Computer Aided Surgery 3:264–268 (1998)

Clinical Paper

Virtual Pancreatoscopy of Mucin-Producing Pancreatic Tumors

Toshio Nakagohri, M.D., Ferenc A. Jolesz, M.D, Shigeo Okuda, M.D., Takehide Asano, M.D., Takashi Kenmochi, M.D., Osamu Kainuma, M.D., Yoshiharu Tokoro, M.D., Hiromichi Aoyama, M.D., William E. Lorensen, Ph.D., and Ron Kikinis, M.D.

Department of Radiology, Brigham and Women's Hospital, Harvard Medical School, Boston, Massachusetts, USA (T.N., F.A.J., S.O., R.K.); Department of Surgery, Chiba University School of Medicine, Japan (T.A., T.K., O.K., Y.T., H.A.); and General Electric Corporate Research and Development Center, Niskayuna, New York, USA (W.E.L.)

ABSTRACT We used computer-based virtual endoscopy techniques as a novel approach to clarify the three-dimensional (3D) surgical anatomy of the pancreas and of mucin-producing pancreatic tumors. Thirteen cases (18 lesions) of mucin-producing pancreatic tumors were investigated by virtual pancreatoscopy. Virtual endoscopic images were generated with virtual endoscopy software application on UNIX workstations. We created surface-rendered virtual endoscopic images derived from a computer reconstruction of the cross-sectional magnetic resonance imaging data. Virtual endoscopy could visualize the surfaces of the pancreatic duct and the bile duct, and also demonstrated all cystic tumors. The surfaces of malignant mucin-producing pancreatic tumors were illustrated as being more irregular than those of benign lesions. The virtual endoscopic technique could demonstrate not only a surface-rendered endoscopic image of the tumors but also a 3D reconstructed image of the pancreas. The relationship to anatomic structures located outside the surfaces is continuously maintained and displayed at the same time. Virtual pancreatoscopy was useful for surgical planning of minimally invasive resection of the pancreas. Comp Aid Surg 3:264–268 (1998).

Key words: **virtual endoscopy, virtual pancreatoscopy, surgical planning, mucin-producing pancreatic tumor**

INTRODUCTION

Virtual endoscopy is a new technology which can generate computer-simulated endoscopic images by processing high-resolution magnetic resonance imaging/computed tomographic (MRI/CT) data.[3,6] Previous studies of virtual endoscopy revealed that this technique has many promising advantages,[1,2,5,9–11] including the ability to generate views that are not possible with actual endoscopic examination.[9] Clinical applications of virtual endoscopy for the pancreas have not previously been reported. In this study, the usefulness of virtual endoscopy for mucin-producing pancreatic tumors (MPPT) was investigated.

PATIENTS AND METHODS

Thirteen cases of MPPT were studied. Two patients had three cystic lesions each and one patient had

Received September 22, 1998; accepted December 22, 1998.

Address correspondence/reprint requests to: Toshio Nakagohri, Department of Surgery, Chiba University School of Medicine, 1-8-1 Inohana, Chuo-ku, Chiba 260-8670, Japan. E-mail: nakagori@med.m.chiba-u.ac.jp.

Table 1. Patients' Profiles

No.	Age/sex	Pathological diagnosis	Location	Virtual endoscopy	Operation
1	37/M	Intraductal papillary adenoma	Head	Smooth	Inferior head resection
2	69/M	Intraductal papillary adenoma	Head	Intermediate	DpPHR
3	72/F	Intraductal papillary adenocarcinoma	Head	Irregular	PpPD
4	57/M	Intraductal papillary adenocarcinoma	Head	Irregular	DpPHR
5	59/M	Intraductal papillary adenoma	Head	Intermediate	Inferior head resection
6	69/F	1. Intraductal papillary adenoma	Head	Smooth	Inferior head resection
		2. Simple cyst	Head	Smooth	
7	65/M	1. Intraductal papillary adenoma	Head	Irregular	PpPD
		2. Intraductal papillary adenoma	Head	Smooth	
		3. Intraductal papillary adenoma	Head	Smooth	
8	65/M	1. Intraductal papillary adenoma	Head	Intermediate	DpPHR + DP
		2. Intraductal papillary adenoma	Head	Smooth	
		3. Intraductal papillary adenoma	Tail	Smooth	
9	61/M	Intraductal papillary adenoma	Head	Intermediate	Inferior head resection
10	72/F	Intraductal papillary adenocarcinoma	Head	Irregular	DpPHR
11	50/M	Intraductal papillary adenoma	Body	Smooth	Segmental resection
12	53/M	Intraductal papillary adenocarcinoma	Body	Irregular	DP
13	68/F	Intraductal papillary adenoma	Body	Intermediate	DP

