http://dx.doi.org/10.14400/JDC.2014.12.3.367

A Study on the Usefulness of 3D Imaging in Micro-CT for Observing the Microstructure of Mice

Sang-Ho Lee[1], Jong-Seok Lee[2], Cheong-Hwan Lim[3], Hong-Ryang Jung[3], Kyu-Yun Chai[4], Beom-Hee Han[1], Sang-Hyun Han[1], Dong-Hee Hong[5], Tae-Jong Han[6], Sung-Hoon Park[7], Eun-Hee Mo[7], Hong-Young Jun[8]

Dept. of Radiological Science, Seonam University[1],
Dept. of Radiological Wonkwang Health Science University[2],
Dept. of Radiological Science Hanseo University[3],
Divion of Bio-Nano Chemistry Wonkwang University[4],
Dept. of Radiological Science, Far east University[5], Dept. of Radiological Science, Jeonju University[6],
Dept. of Radiology Wonkwang University Hospital[7], Dept. of Medicine Wonkwang University[8]

흰쥐 미세구조 관찰을 위한 Micro-CT 3D 영상의 유용성에 관한 연구

이상호[1]. 이종석[2]. 임청환[3]. 정홍량[3]. 채규윤[4]. 한범휘[1]. 한상현[1]. 홍동희[5]. 한태종[6]. 박성훈[7], 모은희[7], 전홍영[8]

서남대학교 방사선학과[1], 원광보건대학교 방사선과[2], 한서대학교 방사선학과[3], 원광대학교 바이오나노화학부[4], 극동대학교 방사선학과[5], 전주대학교 방사선학과[6], 원광대학교병원 영상의학과[7], 원광대학교 의학과[8]

요 약 본 연구는 실시간 동적영상(Real-time dynamic image)을 획득할 수 있는 고해상도 엑스선 영상장치인 마이크로 CT 을 이용하여 흰쥐의 미세 혈관구조를 관찰함은 물론 국내 원광 방사선영상 과학연구 센터에서 개발한 마이크로 CT 에 대한 유용성을 알아보고자 한다. 흰쥐 몸 전체의 2D 영상을 얻은 후 MIP(maximum intensity projection), VRT(volume rendering technique)기법을 이용하여 혈관구조의 조영된 3D 영상을 얻을 수 있었고 이 3D 혈관 영상을 머리, 복부, 심장과 몸 전체의 혈관시스템으로 각각 분류하였다.

주제어 : 마이크로 CT | 미세구조 | 3D영상

Abstract In this thesis we observe microvascular structure in mice by using micro-computed tomography (CT), which is high-resolution X-ray imaging equipment that can acquire Real-time dynamic image, and it aims to investigate the usefulness of micro-CT developed by Institute for Radiological Imaging Science Wonkwang University School of Medicine.

After acquiring the systemic images of rats, contrast-enhanced 3D images of vascular structures could be acquired by using Maximum Intensity Projection (MIP) and Volume Rending Technique (VRT), This was divided into each vascular system of head, abdomen and heart and systemic vascular system.

Key Words : Micro CT | microvasculature | 3D image

Received 11 February 2014, Revised 12 March 2014
Accepted 20 March 2014
Corresponding Author: Cheong-Hwan Lim(Dept. of Health Care, Hanseo University)
Email: LCH116@hanseo.ac.kr

ISSN: 1738-1916

1. Introduction

Optical techniques such as those for imaging and computer graphics by X-ray imaging equipment have been developing[1], as has the equipment used with these imaging techniques, including MRI, CT, US, PET, and optical imaging. Multi-Detector row CT (MDCT) has developed quickly since spiral CT was developed in the 1990s, and currently, there are 256-channel MDCTs on the market. These MCDTs have a spatial resolution of 1-0.23mm. The resolution and scan timeof the MDCT have been improved, and there is not much difference in the imaging systems used for small animals. However, its resolution is much less than that of micro-CT, which can be an issue since small animals are much smaller than the human body[2].

