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Technical Application of Three-dimensional Visualization and Measurement for Breast Cancer Using Multidetector-row CT Scanner

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Introduction

Among women, breast cancer is the most common form of cancer in the world and is the second leading cause of cancer deaths¹⁾. Mammographic screening has been shown to reduce the mortality of breast cancer by as much as 30%^{2, 3)}. Ultrasound of the breast has led to improved recognition of breast tumors⁴⁾. A small percentage of these tumors is clinically, mammographically, and sonographically occult and only visible on MRI⁵⁾. However, these modalities cannot identify the three-dimensional (3D) position of cancer with high spatial resolution. Precise measurement of the tumor's size and volume is important to determine whether to perform total or partial mastectomy or lumpectomy⁶⁾. The recent advent of multi-detector-row CT (MDCT) has made it possible to obtain isotropic 3D spatial resolution⁷⁾. The resolution of CT images is approximately the same in

all directions, in the trans-axial plain as well as in multi-planar reformations. Computer-assisted 3D visualization and measurement tools are computational techniques that are applied to interpret two-dimensional (2D) breast images, especially mammograms. However, too much time is spent in reconstructing optimal 3D images of targeted objects. Moreover, there is no stable process by which to measure the volume and size of the region with 3D images.

The clinical usefulness of 3D visualization of breast cancer includes the detection of breast lesions as a stereoscopic model and the support of surgical operations. The purpose of our study was to increase the efficiency of breast cancer diagnosis and to support surgical operations through the batch processing of 3D visualizations and measurements of breast cancer.

Summary

This paper describes an integrated methodology that addresses the operation of 3D imaging and measurement for the diagnosis and surgical operation of breast cancer. The main system for breast CT imaging used a multi-slice CT scanner and 3D-workstation. The clinical sequence was performed in three phases with non-contrast and biphasic contrast-enhanced studies that were performed with multi-slice helical CT scanning. Acquired DICOM images were directly sent to the 3D workstation that implemented our developed functions. Four types of transfer functions (mammary skin, vessel, lymph node, and tumor) were set based on region-of-interest (ROI) measurements. After that, two types of segmentation were prepared with volumetry and measurement of the size of breast cancer. Batch processing for 3D visualization and the measurement of breast tumors was helpful for diagnosis and surgical planning.

Key words: Breast cancer, Volume rendering, Surgical operation, Multi-slice computed tomography (CT)

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Fig. 1 Schematic diagram of CT data acquisition system in the local area network. Dicom-formatted images were transferred to the 3D workstation at 100 Mbps.

1. Materials and Methods

1-1 CT data acquisition system

Clinical examination for breast cancer was carried out using 0.5-sec four-slice MDCT (Aquilion-V detector; Toshiba Medical Systems Company, Tokyo, Japan). Users can directly transfer DICOM images from the MDCT scanner to three-dimensional (3D) workstations (Virtual Place M, Medical Imaging Laboratory, Tokyo, Japan, and Plug'n View, ver3.1.1, VOXAR, UK deal in KCO, Kobe, Japan) implemented as measurement tools for breast cancer. Both of the 3D workstations used a PC-based graphics system equipped with a 1-GHz Pentium IV processor and 1.5-G-Bytes of random access memory connected with a local area network (LAN). A data storage server (TFS-3001, Toshiba Medical Systems Company, Tokyo, Japan) and patient database system were used as the main controller in LAN (Fig. 1).

1-2 Image Acquisition

The scan parameters for all breast cancer studies were fixed at 120 kVp and 0.5-sec rotation speed. First, a precontrast helical scan of the whole thoracic area (300 mm) was performed at a low dose (less than 100 mAs) as breast cancer screening. The scanning was performed within a single breath-hold with 2 mm detector row collimation (5 mm slice thickness display for filming) and helical pitch of 6:1. Targeted helical scanning (200 mm) of the area containing breast cancer was performed

with 1 mm detector row collimation and helical pitch of 6:1. Then, a contrast-enhanced study was performed using biphasic helical CT scanning. Enhancement was achieved with 100 ml of non-ionic iodinated monomer solution with a concentration of 300 mgI/ml (Iohexol; Daiichi Pharmaceutical Co., Ltd., Tokyo, Japan) injected at a flow rate of 2.0 ml/sec.

In the first phase, scan delay was determined as the interval from the start of injection using an automatic bolus tracking system (RealPrep, Toshiba Co. Tokyo, Japan).

The optimal transit time from intravenous injection to enhancement of the breast cancer was determined using a region of interest (ROI) placed on the aorta at the slice level of the breast lesion. Scanning was started at the time determined by a contrast bolus tracking technique to coincide with peak aortic enhancement of 200 HU. After the automatic bolus-tracking scan, helical scanning (at 120 kV and 200 mA) was performed to the whole thoracic area, with a 0.5-sec rotation time and helical pitch of 6:1. Finally, 180 sec after scanning of the first phase, target helical scanning (200 mm) was performed to the same area of target scanning.

