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A01-3 Model Construction for Computational Anatomy: Progress Overview FY2010

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Abstract— This paper is a summary of the purpose and recent progress of our research work, which is a part of the research project “Computational anatomy for computer-aided diagnosis and therapy: Frontiers of medical image sciences” funded by a Grant-in-Aid for Scientific Research on Innovative Areas, which is awarded by the MEXT, Japan. Our research in this project is mainly aimed at model constructions and their applications to the recognition and analysis of anatomical structures using X-ray CT images, MR images, and functional images (PET). Our work focuses on modeling the universal organ localization approach, developing a shape model for abdominal muscle segmentation in CT images, analyzing normal distributions of the standardized uptake values (SUV) of 2-deoxy-2-fluoro-d-glucose (FDG) in different organs, investigating the normal distributions of bone mineral density (BMD) values on different vertebrae for different ages and genders, and analyzing the stiffness of liver tissue. These models can be expected to facilitate fast detection and segmentation of the target region, as required by doctors, and also to evaluate the normal distributions of some interesting features of the target region to support the diagnosis. The preliminary experimental results, based on a large image database, have demonstrated the potential of the constructed models.

I. BACKGROUND

Morden imaging scanners such as volumetric CT, MRI, PET-CT instruments are widely used in clinical medicine. The high performance of such imaging devices can provide a huge amount of information about the human body to support diagnosis [1], not only showing the geometry and motion of anatomical structures, but also demonstrating functional processes such as blood flow and carbohydrate metabolism. These types of information are stored separately in different sorts of medical images, and need to be adequately arranged for diagnostic support in clinical medicine [2].

Anatomical structures constructed from the locations and ranges of different inner organs and tissues are basic parts, and should be first recognized during medical image interpretation. Automated organ segmentation is still a challenging and necessary task in the research field of medical image analysis. Although many segmentation algorithms have been presented for segmenting a target organ such as the liver or heart in CT images, most of them are based on an ad hoc approach that can only extract a specific organ and cannot

always maintain high accuracy and robustness, especially for abnormal patient cases. Therefore, universal solutions that can be applied to different organ segmentation problems and adapted to different kinds of medical images are expected to be developed.

The features such as volume, smoothness of the surface, stiffness of target organs are required by the doctors for aiding the image diagnosis. The measurement and analysis of these kinds of features from medical images are important functions required of computer-aided diagnosis (CAD) systems. The main issues of this research field are how to measure the features accurately from the medical images, model them on the basis of a normal human body, and detect abnormalities by comparing with the normal model.

In our previous studies [3]-[14], we developed a system for the automatic recognition of anatomical structures in torso CT images and tried to construct a normal human body model for the detection of abnormalities in CT images. This system has been tested with a limited number of CT cases and used for CT image analysis in emergency medical care.

Although the possibility and potential usefulness were confirmed by the preliminary experiments, the robustness and accuracy of this system were not high enough; for example, the anatomical structures in about 30% of CT cases could not be recognized successfully in our experiment based on 334 CT cases. In particular, the proposed segmentation algorithm often failed to recognize the CT cases that have large distortions in anatomical structures.

II. PURPOSE AND CONCRETE PLAN

Our study focuses on a new methodology for anatomical model construction, which is a fundamental part of the whole research project. We will also join in discussions with the other research groups for the definition and application of the model. The primary purpose of our anatomical model is to accomplish the reliable recognition of anatomical structures and accurate organ segmentation in torso X-ray CT images. On the basis of the recognized anatomical structures, we plan to model the normal human body on CT, PET and MR images, and to use these models for the detection of cancer and other lesions in multiple organs. The basic consideration in our model construction is the integration of human anatomy, medical image processing, and machine-learning techniques together.

