pISSN : 1976-0620, eISSN : 2384-0633
https://doi.org/10.7742/jksr.2019.13.5.713 "J. Korean Soc. Radiol., Vol. 13, No. 5, October 2019"

Fundamental Study of Relative Measurement for Accurate Measurement of Stent Size in Computed Tomography Angiography

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Received: July 23, 2019. Revised: October 01, 2019. Accepted: October 31, 2019

ABSTRACT

The purpose of this study was to propose a new measurement method for accurate measurement of vessel diameter in computed tomography angiography(CTA). CTA test was performed after non-ionic iodine contrast agent was flowed at a constant rate to self-maded perfusion phantom. After obtaining raw data, images were reconstructed with multi-planar reconstruction(MPR) and maximal intensity projection(MIP). Diameters of vascular models were measured for each technique. Relative and conventional measurements were then compared. The mean diameter of the vascular model was closer to the actual measurement when relative measurement was used compared to that when conventional measurement was used both in MPR and MIP. Relative measurements of MPR and MIP were closer to actual measurement than those of conventional measurement (34% VS, 24%, $p<0.05$). The relative measurement method proposed in this study was closer to the actual measurement than the conventional measurement method. However, both test methods were still larger than actual results. Therefore, further study of relative measurement method is needed using this study as basic data.

Keywords: Cerebrovascular disorders, Computed Tomography Angiography, Coronary Stenosis, Diagnostic Imaging, Stents

Ⅰ. INTRODUCTION

Cerebrovascular disease is one of diseases that has the highest morbidity and mortality worldwide.[1] Due to its high mortality rate in elderly patients over 60 years old and poor prognosis, it has huge impact on home and society.[2-3] Cerebrovascular disease can be divided into ischemic and hemorrhagic ones. Ischemic brain disease is more likely to occur in patients with cerebrovascular disease.[4] Ischemic cerebrovascular disease can increase cerebral blood flow through stent implantation as an interventional procedure.[5] Stent implantation may reduce the incidence of postoperative stroke. Carotid stent implantation is reported similar postoperative prognosis of carotid endarterectomy.[6-7] Stent implantation is frequently used for ischemic brain disease because of its low risk of the procedure, high success rate, and effective prevention of recurrence.[8-9] Stent implantation should insert a stent size appropriate to the actual vessel size because if the stent size is too large or too small, wall shear stress (WSS) may increase and result in thrombosis or in-stent restenosis (ISR).[10] Therefore, we used computed tomography angiography (CTA) as

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a test to determine actual measurements of blood vessels. The reason for using CTA is that it is possible to diagnose brain parenchyma and cerebral blood flow according to image reconstruction technique with high inspection speed. In addition, since it is possible to reconstruct three-dimensional images with high sensitivity, information of blood vessels could be obtained without overlapping with surrounding structures.[11] Multi-Planar Reconstruction (MPR) as one of typical methods used for reconstructing CT images can treat surrounding structures even when Hounsfield Unit (HU) difference is small because 2D image is processed as 3D image information.[12-13] In addition, Maximal Intensity Projection (MIP) as a technique that extracts only densest values from images and visualizes them is useful for finding intravascular lesions with contrast agents.[14] However, one study has reported that CTA image is larger than the actual measurement. This means that if the size of the stent is determined by the current CTA image, the prognosis of the stent implantation may be poor.[15] Therefore, it is necessary to propose a method to measure the diameter and length of blood vessels close to the actual measurement through CTA image. Thus, the objective of this study was to propose a measurement method close to the actual measurement of blood vessel diameter by comparing the conventional measurement method and the relative measurement method.

Ⅱ. MATERIAL AND METHODS

1. Phantom Production Process

A self-manufactured phantom used in this study was a cylindrical container made of polyethylene terephthalate with a diameter of 60 mm and a height of 195 mm. In phantom production, the phantom body was passed through the center of both ends with a blood vessel shaped polyethylene tube of a polyethylene resin material. The blood vessel model tube was 2.11 mm in diameter and 26 mm^2 in area. An iron ball with a diameter of 10 mm was attached to the center of the phantom body in order to know its magnification ratio. At both ends of the blood vessel model tube, a pressure line connecting the contrast agent auto injector was connected to the injection section. On the opposite side, a tube was extended to create an outlet to implement a blood vessel model so that fluid could flow. The phantom body was filled with H_2O, a tissue equivalent material, as different results could be obtained depending on X-ray absorption as shown in Fig. 1.

