European Journal of Radiology 85 (2016) 150–157

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Pulmonary arteriovenous malformation (PAVM) reperfusion after percutaneous embolization: Sensitivity and specificity of non-enhanced CT

Chantale Bélanger[a], Carl Chartrand-Lefebvre[a,b], Gilles Soulez[a,b], Marie E. Faughnan[c,d,e], Muhammad Ramzan Tahir[b], Marie-France Giroux[a], Patrick Gilbert[a], Pierre Perreault[a], Louis Bouchard[a], Vincent L. Oliva[a], Eric Therasse[a,b,*]

[a] Department of Radiology, Centre hospitalier de l'Université de Montréal (CHUM), Montreal, QC, Canada
[b] Centre de recherche, Centre hospitalier de l'Université de Montreal (CRCHUM), Montreal, QC, Canada
[c] Respirology Division, Department of Medicine, St. Michael's Hospital, University of Toronto, Toronto, ON, Canada
[d] Li Ka Shing Knowledge Institute, St. Michael's Hospital, University of Toronto, Toronto, ON, Canada
[e] Montreal HHT Centre, Pneumology Division, CHUM, Montreal, QC, Canada

ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form 4 November 2015
Accepted 5 November 2015

Keywords:
Pulmonary arteriovenous malformation
Reperfusion
CT

ABSTRACT

Purpose: To evaluate the sensitivity and specificity of non-enhanced chest CT to detect reperfusion after pulmonary arteriovenous malformation (PAVM) embolization.
Materials and methods: The Institutional Review Board approved this retrospective HIPAA-compliant study and waived the need for patient consent. All consecutive patients who underwent PAVM embolization between January 2000 and April 2011 were included. Complex PAVMs and patients without available pre- and/or post-embolization CT were excluded. PAVM artery, aneurysm and vein diameters were measured on non-enhanced chest CT before and after PAVM embolization. Pulmonary angiography (PA) was the reference standard to assess PAVM reperfusion. Reperfusion detection was analyzed with receiver operating characteristic (ROC) curves according to percentage of diameter reduction cut-off. Inter-observer concordance was ascertained with intra-class correlation coefficients (ICCs).
Results: Out of 68 patients with PAVM embolizations, 42 (62%) had 108 PAVMs that met inclusion/exclusion criteria. Areas under the ROC curves for PAVM reperfusion detection were 0.84, 0.87, and 0.78, respectively, for PAVM artery, aneurysm and vein ($p > 0.05$). Sensitivity varied between 51% and 56%, and specificity between 86% and 98% for the <30% diameter reduction cut-off. Sensitivity was between 98% and 100%, and specificity, between 20% and 47% for the <70% diameter reduction cut-off. ICCs for inter-observer concordance were 0.58, 0.88 and 0.68 for percentage reduction of PAVM artery, aneurysm and vein, respectively.
Conclusion: PAVM diameter reduction cut-offs of <30% and <70%, to detect PAVM reperfusion on non-enhanced CT reported in the literature, would respectively result in low sensitivity and specificity.

1. Introduction

Pulmonary arteriovenous malformations (PAVMs) represent direct communications between the pulmonary artery and vein, with these right-left shunts resulting in hemorrhagic complications and paradoxical embolization leading to stroke and brain abscesses [1–6]. Percutaneous PAVM embolization is technically very successful and is now the standard of care for the treatment of these lesions [7,8]. However, PAVM reperfusion rates after embolization are estimated to be between 2 and 25% [9,10] due most often to the recanalization of embolized vessels [11,12]. Pulmonary angiography (PA) is the imaging reference standard for PAVM reperfusion assessment [7,13] but, given its cost and invasive nature, CT is the preferred follow-up imaging modality.

CT detection of PAVM reperfusion after embolization is based on either PAVM enhancement on contrast-enhanced CT or PAVM diameter reduction on non-enhanced CT [9,10,14–17]. Today novel

* Corresponding author at: Department of Radiology, CHUM, 3840, rue Saint-Urbain, Montréal, QC H2W 1T8, Canada. Fax: +1 514 412 7193.
E-mail address: eric.therasse.chum@ssss.gouv.qc.ca (E. Therasse).

http://dx.doi.org/10.1016/j.ejrad.2015.11.014
0720-048X/

techniques such as dual energy scanning and iterative reconstruction algorithms can help reduce such artifacts while limiting radiation dose. However, assessment of PAVM enhancement after intravenous contrast injection may still be impaired by metallic embolization devices and requires good contrast resolution that limits CT radiation dose reduction to this population with long life expectancy subjected to repeated CT examinations. Enhanced CT is also associated with risks of contrast media and air embolism during tubing connection to automatic contrast media injectors [14,18]. Small- and moderate-size air emboli are estimated to occur in 12% to 23% of patients undergoing contrast-enhanced CT examination [18,19]. As patients with hereditary hemorrhagic telangiectasia (HHT) will almost always incur tiny residual PAVMs after treatment, there is some concern over intravenous administrations which may introduce air bubbles [16]. For these reasons, many centers have established PAVM diameter reduction cut-offs on non-enhanced CT to evaluate PAVM reperfusion [9,10,14–16]. However, the cut-offs under which reperfusion is suspected are highly variable, arbitrary and non-validated. Some authors follow 70% reduction criteria for the aneurysmal sac and/or draining vein under which PAVM reperfusion is suspected [9,11,14,15], whereas others consider >30% reduction sufficient for successful outcome after embolization [10,12,13]. To our knowledge, the sensitivities and specificities of these cut-offs are yet unknown, and there are no data in the literature comparing CT measurement of different PAVM structures to detect PAVM reperfusion. The purpose of this study is to evaluate the sensitivity and specificity of non-enhanced chest CT to detect reperfusion after PAVM embolization.