DpPHR = duodenum-preserving pancreatic head resection; PPPD = pylorus-preserving pancreatoduodenectomy; DP = distal pancreatectomy.

two lesions, so we investigated a total of 18 lesions using virtual endoscopy. All patients underwent surgical resection of the pancreas at Chiba University Hospital from 1996 to 1997. The patients' profiles are shown in Table 1.

The MRI data were acquired with a 1.5-T clinical imager (Signal.5; GE). A multislab single-shot fast spin-echo sequence was used. Section thickness was between 2 and 3 mm in the coronal plane. The diagnosis of MPPT was established by findings of endoscopic retrograde cholangiopancreatography (ERCP) and pathological findings. Virtual endoscopic images were generated with virtual endoscopy software application (VESA) on UNIX workstations in the Surgical Planning Laboratory, Department of Radiology and MRI Unit, Brigham and Women's Hospital, Harvard Medical School. Each image was visualized by processing cross-sectional MRI data according to the threshold of the signal intensity. We used an automated path-planning technique to generate the path.[1–3]

RESULTS

It was possible to visualize all the pancreatic ducts and cystic lesions of MPPT by virtual endoscopy. The pancreatic ducts and 18 cystic lesions were all detected correctly. Virtual endoscopy allowed us to observe the pancreatic duct and the inner surface of the cystic lesions (Figs. 1 and 2), and was useful for clarifying the anatomical relationship between the cystic tumor, the pancreatic duct, and the bile duct. The 18 cystic lesions were divided into three groups according to the degree of irregularity of the surface images produced by virtual endoscopy: irregular type ($n = 5$) (Fig. 3), intermediate type ($n = 5$) (Fig. 4), and smooth type ($n = 8$) (Fig. 5).

Four lesions of irregular type ($n = 5$) were intraductal papillary adenocarcinomas, and the other irregular lesion was an intraductal papillary adenoma. All five lesions of intermediate type were intraductal papillary adenomas. Six lesions of smooth type were intraductal papillary adenomas, and one lesion of smooth type was a simple cyst. These results indicate that the surfaces of adenocarcinomas were more irregular than those of benign cystic lesions, as viewed by virtual endoscopy. Cystic lesions adjacent to the pancreatic duct were visualized together with the pancreatic duct (Fig. 6)

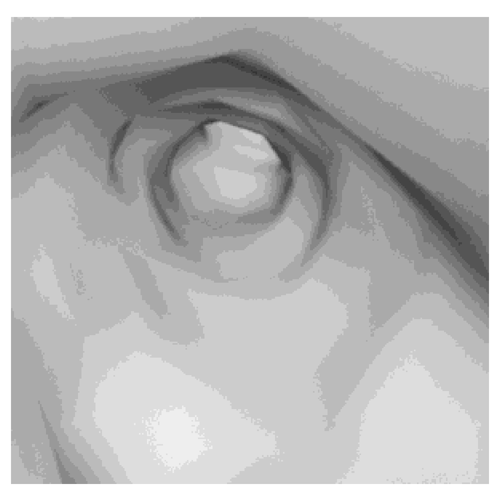

Fig. 1. Virtual endoscopic image of the pancreatic duct. A normal pancreatic duct is visualized.

