原　著

# The development and assessment of program for volume measurement for CT images of DICOM data running on a personal computer
## (Development and assessment of volume measurement program for DICOM on PC)

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**Abstract**　Purpose: Volume estimation of organs or fluid is one of the most important roles in autopsy. The aim of this study is to develop a volume estimation program for CT images of Digital Imaging and Communication in Medicine (DICOM) which runs on a personal computer, and to confirm the usefulness and accuracy of it.
Materials and methods: We developed a program which extracted correct boundaries of the organs in spite of setting of rough region of interest (ROI). We retrospectively evaluated five postmortem CT (PMCT) examinations which were performed with a 64-row detector CT. Volume of five livers, five spleens, and 10 kidneys were evaluated by means of a general image processing program and our developed program. The averages of obtained volume and required time to set ROIs were analyzed with paired t-test.
Results: There were no significant differences for the estimated volume of all organs between with the general image processing program and with our program. However, there were significant differences for the required time to set ROIs between with the two methods in all organs. The mean evaluation time was shortened by 52.0%, 67.2% and 74.0% in liver, spleen, and kidney, respectively.
Conclusion: Our developed program provided correct volume value, and was able to reduce labor and time to set ROIs compared with using the general image processing program. Our program is useful to evaluate the volume on CT images of DICOM data especially in PMCT.

## Introduction

Modern imaging technologies, such as multi-detector computed tomography (MDCT) and magnetic resonance imaging (MRI) have been introduced into forensic fields (1-5). As the conventional autopsy rate declines worldwide, postmortem imaging (PMI) has been used as a substitute for autopsy. In Japan, PMI by means of such digital imaging modalities is called "Autopsy imaging (Ai)" (4, 5). Volume estimation of organs is one of the most important roles in autopsy (6-9). Many investigators have reported the volume measurement methods on PMI (7-10). Volume data are able

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to be obtained from Digital Imaging and Communication in Medicine (DICOM) data. State of the art MDCT provides accurate volume data; hence, MDCT potentially offers the most accurate noninvasive means of estimating volumes of various structures. Exclusive workstations are usually used on DICOM interpretation in order to measure volume of organs (11). Imaging workstations are expensive and are settled only in medical institutes. On the other hand, personal computers (PC) are widespread, less expensive and convenient to deal with. Image processing programs on PC are used to obtain volume of organs on DICOM. However, regions of interest (ROI) must be set correctly with the boundary of the organs in order to extract them. And the measured area should be recorded and the volume is calculated on a spreadsheet. An image processing program for DICOM with easy ROI setting and volume calculation is useful for volume estimation on CT images. The purpose of this study is to develop a volumetry program which extracted the organs in spite of setting of rough ROI using determined threshold, and to confirm the usefulness and accuracy of it.

## Materials and methods

### Program development

We developed a program which ran on a PC to measure volume of structures on DICOM. The program was made with a multi-paradigm numerical computing environment and programming language (MATLAB R2014a; MathWorks, Natick MA, U.S.) on a PC.

On our developed program, we determined a threshold according to the CT value of the target organs (between -40 or -50 HU and 150 HU). And we set ROIs roughly including fatty density which surrounded the target organs on CT images. The volume under the determined threshold, e.g. fatty density, was automatically removed, and then the organs were extracted. After removing the redundant parts around the target organ using binarization and morphological imaging processing. Finally, the volume of the organs was calculated by multiplying the ROIs and slice thickness and adding all of them (Fig. 1).

### Postmortem CT examination and image evaluation

This retrospective study was approved and informed consents were not required by the review board of Niigata City General Hospital (approval number 13-110). We retrospectively evaluated five postmortem CT (PMCT) examinations which were performed with a 64-row detector MDCT (SOMATOM Definition AS; Siemens Healthcare, Erlangen, German). Examinations were performed in the natural supine position with the patients' arms at their sides. No contrast material was administered. Axial images were reconstructed with a 350 mm field of view, a 512 x 512 image matrix, and 2 mm slice section thickness.