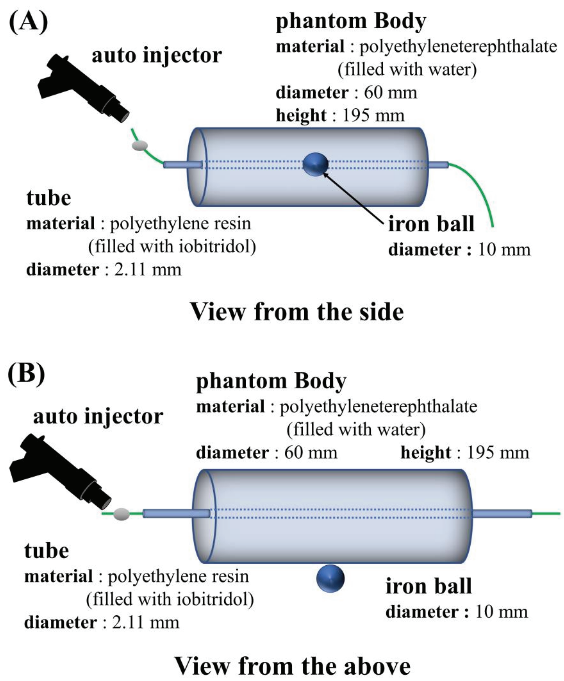


Fig. 1. Perfusion phantom used in this study, view from the side(A), view from above(B). Diameter of the tube was 2.11 mm and the tube extended at both ends to establish an environment in which fluid could flow. To ascertain relative magnification, a 10 mm diameter iron ball was attached to the center of the phantom body side.

2. Experimental Method

The CT scanner used in this study was a 128-channel Dual Source CT (SOMATOM Definition Flash, SIEMENS). Conditions used for the test were as follows: tube voltage, 120 kVp; tube current, 170 mAs; Slice Thickness, 2.0 mm; Gab, 2.0 mm; Matrix, 512×512; Pitch, 0.8; Collimation, 2×1.2×0.6 mm; Rotation Time, 1.0, SAFIRE Strength, 2; Algorithm, Medium; and FOV, 102 mm. After phantom was placed on a table, as shown in Fig. 2, the center of the phantom was aligned with the iso-center of the gantry on the laser center line of the instrument. Fluid was then flowed to the phantom using an auto injector. The fluid was a stock solution of iobitridol (XENETIX 350, Gurbet: iodine content at 350 mg), a non-ionic iodine contrast agent. The fluid was injected at a rate of 3.5 ml/sec.

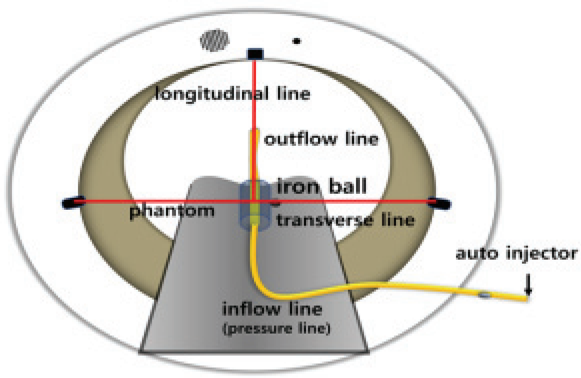


Fig. 2. Experimental materials and equipment used in this study, the isocenter is at the intersection of transverse and longitudinal lasers, whereas a phantom is in the center of a gantry

Flow velocity flowing through the conduit was calculated using the following formula without considering flow resistance of the fluid :

$$flow\,velocity = \frac{quantity\,of\,flow}{conduit\,area} \qquad (1)$$

From formula (1), the area of the conduit was 26 mm^2. Thus, the actual flow velocity through the conduit was 10.01 cm/sec. Using the Syngo Acquisition Workplace provided by SIEMENS, MPR was set to default value (Window Width: 400; Window Level: 40) provided by the equipment manufacturer.