High-resolution micro-CT can be used to observe the progress and elapsed time of a disease without sacrificing small animals using non-invasive methods by imaging. This technology has played a very important role in biotech research since Alexander Sasov published articles on X-ray micro-CT in Russia in 1982, and since the first SKYSCAN1072 device was introduced in 1997[1].

Micro X-ray CT equipment can produce images with much higher resolution than other medical imaging systems. Micro X-ray CT systems can use X-ray-generating equipment using a light source with size of several μm or less. This technology is used explore the structure and changes of the structure of biological cells in a non-invasive way, using a hypersensitive detector due to the relatively low strength of the X-ray light source. Specific proteins can also be imaged using an immuno-chemical technique, and real-time dynamic images (R) can be obtained for use in the development of in-vivo diagnosis and treatment techniques.[2] Until now, methods of scanning small animals with high resolution have not been common, so methods have been used that involve sacrificing and dissecting a large number of animals, or taking out and analyzing their organs and tissues and then processing the results statistically[3]. In contrast, micro-CT provides a method of examining the biological changes in small animals over their lifetime without sacrificing them. Recently, with the developments of computer hardware and software, images with high spatial resolution can be obtained even in small specimens using micro-CT. This technique has gradually been regarded as an important imaging test method for animal experiments.[4-5] Compared to the images obtained in commonly used thin-slice MDCT, the images obtained from micro-CT have very high resolution, so they are assumed to be more accurate for discovering microscopic structures and lesions. However, the imaging of micro-vascular morphological structures of small animals is still lacking. In particular, due to low resolution, it is very difficult to view biological changes over time, and to visualize the structure of the blood vessels in the head, the shape of the heart, and the entire anatomical micro-vascular systems of a white mouse in vivo.

This study attempts to provide basic figures that can be applied to clinical images by observing the micro-vascular structures of the whole body of a mouse. Images of the micro-components of mice were obtained through various imaging acquisition techniques with a micro-CT imaging system developed at the Wonkwang University Institute for Radiological Imaging Science.

2. Subjects and methods of experiment

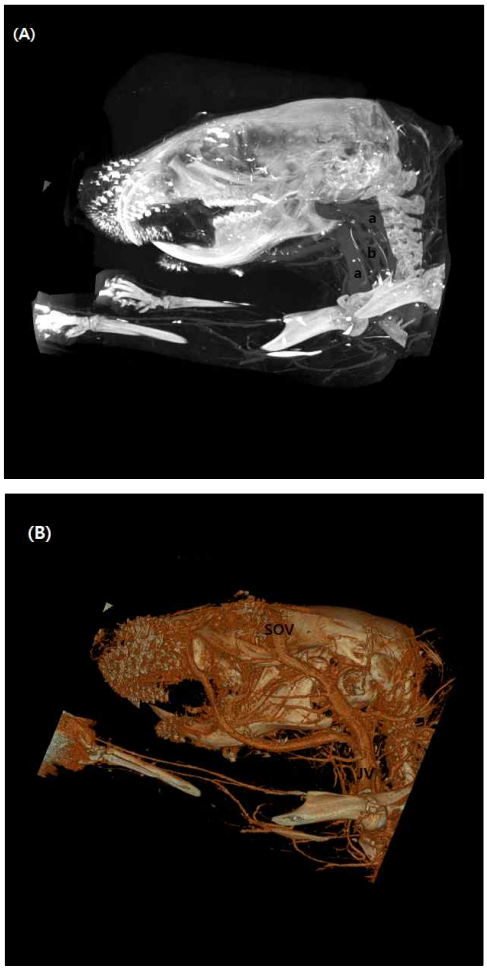
The subjects were two 7 to 12-week-old BALB/C mice with a weight of 20-25 g. To anesthetize these mice, 4% isoflurance was infused with oxygen in a chamber. According to another research report, there was some differences in the viscosity of gelatin, so a

