LCV (mm)	Distance to LGA (mm)	LGA branch variation
1	F	66	identified	RGEV	27.4	SMV	0	5.28	contralateral	splenic†	17.1	10.4	absent
2	M	61	identified	RGEV	38	GCT	8.83	15.6	lesser sac	splenic	11.9	10.7	absent
3	M	73	identified	RGEV	39.4	GCT	9.48	14.8	lesser sac	splenic	14.1	7.52	absent
4	M	59	identified	RGEV	32.7	GCT	14.08	7.98	lesser sac	splenic	10.2	0	absent
5	M	68	identified	GDA	26.9	SMV	0	8.6	contralateral	splenic	8.45	7.9	absent
6	M	48	identified	GDA	13.6	GCT	13.87	5.33	contralateral	portal‡	3.95	5.19	absent
7	M	71	identified	GDA	27.9	GCT	8.2	20.31 * *	contralateral	portal	7.79	6.18	accessory§
8	F	58	identified	RGEV	33.3	GCT	12.52	4.01	lesser sac	confluence¶	0	7.57	absent
9	M	75	identified	RGEV	31.7	GCT	5.66	5.15	anterior	splenic	14.62	5.83	replaced§§
10	M	66	identified	GDA	41.6	GCT	18.34	14.76	lesser sac	portal	11.77	10.72	accessory
11	M	43	identified	GDA	25.23	GCT	8.5	22.84	lesser sac	splenic	3.37	12.56	absent
12	M	45	identified	RGEV	42.7	GCT	14.43	0	anterior	LPV	-	8.81	absent

LGEA: left gastroepiploic artery, RGEV: right gastroepiploic vein, GDA: gastroduodenal artery, SMV: superior mesenteric vein, GCT: gastrocolic trunk, RGA: right gastric artery, PV: portal vein, LPV: left portal vein, LCV: left coronary vein, LGA: left gastric artery

* distance from root of gastroduodenal artery to right gastric artery

* * right gastric artery from accesory left hepatic artery

**direction to which right gastric artery is branched off (contralateral means the opposite side of lesser sac side and anterior means the ventral part of RGA)

† means that left coronary vein drains into splenic vein

‡ means that left coronary vein drains into portal vein.

¶ means that left coronary vein drains into confluence of superior mesenteric vein and splenic vein.

§ means that left accessory aberrant hepatic artery is originated from left gastric artery.

§§ means that left replaced aberrant hepatic artery is originated from left gastric artery.

IV. DISCUSSION

This prospective clinical intervention trial involving gastric cancer patients undergoing elective CT image guided robotic radical gastrectomy with lymph node dissection showed that it is clinically feasible and useful.

Modern image guided intervention techniques have been performed for about 20 years, and all utilize some form of preoperatively performed data, mostly in the form of tomographic images combined with some technology to link these images to the patient. This technology employs computer-based systems to help physician precisely visualize and target the surgical site with providing virtual image overlays. Neurosurgeons have started using this technology when they plan and simulate their operations and perform functional surgery[12, 18, 19, 20]. Use of image guided intervention technique has been expanded in orthopedics[21, 22], cardiac[11] and thoracoabdominal[18, 23, 24, 25] areas and the applications have been also extended not only supporting manipulation; planning, simulating, and localization but also being one of the treatment options; stent insertion and stereotactic surgeries.[18, 25]

In clinical practice, this technique has been utilized successfully in many surgical area, especially most of concern are bony structures such as the spine or are surrounded by a rigid enclosing structure like brain. However, it is also clear that for many surgical procedures, as in the abdomen, the applications of this technology are limited to relatively fixed organs like kidney, liver and spleen because of easy manipulation of images. The current technology which has been based on formable and rigid-body model is not sufficient to apply for hollow viscus[16]. Although our attempt is not a true image-guided surgery, currently it is image based surgery. In this study, we find out that all of vascular structures encountered when we perform gastrectomy are identified in all of 12 patients by radiologist and those are exact as compared with surgical findings of perigastric vascular structure confirmed by surgeon. We have tried to investigate the accuracy of this navigation technique using existing system (with current devices and software) in hollow viscus abdominal surgery. Very small vessels were able to be identified and localized with measuring distance from their reference points in abdominal cavity. Quantification of distance from reference point makes it safe and easy to dissect the lymph nodes around stomach.

Another significance of this study is to present surgeon patient's anatomical variation during the operation. When surgeons operate specific areas of the body, individual anatomical variations are one of the obstacles faced surgeons and they need to have a lot of experience in that surgical field, especially cancer surgeries. In this study, 3D-reconstructed CT images integrated into surgeon's console present surgeon the individual variation of vessels around stomach and abdominal aorta and this is not statistical or textbook-based anatomical variation. It is equivalent of really seeing the body structures not guessing during the operation. Image-guided minimally invasive robotic surgery using preoperative CT scan for gastric cancer patients will make it easier and safer to perform more complicated or more advanced minimally invasive surgery, especially in less experienced surgeons or institutions. It maybe is a key of ongoing problems that the surgeon should master safely robotic surgery or minimally invasive techniques for treating surgical disease without incurring an unusually high cost to the patient. Also that will make it possible to perform literally patient tailored surgery based on individual anatomy.