MIP was also set to default value (Window Width: 400; Window Level: 40) provided by the equipment manufacturer. MPR images were measured using the Distance Measurement Program provided by the workstation and diameters of blood vessels and iron balls were measured 30 times in axial, sagittal, and coronal planes. MIP images were measured by using the Distance Measurement Program provided by the workstation and diameters of blood vessels and iron balls were measured 30 times ineach axial, sagittal, and coronal planes. The mean value of each data was obtained by conventional measurement. The diameter of the blood vessel model was then measured using a relative measurement method. The method of obtaining the diameter of the bloodvessel model using the relative measurement method was as follows. We used proportional expression (the ratio between actual measurement of the iron ball's diameter and blood vessel model's diameter) which was the same as the ratio between iron ball's diameter measured by conventional measurement method and blood vessel model's diameter measure by relative measurement method.

$$A : A' = x : B \qquad (2)$$

A was actual diameter of iron ball, A` was measured diameter of iron ball, x was actual diameter of blood vessel model, and B was measure diameter of blood vessel model.

Magnification ratio of blood vessel model's diameter used the following formula:

$$Magnification(M) = \frac{Measured\,diameter}{Actual\,diamenter} \qquad (3)$$

Data were analyzed with independent t-test using SPSS 18.0 (IBM, USA). Statistical significance was considered when p-value was less than 0.05.

Ⅲ. RESULT

As a result of this study, as shown in Table 1, among mean measurements of blood vessel of axial, sagittal and coronal planes, that of sagittal plane was the largest at 4.4 ± 0.17 mm while that of coronal plane was the smallest at 4.1 ± 0.11 mm. The mean value of the iron ball diameter was 11.8 ± 0.09 mm. Regarding relative measurement values, as shown in Fig. 3, axial plane had the largest value (average: 3.9 ± 0.07 mm) while coronal plane had the smallest value (average: 3.6 ± 0.10 mm, $p < 0.05$).

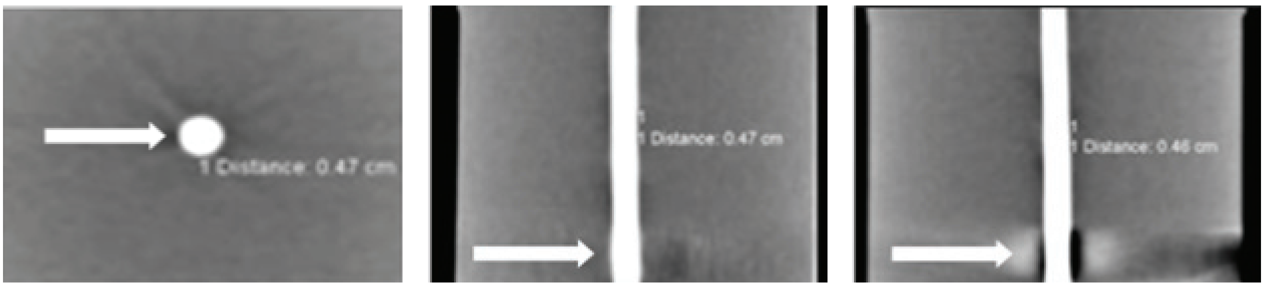
Among conventional measurements of axial, sagittal, and coronal diameters after MIP application, as shown in Table 2, sagittal one was the largest at 4.6 ± 0.02 mm while coronal one was the smallest at 4.2 ± 0.01 mm.

The mean value of iron ball diameter was 11.7 ± 0.12 mm. Among relative measurement values, as shown in Fig. 4, axial one was the largest at 4.0 ± 0.02 mm average while coronal one was the smallest at 3.7 ± 0.01 mm on average ($p < 0.05$).