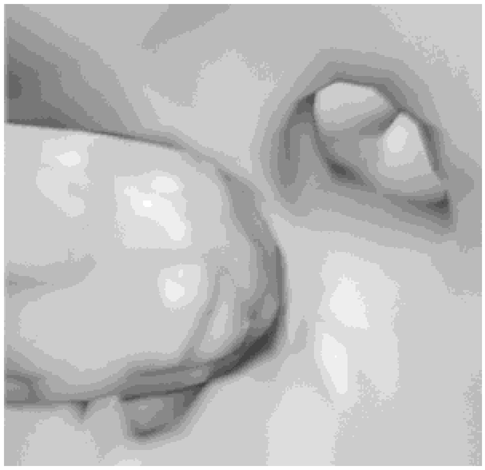

Fig. 2. Virtual endoscopic image of a mucin-producing pancreatic tumor. Virtual endoscopy demonstrates the pancreatic duct (right side) and the cystic lesion (left side) simultaneously.

because thin septa between cystic lesions and the pancreatic ducts could not be visualized.

DISCUSSION

There are two technical approaches for virtual endoscopy: perspective volume rendering and surface rendering. To improve interpretation and exploration, we made surface-rendered images derived from computer reconstructions of cross-sectional MRI data.[1–3] Walls of fluid-containing organs, such as the pancreatic duct and bile duct, are well demarcated in MRI and CT. Virtual endoscopy depicts the surfaces of the pancreatic duct, the bile duct, and cystic lesions in the pancreas, and we can explore the inner space of the pancreatic ducts and cystic lesions interactively. Our virtual endoscopic technique can generate not only a surface-rendered image but also a 3D reconstructed image of the pancreas. Therefore, the relationship of anatomic structures located outside the surfaces is continuously maintained and displayed at the same time. Changing the transparency of the images helps the operator to view the bile duct and cystic tumors from the lumen of the pancreatic duct. The viewer may penetrate the walls and see the extent of lesions within and beyond the walls as well as adjacent organs, such as the bile duct and duodenum. We can also view the pancreatic duct from the outside at the same time using a split-screen display (Fig. 7). This technique can generate 3D reconstructed images of the pancreatic duct and bile duct. The operator can perceive his own position in the lumen of the pancreatic duct. Precise and interactive 3D images also provide information useful for

Fig. 4. Virtual endoscopic image of intermediate type (case 9).

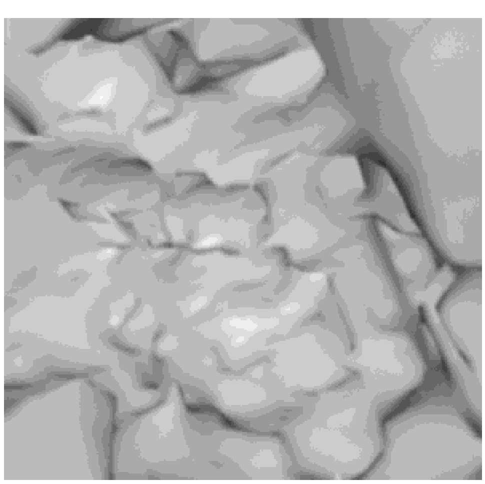

Fig. 3. Virtual endoscopic image of irregular type (case 4).

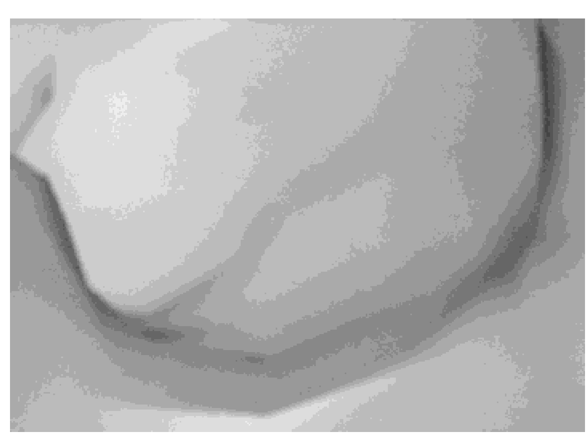

Fig. 5. Virtual endoscopic image of smooth type (case 11).