Images were evaluated by two medical students by means of a public domain image processing program (ImageJ; National Institutes of Health, Bethesda MD, U.S.) and the developed program. Figure 2 shows the process of the evaluation with each program. The evaluation with both programs was performed using with two same capabilities Windows 7 professional PCs (Zcosmos, Niigata, Japan) with 3.30GHz CPU (Core i5-2500K; Intel Corporation, Santa Clara, CA, U.S.) and 4 GB RAM. Volume of five livers, five spleens and 10 kidneys were measured on the five PMCT with both programs independently. The total evaluated image numbers were 67 – 115 (average, 90.6), 30 – 52 (average, 41.2), 44 – 57 (average, 50.8) for livers, spleens, and kidneys, respectively. The required time from opening the images to finishing setting ROIs on all images was measured. The ROIs set by the students were confirmed by the experienced board-certified radiologist. The volume of the organs was calculated with a spreadsheet (Excel 2010; Microsoft Corporation, Redmond, WS, U.S.) when we used the general image processing program. The volume was calculated automatically with our developed program.

## Statistical analysis

The averages of obtained the volume and the required time to set ROIs of the two operators were analyzed. The volume of the organs estimated using ImageJ was determined as gold standard. The each volume and the required time using ImageJ and the developed program were statistically analyzed with a free software (R; the R Foundation for Statistical Computing, Vienna, Austria). Paired t-test was used because normal distribution was determined in all paired subgroup with Shapiro-Wilk test. A $p$ value of less than 0.05 was considered to indicate a statistically significant difference.

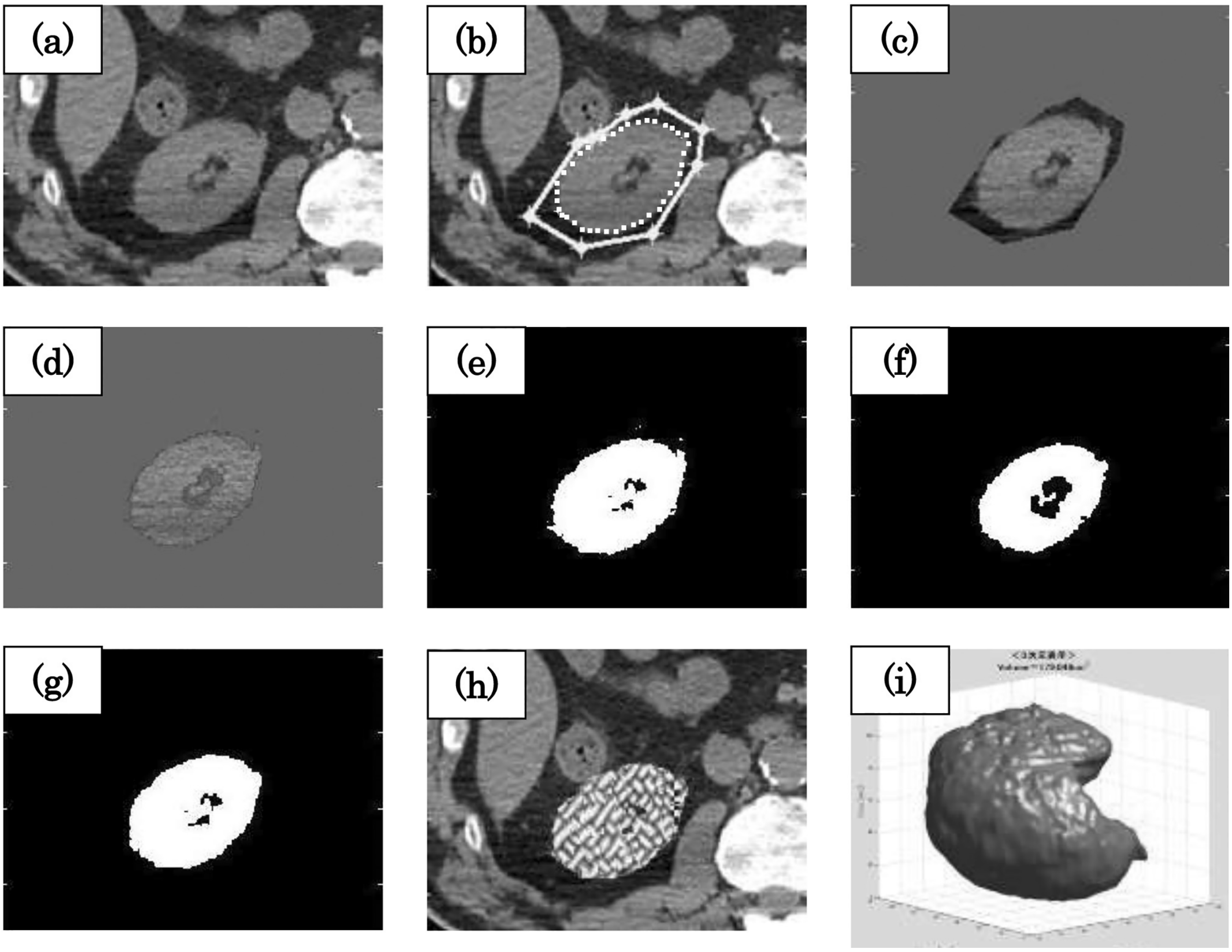



Figure 1：Procedure of image processing on our program.