mixture of 40% BaSO4 by volume and 5% gelatin by weight was produced using 4 g of barium sulfate (BaSO4), 0.5 g of gelatin, and 10㎖ of distilled water. However, this study used Solotop Suspension140 contrast medium mixed with 140 g of barium sulfate (BaSO4) per 100㎖with distilled water at a mixture ratio of 50:50. After infusing the mixed Solotop contrast medium into the white mice's tail veins at 0.01 ml per 1 g of body weight, CT scans were performed. Images were obtained 6 minutes after the infusion of the contrast medium, and each of the experiments was repeated five times

3. Result and Discussion

2D cross-section data were obtained five times with approximately 6 minutes of scanning to obtain images of organs and the micro-vascular structures of the head, heart, and whole body using micro-CT. Since it is difficult to evaluate 2D sectional data due to visual obstructions, all 2D data were transmitted to a workstation. As a result of applying Maximum Intensity Projection (MIP) and Volume Rendering Technique (VRT), contrasted 3D images could be obtained in vivo. The best of 5 images are shown in Figures 1 through 4, which showed reproducibility.

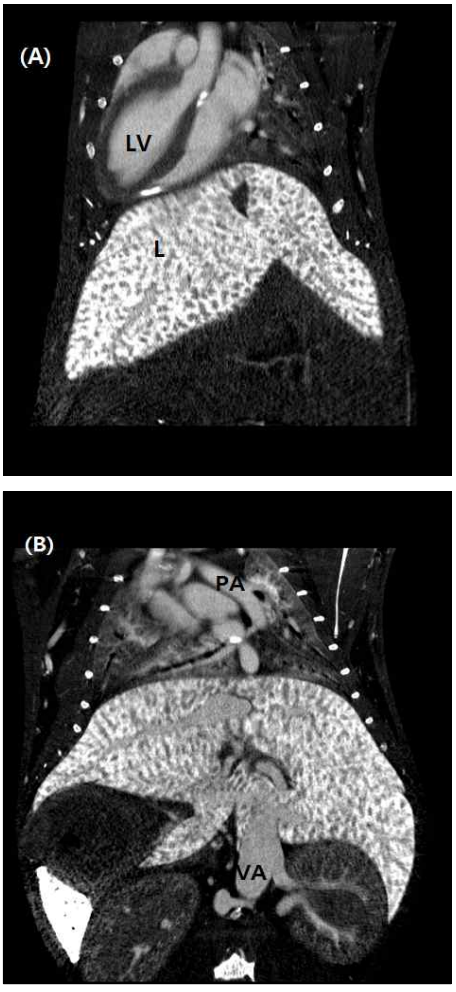
Figure 1(A)shows images of large blood vessels from the heart toward the cerebrum observed on the sagittal plane after virtually cutting the head to observe the shape of the head and the blood vessel structure. The major blood vessel structure, external jugular veins (a), and extra-cranial arteries (b) in the blood system of the cerebrum could be observed by the MIP technique. As shown in Figure 1B, clear images of the external jugular vein (JV) and the SupraOrbital Vein (SOV) could be obtained.



[Fig. 1] Sagittal Maximum intensity projections (MIP) A and 3D reconstruction B showing murine (BALBc) cerebral vessels clearly stand out from the skeleton (white) in this enhanced micro-CT image of a normal living mouse. (A) The anatomy of the external jugular veins (a) and extracranial arteries (b). (B) External jugular vein (JV) and supra-orbital vein (SOV) as determined by in vivovCTA in a C57BL/6 mouse.