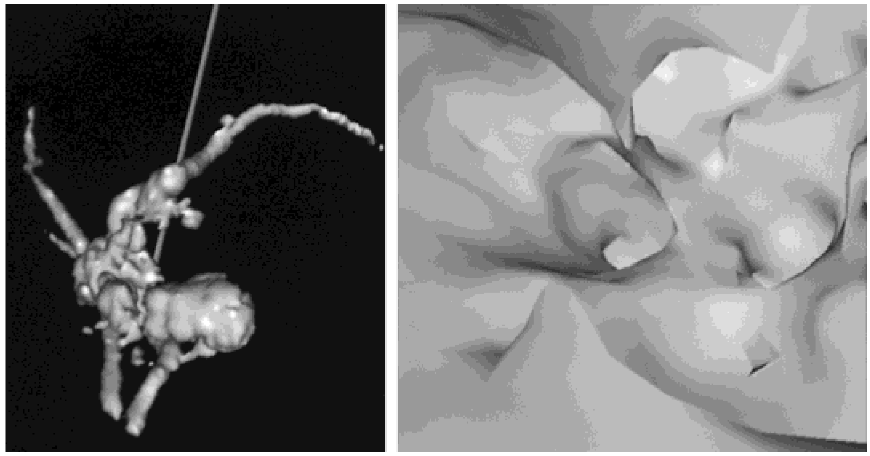

Fig. 6. Cystic lesion next to the pancreatic duct generated together with the pancreatic duct. Pillarlike septa between the pancreatic duct and the cystic lesion were demonstrated in some cases.

the surgical procedure[4,5]: A multiwindow display helps the surgeon to recognize the anatomical relationship between the cystic lesion, pancreatic duct and bile duct. In contrast, conventional MRI produces flat two-dimensional images that give a poor picture of the location and extent of the tumor in the pancreas.

Nowadays, when treating low-grade malignant tumors of the pancreas such as MPPT, minimally invasive surgical procedures are advocated because of concern for the patient's quality of life.[8] For surgical planning of pancreatectomy, it is necessary to clarify the anatomical relationship between the tumor, the pancreatic duct and the bile duct. Whether the bile duct can be preserved is one of the most important factors in selecting the operative procedure, and preservation of the bile duct depends on the degree of involvement with the tumor. When the bile duct is not involved with the tumor, we perform a resection of the inferior head of the pancreas[8] or a duodenum-preserving pancreas head resection (DpPHR), according to the degree of tumor extension to Santorini's pancreas. Anatomical identification of a lesion in the head of the pancreas is useful for surgical planning.

Virtual endoscopy proved to have diagnostic potential for pancreatic disease. The surfaces of cystic lesions could be visualized in all cases in our

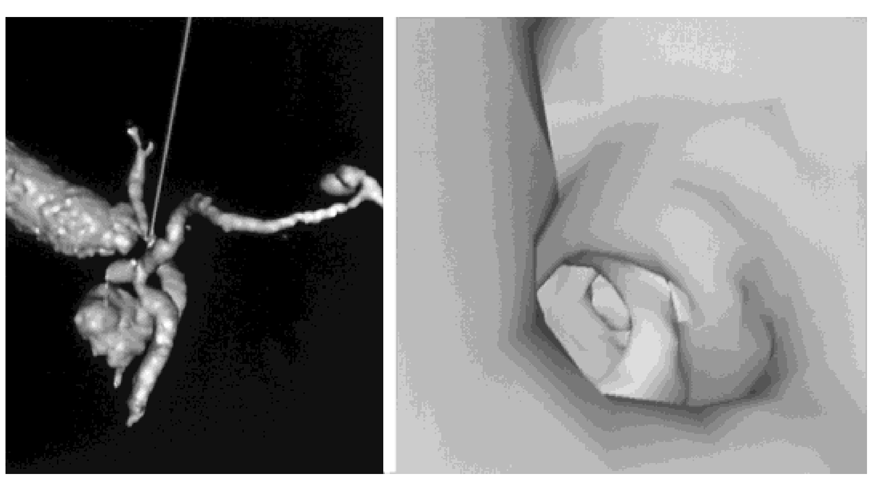

Fig. 7. Our virtual endoscopic technique can make 3D reconstructed images of the pancreatic duct and the bile duct. A split-screen display helps the surgeon to recognize the anatomical relationship between the cystic lesion, the pancreatic duct, and the bile duct. 3D images and virtual endoscopic images aid diagnosis of patients and surgical planning for mucin-producing pancreatic tumors.

