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Usefulness of Non-Enhanced 3-Dementional CT with Partial Maximum Intensity Projection for Planning Embolotherapy for Pulmonary Arteriovenous Malformations

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Abstract

Purpose: Computed Tomography (CT) with contrast material is often used for preoperative assessment and planning of embolotherapy in the treatment of Pulmonary Arteriovenous Malformations (PAVMs). However, pulmonary vasculature is well demonstrated in the lung window setting without the need for contrast material; thus, risks of adverse effects of contrast material itself or paradoxical emboli through PAVMs can be avoided. The purpose of this study was to determine the usefulness of non-enhanced 3-Dimentional (3D)-CT angiography for planning of embolotherapy for PAVMs.

Materials and methods: Between February 2004 and October 2011, 20 patients (nine males, 11 females) with 41 PAVMs underwent non-contrast CT using a multi-detector-row CT prior to coil embolotherapy. A high-resolution tailored 3D-CT angiogram was reconstructed on a workstation with partial Maximum Intensity Projection (MIP) in the lung-window to assess the angioarchitecture of the lesions for preoperative planning of embolotherapy. For each lesion, location, number, and diameter of feeding arteries and draining veins were measured. It was determined whether there was any side branch close enough to the sac to anchor the first coil to prevent coil migration. The difference between the diameter of the first coil and the feeding artery was measured. Based on findings, diagnostic pulmonary angiography and coil embolotherapy were performed. The depiction of the side branch of the feeding artery close to sac between preoperative partial MIP 3D-CT images and selective pulmonary angiography was evaluated by using the un-weighted κstatistical analysis.

Results: A total of 49 feeding arteries were embolized. Mean diameter of the feeding arteries and drainage veins were 3.6 mm and 4.6 mm, respectively. Sixteen and eighteen feeding arteries with a side branch to anchor were depicted on CT and angiography, respectively. In the depiction of the side branch of the feeding artery close to sac between preoperative partial MIP images and selective pulmonary angiography, excellent agreement was obtained (κ=0.91).

The mean difference between diameter of the first coil and the feeding artery was 1.5 ± 1.47 mm. All 41 lesions could be identified on angiography, and embolization procedures could be executed as planned based on partial MIP images.

Conclusion: Non-enhanced tailored partial MIP 3D-CT in the lung window appears to be a feasible and useful vascular imaging technique for planning coil embolotherapy of PAVMs.

Introduction

Pulmonary Arteriovenous Malformations (PAVMs) are anomalous arteriovenous communications without intervening capillary beds and consist of a dilated, tortuous feeding artery, an aneurysmal sac, and a drainage vein. Symptoms are mainly caused by right-to-left shunting or rupture and include dyspnea, cyanosis, polycythemia, and hemoptysis. In addition, more serious neurological complications such as cerebral stroke and brain abscess can be caused by paradoxical embolization, the risk of which is significantly higher for PAVMs with feeding arteries that are 3 mm or more in diameter [1]. This is the threshold size for which occlusion is required. For symptomatic PAVMs or lesions at risk, transcatheter embolization is the treatment of choice to control symptoms or reduce risk [2-6].

The goal of imaging studies, especially Computed Tomography (CT), is to identify all PAVMs with feeding arteries that are 3 mm or more in diameter. In addition, 3-Dimensional (3D)-CT images are helpful to understand the angioarchitecture of the individual lesion and aid in the planning of embolotherapy. Because a PAVM is a "vascular lesion," Contrast-Enhanced CT (CECT) for the mediastinal window view is often preferred to identify the anomalous vessel components for pre- and/or post-treatment evaluation [7,8].

Although infrequent, intravenous administration of contrast material carries the risk of paradoxical embolization due to possible contamination of air bubbles. Although we are unable to quantify the risk of paradoxical embolization during CECT, a complication such as cerebral infarction could be serious if paradoxical embolization occurs. In addition, contrast enhancement does not enhance the lung-window display. On the other hand, PAVMs can be clearly identified on non-enhanced 3D-CT images in the lung window.