III. RECENT ACHIEVEMENTS

In our latest project [15], we focused mainly on the five subjects detailed below as shown in Fig. 1. (1) We proposed a universal approach for the development of an organ localization scheme based on machine-learning techniques. This approach can generate a fast scheme that can be used to detect automatically the 3D bounding box of an inner organ of interest in CT images. (2) We constructed a model to demonstrate the normal standardized uptake values (SUV) in different parts of the human body on PET images under the

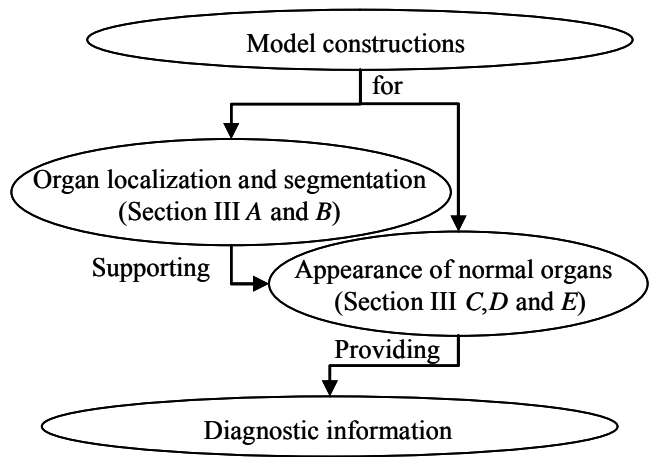


Fig. 1. Overview of the model constructions.

anatomical structures. We plan to apply these models to cancer detection in multi-organ regions on the basis of PET images. (3) A new technique is proposed to measure stiffness from MR images by analyzing the movements of anatomical structures during the breathing cycle. This technique is adopted to carry out the image diagnosis of liver cirrhosis. (4) We carried out an investigation on the BMD values in each of the vertebrae by using a large database containing more than 1000 CT cases for different ages and genders. The results demonstrated the individual variation in the normal human body. These results will support further discussions on the potential for the prognosis of osteoporosis based on CT images. (5) A shape-model-based approach was developed to recognize and extract abdominal muscle wall structures. This approach can be used to measure the volume of the psoas major muscles from CT images. Because the psoas major muscles naturally support lumbar vertebrae, their strength is expected to provide an indirect prediction of osteoporosis. This approach also facilitates the investigation of the relation between major muscles and lumbar vertebrae through CT image analysis.

The current progress of each part is reported in following sections.

A. Automatic localization of solid organs on 3D CT images by a collaborative majority voting decision based on ensemble learning [16,17]

Organ segmentation is an essential step in the development of computer-aided diagnosis/surgery systems based on CT images. A universal segmentation approach/scheme that can be used to carry out the segmentation of different organs can substantially increase the efficiency and robustness of such computer-aided systems. However, this is a very challenging problem. An initial determination of the approximate position and range of a target organ in CT images is a prerequisite for precise organ segmentation. In this study, we propose a universal approach that enables the automatic localization of the approximate position and range of different solid organs in the torso region on three-dimensional (3D) CT scans.

The location of a target organ in a 3D CT scan is presented as a 3D rectangle that bounds the organ region tightly and accurately. Our goal was to automatically and effectively detect such a target-organ-specific 3D rectangle. In our proposed approach, multiple 2D detectors are trained using ensemble learning and their outputs are combined using collaborative majority voting in 3D to accomplish reliable organ localization. We compared the performance of our approach with an atlas-based approach and investigated the usefulness of the localization results by applying them to facilitate kidney segmentation in non-contrast CT images.

We applied this approach to the localization of the heart, liver, spleen, left kidney, and right kidney regions independently using a CT image database comprising 660 torso CT scans. In the experiment, we manually labeled the abovementioned target organs from 101 3D CT scans as training samples, and used our proposed approach to localize the five target organs separately on the remaining 559 torso CT scans. The localization results of each organ were evaluated quantitatively by comparing with the corresponding true locations obtained from the target organs (labeled manually by human operators). The experimental results for the 559 test CT scans showed the success rates of these organ localizations to be distributed from 99% to 87%. The errors of the detected organ-center positions (except for the liver) in the successful CT cases were distributed within 15 voxels, which was considerably smaller than the errors from the atlas-based approach (within about 50 voxels). The potential usefulness of the proposed organ localization was shown in a preliminary investigation of left kidney segmentation in non-contrast CT images.

B. Automated recognition of abdominal muscle region using a shape model in X-ray CT images [13,14,18,19]

The psoas major muscle is a deep muscle located in the inner region, and plays a major role in walking. It is particularly important to analyze this muscle because of the age-related hypokinesia that is associated with changes in this muscle region. Our aim is to provide an automatic tool to radiologists and orthopedic surgeons that can assist them in improving the quality of life of an aging population.

