Comparison of three software programs for three-dimensional graphic imaging as contrasted with operative findings†,‡

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Abstract

OBJECTIVES: Several types of practical three-dimensional (3D) imaging software programs are available, including those attached to computed tomographic devices. Three different software programs (Advantage Workstation Volume Share 4, OsiriX and CTTRY) were used to generate 3D images on the basis of imaging data obtained by 64-slice multidetector-row computed tomography in the same patient.

METHODS: Surgery was then performed referring to these 3D images in five patients. The characteristics, advantages, disadvantages and utility in the operative field of the images generated with each software program were compared with respect to actual operative findings.

RESULTS: There were no marked differences in vascular images at the segmental level among the software programs, and all three were considered useful for surgery. However, vascular images at the subsegmental level differed among the three programs.

CONCLUSIONS: The depiction of blood vessels at the subsegmental level lacked accuracy when compared with operative findings.

Keywords: Three-dimensional computed tomographic angiography • Thoracoscopic surgery • CTTRY • OsiriX • Workstation

INTRODUCTION

Recent progress in imaging techniques has allowed the detection of early small-cell lung cancer. Surgical procedures for early disease are shifting from lobectomy to segmentectomy, and limited resection has attracted considerable attention.

Because the lung shows marked variations in the courses of blood vessels, pulmonary surgery is particularly challenging. Preoperative confirmation of the branching patterns of pulmonary arteries and veins thus plays an important role in preventing vascular injury during thoracoscopic surgery, associated with a limited field of vision and in ensuring that the scheduled procedure can be carried out safely and promptly [2, 3]. Three-dimensional (3D) angiographic imaging is a useful tool that facilitates the intuitive understanding of the vascular anatomy and has been increasingly used since the recent development of multidetector-row computed tomography (MDCT) [4–10].

Using 64-slice MDCT images obtained from the same patient, we generated 3D graphics with the use of three different software packages [Advantage Workstation Volume Share 4 (AW), OsiriX and CTTRY]. Surgery was then performed referring to these 3D images in five patients. The characteristics and procedural utility in the operative field were compared among the images generated with each software program.

SUBJECTS AND METHODS

Subjects

Among 18 patients who underwent lung resection in our department from June 2010 through October 2010, we studied five patients (four men and one woman) in whom 3D imaging was performed preoperatively, followed by segmentectomy or more extensive resection. Four patients had primary lung cancer and one had a metastatic lung tumour. Their mean age was 67.8 years (range, 60–74). The surgical procedure was right upper lobectomy in three patients (primary lung cancer in two and a
metastatic lung tumour in one). We performed segmentectomy in two patients (lingular segmentectomy in one and right S3 segmentectomy in one) with lung cancer whose tumours were <2 cm in diameter and mainly showed ground-glass opacity. Because these patients required blood vessel procedures during operation, we performed 3D CT imaging. We performed only partial resection of the lung in two patients with lung cancer who were in poor general condition, one patient with a metastatic pulmonary tumour, one patient with an inflammatory nodule and nine patients with pneumothorax. We did not need 3D CT imaging for these patients.

Preoperative three-dimensional imaging

Chest computed tomography imaging techniques. Plain CT scanning was performed with a 64-slice MDCT unit (Discovery CT 750 HD, GE Healthcare Co., Milwaukee, WI, USA). A timing test was then done, using 10 ml of contrast medium (Iopamiron 370®, Bayer Co., Ltd, Osaka, Japan). On the basis of the time density curve obtained from the time of injection of contrast media to the visualization of the pulmonary veins, dynamic CT was performed with 40 ml of contrast medium. Images were obtained at a slice thickness of 0.625 mm for five time phases (one mask phase, two pulmonary arterial phases and two pulmonary venous phases). The exposure dose on plain radiography plus dynamic CT was ~2.2 times that of plain radiography alone.

Three-dimensional imaging. We generated 3D graphics by using three different software programs (Table 1, Fig. 1).

Image generation by Advantage Workstation Volume Share 4. Images with a CT value of at least 300 were obtained by subtracting the mask images. The vascular images were then processed by the automated imaging function of the software to obtain peripheral vascular images with a CT value of ≤50. The bronchi were visualized by using the CT values for air.