2. Materials and methods

2.1. Patients and PAVM embolization

The Institutional Review Board approved this retrospective study and waived informed consent. We included all consecutive patients from a database of subjects who received PAVM embolotherapy in our institution between January 2000 and April 2011. The inclusion criteria were: all patients with de novo PAVM embolization who had chest CT scan before and at least 6 months after embolization. Complex PAVMs, defined as multiple feeding arteries, and those without CT imaging follow-up of at least 6 months after embolization, were excluded from this study. Imaging and medical files were reviewed to obtain clinical data as well as laboratory and procedural reports.

PAVM embolization was generally performed via a venous transfemoral approach, with a 7F guide catheter (Guider Softip XF, Boston Scientific, Freemont, CA, USA), with 40 degree tip angulation, through a 7F introducer. Embolization was secured with various detachable plugs, balloons and coils until complete occlusion was confirmed by PA. The PAVM feeding artery was embolized as close as possible to the aneurysmal sac. Multiple PAVMs were embolized during a single session in some patients.

2.2. Follow-up CT

Follow-up chest CT was performed without intravenous contrast with a 16-detector row scanner (Somatom Sensation 16, Siemens Medical Solutions, Forchheim, Germany) and a 128-detector row scanner (Brilliance iCT, Phillips Healthcare, Cleveland, OH, USA). X-ray tube voltage was 120 kV, and tube current was 40 mA (low-dose protocol). The following scanning parameters were used: for the 16—detector row scanner, 16×0.75-mm collimation, a pitch of 1.15, and a rotation time of 0.5 s and for the 128—detector row scanner, 128×0.625-mm collimation, a pitch of 0.915 and a rotation time of 0.50 s. At the time of the study, iterative reconstruction algorithm was not available on either scanner and filtered back projection was used for image reconstruction. The effective radiation dose of MDCT angiography was estimated by the dose-length product (DLP), as indicated on the dose report of the CT scanner, and a conversion coefficient for the chest ($k = 0.014\,\text{mSv} \times \text{mGy}^{-1} \times \text{cm}^{-1}$). The mean effective doses were 2.16 ± 1.12 mSv and 1.49 ± 0.105 mSv, respectively for the 128- and for the 16—detector row scanners.

Axial images were reconstructed with a medium soft-tissue kernel (B70 lung for Somatom Sensation 16 and L (lung) for Brilliance iCT), with a slice thickness of 2 mm and an increment of 2 mm for both scanners. Image quality and diagnostic performance of the two scanners were comparable and there was no impact on subjective image quality and detection of CT findings of PAVM reperfusion. In our institution both CT could be used interchangeably for all applications using a collimation of 2 mm or greater, such as in this study.

Patients were evaluated in a specialized HHT center under the supervision of one of the authors. Unenhanced chest CT was performed routinely 1 year after embolization. PAVMs were considered to be successfully treated if there was at least a 70% decrease in size of the aneurysm sac and draining vein, as assessed subjectively on CT. Patients with PAVMs suspicious for recanalization were referred to PA and recanalized PAVMs were re-embolized during the same session.

2.3. Follow-up PA

Follow-up PA was performed either in the setting of embolization of new or not previously-embolized PAVMs or if at least 1 previously-embolized PAVM was suspected to be reperfused with CT. Only follow-up PAs at ≥6 months after embolization were considered for the assessment of PAVM reperfusion. When PA was performed because one PAVM was suspected to be reperfused on CT, all other PAVMs of that patient were also assessed at the same occasion. Most PAs were performed with an Artis Zee angio suite (Siemens, Erlangen, Germany). Selective right and left postero-anterior and contralateral anterior oblique view PAs were obtained via a transfemoral approach with a 5 F pigtail catheter and, in case of doubt, super-selective injections were also frequently performed. Iodixanol (270 mg I/mL, Visipaque 270, GE Healthcare, Princeton, NJ, USA) was injected at 20 mL/s for a total 40 mL. Follow-up PAs were reviewed by a board-certified interventional radiologist with 18 years of experience, to confirm or exclude reperfusion. Occluded PAVMs were defined by the absence of contrast material flowing through the treated PAVM aneurysmal sac on PA. PAVM reperfusions were evaluated and classified as either: (a) feeding artery recanalization, defined as restoration of blood flow through the embolized feeding vessel, (b) collateral reperfusion of feeding arteries by adjacent pulmonary artery collaterals, or (c) reperfusion of distal feeding arteries via systemic artery branches. Systemic arteriography was not routinely undertaken to rule out reperfusion by systemic collaterals.

2.4. CT assessment of PAVMs

For each PAVM, aneurysmal sac, draining vein and feeding artery diameters were measured by an experienced, board-certified interventional radiologist with 20 years of experience, both on pre- and post-embolization non-enhanced CT scans, using 2-mm axial slice series in lung window reformat, at the same location. Draining veins were measured as close as possible to the aneurysmal sac, where vessel walls were parallel, beyond any transitional dilation to the aneurysmal sac, if present. Aneurysmal sacs were measured in their lesser diameters, perpendicular to the long axis. On pre-embolization CT scan, the feeding artery was measured proximally