We proposed a method for generating a shape model for the psoas major muscle. We also proposed a fully automated scheme for segmenting the psoas major muscle in torso X-ray CT images using the shape model.

The shape model describes the muscle outer shape and has two parameters: an outer shape parameter and a fitting parameter. The outer shape parameter is determined by approximating the outer shape of the psoas major muscle region in the training stage. In the recognition process, the fitting parameter, that is, the residual parameter of the shape model is first determined to be suitable for a test case. Next, the initial mask region, which is generated from this shape model, is used as the initial region of the muscle. Finally, the psoas major muscle is recognized using the initial mask.

To evaluate the method's performance, we applied it to CT images for the construction of the shape models, using 20 cases as training samples and 80 cases for testing. The

accuracy of this method was quantitatively evaluated by comparing the extracted muscle regions with regions identified manually by an expert radiologist. The experimental results of the segmentation of the psoas major muscle showed a mean Jaccard similarity coefficient (JSC) of 72.3%.

We confirmed that the proposed method can be used for the analysis of cross-sectional area (CSA) and muscular thickness in a transverse section, and thus offers radiologists an alternative to manual measurement, which could save time and improve the reproducibility of segmentation.

C. Automated analysis of standard uptake value for torso FDG-PET images [12,20,21,22]

The purpose of this study was to develop an automated method for the calculation of the z-score of SUV for the torso region on FDG-PET scans. The 3D distributions for the mean and standard deviation (SD) values of SUV were stored in each volume to score the SUV in the corresponding pixel position within unknown scans. The modeling method is based on the statistical parametric mapping (SPM) approach using the Euler characteristic and resel (resolution element) correction techniques. We employed 193 normal cases to assemble the normal metabolism distribution of FDG. The physique were registered each other in a rectangular parallelepiped shape using an affine transformation and the thin-plate-spline (TPS) technique. The regions of the three organs were determined using a semi-automated procedure. Seventy-three abnormal spots were used to estimate the effectiveness of the scoring methods. As a result, the z-score images correctly indicated that the z-scores for normal cases were between 0 and ± 2 SD. Most of the z-scores of abnormal spots associated with cancer were larger than the upper of the SUV interval of normal organs.

D. Computer-based vertebral body geometry analysis [23-27]

It has been estimated that osteoporosis affects more than 200 million individuals worldwide, and therefore, it is an important public health problem. Bone quality is used to determine the risk of osteoporotic vertebral fractures as well as bone mineral density (BMD). In order to gain a better understanding of bone quality, considerable attention has been paid to vertebral geometry in anatomy. The objective of this study was to design a computer-assisted scheme for the quantification of vertebral body geometry on thin-section CT body scans, and to carry out a population-based analysis of this geometry.

The process flow of vertebral body geometry analysis involves the following steps: (i) the localization of individual vertebral bodies using a template-matching technique, (ii) the quantification of the vertebral body geometry, and (iii) the analysis of the correlation between vertebral body dimensions such as trabecular volumetric bone mineral density (vBMD), width, depth, and cross-sectional area (CSA). Simple contour structures built using only three sections (axial, coronal, and sagittal) were used as the reference patterns in the template-matching process.

In the experiment, the quantitative results from our scheme in most CT cases were regarded to be appropriate

according to the subjective assessment of an anatomy expert. Therefore, our scheme was adopted to analyze the vertebral body geometry of first lumbar vertebra by using a database of CT scans of 475 Japanese subjects. The findings of this study indicated that the vertebral body geometry (width, depth, and CSA) was inversely correlated with trabecular vBMD. This may be explained by the compensatory periosteal growth of vertebrae with lower BMD and hence lower bone strength.

E. Construction of an elastic liver model for quantitative assessment of cirrhosis [8,28,29,30]

An elastic liver model is constructed for the automatic assessment of the stiffness of the liver by calculating the non-rigid deformation on MR tagging images, which show the movements of the human body during the breathing cycle by attaching tags on different organ and tissue regions. Our research work analyzed the deformation patterns of the tags inside the liver region and calculated the stiffness of the liver tissue from the MR images.