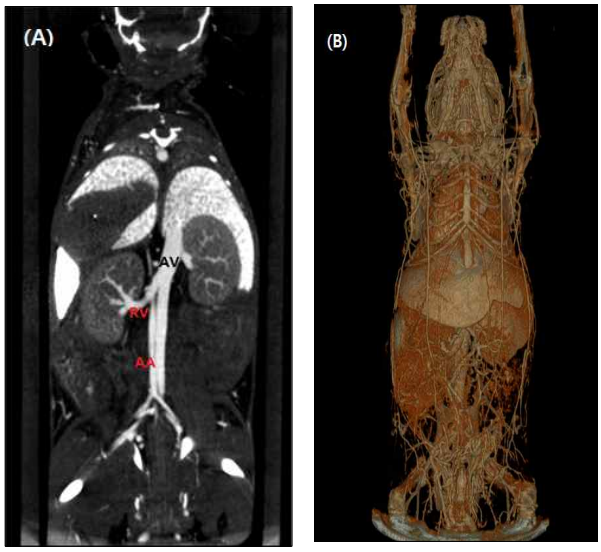
Figure 2(A) shows a 3D image expressing the liver (L) and the left ventricle (LV) in thefour-way sagittal plane of the heart and the abdomen. In the contrast image, up to 4 normally contrasted chambers could be observed. Figure 2(B) shows the coronal plane of the heart and the abdomen, in which the heart structure and pulmonary arteries (PA) could be observed. A

notable overview of the major blood vessels of each of the organs could be obtained, and the smallest blood vessels such as those of the kidney and the glomerulus could be observed.



[Fig. 2] The isotropic resolution in micro-CT allows for re-slicing along any arbitrary plane without loss of resolution. (A) The oblique sagittal plane demonstrates the left ventricle (LV) and liver (L). (B) A number of anatomical features are indicated, including pulmonary arteries (PA) and the abdominal vein (AV).

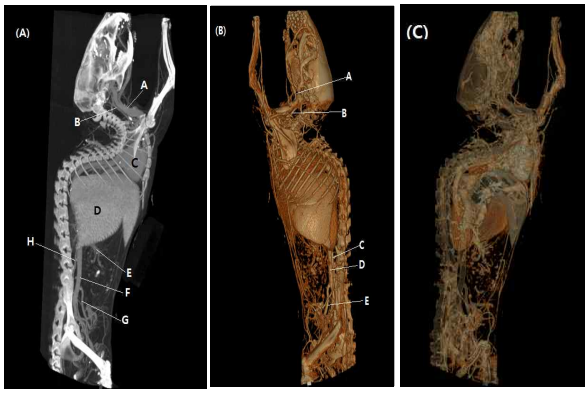
Figure 3(A)shows the coronal plane of the abdomen, clearly expressing the abdominal vein (VC), renal vein (RV), and abdominal artery (AA). The micro-vascular scan and kidney shape are also observed. The 3D VRT image in Figure 3(B) visualizes the small blood vessels of the 100μm epidermis, and expresses more three-dimensional and quantitative imaging.



[Fig. 3] Reconstructed coronal cross-sectional images (A) and 3D reconstruction (B) showing that the murine (BALBc) vascular system clearly stands out from the skeleton (white) in this enhanced micro-CT image of a normal living mouse. (A) The coronal plane demonstrates the abdominal vein (AV), renal vein (RV), and abdominal artery (AA). (B) Surface blood vessel as determined by in vivovCTA in a C57BL/6 mouse.

Figure 4(A)shows an image of the sagittal plane including the head, throat, lungs, and abdomen, which expressed a better image than the blood vessel structure in Figure 3 with the MIP technique. The external jugular veins (A), extra-cranial arteries (B), heart (C), liver (D), renal artery (E), abdominal artery (F) and iliac artery (G) are were well expressed, and other micro-vessels could be visualized. Figure 4(B) is a VRT image, which could visualize more three-dimensional, factual, and quantitative information bygiving the different areas of the parts different transmittance and color. Figure 4(C)shows the blood vessels of the whole body in more detail with imaging

that removed bones or organs, but not blood vessels.