The 2009 International Guidelines for the Diagnosis and Management of Hereditary Hemorrhagic Telangiectasia also state that unenhanced CT should follow a positive contrast echocardiogram [9].

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We demonstrate here the usefulness of non-enhanced 3D-CT for planning treatment of PAVMs using embolotherapy.

Materials and Methods

Patient population and back ground

Our institution review board does approve this study as retrospective study. Informed consent was obtained from all patients before procedures. Between February 2004 and April 2011, 20 patients (9 men and 11 women) with a total of 41 PAVMs underwent coil embolotherapy. Fifteen patients were suspected as Hereditary Hemorrhagic Telangiectasia. In the remaining 5 patients, 3 patients were incidentally suspected by the chest X-ray. The one patient was hypoxemia and the other was post cerebral infarction. The mean patient age was 40 years (range, 13-72 years). For preoperative planning, all patients were evaluated with non-enhanced CT.

CT technique

CT angiography equipment and CT scanners changed during the study. An 8-detector CT scanner (Lightspeed Ultra; General Electric Medical Systems, Milwaukee, WI) was used for two patients from February 2004 to March 2005 and a 64-detector CT scanner (LightSpeed VCT; General Electric Medical Systems) was used for eighteen patients from April 2005 to April 2011. The imaging parameters for the 8-detector CT scanner were as follows: collimation, 1.25 mm; and pitch, 1.375. The imaging parameters for the 64-detector CT scanner were as follows: collimation, 0.625; and pitch, 1.375.

None of the patients was administered nonionic contrast material. The scan region ranged from the apical portion of the lung to the bottom of the diaphragm. A high-resolution tailored 3D-CT angiogram was reconstructed with partial Maximum Intensity Projection (Mip) in the lung window on a workstation (Advantage Windows version 4.2; General Electric Medical Systems) to assess the 3D-angioarchitecture of each of the 41 lesions.

Planning assessment for embolotherapy

Planning of embolotherapy was based on the locations, numbers, and diameters of feeding arteries and draining veins. Planning also involved deciding how to place the first coil. This required determining whether the embolized feeding artery was at an adequate distance to place a sufficient numbers of coils before a major segmental branch to avoid significant pulmonary infarction as well as whether there was any side branch close enough to the sac to anchor the first coil to prevent coil migration. In case of no side blanch on 3D-MIP CT, the coils were placed using Scaffold technique described later. If there was short distance for the coil placement, we were planning to place the coils using Sac embolization technique described later. We defined the following four techniques for coil placement: "Push technique" indicated that the first coil was placed without anchoring the side branch; "Anchor technique" indicated that the tip of the first coil was placed into the side branch to avoid coil migration; "Scaffold technique" indicated that the large first 2 or 3 coils were placed in the feeding artery for scaffold formation to avoid coil migration; and "Sac embolization technique" indicated that the coil was placed in only the aneurysmal sac because the distance to the feeding artery was too short to be embolized.

Embolization procedure

Before embolotherapy, all patients underwent pulmonary angiography with a 4-F pig tail catheter and a 6-F multipurpose catheter through the right common femoral vein. First, the main pulmonary angiogram was obtained to detect the lesions of PAVMs, followed by selective catheterization of the feeding artery with either a 4-Fr end-hole or a 2.3-Fr microcatheter (Rapidtransit, Cordis Corporation, Miami Lakes, FL), depending on the partial MIP image obtained for pre-therapeutic planning. The embolic materials used in this study were high radial force Inconel coils or soft platinum coils. The success of the procedure was determined by whether PAVMs were embolized or not in accordance with the preoperative planning based on partial MIP images as described earlier.

For each patient, we investigated the size of the first coil, the number of coils placed, and which technique was used to place the coils. We also evaluated whether the side branch to anchor the first coil was depicted on the angiographic image.

Statistical analysis

The depiction of the side branch of the feeding artery close to sac between preoperative partial MIP 3D-CT images and selective pulmonary angiography was evaluated. We used the unweighted κ statistic with binary data to measure the extent of agreement for the depiction of the side branch among two modalities by using a statistical software package (SPSS 11.0 for Windows; SPSS Japan, Tokyo, Japan). values of up to 0.40 were considered to indicate positive but poor agreement; κ values of 0.41-0.75, good agreement; and κ values greater than 0.75, excellent agreement [10].