Our method was based on the fact that the stiffness of the liver region should be related to the distortion of the tags on MR images. We developed two major processing procedures to analyze the tag distortions: (i) quantification of the non-rigid deformation of the liver region by calculating the bending energy of TPS in a spatial domain, and (ii) calculation of the blur ratio of tags based on the differentiation of the power spectral values by using Fast Fourier Transform (FFT) in the frequency domain. In the final stage, the results of these two procedures were combined to estimate the liver stiffness.

The proposed method was applied to a total of 34 cases consisting of 17 normal and 17 abnormal (chronic hepatitis, cirrhosis) livers. The normal and abnormal livers were identified on the basis of the estimated stiffness. The abnormal liver cases were all identified, and there was one false positive identification (one normal liver case was incorrectly classified as abnormal). This result demonstrated the potential usefulness of the proposed method, and we can expect our method of non-invasive assessment of liver fibrosis to replace traditional liver biopsy. This technique will be integrated into a liver CAD system to support the diagnosis of liver cirrhosis.

IV. CONCLUSION

We have described our work on model construction applications for CT, PET, and MR imaging. According to our research plan in 2010, we proposed model-based approaches for localizing the inner organs on CT images, segmenting the abdominal psoas major muscle regions on CT images, demonstrating the normal SUV values on PET images, showing the BMD values of the vertebrae on CT images, and measuring the stiffness of the liver regions on MR images for the diagnosis of liver cirrhosis. All of these studies showed the usefulness and validity of our model constructions.

In the future, we will continue to collaborate with the other groups in this research project to accomplish anatomical model definition, construction, and application.

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REFERENCES

- [1] K. Doi, "Computer-aided diagnosis in medical imaging. Historical review, current status and future potential," *Computerized Medical Imaging and Graphics*, vol. 31, pp. 198–211, Mar. 2007.
- [2] H. Kobatake, "Future CAD in multi-dimensional medical images - Project on multi-organ, multi-disease CAD system," *Computerized Medical Imaging and Graphics*, vol. 31, pp. 258–266, Mar. 2007.
- [3] X. Zhou, T. Hara, H. Fujita, R. Yokoyama, T. Kiryu, M. Kanematsu, and H. Hoshi, "Preliminary study for automated recognition of anatomical structure from torso CT images," *Proc. of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference*, Shanghai, China, paper#340, 2005.
- [4] X. Zhou, T. Hayashi, T. Hara, H. Fujita, R. Yokoyama, T. Kiryu, and H. Hoshi, "Automatic segmentation and recognition of anatomical lung structures from high-resolution chest CT images," *Computerized Medical Imaging and Graphics*, vol. 30, pp. 299–313, Jul. 2006.
- [5] X. Zhou, T. Kitagawa, T. Hara, H. Fujita, X. Zhang, R. Yokoyama, H. Kondo, M. Kanematsu and H. Hoshi, "Constructing a probabilistic model for automated liver region segmentation using non-contrast X-ray torso CT images," *Proc. of 9th International Conference for Medical Image Computing and Computer-Assisted Intervention - MICCAI 2006, Part II*, vol. 4191, pp. 856–863, Springer Berlin/Heidelberg, 2006.
- [6] X. Zhou, H. Ninomiya, T. Hara, H. Fujita, R. Yokoyama, H. Chen, T. Kiryu, and H. Hoshi, "Automated estimation of the upper surface of the diaphragm in 3-D CT images," *IEEE Transactions on Biomedical Engineering*, vol. 55, pp. 351–353, Jan. 2008.
- [7] X. Zhou, M. Han, T. Hara, H. Fujita, K. Sugisaki, H. Chen, G. Lee, R. Yokoyama, M. Kanematsu, and H. Hoshi, "Automated segmentation of mammary gland regions in non-contrast X-ray CT images," *Computerized Medical Imaging and Graphics*, vol. 32, pp. 699–709, Dec. 2008.
- [8] H. Watanabe, M. Kanematsu, H. Kondo, S. Goshima, T. Kitagawa, and H. Fujita, "MR elastography of the liver with cine-tagging and physical bending energy analysis using 3T MRI: Phantom study and preliminary clinical application," *94th Scientific Assembly and Annual Meeting of the Radiological Society of North America, Abstract in the RSNA2008 Program*, p. 828, 2008.
- [9] X. Zhou, T. Hayashi, H. Chen, T. Hara, R. Yokoyama, M. Kanematsu, H. Hoshi, and H. Fujita, "Automated measurement of bone-mineral-density (BMD) values of vertebral bones based on X-ray torso CT images," *Proc. of the 31st Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 3573–3576, 2009.
- [10] P. Dalal, B. C. Munsell, S. Wang, J. Tang, K. Oliver, H. Ninomiya, X. Zhou, and H. Fujita, "A fast 3D correspondence method for statistical shape modeling," *Proc. of IEEE Conference on Computer Vision and Pattern Recognition (CVPR) 2007*, pp. 1–8, 2007.
- [11] P. Dalal, L. Ju, M. McLaughlin, X. Zhou, H. Fujita, and S. Wang, "3D open-surface shape correspondence for statistical shape modeling: Identifying topologically consistent landmarks," *Proc. of 2009 IEEE 12th International Conference on Computer Vision (ICCV)*, pp. 1857–1864, 2009.
- [12] T. Hara, S. Ito, T. Katafuchi, D. Fukuoka, H. Fujita, K. Doi, and X. Zhou, "Quantitative analysis of FDG-PET scans by use of a statistical model for normal cases," *Proc. of RSNA2009*, CODE: SST14-05, p. 694, 2009.
- [13] N. Kamiya, X. Zhou, H. Chen, T. Hara, H. Hoshi, R. Yokoyama, M. Kanematsu, and H. Fujita, "Automated recognition of the psoas major muscles on X-ray CT images," *Proc. of the 31st Annual International*