1-3 Tools of 3D imaging and measurement of breast cancer

The transfer function of volume rendering is responsible for mapping the information at a voxel location into different values, including material, color, or opacity.

Fig. 2 Segmentation method.

Threshold HU values were decided at the midpoint between two mode values on a bimodal histogram.

(a) An example of the ROI on the original image. (b) Histogram of ROI.

a | b

Transparency and its complement, opacity, were referred to as alpha in this study⁸⁾. An alpha value of one represents an opaque object, while a value of zero represents a completely transparent object. Four transfer functions to visualize mammary skin, breast cancer, lymph nodes, and vessels were set after ROI measurement for each region. Mean HU value in the ROI on the images was set at a high alpha value, and the transfer functions were saved as a default set into 3D workstations.

1-4 Measurement tools for breast cancer

Automatic and semi-automatic segmentations were performed for volumetry of tumors and lymph nodes. Two segmentation methods, based on voxel counting, were compared to find the simpler method. Automatic segmentation is the mode method^{9, 10)}, which explains the most basic technique. Tumors and lymph nodes were segmented by statistical value (mode value) depending on the image histogram¹¹⁾. The threshold HU values were selected at the midpoint between two mode values on a bimodal histogram (Fig. 2). The semi-automatic segmentation is a manual selection of a specific color-coded object of the organ using a volume histogram with 3D image. Users can measure the volume of the 3D object by pointing and one click segmentation. The size of the tumor was determined by measurements of the three maximal diameters using MPR (trans-axial, coronal, and sagittal images) views. Fig. 3 shows all the process steps

Fig. 3 Flowchart of process from acquisition of DICOM data to volumetry of breast cancer lesions.

used in our technique.

2. Results and discussion

Examples of the average Hounsfield unit (HU) values in the ROI on the breast CT images are shown in Figs. 4 and 5 (early and late phases). The four types of transfer functions used to visualize 3D breast imaging (tumor, skin, lymph node, and vessel) are shown in Fig. 6. In cases of equivalent density between lymph node and tumor, the transfer function of the lymph node had a larger dynamic range of alpha value (-50 HU to 100 HU) than that of the tumor (0 HU to 100 HU). Resultant 3D images are shown in Fig. 7. Utilization of the transfer func-

Fig. 4 Examples of the average HU values in the ROI on breast CT images (early phase of contrast-enhanced study).

(a) Setting the ROI using Viewer. (b) Average HU value of tumor (average HU value = 68.3, SD=13.2). (c) Average HU value of fat area (average HU value = -106.0, SD=15.9). (d) Average HU value of muscle (average HU value = 55.9, SD=13.4). (e) Average HU value of contrast medium (average HU value = 376.8, SD=12.5). (f) Average HU value of lymph node (average HU value = 76.0, SD=16.4).

a	b	c
d	e	f

Fig. 5 Examples of average HU values in the ROI on breast CT images (late phase of the contrast-enhanced study).

(a) Setting the ROI using Viewer. (b) Average HU value of tumor (average HU value = 117.6, SD=12.5). (c) Average HU value of fat area (average HU value = -105.2, SD=10.8). (d) Average HU value of muscle (average HU value = 70.3, SD=14.0). (e) Average HU value of contrast medium (average HU value = 155.6, SD=11.7). (f) Average HU value of lymph node (average HU value = 79.7, SD=15.4).

a	b	c
d	e	f

Fig. 6 Four types of transfer functions used for visualization in 3D breast imaging.
(a) Mammary skin. (b) Vessel. (c) Lymph node. (d) Tumor.

Fig. 7 Resultant 3D images reconstructed from the four types of transfer functions.
(a) Mammary skin. (b) Vessel. (c) Lymph node. (d) Tumor.

Fig. 8 Examples of visualization of the internal thoracic arteries using the vessel transfer function.

Fig. 9 Example of a visualization technique with separation of materials using parallel shifting of transfer function. In this example, ligaments were eliminated by +50 HU shifting using the vessel transfer function.

tion based on ROI measurement was helpful to generate a precise description of vessels such as the internal thoracic artery (Fig. 8). In cases of overlapping of ligaments and vessels, a parallel shift of the transfer func-

tion was used to separate the objects (Fig. 9). There was no need to change the transfer function to visualize the tumor in accordance with early and late phases in our studies (Fig. 10). A multi-oriented cine view with con-

Fig. 10 Difference between early and late phases of contrast-enhanced study.

(a) Early phase (average HU value=68.3). (b) Late phase (average HU value=117.6).
The transfer function used to visualize the tumor did not need to be changed in strict accordance with the early and late phases in our studies.

a | b

Fig. 11 Procedure for volumetry using the image-based histogram (mode method).