Results

Assessments of the planning and results of embolotherapy are shown in the Table 1. Embolization was feasible in all 20 patients. The

No.	Age	Sex	Location	Feeding artery No. / size (mm)	Drainage vein size (mm)	Coil No. / TQ	Size of 1st coil (mm)	Side branch to anchor MIP / DSA
1	30	M	Lt S5	1 / 5.8	6.2	8 / sca	10	× / ×
2	14	M	Rt S1	1 / 3.5	5	3 / anch	6	× / ○
			Rt S2	2 / 4.8	7	6 / anch	7	○ / ○
			same as above	/ 3.2	same as above	3 / anch		
	2nd session		Rt S4	1 / 3.4	3.4	3 / anch	4	○ / ○
			Rt S8	1 / 3.4	3.3	3 / anch	4	○ / ○
			Rt S10	1 / 3.6	4.3	3 / anch	3	○ / ○
	3rd session		Rt S1	1 / 2.8	3.7	4 / anch	3	○ / ○
			Rt S8	1 / 2.1	2.5	2 / push	4	○ / ○
			Lt S4	1 / 4.2	3.8	2 / anch	5	○ / ○

3	46	F	Lt S6	1 / 3.6	2.9	4 / sac	6	× / ×
			Lt S8	1 / 2.2	3.2	4 / anch	3	× / ○
			Lt S8	1 / 2.3	2.6	6 / push	3	× / ○
4	29	M	Rt S8	1 / 3.8	4.6	3 / anch	6	× / ×
5	65	F	Rt S2	1 / 3.8	5.7	4 / coil anch	6	× / ×
6	26	M	Rt S8	1 / 5	7.2	6 / anch	8	○ / ○
			Rt S8	4 / 4.5	7	6 / push	8	× / ×
			same as above	2.2	same as above	5 / push	3	× / ×
			same as above	2.7	same as above	3 / push	3	× / ×
			same as above	2.5	same as above	5 / push	3	× / ×
			Rt S9	1 / 3.2	4.9	4 / push	3	× / ×
7	16	M	Rt S3	1 / 3.5	5.2	4 / push	4	× / ×
8	27	F	Lt S6	1 / 3.3	2	5 / push	5	× / ×
			Lt S9	1 / 3.1	3.3	2 / push	3	× / ×
9	72	F	Rt S5	1 / 5.0	5	7 / anch	8	○ / ○
10	71	F	Lt S5	1 / 8.0	10	8 / anch&sca	12	○ / ○
11	41	M	Rt S3	1 / 3.3	3.8	5 / push	4	× / ×
			Rt S3	1 / 3.3	4	4 / push	4	○ / ○
			Rt S3	1 / 4.7	6.6	7 / push	7	× / ×
			Rt S3	1 / 3.6	6	3 / push	5	× / ×
12	13	M	Lt S9	2 / 3.2	6.4	7 / push	3	× / ×
			same as above	2.7	same as above	4 / push	4	× / ×
			Rt S5	1 / 3.2	3.2	3 / push	4	× / ×
13	47	M	Lt S10	1 / 4.2	5	4 / push	8	× / ×
			Lt S10	1 / 2.3	3.2	2 / push	4	× / ×
14	64	F	Lt S4	1 / 3.1	3.4	2 / anch	4	○ / ○
			Lt S10	1 / 3.6	2.6	3 / push	4	× / ×
15	31	M	Rt S3	1 / 3.7	4	6 / anch	6	○ / ○
16	58	F	Lt S8/9	1 / 6.6	8.9	9 / push	12	× / ×
17	51	F	Lt S9	1 / 3.7	3.4	2 / push	4	○ / ○
			Lt lig	1 / 2.9	2.9	2 / push	4	× / ×
18	23	F	Lt S5	1 / 3.4	3.8	4 / push	6	× / ×
19	18	F	Rt S8	2 / 4.2	4	4 / push	6	× / ×
			same as above	2.8	same as above	3 / push	3	× / ×
			Lt S1+2	3 / 2.2	6.4	9 / push	6	× / ×
			same as above	2.7	same as above	embolized together		× / ×
			same as above	2.7	same as above	5 / push	5	× / ×
20	48	F	Rt S8	1 / 3.2	4	3 / anch	6	○ / ○