Table 1. Mean value of perfusion phantom measured by conventional method and relative method in MPR

Orientation	n	MVI [mm]	MVC [mm]	MC [%]	RCV [mm]	MRC [%]	Difference between MC and MRC[%]	p
axial	30	11.3±0.05	4.4±0.09	209	3.9±0.07	185	24	0.000
sagittal	30	11.8±0.09	4.4±0.17	209	3.7±0.02	176	33	0.000
coronal	30	11.3±0.07	4.1±0.11	195	3.6±0.10	171	24	0.000

MVI: Measured value of iron ball, MVC: Measured value of conduit, MC: Magnification of conduit, RCV: Relative correction value, MRC: Magnification of relative correction



(A) (B) (C)

Fig. 3. Perfusion phantom images reconstructed with MPR, axial (a), sagittal (b), coronal (c),The white arrow that artifact occurred under the measured part was result of the beam hardening effect by the iron ball. Experimental measured value was not measured at this part.

Table 2. Mean value of perfusion phantom measured by conventional method and relative method in MIP

Orientation	n	MVI [mm]	MVC [mm]	MC [%]	RCV [mm]	MRC [%]	Difference between MC and MRC[%]	p
axial	30	11,3±0.06	4.5±0.01	214	4.0±0.02	190	24	0.000
sagittal	30	11,7±0.12	4.6±0.02	219	3.9±0.02	185	34	0.000
coronal	30	11,3±0.14	4.2±0.01	200	3.7±0.01	176	24	0.000

MVI: Measured value of iron ball, MVC: Measured value of conduit, MC: Magnification of conduit, RCV: Relative correction value, MRC: Magnification of relative correction

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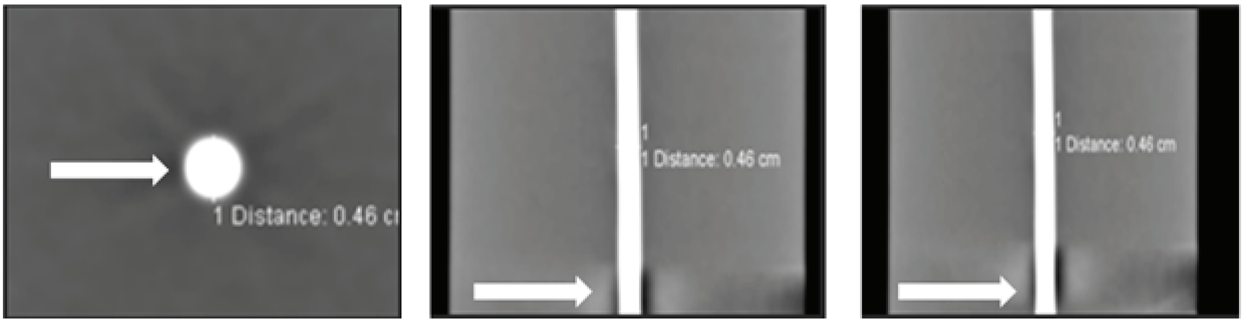

(A) (B) (C)

Fig. 4. Perfusion phantom images reconstructed with MIP, axial (a), sagittal (b), coronal (c), The white arrow that artifact occurred under the measured part was result of the beam hardening effect by the iron ball. Experimental measured value was not measured at this part.

Ⅳ. DISCUSSION

Stent implantation used in treatment of ischemic brain disease may cause thrombosis or ISR due to increased WSS when the size of the stent is too large or too small.[10] Therefore, it is important to know the actual diameter of the blood vessel in stent implantation to determine success or failure of the procedure. The diameter of the blood vessel can be measured through CTA. Precise measurement of blood vessel diameter via CTA is important to determine the prognosis of patients with stent implantation. In this study, we investigated actual reflection of conventional measurement method, pixel-based measurement method, and relative measurement method using actual measurement of reference material.

We made self-manufactured perfusion phantom for this study. The perfusion phantom was 2.11 mm in diameter of blood vessel model tube. It was connected to an auto injector to quantify and calculate the velocity of blood flow using the flow velocity formula. In addition, an iron ball with a diameter of 10 mm was fixed to the side of the perfusion phantom and used as a reference material of the relative measurement method. The parameter used in CTA was fixed. Raw data were obtained and reconstructed by using MRP and MIP technique. The diameter of the iron ball in the reconstructed image was measured 30 times for axial, sagittal, and coronal images. Measured data were recalculated with a relative measurement method proportional to the magnification ration of the iron ball.