[Fig. 4] Reconstructed sagittal crosssection images A, B and 3D reconstruction C showing of murine (BALBc) vascular system clearly stand out from the skeleton (white) in this enhanced micro-CT image of a normal living mouse. (A); the sagittal plane demonstrates the external Jugular Veins (A), common carotid artery (B), heart (C), liver (D), renal artery (E), Abdominal Artery (F), iliac artery (G). (B); number of anatomical features are indicated including Jugular Veins (A), common carotid artery (B), Abdominal Artery (D), iliac artery (E).

Rodents like mice are used in various ways in basic experiments in many academic fields, such as disease, pathologic study, and micro-structural morphology, but there is almost no anatomical imaging information about them.[6] The blood vessel structure of the whole body of a white mouse, including the head, is composed of complex and subtle forms similar to human blood vessel structure, and its size is 300 μm or less. As such, it is very difficult to visualize the structure. New attempts at imaging techniques to obtain higher resolution will historically be evaluated as a significant achievement in many scientific areas, including life science.

Previously, to visualize the micro-vascular structure of a small animal, each part was removed and a biopsy specimen without pre-treatment was used, or the parts were observed through an optical microscope after infusing a contrast medium into a blood vessel. However, optical images do not have good transmission power, so it is difficult to visualize deep parts in humans, and there is much signal scattering, so it is inadequate to make and quantify tomography.[7] In addition, a system that can obtain high resolution such as electron microscopy and atomic force microscopy needs a physical or chemical pre-treatment process for a biopsy specimen to be observed, so the specimen cannot be observed in a living state, and it is difficult to observe thick samples. In order to compensate for these shortcomings, using micro osteotomy, a cross section of each part is produced for observation. Yet, a large number of single slices should be produced, and the complete organ tissue is damaged in the process of producing a slice, making some research impossible. Thus, this technique is insufficient for understanding the micro-vascular structure of an entire area. [8]

There has been much research to analyze the structure and shape of blood vessels, but focus has mostly been centered on applications to human bodies, with limitations in analyzing micro-vessels. There is still no system to visualize the micro-vessels of the whole body. Using mice models, which are morphologically and functionally most similar to humans among experimental animals, Kwon-ha Yoon et al.[9]studied the changes and features of the micro-structure of a variety of animal models. It was reported that in a cirrhosis model, 3D observation of the micro-structure of the portal vein through micro-CT regarding the impacts ofangiopoietin on the liver blood flow in the hepatic portal vein provided information beyond the pathological structure. Recently, in osteoporosis research and the study of arthritis, quantitative information about bone and cartilage were provided, and functional information about the volume, surface area, thickness, continuity, and intensity of trabecular bone could not be determined by other imaging equipment. Erik L. Ritman et al[10]. reported

that the 3D quantitative anatomical characteristics imaging in the blood vessel of the lungs and bronchi could be visualized, so new information about the temporal transit of the pulmonary blood flow along the branch of dynamic movements and anatomical structure of the Pulmonary Arteries (PA) could be provided. Seung-hyun You et al. observed the micro-vascular structure of a complete kidney by micro-CT, and obtained three-dimensional imaging information. Garcia-Sanz et al.[11] reported the results of division of the kidney according to the micro-vascular distribution using micro-CT in white mice into four regions.

This study divided the head, heart, and abdomen through the visualization of the blood vessel structure of the whole body to visualize the micro-vascular structure of each part. In addition, the imaging directions of each part on the sagittal plane and the coronal plane are shown, so that quantified information like a more accurate size of the blood vessels could be visualized. Until now, most researchers have obtained images using damaged organ tissue, while this study could obtain images by the contrast enhancement of living white mice. Because it was difficult to evaluate 2D sectional data of each part since they were not visible, all 2D data were transmitted to a workstation. As a result of the use of MIP and VRP, contrasted 3D images of the organs and micro-vascular structure of the head, heart, and whole body could be obtained.