However this image-based surgery in patients with gastric cancer using robotic surgery with Tile-pro program is radiologist dependent. All the images should be made at each operative steps and we need another specialist of software in the operating room. Therefore, the first step for the establishment of image-based surgery will be making automation of image reconstruction during surgery. Automation can be achieved by synchronization of camera position and image reconstruction program. Simultaneously, simulation of abdominal cavity after making pneumoperitoneum has to be carried out (calculating position or distance changes by pneumoperitoneum). Simulation of abdominal cavity could help in guiding the position of the trocar location for every operation. This will be basic system for the intra-operative navigation. Not only the simulation of abdominal cavity but also the analysis of the standardized image-based operation can provide simulation model. At this step, graphic rendering, 3D reconstruction of CT images for each organ, tissue specific properties, and operation procedure modeling should be incorporated and it can be a good base for application of image guided surgery for various field of abdominal surgery, such as colorectal, liver, and bilio- pancreas surgery[26, 27, 28].

3D reconstructed CT images during the operation provide diverse information, especially such as a vascular map which is critical for surgical guidance, and prevent the risks involved in minimal invasive surgery. Combining two ideas of minimally invasive surgery with using imaging technology affords surgeons another tool to overcome limitations of minimally invasive surgery[28]. Although there are many problems to solve for the better application of image-guided robotic surgery for gastric cancer, our attempt could be a transition to image-guided surgical planning and surgical navigation for gastric cancer surgery. Still more sophisticated, comprehensive, simple and practical system for image guided robotic gastrectomy is needed, however the application of image-guided technology for minimally invasive gastric surgery will become essential in near future.

V. CONCLUSION

The Image-guided robotic gastrectomy for gastric cancer is feasible and safe. 3D-recontructed CT images during the operation provide diverse information especially a vascular map which is critical for surgical guidance, and prevents the risks involved in minimal invasive surgery. Although more remedied and developed system is needed, Image-guided robotic surgery could support to surmount limitations of minimally invasive surgical approach and to apply image guided technology for deformable body structures.

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ABSTRACT (IN KOREAN)

위암환자에서 수술 전 촬영한 CT 영상을 이용한 영상유도 최소침습 로봇 수술의 적용가능성에 대한연구.

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목적: 본 연구의 목적은 조기위암 환자에서 로봇 위 절제술 시 Tile-pro® program 을 이용하여 영상 유도 하 surgical robot을 이용한 미세 침습 수술의 가능성 및 유용성을 평가하는 것이다.

방법: 2009년 8월부터 10월까지 연세대학교 세브란스 병원에서 조기위암으로 수술 하는 환자 12명을 대상으로 수술 전 검사로 CT abdomen and pelvis with angiography 를 촬영하고 로봇 위 절제술을 시행하였다. 로봇 수술 시 수술 장면과 외부 입력 영상을 동시에 볼 수 있게 하는 Tile-pro program을 이용하여 수술 전 촬영한 CT 를 이용, 수술의 각 단계마다 절단 혹은 보존하게 되는 주요 혈관의 해부학적 image를 3차원으로 재구성하여, 집도의의 로봇 console에 제공하였다. 이로 인하여 수술 중 주요혈관의 해부학적 구조에 대한 환자 개인의 특성을 제공하여 보다 용이한 수술이 가능한지를 알아보았다.

결과: 총 12명의 환자 모두에서 수술 전 시행한 CT에서 위 절제술시 절단 혹은 보존하는 7개의 위 주위 주요혈관을 확인할 수 있었으며, 이는 수술 중 3차원으로 재구성되어, 집도의의 console에 수술 부위와 한 화면에 제공 되었으며, 집도의에 의하여 환자의 수술 소견과 일치함을 확인하였다. 수술 중 개복 및 복강경 수술로의 전환은 없었으며, 수술 관련 사망은 없었다.

결론: 조기 위암 환자에서 영상유도 하 최소 침습 로봇 위 절제술 및 림프절 곽청술은 가능하며 안전하다. 로봇 수술 중 제공된 3차원으로 재구성된 수술 전 CT image는 집도의에게 vascular map등의 다양한 정보를 제공하며, 이는 최소 침습 수술의 위험성 감소에 도움을 줄 수 있을 것이다.

핵심 되는 말: 영상 유도 하 수술, 최소 침습 수술, 로봇 위 절제술, 3차원 재구성된 컴퓨터 전산화 단층 촬영