As a result, both conventional and relative measurements were larger than the actual measurement of 2.11 mm, similar to findings of many studies. Jung et al. reported that panoramic CT used in dental implant surgery resulted in a 135% enlargement compared to the actual measurement in the application of MPR. Hong et al. reported that image enlargement occurs in the bone, vessel, and tissue in CT when MIP was applied.[16-17] In addition, Yutaka et al. reported that undiluted contrast agent resulted in enlargement of the image in CT angiography. It was caused by blooming artifact due to undiluted contrast agent.[18] Results of this study are consistent with findings of the previous study, indicating that the use of undiluted contrast agent is a promising factor to expand MIP images due to blooming artifact. This means that precise actual measurements cannot be measured with conventional measurement methods. Therefore, when measuring the diameter and length of blood vessel through CT angiography image, a method that can measure it close to the actual measurement is needed. In this study, we investigated the possibility of using a relative measurement method to minimize enlargement which is a problem of existing conventional measurement method. Our results showed that MPR and MIP were increased from 219% to 195% at maximum in the conventional measurement method. In the relative measurement method, they were increased from 190% to 171% at maximum. These results confirmed that the relative measurement method was closer to the actual measurement since it was reduced by up to 34% compared to the conventional measurement method. However, the relative measurement method did not provide data close to the actual measurement. It still showed higher magnification than the actual measurement. It seemed that CT number of the iron ball used as the reference material was higher than that of the contrast agent and that the use of undiluted contrast agent resulted in blooming artifact. Therefore, if we use various reference materials or investigate the appropriate dilution ratio of contrast agent, we can provide a measurement method that is closer to the actual measurement to improve the magnification ratio of CTA test.

Ⅴ. CONCLUSION

Results of this study confirmed that the relative measurement method provided more accurate data than the conventional measurement method in the measurement of blood vessel diameter of CTA. Theoretically, relative measurement can be used as an alternative to the current conventional measurement method since magnification ration of the reference material with known actual measurement is applied to the measured blood vessel value. However, this study suggests that additional studies such as dilution ration of contrast agent and finding a reference material with low CT number are required as a basic study step of the relative measurement method. This study is expected to provide basic data for further study to reflect the actual measurement of blood vessel diameter of CTA.

Acknowledgement

Seung-Young Lee and Joo-Wan Hong equally contributed to this work. They are co-first authors. This paper was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. NRF-2019R1G1A1010922).

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컴퓨터단층 혈관조영술에서 스텐트 사이즈의 정확한 측정을 위한 상대적 측정법의 기초연구

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요 약

본 연구의 목적은 컴퓨터단층 혈관조영술에서 혈관 직경을 정확하게 측정할 수 있는 새로운 측정 방법인 상대적 측정법의 기초연구 자료를 제공하고자 한다. 비이온성 요오드 조영제를 자체 제작한 관류 팬텀에 일정한 속도로 흐르게 한 후 컴퓨터단층 혈관조영술 검사를 시행하였다. 원시 데이터를 얻은 후 다중평면재구성 및 최대강도투사법으로 영상을 재구성하였고 장비 사에서 제공하는 거리측정 장치를 사용하여 팬텀의 직경을 측정하였다. 측정법은 고식적 측정법과 본 연구에서 제안하는 상대적 측정법을 사용하였다. 관류팬텀의 평균 직경은 다중평면재구성기법과 최대강도투사법 모두에서 상대적 측정법이 기존 측정법 보다 실측에 더 가깝게 나타났다(34% VS 24%, $p<0.05$). 하지만 두 가지 측정법 모두 실측보다 여전히 확대된 결과를 나타내고 있음을 확인하였다. 따라서 상대적 측정 방법에 대한 추가 연구가 필요한 실정이며, 이에 본 연구가 기초 자료를 제공할 수 있을 것이라 사료된다.

중심단어: 뇌혈관장애, 컴퓨터단층 혈관조영술, 관상동맥 협착증, 영상 진단, 스텐트

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