Image generation by OsiriX. Imaging was done with the use of OsiriX 64-bit, version 3.7.1, an open source application for Mac mini: Apple Co. Ltd, Cupertino, CA, USA). Images were obtained by the volume-rendering method, using CT values for the pulmonary arterial phase. The window level and the window amplitude were freely altered by moving the mouse, thereby generating vascular images. Images of the rib and spine and unnecessary vascular images were deleted by means of the cut function.

Image generation by CTTRY. CT images were uploaded on a Windows personal computer. Bronchial and pulmonary vessels were traced with the use of CTTRY, a free software program. Numerical values were reconstructed as 3D graphic images with the use of Metasequoia, a shareware software package.

Usage of three-dimensional images in the surgical field. In our hospital, the images created with an iPad (32 GB, operating system 3.2.2, Apple Co., Ltd) were contrasted with the operative field. Data were transmitted to the iPad by means of Bonjour, a networking protocol, to a personal computer through Wi-Fi. A DICOM viewer was used to visualize images processed by AW and OsiriX on the iPad. For data processed by CTTRY, 3D images formatted in Metasequoia were converted into a 3DM file with the use of OBJto3DM, a free software application, and were coloured using Rhinoceros (Rhinoceros 4.0, AppliCraft Co., Ltd, Tokyo, Japan). The use of iRho 3D (Robert McNeel & Associates Co. Ltd, Seattle, WA, USA) allowed the images to be visualized on iPad. In the surgical field, the iPad was sealed in a sterilized polyethylene bag (Ziploc®, 27.3 x 26.8 cm, Asahi Kasei Home Products Co. Ltd, Tokyo, Japan) for use (Fig. 2).

RESULTS

Comparison of three-dimensional imaging software systems

CTTRY was the only software application that could generate plain CT images on CT scanning of the chest, without the use of contrast medium (Table 2). AW and CTTRY could display images of the pulmonary vasculature and bronchi in any desired colour on a monitor. CTTRY was the only software that allowed blood vessels to be altered after 3D representation or allowed constructed images to be modified after division of blood vessels. An understanding of the anatomic spatial relationship with the surrounding organs was possible with AW and OsiriX. As for image correction on the basis of information obtained from the operative field, OsiriX allowed images to be easily generated and displayed on a personal computer. CTTRY rated high in terms of educational effectiveness because it consistently generated images as the surgeon followed the pulmonary vasculature and

<table>
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<tr>
<th>Table 1: General description of each software program</th>
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<tr>
<td><strong>3D method of construction</strong></td>
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<tr>
<td>Developer</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Price</td>
</tr>
<tr>
<td>OS</td>
</tr>
<tr>
<td>CPU of computer</td>
</tr>
<tr>
<td>Memory capacity of computer</td>
</tr>
<tr>
<td>Image produced by radiological</td>
</tr>
<tr>
<td>technologist</td>
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<td>Time needed to produce image</td>
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OS: operating system.
while referring to CT scans. In the operative field, all three software programs allowed referenced to images on an iPad. AW required the cooperation of a radiologist for the generation of images, but only a physician was required to prepare images with the other two software packages. As for the data volume, the total data volume with CTTRY, including the bronchi and cut surfaces, was only 3–5 MB. With AW ~55 MB was required per generated image, and 110 MB was required if images of the pulmonary arteries and pulmonary veins were generated separately. With OsiriX ~30 MB was required (pulmonary arteries and veins displayed on the same image). The data volume thus differed considerably. Because vascular 3D images could not be modified by AW or OsiriX, these packages were not suited for reference image simulation. In contrast, CTTRY was the only software that could perform simulations such as displaying images of cut surfaces at the time of segmentectomy or modifying images of cut blood vessels.