(a) The DICOM image of the target organ was opened.

(b) A region of interest (ROI) was set along the target organ roughly with surrounding fatty density (a solid line). Reference: A ROI must be set along the organ correctly with the public domain image processing program (a dashed line).

(c) The target organ with surrounding fatty density was extracted according to the ROI.

(d) The volume under the determined threshold, e.g. fatty density, was automatically removed, and then the organs were extracted. The thresholds were used between -40 or -50 HU and 150 HU.

(e) Binarization processing was performed.

(f and g) In order to remove the redundant parts around the target organ, morphological imaging processing of erosion and dilatation were performed.

(h) The final ROI was confirmed by alpha compositing.

(i) After setting ROIs on all 2-dimentional images, volume of the organ was calculated with 3-dimentional image.

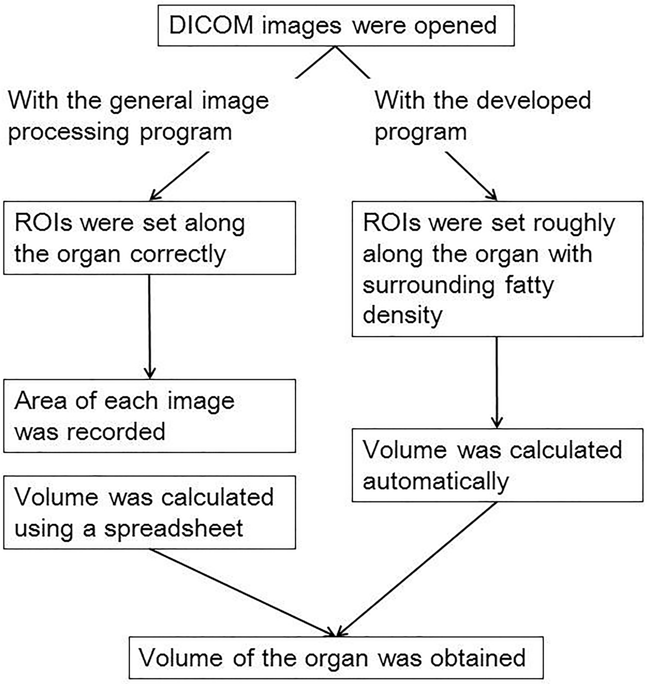



Figure 2 : Diagram of the process of the evaluation with each program.
ROI: Region of interest