Conference of the IEEE Engineering in Medicine and Biology Society, pp. 3557–3560, 2009.

- [14] N. Kamiya, X. Zhou, H. Chen, T. Hara, H. Fujita, H. Hoshi, R. Yokoyama, and M. Kanematsu, "Automated recognition of structure of abdominal skeletal muscles from X-ray CT images," *International Journal of Computer Assisted Radiology and Surgery*, vol. 4, Suppl. 1, pp. 324–325, June 2009.
- LIST OF ACCEPTED AND PUBLISHED PAPPERS SINCE 1ST APRIL 2010
- [15] H. Fujita, X. Zhang, S. Kido, T. Hara, X. Zhou, Y. Hatanaka, and R. Xu, "An introduction and survey of computer-aided detection/diagnosis," *Proc. of 2010 International Conference on Future Computer, Control and Communication (FCCC 2010) - International Forum on Computer Science-Technology and Applications (IFCSTA 2010)* -, vol. 2, pp. 200–205, 2010.
- [16] X. Zhou and H. Fujita, "Automatic organ localization on X-ray CT images by using ensemble learning techniques," in *Machine Learning in Computer-aided Diagnosis: Medical Imaging Intelligence and Analysis*, ed. by K. Suzuki, in press, IGI Global, USA, 2011.
- [17] X. Zhou, S. Wang, H. Chen, X. Zhang, T. Hara, R. Yokoyama, M. Kanematsu, H. Hoshi and H. Fujita, "Rapid organ localization in 3D torso CT images based on ensemble learning," *Proc. of 2010 International Conference on Future Computer, Control and Communication (FCCC 2010) - International Forum on Computer Science-Technology and Applications (IFCSTA 2010)* -, vol. 2, pp.312–315, 2010.
- [18] N. Kamiya, X. Zhou, H. Chen, T. Hara, H. Hoshi, R. Yokoyama, M. Kanematsu, H. Hoshi, and H. Fujita, "A model based method for recognizing psoas major musclessin torso CT images," in *Medical Imaging 2010: Computer-Aided Diagnosis*, ed. by N. Karssemeijer, R. M. Summers, Proc. of SPIE, vol. 7624 (SPIE, Bellingham, WA 2010), 76241X, 2010.
- [19] N. Kamiya, X. Zhou, H. Chen, C. Muramatsu, T. Hara, R. Yokoyama, M. Kanematsu, H. Hoshi, and H. Fujita, "Automatic segmentation of psoas major muscle using outer shape model," *Proc. of International Forum on Medical Imaging in Asia*, pp. 404–405, 2011.
- [20] T. Hara, T. Katafuchi, T. Kobayashi, X. Zhou, S. Itoh, and H. Fujita, "Automated analysis of standard uptake value for torso FDG-PET images," *Proc. of 2010 International Conference on Future Computer, Control and Communication (FCCC 2010) - International Forum on Computer Science-Technology and Applications (IFCSTA 2010)* -, vol. 2, pp. 277–279, 2010.
- [21] T. Asai, T. Suzuki, T. Hara, T. Kobayashi, X. Zhou, S. Ito, T. Katafuchi and H. Fujita, "Automatic detection and temporal comparison methods for lesions on torso FDG-PET scans," *IEICE Technical Report*, vol. 110, MI2010-46, pp. 51–56, in Japanese, July 2010.
