Evolution of Virtual CT Laparoscopy for Preoperative Imaging in Laparoscopic Cholecystectomy

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Summary: The purpose of this study was to determine the feasibility of virtual endoscopy, named as “virtual CT laparoscopy”, in the hepatobiliary system prior to laparoscopic cholecystectomy. We applied this technique to 28 patients suspected of having biliary disease. These images were compared and analyzed qualitatively based on visualization of the structures critical to operative cholangiography and surgical findings. Twenty-four patients, who underwent laparoscopic cholecystectomy, were evaluated as follows: the common bile duct and the hepatic duct were adequately visualized in 23 (96%) of the 24 patients, the cystic duct in 21 (88%), the gallbladder opacification in 20 (83%), the liver inferior surface in 20 (83%). Four patients had anatomic variations detected virtual CT laparoscopy and were proven by operative cholangiography and surgical findings. We emphasize that our new technique may contribute to the laparoscopy during surgery as the aid of understanding of anatomical structures in these organs.

Key words: computed tomography (CT), three-dimensional, bile ducts

INTRODUCTION

The recent development of helical technology has enabled volumetric acquisition to be performed during a single breath-hold period. Helical scans, which use a slip-ring technology consisting of multiple sets of parallel rings and electrical components that rotate without the constraint of cables, have an acquisition time that is generally 1 second. Some recent helical machines can even scan in the subsecond range and can carry out a multi-slice volume scan. The latest developments in the technology of helical scanning computed tomography (CT) provide a rapidly acquired data set during the phase of maximum vascular and parenchymal enhancement, allowing for the acquisition of continuous raw data for a detailed reconstruction of three-dimensional (3D) images [1-7]. Recently, endoscopic 3D reconstruction has permitted computer-simulated intra-abdominal viewing through body cavities and hollow viscera. Another development in treatment is laparoscopic surgery, which is a relatively new technology that allows for a minimally invasive treatment of intra-abdominal lesions [8,9]. Furthermore, laparoscopic techniques are now being used successfully as minimally invasive alternatives to many open surgical procedures. These techniques have recently been applied to laparoscopic surgery of the biliary disease for minimal invasion [10]. Ideally, the next step is endoscopic 3D reconstruction, permitting computer-simulated intra-abdominal viewing through body cavities and hollow viscera. Thus, laparoscopic-like images of various regions in the body are generated by applying this internal perspective to CT imaging data [11]. The present study describes the feasibility of performing virtual endoscopy in the hepatobiliary system through the use of helical CT data.

MATERIALS AND METHODS

From June 1999 to May 2000, 28 consecutive patients were referred for evaluation of biliary dis-
ease after discovery based on clinical symptoms and ultrasound. All patients who underwent helical CT with 100 ml of iotroxate megulmine (billiscopine, Schering, Japan) were infused intravenously (drip-infusion cholecysto cholangiography). Twenty-six of 28 patients received surgery. One of the remaining two patients could not receive surgery because of a bad systemic status. The other one refused surgery and was observed in follow-up care. Twenty-four of the 26 patients who received surgery underwent laparoscopic cholecystectomy. The remaining two patients received open surgery because laparoscopic cholecystectomy was ruled as too difficult for them to undergo based on a past history of surgery for gastric and ovarian carcinoma. A diagnosis was made for all 24 patients who underwent laparoscopic cholecystectomy; 20 of the 24 patients had cholecystolithiasis, 3 of the 24 patients had polypoid lesion, and the remaining 1 patient had adenomyomatosis. There were 10 men and 14 women, ranging in age from 42 to 78 years (mean: 57 years). Informed consent for participation in the study was obtained from each patient or their guardian as part of the protocol approved by the Institutional Clinical Subpanel on Human Studies at our university hospital.

Imaging protocol

The helical CT scans of the biliary system (CT cholangiography) were performed using ProSeed SA systems (GE Yokogawa Medical Systems, Tokyo, Japan). The intrahepatic and extrahepatic bile ducts and gallbladder were scanned with a slice thickness of 3 mm, with the couch being moved continuously at a speed of 3 mm per second during a single breath-holding period. Over a period of 30 min, 100 ml of iotroxate megulmine (billiscopine, Schering, Japan) was infused intravenously (drip-infusion cholecysto cholangiography). The patients were scanned 30 min after the infusion of the contrast material. If the imaging of the biliary ducts was insufficient, a scan was performed within 30-60 min. During transfer to the CT units, the patients were placed in an LAO (left anterior oblique) position in order to delay emptying of the biliary ducts. It tends to form fluid-fluid levels in the biliary tree and gallbladder, by turning the patient prior to the examination, the mixing of bile is accomplished. The scanning parameters (120 kVp, 160-220 mA, 25-35 cm field of view with a 512×512 matrix) varied slightly depending on each patient’s size. The full set of images was acquired in 26-35 sec. No contrast material was given orally. No inhalation of oxygen was provided to patients either before or after the helical examination.