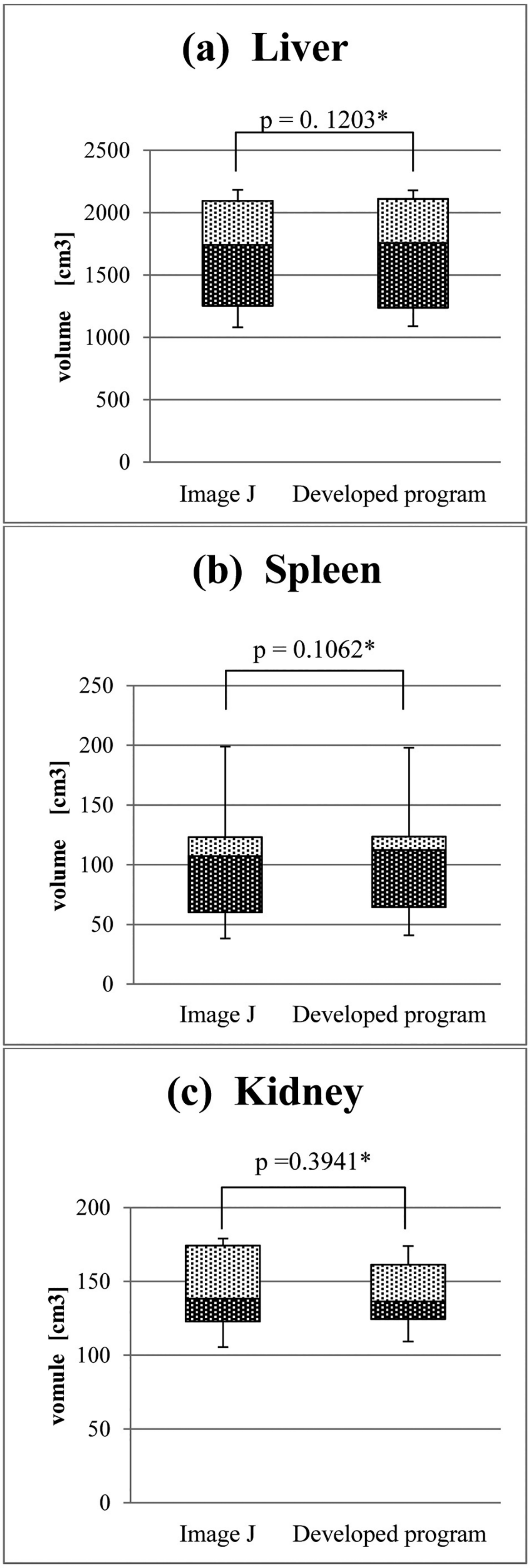
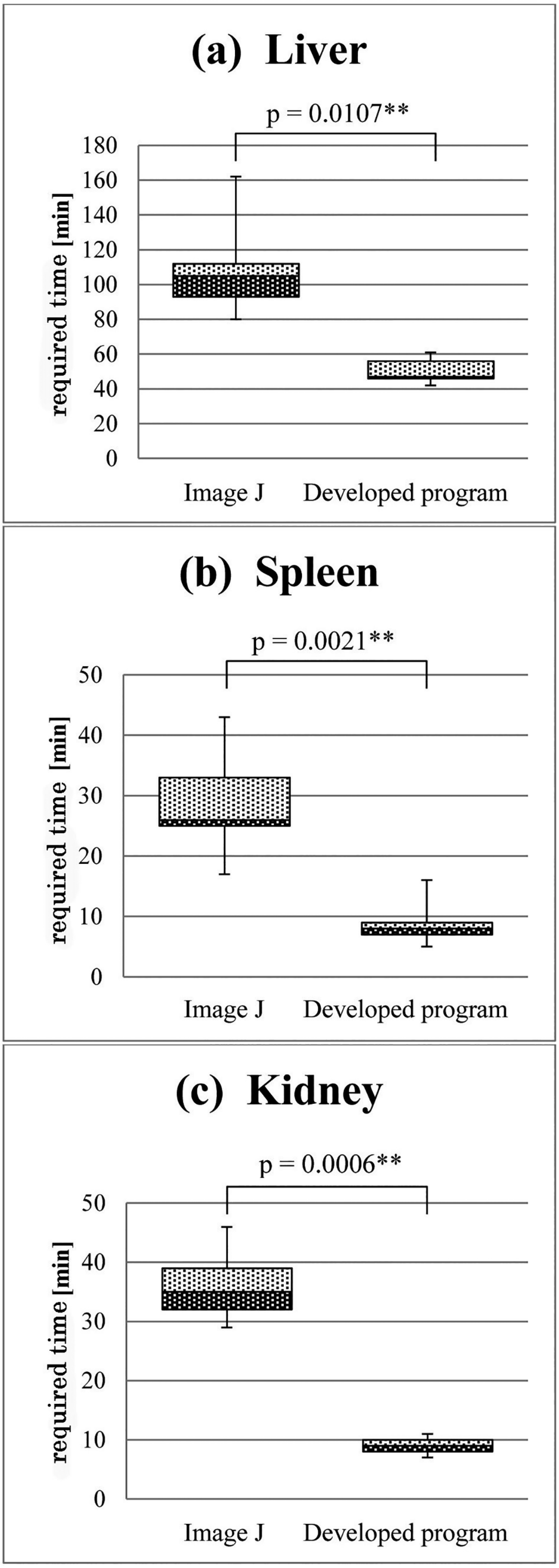



Figure 3 : Evaluated organ volume with the general image processing program (ImageJ) and the developed program. (a); liver, (b); spleen, (c); kidney.
*: Paired t-test. There are no significant differences in all organs.