- [22] T. Kobayashi, A. Wakahara, T. Hara, T. Katafuchi, X. Zhou and H. Fujita, "Depth measurement of accumulation position in stereoscopic scintigraphy," *IEICE Technical Report*, vol. 110, MI2010-78, pp. 67–70, in Japanese, Nov. 2010.
- [23] T. Hayashi, X. Zhou, H. Chen, T. Hara, K. Miyamoto, T. Kobayashi, R. Yokoyama, M. Kanematsu, H. Hoshi, and H. Fujita, "Automated extraction method for the center line of spinal canal and its application to the spinal curvature quantification in torso X-ray CT images," in *Medical Imaging 2010: Image Processing*, ed. by B. M. Dawant, D. R. Haynor, Proc. of SPIE, vol. 7623 (SPIE, Bellingham, WA 2010), 76233F, 2010.
- [24] T. Hayashi, H. Chen, K. Miyamoto, X. Zhou, T. Hara, R. Yokoyama, M. Kanematsu, H. Hoshi, and H. Fujita, "A computerized scheme for localization of vertebral bodies on body CT scans," in *Medical Imaging 2011: Image Processing*, ed. by B. M. Dawant, D. R. Haynor, Proc. of SPIE, vol. 7962, in press, 2011.
- [25] T. Hayashi, H. Chen, K. Miyamoto, X. Zhou, T. Hara, R. Yokoyama, M. Kanematsu, H. Hoshi, and H. Fujita, "A decision support scheme for vertebral geometry on body CT scans," in *Medical Imaging 2011: Image Processing*, ed. by B. M. Dawant, D. R. Haynor, Proc. of SPIE, vol. 7962, in press, 2011.
- [26] T. Hayashi, H. Chen, Y. Tajima, K. Miyamoto, X. Zhou, T. Hara, R. Yokoyama, M. Kanematsu, H. Hoshi, and H. Fujita, "Correlation between vertebral body geometry and trabecular volumetric bone mineral density (vBMD) using X-ray CT images," ECCEO11-IOF, in press, 2011.
- [27] T. Hayashi, H. Chen, Y. Tajima, K. Miyamoto, X. Zhou, T. Hara, R. Yokoyama, M. Kanematsu, H. Hoshi, and H. Fujita, "Investigation of vertebral body dimensions on X-ray CT images," *The 31st Annual Meeting of the Japanese Society for Bone Morphometry*, in Japanese, in submission, 2011.
- [28] H. Watanabe, M. Kanematsu, T. Kitagawa, Y. Suzuki, H. Kondo, S. Goshima, K. Kajita, K. T. Bae, Y. Hirose, S. Miotani, X. Zhou, and H. Fujita, "MR elastography of the liver at 3 T with cine-tagging and bending energy analysis: Preliminary results," *European Radiology*, vol. 20, pp. 2381–2389, Oct. 2010.
- [29] X. Zhang, X. Zhou, T. Hara, R. Yokoyama, M. Kanematsu, T. Qin, and H. Fujita, "Computer-aided detection and diagnosis on hepatic MR and CT images," *Proc. of 2010 International Conference on Furure Computer, Control and Communication (FCCC 2010) - International Forum on Computer Science-Technology and Applications (IFCSTA 2010)* -, vol. 2, pp. 323–326, 2010.
- [30] S. Miotani, X. Zhang, T. Kitagawa, X. Zhou, T. Hara, R. Yokoyama, H. Watanabe, M. Kanematsu, and H. Fujita, "Automatic measurement of elasticity of liver region using MR tagging image," *Proc. of International Forum on Medical Imaging in Asia*, pp. 316–319, 2011.