TQ: the technique of coil embolization; **push:** the first coil was placed without side branch for anchoring; **anch**: the tip of the first coil was place with side branch for anchoring; **sca**: the larger first two or three coils were placed in feeding artery for scaffold formation to avoid coil migration (i.e. scaffold technique); **sac**: the coil was placed in the only aneurysmal sac.

Table 1: Summary of PAVM lesion.

41 PAVMs could be successfully occluded according to the planning based on partial MIP images (Figures 1-4). There were no immediate or delayed complications related to angiography or embolization such as paradoxical embolization. Five PAVMs contained two to four feeding arteries, and altogether, 49 feeding arteries of 41 PAVMs were detected. Thirty-five feeding arteries were 3 mm or more in the diameter and 14 feeding arteries were less than 3 mm (mean, 3.6 mm). All these 14 feeding arteries were multiple PAVMs and the largest feeding are more than 3mm. We embolized these 14 arteries in one session for avoiding to additional procedure in the future. Diameters of drainage vein were 2 to 8.9 mm (mean, 4.6 mm)**.** All feeding arteries could be detected on planning CT. The number of coils required for the embolotherapy was two to nine coils per PAVM (mean: 4 coils). The mean difference between diameter of the first coil and the feeding artery was 1.5 ± 1.47 mm.

Partial MIP images showed 16 feeding arteries with a side branch close enough to the sac to anchor the first coil, while the pulmonary angiogram showed 18 feeding arteries (Figure 1). Eighty-nine percent (16/18) of the side branches of the feeding arteries were depicted in preoperative partial MIP images. Fifteen feeding arteries (83%, 15/18) were embolized by the anchor technique. Only one PAVM had a short feeding artery on a partial MIP image, and the distance in the feeding artery was not adequate to deploy enough coils before another segmental branch. Therefore, the aneurysmal sac was embolized with 4 microcoils (Figure 2).

In the depictions of the side branch of the feeding artery close to sac between preoperative partial MIP images and selective pulmonary angiography, the κ values were 0.91. Excellent agreement was obtained between two modalities.

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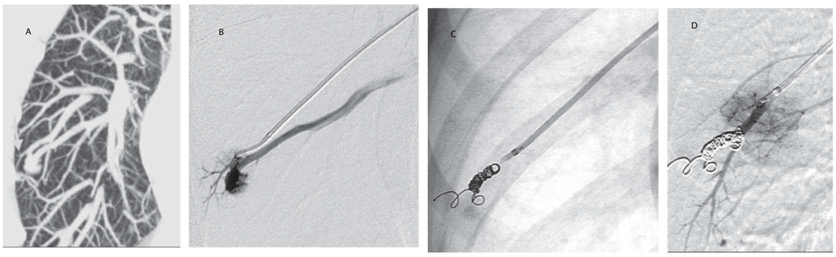

Figure 1: 14-year-old boy
A. The partial MIP 3D-CT image shows a PAVM in the periphery of the right middle lobe. A small side-branch (arrow) is seen close to the sac. **B.** The finding is well correlated with the selective angiogram. **C.** In the procedure, a 4 mm fibered platinum microcoil (Micronester, Cook) was used by anchoring the initial 2-3 cm of the coil into the side branch to prevent coil migration. **D.** The remaining two 3 mm coils were safely packed proximal to the first coil to obtain cross-sectional occlusion ("Anchor technique").