Table 2. Advantages of Virtual Endoscopy

1.	Visualization of inner surface of cystic lesions and pancreatic duct
2.	Display of anatomical relationships between the lesion, pancreatic duct, and bile duct
3.	Preoperative evaluation of oncological features by observing the surface of cystic lesions

series, but real pancreatoscopy does not always provide a view of the inner space of cystic lesions in the pancreas. All intraductal papillary adenocarcinomas ($n = 4$) had irregular surfaces as illustrated by virtual endoscopy, whereas 13 of 14 benign lesions had a smooth or slightly irregular surface. Preoperative diagnosis of MPPT is difficult, especially concerning the oncological features of this kind of tumor. Thus, virtual endoscopy would be useful for evaluating the oncological characteristics preoperatively. The advantages of virtual endoscopy are summarized in Table 2.

CONCLUSION

Virtual endoscopy of the pancreas proved to be a valuable method for clarifying the anatomical relationship between the pancreatic ducts and cystic lesions. Virtual endoscopy also has the diagnostic potential to evaluate oncological features by illustrating the inner surface of cystic lesions. It is concluded that virtual endoscopy is useful for surgical planning of minimally invasive resection of the pancreas.

ACKNOWLEDGMENT

Information in this article was presented at the First International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI ’98), Massachusetts Institute of Technology, Cambridge, Massachusetts, October 11–13, 1998. This study was supported by the Japan Association for the Advancement of Medical Equipments.

REFERENCES

1. Ecke U, Klimek L, Müller W, Ziegler R, Mann W. Virtual reality: Preparation and execution of sinus surgery. Comput Aid Surg 1998;3:45–50.
2. Gilani S, Norbash AM, Ringl H, Rubin GD, Napel S, Terris DJ. Virtual endoscopy of the paranasal sinus using perspective volume rendered helical sinus computed tomography. Laryngoscope 1997;107:25–29.
3. Jolesz FA, Lorensen WE, Shinmoto H, Atsumi H, Nakajima S, Kavanaugh P, Saiviroonporn P, Seltzer SE, Silverman SG, Phillips M, Kikinis R. Interactive virtual endoscopy. AJR 1997;169:1229–1235.
4. Kikinis R, Gleason PL, Moriarty TM, Moore MR, Alexander E, Stiege PE, Matsumae M, Lorensen WE, Cline HE, Black PM, Jolesz FA. Computer assisted interactive three-dimensional planning for neurosurgical procedures. Neurosurgery 1996;38:640–651.
5. Lee H. Three-dimensional imaging of the stomach by spiral CT. Comput Assist Tomogr 1998;22:52–58.
6. Lorensen WE, Jolesz FA, Kikinis R. The exploration of cross-sectional data with a virtual endoscope. In Satava RM, Morgan K, Sieburg HB, et al. (eds). Interactive Technology and the New Paradigm for Health-Care: Medicine Meets Virtual Reality III Proceedings. Amsterdam, Holland: IOS Press; 1995. p 221–230.
7. Nakajima S, Atsumi H, Bhalerao AH, Jolesz FA, Kikinis R, Yoshimine T, Moriarty TM, Stieg PE. Computer-assisted surgical planning for cerebrovascular neurosurgery. Neurosurgery 1997;41:403–409.
8. Nakagohri T, Asano T, Takayama W, Uematsu T, Hasegawa M, Miyauchi H, Maruyama M, lwashita C, Isono K. Resection of the inferior head of the pancreas: Report of a case. Surg Today 1996;26:640–644.
9. Rogalla P, Werner-Rustner M, Huitema A, van Est A, Meiri N, Hamm B. Virtual endoscopy of the small bowel: Phantom study and preliminary clinical results. Eur Radiol 1998;8:563–567.
10. Springer P, Dessel A, Giacomuzzi SM, Buchberger W, Stoger A, Oberwalder M, Jaschke W. Virtual computed tomography gastroscopy. Endoscopy 1997;29: 632–634.
11. Summers RM. Navigational aids for real-time virtual bronchoscopy. AJR 1997;168:1165–1170.