By using micro-CT, much imaging information about small animals like rodents can be obtained. but problems that have not yet been solved remain in various research processes and experiments:

1. Despite micro-CT having many advantages, its scanning parts are narrow, so the scanning is very limited. The equipment is also expensive, which limits its use.
2. The current technique of micro-CT imaging provides data for many useful experiments. However, in in vivoscanning, there challenges in terms of scan speed, irradiation research, and soft tissue contrasting difference, so the technique is still lacking for expressing the micro-vascular imaging of the whole body. Nevertheless, this did not greatly affect the present study.
3. SSD imaging loses information about the actual density of the tissue by the configuration method of the imaging. If partial volume averaging effects are overlapped, the quality of the imaging is noticeably reduced. According to Rubin et al., in neo-artery stenosis patients, MIP imaging showed a highly sensitive and unique level compared to SSD imaging. Also, in stenosis degree evaluation, MIP imaging was more accurate.[12-13] Nevertheless, the analysis of small blood vessels may still make mistakes of overrating or underrating the degree of stenosis.
4. To contrast the micro-vessels of white mouse organs with micro-CT, the particles of the contrast medium should overall be evenly distributed to the entire blood vessel system, and the contrasting should be done while maintaining proper temperature so that the particles of the contrast medium are not weighted by gravity. A heat pad was used to maintain the temperature at 34℃ but there was a limitation in maintaining the particles of the contrast medium appropriately. In the micro-CT image, unlike bones, the blood vessels have very low contrast. The X-ray contrast medium used in most clinics is based on iodine atoms, which is soluble in water, so it is appropriate for clinical radiology, but it cannot be used as a contrast medium for small animals. Thus, the selection of the contrast medium of barium sulfate (BaSO4)used in this study depended on the researcher, so it was difficult to prove its objectivity. However, images that might not be problematic in the results of this research were obtained.

5. Conclusion

This study obtained blood vessel contrast images of the whole body of white mice using the micro-CT developed by the Wonkwang University Institute for Radiological Imaging Science. In addition, the blood vessel systems of the head, abdomen, heart, and whole body were classified. Maximum Intensity Projection (MIP) and Volume Rendering Technique (VRT) were used for the 2D sectional data of each part to obtain contrasted 3D images of the blood vessel structures. The conclusions are as follows:

1. To observe the shape of the head and the blood vessel structure of a mouse, the large blood vessels from the heart toward the cerebrum were visualized on the sagittal plane. The major blood vessel structure, external jugular veins, and extra-cranial arteries in the blood system of the cerebrum could be observed by the MIP technique, and clear images from the external jugular vein and the supraorbital vein could be obtained.
2. The heart and the abdomen were visualized on the four-way sagittal plane. 3D images expressing the liver and the left ventricle were obtained, and in particular, a normally contrasted heart imaging structurecould be observed. Regarding the observation level, contrast images in which up to 4 chambers could be observed were obtained.
3. In The coronal plane of the heart and the abdomen, the abdominal vein), renal vein, and abdominal artery (AA) could be expressed well, through which micro-vessels and the liver, heart, and the kidney shape could be observed. 3D VRT images express three-dimensional and quantitative images, so that micro-vessels with 100 μm epidermis could be observed.
4. In the sagittal plane including the head, throat, lungs, and abdomen, external jugular veins, extra-cranial arteries, the heart, liver, and renal artery, and the abdominal artery and iliac artery could be observed. Othermicro-vessels were expressed in 3D imaging and VRT imaging, so that the realistic and quantitative information could be observed visually.

In a half-way vital histological analysis on small animals of which the internal organs and micro-vessels are too small, once they are sliced, their tissue is damaged, so other examinations cannot be carried out. Accordingly, as the methods of obtaining internal structures or tissue status with a non-invasive method at higher resolution have been developed, research on the observation of the micro-vascular structures of small animals have been carried out, but there has been almost no studies on visualizing the blood vessel structures of the whole body of white mice in vivo.