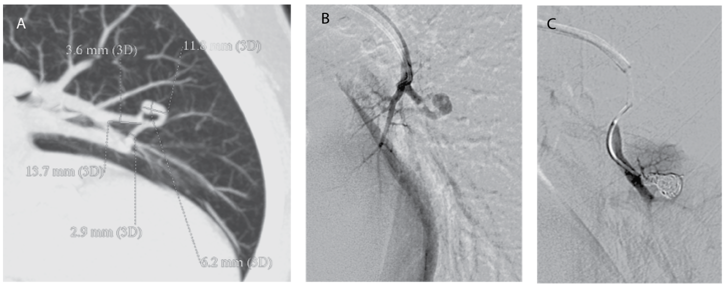

Figure 2: 46-year-old woman
A. The partial MIP 3D-CT image shows a small PAVM with a short feeding artery. The distance to the feeding artery was not adequate to deploy enough coils before another segmental branch. **B.** Findings on 3D-CT were well correlated with the selective arteriogram. **C.** To avoid sacrificing the normal segmental branch, the aneurysmal sac was embolized with 3-6 mm detachable microcoils (Detach, Cook).

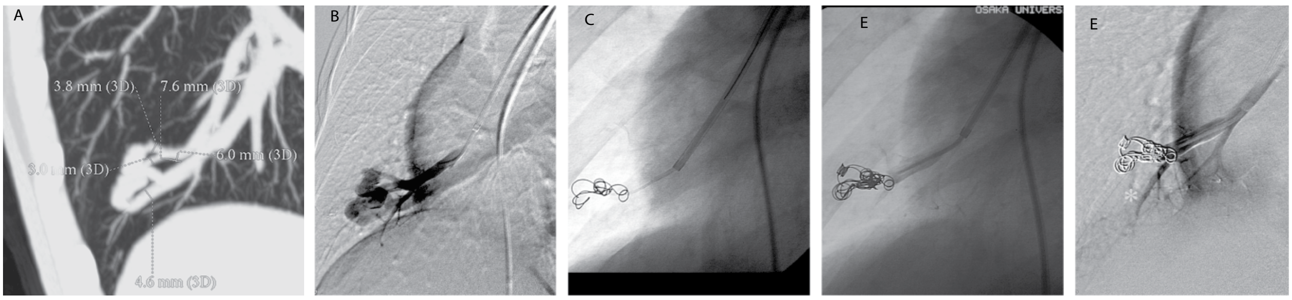

Figure 3: 29-year-old man
A. Partial MIP 3D-CT image shows the complex architecture of the PAVM in the right anterior segment. Both the feeding artery and draining vein bifurcated at the entrance to the sac. The distance to a normal artery (overlapped with the draining vein) was too short and proximal to the feeding artery to be occluded. **B.** The selective angiogram demonstrated similar findings to the 3D-CT image. **C** .The first 6 mm fibered microcoil (Micronester, Cook) straddled the bifurcation of the feeding artery and formed a scaffold. **D.** Two additional 3-4 mm coils were used for the remaining cross-sectional occlusion. **E.** The normal branch proximal to the last coil is pictured (asterisk).

Discussion

Remy et al. first reported the results of a pre- and post-treatment evaluation of PAVM using chest CT [5]. They also mentioned the usefulness of 3D helical CT to help understand the angioarchitecture of PAVMs without using contrast material [11]. In our study, non-enhanced tailored partial MIP 3D-CT images obtained in the lung window also clearly demonstrated the angioarchitecture of PAVMs, and findings based on partial MIP 3D-CT images correlated well with those based on pulmonary angiography. The partial MIP 3D-CT images allowed for accurate measurement of the diameter or length of the feeding artery to be occluded and were helpful for choosing the embolization technique to use, including the size of the coils and the points of occlusion. Transcatheter embolotherapy could be efficiently carried out based on the findings of partial MIP 3D-CT images without use of contrast material. There were some techniques for the coil embolization of PAVMs such as anchor technique, scaffold technique and sac embolization [12]. If the preoperative CT clearly demonstrates the side branch of the feeding artery close to sac, we can plan to embolize the feeding artery by anchor technique in advance. In this study, the depictions of the side branch of the feeding artery close to sac between preoperative partial MIP images and selective pulmonary angiography were excellent agreement. Therefore, unenhanced CT would be useful to evaluate the side branch of feeding artery for preoperative study.