3D-reconstruction

The acquired raw data was retrospectively reconstructed at 1.5-mm intervals. The raw data were then transferred to a workstation (ZIO M-900, AMIN Co., Tokyo, Japan) in a 512×512 pixel format via an Ethernet connection. The images were reviewed as consecutive axial sections and were analyzed using a software package (ZIO Software Co., Tokyo, Japan) for 3D reconstruction and rendering. Approximately 5 min of user time was required to generate the necessary 3D images after acquisition of the images. The user completed visual optimization of the 3D image, and a user-selected color and opacity were assigned to each set of material. We reconstructed the 3D image of relevant organs presented under an opacity table based on the full-scale 3D images. The multi-object images were produced from the data acquired from the relevant organs, that is, the liver, biliary tract, bone, and skin. Reconstruction of the view to the intra-abdomen from the surface of skin was based on the 3D image using virtual endoscopy following a fly-around technique. Virtual endoscopy was generated with a dedicated software tool running on a workstation that allows the creation of intra abdominal views of anatomical structures. The use of a fly-around technique allowed for the observation of the regions of interest, the intra-abdomen from the surface of the skin. This technique allows these observations to be made from the free projections [6]. Figure 1 shows method of virtual CT laparoscopic image.

Image interpretation

Three observers blinded to the patients’ clinical
status, to the laboratory data, and to the results of ultrasound imaging, reviewed the virtual laparoscopic images on the workstation at the same time and rendered a consensus opinion about the visualization of the common bile duct (CBD), common hepatic duct (CHD), right and left hepatic duct of the extrahepatic region, gallbladder, cystic duct, and liver inferior surface. In instances of disagreement, the majority opinion prevailed. The CT attenuation values in Housfield units were measured within a 2-cm\(^2\) circular region of interest in the liver in all subjects.

We determined the value of virtual CT laparoscopic imaging in finding anatomic variations of bile ducts in the 24 patients in whom laparoscopic cholecystectomy was performed after CT cholangiography. We used cholangiography in 18 patients during surgery as a gold standard, and laparoscopy in the remaining 6 patients during surgery.

RESULTS

All patients were able to maintain the 26-35 sec breath hold without difficulty. Patients experienced no adverse reaction after slow infusion of 100 ml of iotroxfate meglumine. The 24 patients who underwent laparoscopic cholecystectomy were evaluated as follows: CBD, CHD and right and left hepatic duct of the extrahepatic region were adequately visualized in 23 (96%) of the 24 patients. The cystic duct was adequately visualized in 21 (88%). The gallbladder opacification was noted in 20 (83%). The liver inferior surface was clearly visualized in 20 (83%). The mean CT attenuation values in the liver ranged from 68 to 88 HU (mean, 76 HU) in 20 clearly visualized patients and from 52 to 65 HU (mean, 59 HU) in 4 patients not clearly visualized.

Anatomic variations of the bile ducts were shown in 5 patients. Two cases of low junction of the cystic duct were proven with operative cholangiography, two cases of spiral cystic duct were proven with operative cholangiography in one case and operative laparoscopic finding in another case, and a cystic duct entering a right hepatic duct was shown with operative cholangiography. Four of these five variations were detected with virtual CT laparoscopic imaging. One spiral cystic duct was missed because of poor depiction of the cystic duct, which made it difficult to visualize the flow. Representative virtual CT laparoscopic images are shown in Figs 2-4. Figures 2-4 clearly demonstrate cystic duct and common bile duct.