Through the present study, in vivo 3D images and MIP images of the blood vessel systems of the whole body of white mice could be obtained. However, imaging techniques using micro-CT are still at a very rudimentary stage with critical points. And yet, if much research is continuously carried out, not only the organs and blood vessel structures of small animals but also imaging information with nano-level high resolution can be provided. Through the observations of the forms and functions of the micro-structures of vital phenomena, it is expected that models can be derived for evaluating new drugs and medicine currently used in clinics. The results of these efforts can contribute to improving human welfare.

References

[1] Seong-nae Kim; Understanding in-vivo micro-CT using the experimental animal model. Optoscan.
[2] Paciotti GF, Myer L, Weinreich D; Colloidal gold: anovel nanoparticle vector for tumor directed drug

delivery. Drug Deliv. 2004, 11, 169-183.
[3] Su-yeol Lee & Sang-cheol Lee; Micro-topography for scanning small animals, Physics and Cutting-edge Techniques. 2004, November.
[4] Winter TCIII, Freeny PC, Nghiem HV;Hepatic arterial anatomy in transplantation candidates evaluation with three-dimensional CT arteriography. Radiology. 1995, 195, 363-370.
[5] Takahashi S, Murakami T, Takamura M, Kim T, Hori M, Narumi Y, Nakamura H & Kudo M; Multi-detector row helical CT angiography of hepatic vessels; depiction with dual-arterial phase acquisition during single breath hold. Radiology. 2002, 222, 81-88.
[6] Ki-Yong Nam, Kwon-Ha Yoon; micro-CT System for Small animal imaging.
[7] Tae-jung Eom, Cheol Gang, Biophotonics imaging. Physics and Cutting-edge Techniques. 2007, June pp, 65-69.
[8] Bentley MD, Ortiz MC, Ritman EL & Romero JC; The use of micro-computed tomography to study micro-vasculature in small rodents. Am. J. Physiol Regul Integr Comp. Physiol. 2002, 282, F1267-79.
[9] Gweon-ha Yoon & Gweon-su Cheon; X-ray optics and bio medical imaging. optical technique. 2006, Vol. 12, No. 1.
[10] Erik L. Ritman; Micro-Computed Tomography of the Lungs and Pulmonary-Vascular System. Proc. Am. Thorac. Soc. 2005, Vol 2, pp 477 - 480.
[11] Garcia-Sanz A, Rodriguez-Barbero A, Bentley MD, Ritman EL & Romero JC; Three-dimensional micro-computed tomography of renal vasculature in mice. Hypertension. 1998, 31, 440-4.
[12] Rubin GD, Dake MD & Napel S; Spiral CT of renal artery stenosi technique and resolution compared with conventional CT. AJR. Am. J. Roentgenol. 1994, 162, 561-567.s Comparison of three-dimensional rendering techniques. Radiology. 1994, 190,181-189.
[13] Paranjpe DV & Bergin CJ; Spiral CT of the lungs Optimal

이 상 호(Lee. Sang Ho)

・2009년 8월 : 한서대학교 방사선학과(방사선학석사)
・2012년 3월 : 원광대학교 화학과(이학박사)
・2010년 8월 ~ 현재 : 서남대학교 방사선학과 교수
・관심분야 : 방사선학, 분자영상
・E-Mail : ho8350@hanmail.net

이 종 석(Jong-seok Lee)

・1988년 3월 : 원광대학교 전기전자공학과 (공학박사).
・1983년 3월 ~ 현재 : 원광보건대학교 방사선과 교수
・관심분야 : 방사선 응용 기술학
・E-Mail :jslee@wu.ac.kr

정 홍 량(Jung. Hong Ryang)