There remains disagreement as to the use of contrast materials for the evaluation for PAVMs. Some authors reported that contrast-enhanced CT provides information beyond unenhanced CT,

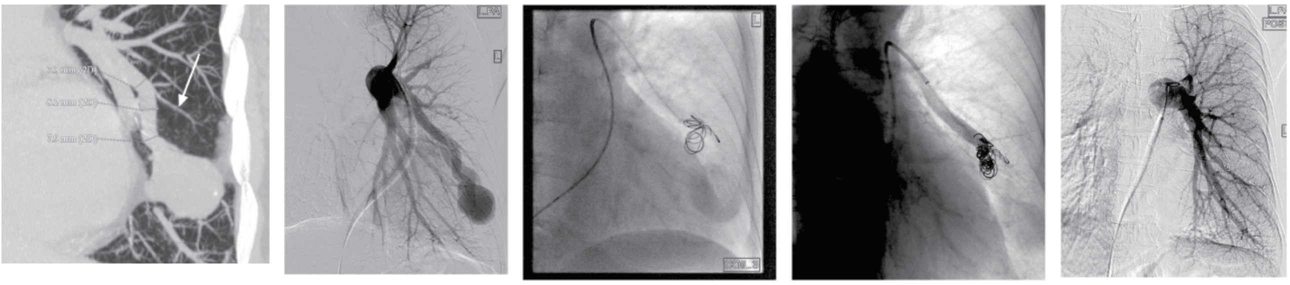

Figure 4: 71-year-old woman
A. The partial MIP 3D-CT image shows a simple PAVM adjacent to the pleura in the left lingual lobe. The course of the feeding and draining vessels was clearly seen. The feeding artery was slightly widened at the entrance to the sac. In addition, there was a side branch to anchor the first coil close to the sac (arrow). Transcatheter embolotherapy was performed. **B.** Main pulmonary angiography was well correlated with the 3D-CT findings. **C, D, E.** Following the first two oversized 12 or 10 mm high radial-force Inconel fibered coils (IMWCE, Cook, Bloomington, IN) to form a scaffold was placed with anchoring a side branch and six 6-8 mm soft-platinum fibered coils (Tornado, Cook) were used for the remaining cross-sectional occlusion ("Combination of Anchor and Scaffold technique").

particularly during follow-up, which warrants the minor additional risk of contrast administration [13,14]. Some reports also have highlighted the clinical usefulness of reconstruction with partial MIP 3D-CT with contrast material for PAVMs after embolotherapy [7, 8, 11]. However, there are some well-recognized groups which continue to use unenhanced CTand the 2009 International Guidelines for the Diagnosis and Management of Hereditary Hemorrhagic Telangiectasia treatment state that unenhanced CT should follow a positive contrast echocardiogram [9,15,16].

Another report dealt with a paradoxical air embolism occurring during CECT in a patient who had a congenital heart disorder with a right-to-left shunt [17]. Furthermore, PAVMs with feeding arteries 3 mm or more in the diameter carry an increased risk of paradoxical emboli. It is estimated that 24% of patients with PAVMs experience transient ischemic attacks or stroke and 9% show brain abscess on presentation of PAVMs due to right-to-left shunt [18]. Although an actual case of a paradoxical air embolism associated with contrast enhanced CT has not been reported in patients with PAVM and it was obscure in the incident of paradoxical embolism associated with contrast enhanced CT, the use of contrast material should be carefully limited to the minimum required for the pre-treatment assessment of PAVMs.

There are some limitations to our study. First, this study is a single, retrospective study. Second, only a small number of patients were enrolled. Third, the PAVMs treated in our study were generally small lesions which were 3.6mm in the mean diameter of feeding artery. Thus the findings of our study may not apply to PAVMs with larger feeding artery. A prospective study of a larger number of patients is needed to determine the efficacy of partial MIP images in the lung window.

In conclusion, non-enhanced tailored partial MIP 3D-CT in the lung window appears to be a feasible and useful vascular imaging technique for planning coil embolotherapy of PAVMs, especially in the evaluation for the side branch of the feeding artery.

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