**Table 2: Characteristics of each method**

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<tr>
<th></th>
<th>AW</th>
<th>OsiriX</th>
<th>CTTRY</th>
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<tr>
<td>Is contrast medium necessary?</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Is free dyeing of the blood vessels and bronchial trees possible?</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Is transformation of the description image possible?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Exposure (simple CT ratio)</td>
<td>×2.2</td>
<td>×2.2</td>
<td>×1</td>
</tr>
<tr>
<td>Method of referring to images in operating room</td>
<td>DICOM viewer (OsiriX)</td>
<td>DICOM viewer (OsiriX)</td>
<td>iRhino3D</td>
</tr>
<tr>
<td>Is retouching the description image easy?</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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</table>

**Figure 1:** (A) 3D images produced by AW. (B) 3D image produced by OsiriX. (C) 3D images produced by CTTRY.

**Figure 2:** An iPad placed in a sterilized bag (Ziploc®) was used during operation.

**Contrast with operative findings**

In patients who underwent right upper lobectomy or left segmentectomy, 3D images were useful for navigating the operation by confirming that the courses of blood vessels were consistent with operative findings (Fig. 3). This was because relatively small
blood vessels <1.5 mm in diameter were not seen in the patients who underwent right lobectomy or left segmentectomy in our study.

In the patient who underwent right S3 segmentectomy, the blood vessels depicted at the subsegmental level on the 3D images differed among the three types of software (Fig. 3). On operation, the courses of A3a and V3d were in extremely close proximity from the left side of A3a (Fig. 3B). However, each software had specific characteristics. (i) On AW imaging, the pulmonary arteries and veins at this site were both depicted as pulmonary veins (Fig. 3C), and images that were consistent with operative findings were reconstructed and studied post-operatively. With AW, vascular images of thin peripheral branches are generated by the automatic imaging function when the cursor is adjusted to the blood vessels obtained from CT values. This can apparently result in errors when branching sites of pulmonary arteries and veins are near each other and have close CT values. (ii) On preoperative OsiriX images, the pulmonary vein V3d 1.2 mm in diameter was depicted as indicated by the green arrow in Fig. 3D, where pulmonary artery A3a, which was of similar diameter, was not depicted. When images of this site were regenerated post-operatively, the pulmonary artery unable to be visualized previously could be depicted. Because OsiriX generates grey-scale 3D images, it is important to select a phase that is suitable for imaging of small vessels <1.5 mm in diameter and to carefully image and compare branches with CT findings [4]. (iii) On images generated with CTTRY, pulmonary arteries and veins at the same site were depicted similarly to...
operative findings (Fig. 3E). Because images generated by CTTRY are compared with CT findings many times during the process of continuously imaging blood vessels and bronchi, either from the central blood vessels and the bronchi to distal blood vessels and the bronchi or in the reverse order, pulmonary blood vessels are accurately depicted [4].

DISCUSSION

Progress in imaging diagnostics has increased the detection rate of small lung cancers, including many cases amenable to surgical therapy. In recent years, segmentectomy has been performed to treat small lung cancers, and the 5-year survival rate is now equivalent to that after lobectomy. Internationally, segmentectomy has been accepted in the field of surgical oncology and has become an option for curative surgery in patients with small lung cancers [11]. In respiratory tract surgery, thoracoscopic surgery is now used to treat various diseases. The indications of thoracoscopic surgery have been broadened, making it an important treatment option.

In primary lung cancer, long-term outcomes of thoracoscopic lobectomy have been reported to be generally equivalent to those of open lobectomy, suggesting that thoracoscopic lobectomy is an appropriate treatment for early small lung cancers [12].

A good operative field is essential to ensure that surgery is performed safely and reliably. Because the field of vision is limited in thoracoscopic surgery, preoperative confirmation of the branches of pulmonary arteries and veins, characterized by widely varying courses, would enable respiratory tract surgery to be performed more safely and expeditiously. Bleeding caused by intraoperative injury to a blood vessel negatively affects the field of view during thoracoscopic surgery, in which the operative field is already limited. Preoperative pulmonary 3D modelling is a useful tool that provides information that compensates for the limited field of view, as well as helps to prevent vascular injury.