Fig. 2. 44-year-old female: cholelithiasis.

a: Two-dimensional (2D) image of helical CT cholangiography. This image shows the gallstone in the gallbladder (arrow).

b: Virtual laparoscopic image (the view point is near the liver inferior in the abdomen). Virtual laparoscopic image shows clearly stereotypical configuration of the liver surface, the common bile duct (arrow), the cystic duct (arrow head), and depict to separate the surrounding structures of the other organs.
DISCUSSION

Recently developed laparoscopic techniques are now being used successfully as minimally invasive alternatives to many open surgical procedures, and these techniques have been applied to the hepatobiliary system. Laparoscopic cholecystectomy has become a routine procedure for the management of benign disease of the biliary system, such as cholelithiasis or gallbladder polyps [10]. Laparoscopic surgery has many advantages as a minimally invasive procedure, but it also proposes
new challenges. Because the surgical field of view is limited to indirect visualization of a relatively small region, it is difficult to elucidate the correct anatomical structures of the cystic duct during laparoscopic cholecystectomy [12,13]. A major problem in clinical practice is the injury of the bile duct during cholecystectomy [14,15]. Given the limited field of view available with laparoscopic techniques, the role of preoperative radiological evaluation in laparoscopic surgery has expanded to include the anatomical definition of the organs. Virtual CT laparoscopy has proven to be a minimally invasive alternative to conventional radiological examination during preoperative evaluation [9]. CT is most frequently used in the initial evaluation of the biliary tract. CT cholangiography is a useful tool in the radiological work-up of patients with jaundice and suspected biliary diseases; its use enables physicians to make a number of useful decisions [16-20]. Acute cholecystitis due to gallstones is usually treated by laparoscopic cholecystectomy. Surgeons can be better prepared if they can observe the detailed anatomic pathology with a three-dimensional view, rather than a simple axial one, in order to plan the laparoscopic surgery [21,22]. CT cholangiography is the method of choice for visualizing the bile duct, as it provides images of high resolution [23].

There are many reports on the usefulness of 3D-CT cholangiography, and these reports describe whether the separated lesion of the intra-hepatic bile duct is depicted in the technique [16,17]. However, under laparoscopic surgery physicians need to understand the flow of the outer-hepatic bile duct, common bile duct, and cystic duct rather than the intra-hepatic bile duct. It is also useful to produce images of the lower region of the liver, the projection, and the view under laparoscopy during surgery. Although 3D-CT image sets using CT cholangiography promise to confirm the anatomical structure and stereotactical tract, virtual CT laparoscopy images enhance our ability to confirm the free tract and angle of the bile duct as well as the surrounding structure of the liver and other organs. This technique may be available to reduce the number of complications during surgery if this one is widespread.

Virtual laparoscopic imaging can be carried out in correlation with other imaging modalities. Virtual laparoscopic imaging has proven useful in preoperative imaging [11,22,24]. Furthermore, virtual laparoscopic imaging, using a helical scan, can aid in surgical planning and serve as a visual aid in discussions between radiologists, surgeons, and patients. A major potential role of virtual laparoscopic imaging could be in the preoperative evaluation of the hepatobiliary system for careful planning of laparoscopic surgery. In the evaluation of the full-scale 3D and virtual laparoscopic images obtained by our institute, the images were clearly depicted in most cases.

Depiction of the CBD and CHD in one patient and of the cystic duct in three patients were poorly rendered. Enhancement of the CBD and CHD was poor, and the cystic duct was difficult to depict because it was a small and dull duct. Poor depiction of the gallbladder resulted in a poorly enhanced biliary tract in 2 patients and a poorly enhanced gallbladder in two other patients. In 20 cases, the liver images could be reconstructed with significant differences in the attenuation value between the liver and the regions around the structures; nevertheless, the liver enhanced poorly in 4 cases, where it was difficult to produce the image because of low attenuation values around the structure [25]. In the present study, we found that virtual CT laparoscopy is a feasible technique that can aid in obtaining helical CT data sets of the abdomen that allow intra-abdominal viewing. Relatively concise observations were made possible prior to surgery, and the images of the complicated structures obtained from virtual CT laparoscopy were understood more readily than those created with other conventional radiological examinations. Our study suggests that virtual CT laparoscopy is likely to be a useful technique in a clinical setting, including the preoperative work-up before laparoscopic surgery. Our data suggest that our images are extremely helpful to surgeons in localizing lesions and minimizing operating time, the extent of surgical resection, and blood loss. Although virtual CT laparoscopy is a superior technique, it is limited to confirm the flow of the cystic artery. Because it is important to understand the bile duct and the flow of the cystic artery, further study is warranted to evaluate the data obtained with the multi-detector row CT. In conclusion, our new technique may contribute to the laparoscopy during surgery as the aid of understanding of anatomical structures in the hepatobiliary system.

REFERENCES