## Results

The average volumes and the required time to set ROIs of the corresponding organs are presented in Table 1, Figure 3, and Figure 4. While there were no significant differences for the estimated volumes between with the general image processing program and with the developed program in all organs (Fig.3), there were significant differences for the required time to set ROIs between with the two methods in all organs (Fig.4). By utilizing the developed program, the mean required time was shortened by 52.0%, 67.2% and 74.0% in livers, spleens, and kidneys, respectively.

## Discussion

Many investigators have reported the importance of postmortem volume estimation of organs and fluid in body cavities, e.g. pericardial, pleural, abdominal and retroperitoneal (7-9). The fluid or blood volume is important in forensic scenes as it may be directly related to the cause of death or a proximate cause of it (7, 9, 12). Meanwhile, the volume of organs is hardly to be measured by autopsy (10). The weights of the organs are usually used for evaluation. The weight of organs reflects the conditions at death, e.g. edema, emaciation, and congestion (6). A few of formulas which estimate weight of organs from their volume have been reported. The weights of the organs are able to be estimated using CT data without autopsy (13, 14). Therefore, it is important to evaluate the volume of the organs on CT data.

The accuracy and reproducibility of CT in volume estimation has been established with phantoms and organs of animals or humans by many investigators (10, 14-16). Accurate and noninvasive measurement of the organs has also potential clinical application (17, 18). In order to measure the volume of the organs, automatic or semiautomatic

Figure 4: Required time to set ROIs with the general image processing program (ImageJ) and the developed program. (a); liver, (b); spleen, (c); kidney.
**: Paired t-test. There are significant differences in all organs.

Table 1: The volume and required time to set ROIs of liver, spleen and kidneys with the general image processing program and with the developed program

| | liver (n=5) | | spleen (n=5) | | kidney (n=10) | |
|---|---|---|---|---|---|---|
| | General image processing program | Developed program | General image processing program | Developed program | General image processing program | Developed program |
| Estimated volume ($cm^3$) | 1671.2 ± 492.6 * | 1690.3 ± 505.1 * | 105.5 ± 62.4 ** | 107.9 ± 60.7 ** | 143.9 ±32.1 *** | 141.1 ± 26.4 *** |
| Required time to set ROIs (minute:second) | 110:50 ± 31:9 + | 50:47 ± 7:51 + | 29:5 ± 9:51 ++ | 9:40 ± 4:15 ++ | 36:33 ± 6:38 +++ | 9:20 ± 1:28 +++ |

mean ±standard deviation

*, **, ***: Paired t-test. There are no significant differences.

+, ++, +++: Paired t-test. There are significant differences.

segmentation program is able to be used on exclusive workstations (11). Image processing programs are used for treating DICOM data on a PC. ImageJ is an open source imaging processing program and has a large and knowledgeable worldwide user community (19, 20). It needs manual tracing of the entire organ contour on every CT slice. State of the art CT scanners are able to provide accurate volume data. Consequently huge number of CT images with thin slice thickness has to be evaluated. Manual tracing requires a great deal of time. In our study, we had to set ROIs approximately 100 slices, 40 slices, and 50 slices on two millimeter slice thickness images, and needed 100 minutes, 30 minutes, and 35 minutes for livers, spleens, and kidneys using ImageJ, respectively. It was a minute work with perseverance to set ROIs correctly. The volumetry program we developed was able to reduce labor and time to evaluate of CT images compared with using ImageJ. The evaluated volumes were not significantly different between using the general image processing program and the developed program. The required time was about half for livers or one third for spleens and kidneys. Especially, spleens and kidneys were surrounded by adipose tissue in most cases; hence, it is easier to set ROIs than for liver which is adjacent to the diaphragm and stomach (Fig.1). Furthermore, although we had to use the spreadsheet to obtain the volume of organs when we used ImageJ, it was calculated automatically on our developed program. Our developed program dispensed with more labor than the general image processing program.

Recently, automatic organ segmentation techniques on CT images have been developed for clinical use (18). Saito et al. reported statistical shape model of organs for PMI (21). Because contrast material agent is not able to be used for PMI, the organ boundary is not clear compared with that on clinical images with contrast material agent. Further deformation of some organs after death (22-24) makes it difficult to estimate their positions (21). Currently manual setting ROIs is a realistic method to estimate volume on CT images.

## Conclusion

We developed the program which ran on a PC to measure volume of structures on DICOM images. The program provided correct volume value, and was able to reduce labor and time to set ROIs in comparing with using the general image processing program. The program is useful to evaluate the volume on CT images of DICOM data especially in Ai.

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