We used three different types of software to prepare 3D models from CT data (Tables 1 and 2). As for the 3D imaging techniques, AW and OsiriX are based on volume-rendering techniques specially designed for medical applications in general, whereas CTTRY is based on surface-rendering techniques, widely used for 3D movies and other applications. The operating systems are Linux, Mac OS and Microsoft Windows, respectively. AW was developed by the project team of a private company, OsiriX was basically developed by radiologists at Geneva University and CTTRY was developed by a Japanese radiologist [4]. OsiriX and CTTRY are free software programs. The 3D images generated by OsiriX and CTTRY are produced by physicians, whereas a radiologist usually produces those generated by AW. The time required from the receipt of the imaging information to the construction of 3D images is ~1 h for AW and CTTRY. A shorter time is required for OsiriX. AW produces images that most closely approximate the actual object, but branches unnecessary for surgery are also depicted. Image preparation thus requires cooperation between a physician and radiologist. On the other hand, with OsiriX a physician can readily produce images by volume rendering, but the computer system must meet the specifications of at least an iMac and have a RAM of 6 GB or higher. There are thus limitations with regard to the hardware. CTTRY can generate 3D images from plain CT data, and the data volume is small, allowing the images to be easily edited on a notebook personal computer or on an older-model, low-specification, Pentium four-class personal computer. The program can rotate and modify 3D images, allowing pulmonary arteries, veins and bronchi to be confirmed from every possible angle and direction. Imaging with the use of CTTRY requires experience and ability on the part of the user, but it also has educational aspects with respect to CT interpretation and anatomy. Learning about 3D imaging is possible if a personal computer is available [4, 5].

The courses of blood vessels on images produced with the three software programs used in this study showed a good agreement with operative findings at the segmental level, but differed at the subsegmental level. With AW, the cursor is applied to images of blood vessels (most of which are ≥3 mm in diameter) generated from CT values, and narrow branches of these vessels are automatically depicted. Consequently, the close proximity of bifurcations of pulmonary arteries and veins can lead to imaging errors. Because OsiriX depicts blood vessels as grey-scale images, it is necessary to select the phase best suited for the depiction of small vessels <1.5 mm in diameter and to very carefully image branches. With CTTRY, pulmonary arteries and veins at the subsegmental level were depicted similarly to operative findings. On imaging with CTTRY, blood vessels and bronchi are continuously depicted manually. This method can lead to differences in the interpretation of branches, similar to AW. However, because images are always prepared by referring to CT data, there is a high probability that branches will be correctly depicted [4].

Each of the three software programs used in this study had advantages and disadvantages (Table 3). With the cooperation of a radiologist, AW can produce easy-to-view clear images, but requires a large data volume for imaging and can erroneously depict small-calibre arteries and veins that are in close proximity.

<table>
<thead>
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<th>Table 3: Advantages and disadvantages of each method</th>
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<tr>
<td><strong>AW</strong></td>
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<td><strong>Advantages</strong></td>
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<tr>
<td><strong>Disadvantages</strong></td>
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OsiriX is a simple procedure for imaging, but also requires a large data volume, and some blood vessels are not depicted depending on the contrast medium density. CTRY images require a small data volume and allow image modification and simulated surgery. Imaging does not require the use of contrast media, and bronchi can be clearly depicted. A disadvantage is that blood vessel identification requires experience and ability of the operator. Generally, the production of CTRY images takes ~4 h in first patient, but requires only ~1 h after performing CTRY in five to six patients. We had the impression that the decision to use a specific software should be based on factors such as the environment in which it is used, manpower, educational tools and economic considerations, rather than advantages and disadvantages per se.

3D models prepared on the basis of CT images with these software programs represent the introduction of information technology to respiratory tract surgery. Not only the operator, but also the surgical assists performed surgery after surgical simulation using the 3D images. This affected the progress and order of surgery and contributed to safe accomplishment of the surgical procedure. The use of 3D models for preoperative simulation is one technological innovation.

Anyone can prepare 3D images by the volume rendering method, but the practical application of such images is limited. 3D images prepared by the surface rendering technique are widely applicable, but require considerable time, effort and experience. Users want to obtain simulation images without considering effort. The development of programs that easily convert volume rendering images into surface rendering images is needed to avoid such difficulty. Feedback on operative findings from respiratory tract surgeons will contribute to further advances in respiratory tract surgery by leading to continuous innovations such as the future development of software that combines the ease of volume-rendering techniques with the practical advantages of surface-rendering techniques. It will also promote the development of improved 3D imaging software, safer and more reliable surgical procedures and educational and learning tools.

CONCLUSIONS

Three currently available 3D graphic software programs were used to simulate surgery. All three software programs generated 3D images that facilitated the understanding of 3D structures. The depiction of blood vessels at the subsegmental level lacked accuracy when compared with operative findings. The development of software that combines the ease of volume-rendering techniques with the practical advantages of surface-rendering techniques is awaited.

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REFERENCES