・1995년 2월 : 단국대학교 행정대학원 보건행정학과(보건학석사)
・2004년 8월 : 순천향대학교 환경보건학과(보건학박사)
・1999년 3월 ~ 현재 : 한서대학교 방사선학과 교수
・관심분야 : 방사선학, 보건역학
・E-Mail : rjung@hanseo.ac.kr

임 청 환(Lim. Cheong Hwan)

・1997년 8월 : 단국대학교 행정대학원 보건행정학과(보건학석사)
・2005년 2월 : 경원대학교 의료경영학과(보건학박사)
・2001년 3월 ~ 현재 : 한서대학교 방사선학과 교수
・관심분야 : 방사선학, 영상정보학
・E-Mail : LCH116@hanseo.ac.kr

채 규 윤(Kyu-Yun Chai)

・1990년 2월 : 경희대학교 화학과(이학박사)
・1990년 3월 ~ 현재 : 원광대학교 생명나노학부 교수
・관심분야 : 무기화학, 천연화합물, 의약품합성
・E-Mail : geuyoon@wonkwang.ac.kr

한 범 희(Han. Beom Hee)

・2009년 2월 : 한서대학교 방사선학과(방사선학석사)
・2011년 2월 : 전북대학교 방사선과학기술학과(박사수료)
・2010년 3월 ~ 현재 : 서남대학교 방사선학과 교수
・관심분야 : 방사선물리, 방사선방호
・E-Mail :raphael121215@seonam.ac.kr

한 상 현(Han. Sang Hyun)

・2008년 2월 : 건양대학교 보건대학원(보건학석사)
・2012년 3월 : 충북대학교 의용생체공학과(박사과정)
・2011년 3월 ~ 현재 : 서남대학교 방사선학과 교수
・관심분야 : 핵의학, 보건학
・E-Mail : luck2han@hanmail.net

홍 동 희(Hong. Dong Hee)

・2005년 8월 : 한서대학교 방사선학과(방사선학석사)
・2013년 3월 : 한서대학교 보건의료학과(박사과정)
・2011년 9월-2014년 2월 : 서남대학교 방사선학과 교수
・2014년 3월 ~ 현재 : 극동대학교 방사선학과 교수
・관심분야 : 방사선학, 초음파영상
・E-Mail : hansound2@hanmail.net

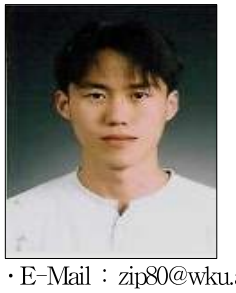
모 은 희(Mo. Eun Hee)

・2009년 8월 : 한서대학교 방사선학과(방사선학석사)
・2013년 8월 : 전북대학교 방사선과학기술학과(이학박사)
・1995년 1월 ~ 현재 : 원광대학교병원 영상의학과
・관심분야 : 방사선치료학, 초음파
・E-Mail : mo0428@hanmail.net

박 성 훈(Park. Seong Hoon)

・2002년 2월 : 원광대학교 의학과(의학석사)
・2008년 3월 ~ 현재 : 원광대학교 의과대학병원 영상의학과 조교수
・2011년 7월 ~ 현재 : 원광대학교 대사성질환연구소장
・관심분야 : 영상의학, 분자영상
・E-Mail : shpark99@wku.ac.kr

전 홍 영(Jun Hong Young)



・2008년 2월 : 원광대학교 화학과(석사)
・2013년 2월 : 원광대학교 의학과(이학박사)
・2013년 3월 ~ 현재 : 원광대학교 Postdoctoral
・관심분야 : 분자영상의학, 생명과학
・E-Mail : zip80@wku.ac.kr

한 태 종(Tae Jong Han)

・1983년 2월 : 고려대학교 물리학과(이학박사)
・1984년 3월 ~ 현재 : 전주대학교 방사선학과 교수
・관심분야 : 분자영상의학, 방사선학
・E-Mail : tjhan@jj.ac.kr