(a) Measuring the histogram. The ROI was copied for slices, and unnecessary areas of the image were easily cut out. (b) Segmented image (automatic threshold).
(c) Volume rendering of the segmented images.

a | b
c

secutive conversion of transfer function from skin to vessels supported the surgical planning of breast cancer (Movie: CD-ROM).

In volumetry or measurement of lesion size, the mode

method using an image histogram was highly dependable owing to its automatic threshold (Fig. 11). Direct segmentation from the volume histogram was practical and efficient for volumetry and tumor measurement by

Fig. 12 Example of direct segmentation using a 3D image.

(a) Segmented tumor region on the 3D image. (b) Contour display on the mammary skin for surgical operation. (c) MPR views for verifying the results of segmentation.

Fig. 13 Size measurements of a breast cancer lesion.

Multi-oriented length of the tumor can be displayed on the MPR views and 3D images. Numbers of length (①, ② and ③) on the MPR views and 3D images are synchronized with each other.

pointing to the target lesion and clicking once on the 3D image (Fig. 12). MPR views were helpful to confirm the segmented area and measure the size of the tumor from multiple directions (Fig. 13). These two methods were useful to validate the accuracy of the volumetry

and measurements of tumor.

3. Conclusion

Batch processing for 3D visualization and measurement of breast tumors was helpful to surgeons for both

diagnosis and surgical planning. It was useful to decide whether to carry out total or partial mastectomy or lumpectomy. We will conduct further experiments aimed

at several other surgical applications in the near future, and we will consider the possibility of application to other cancers.

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図表の説明

- Fig.1 ローカルネットワークシステムによるCTデータの獲得。
DICOM画像是、100Mbpsで3D画像ワークステーションに転送される。
- Fig.2 セグメンテーションの方法。
HU値の閾値は2峰性ヒストグラムの二つのモード値の中間値で決定される。
(a)オリジナル画像上のROIを置いた画像、(b)ROI内の画像ヒストグラム
- Fig.3 DICOMデータの取得から乳癌部の体積計算までの処理過程フローチャート。
- Fig.4 乳房CT画像(造影CTの早期相)上のROI内における平均HU値の計算例。
(a)ビューワーによるROI設定、(b)乳癌部の平均HU値(平均HU値: 68.3, SD: 13.2), (c)脂肪領域の平均HU値(平均HU値: -106.0, SD=15.9), (d)筋組織の平均HU値(平均HU値: 55.9, SD: 13.4), (e)血管造影部の平均HU値(平均HU値: 376.8, SD: 12.5), (f)リンパ節の平均HU値(平均HU値: 76.0, SD: 16.4)
- Fig.5 乳房CT画像(造影CTの後期相)上のROI内における平均HU値の計算例。
(a)ビューワーによるROI設定、(b)乳癌部の平均HU値(平均HU値: 117.6, SD: 12.5), (c)脂肪領域の平均HU値(平均HU値: -105.2, SD=10.8), (d)筋組織の平均HU値(平均HU値: 70.3, SD: 14.0), (e)血管造影部の平均HU値(平均HU値: 155.6, SD: 11.7), (f)リンパ節の平均HU値(平均HU値: 79.7, SD: 15.4)
- Fig.6 乳房三次元画像における4種類の不透明度関数。
(a)乳房表皮画像、(b)血管、(c)リンパ節、(d)腫瘍部
- Fig.7 4種類の不透明度関数から再構成した三次元画像。
(a)乳房表皮画像、(b)血管、(c)リンパ節、(d)腫瘍部
- Fig.8 血管用の不透明度関数と用いた内胸動脈の表示例(シェーディングなし)。
- Fig.9 不透明度関数の平行移動による臓器間の分離例。
この例では、血管用の不透明度関数を+50HUシフトさせることによって靱帯を消して血管を重ねなくなり表示している。
- Fig.10 造影検査による早期相と後期相の違い。
(a)早期相(平均HU値: 68.3), (b)後期相(平均HU値: 117.6)
腫瘍部の表示用の不透明度関数は、造影早期と後期との間で変化させる必要がなかった。
- Fig.11 画像ヒストグラムを用いた体積計算の手順。
(a)ヒストグラムの測定。ROIは、スライスごとにコピーされ、腫瘍部以外の部分は簡単に除去できる。
(b)領域分割された画像(自動閾値処理)。
(c)領域分割された画像のボリュームレンダリング。
- Fig.12 三次元画像を用いたダイレクトセグメンテーションの例。
(a)三次元画像上で領域分割を施した腫瘍部。
(b)外科手術支援のための乳房表皮上の腫瘍部輪郭抽出像。
- Fig.13 乳癌部の大きさの測定。
乳癌のあらゆる方向の長さはMPRと三次元画像に表示される。MPRと三次元画像における3方向(①, ②および③)の長さは、お互いに同期して表示される。