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Original Article

A new time-resolved 3D angiographic technique (4D DSA): Description, and assessment of its reliability in Spetzler–Martin grading of cerebral arteriovenous malformations

suppl. Informations

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Background and purpose. – The Spetzler and Martin (SM) cerebral arteriovenous malformation (AVM) classification is a widely used 5-tier classification. This common language allows specialists to exchange about AVMs and must be reliably characterized by the imaging methods. We presented an agreement study on a new method of digital subtracted 3D rotational angiography resolved in time (four-dimensional DSA: 4D DSA) compared to the gold standard (two-dimensional digital DSA: 2D DSA) in AVM grading using the SM classification.
Methods. – Ten patients with AVMs were included during one year, they had an angiographic exploration with both 4D DSA and 2D DSA. Three readers assessed the SM classification. One reader conducted a second reading. The inter-, intra-observer and intermodality agreements were calculated by Kappas. Dose to patient was reported.
Results. – Considering the SM grade, the inter-observer agreement between 4D DSA and 2D DSA was equivalent ($\kappa = 0.45$ and 0.46), and calculated as substantial $\kappa = 0.76$ between the 2 methods. The agreement between 4D DSA and 2D DSA was calculated as moderate $\kappa = 0.46$ assessing the size of the nidus, slight $\kappa = 0.18$ analyzing the drainage and almost perfect $\kappa = 0.95$ depicting the localization. 4D DSA performed during a standard initial angiographic assessment of AVM represented approximately 6% of the total dose.
Conclusion. – The addition of this new technique 4D DSA could be performed regularly in addition to the 2D DSA if available, to assess SM grading, with an acceptable exposure to ionizing radiation cost.

Introduction

Arteriovenous malformations (AVMs) are intracranial arteriovenous shunts. These lesions are rare and heterogeneous; intracranial hemorrhage remains their main risk, and their management is still discussed [1]. Classification of AVMs in five grades according to Spetzler and Martin (SM) is a tool originally created to predict morbidity and mortality after surgery [2]. Ultimately time-honored, its widespread use has created a common language between specialists. This classification is also frequently used to compare or validate imaging techniques for the evaluation of AVMs [3,4]. Two-dimensional DSA (2D DSA) is the gold standard in evaluating the angioarchitecture of AVMs, thanks to its high spatial and temporal resolution [5]. Due to the overlap of the vascular structures in 2D, the use of three-dimensional (3D) data is often required to overcome this limitation [6]. However, as the 3D DSA models are not resolved in time and display a fully opacified vasculature, close structures are often difficult to distinguish and to analyze. In this

Abbreviations: 2D, two dimensions/two-dimensional; 3D, three dimensions/three-dimensional; 4D, four dimensions/four-dimensional; KAP, Kerma air product; SM, Spetzler and Martin; VRT, volume rendering technique.

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new rotational angiographic acquisition, the different phases of the dynamics of vascular opacification have been extracted and used to compute a three-dimensional time-resolved acquisition, resulting in four-dimensional data (4D) [7]. The main idea of the 4D DSA is to provide multiple 3D volumes that can be viewed in an infinite number of projections while representing the different vascular phases at any time of the acquisition. The feasibility of 4D DSA has been reported on several series that have studied arteriovenous shunts [8]. Our purposes were to show the feasibility of this technique in the exploration of brain AVMs, to study the radiation related to the use of this technique, and finally to compare 4D DSA to 2D DSA for grading AVMs according to the SM classification.

Materials and methods

One author (SA) is an employee of Siemens Healthcare (Erlangen, Germany), the other authors have no affiliation or conflict of interest with Siemens and had permanent control of inclusion and data.

Patients

From July 2015 to July 2016 were consecutively included 10 patients with AVM in our institution, with clinical indication of DSA exploration (8 men, 2 women, average age 47.9 years, range from 21 to 63 years). During a single procedure, a 4D DSA acquisition and 2D DSA projections were acquired. This assessment was done as usual, only the rotational period (six or 12 seconds against usually five for 3D) and post-treatment differed. Nine AVM were supra-tentorial and one infra-tentorial. None of the ten patients were previously treated.

DSA acquisitions

Cerebral angiographies were performed on the same biplane angiography system (Siemens Artis Q, Siemens Healthcare, Erlangen, Germany). Post-treatment was done with a commercial software available (Syngo4D) in Artis series equipped with VD11 software. 2D DSA acquisition (Fig. 1) were carried out according to conventional techniques, with a manual injection of nonionic contrast medium (Iomeron 250, Bracco Imaging, Milan, Italy) with a 5 French catheter. The contents of exploration 2D DSA was left to the operator's discretion and could therefore contain several projections in different fields of view (32×32 to 16×16 cm) and frame rates (two to five frames per second). Two protocols were used (A or B) for 4D DSA acquisitions (Fig. 1) according to the patient's cooperation (movements). They had common characteristics: 70 kV, pulse width: 12.5 ms, field of 32 cm, rotation of 260°. The acquisition of the mask and the injected images was done following the same protocol. Protocol A: acquisition time of six seconds, with a projection acquired every 1.5° (173 projections). Protocol B: acquisition time of twelve seconds, and a projection acquired every 0.85° (305 projections). The injection rate was 3 mL per second (Mark 7 Arterion, Medrad, Beek, Netherlands), without delay period neither dilution of injected contrast medium (Iomeron 250).

Image processing and reading

All images were transferred to a single workstation (X Workplace syngo, Siemens Healthcare, Erlangen, Germany). After anonymization, 4D and 2D DSA data were pooled and randomized (Excel 2016 15.27, Microsoft). The reading was performed on a single workstation. Three readers analyzed the acquisitions with a standardized reading grid to assess for each exam the SM grade (Table 1) (JO, resident in interventional neuroradiology with 2 years of experience, JCG interventional neuroradiology practitioner with more than 5 years of experience and EM vascular neurosurgeon with more than 5 years of experience). One reader (JCG) completed a second reading after one month. No readers had been driven before and during reading. Readers could access all reconstruction and visualization tools available in the workspace; they had no knowledge or access to clinical patient names or stories, or to the results of other diagnostic procedures.

Dosimetry records

For each, 4D DSA acquisition were reported the maximum skin dose and the Kerma air product (KAP). It was the same for the whole of the angiography session (thus including 2D DSA series and 4D DSA acquisition). The dose being substantially the same between a mask image and an image after injection, only the total dose of 4D DSA acquisition is reported. The term dose is used to designate the absorbed dose in the tissue. KAP is considered as surrogate measure to the entire amount of energy delivered to the patient [9].

Statistical analysis

Descriptive statistics on patient data and dosimetry were performed by calculating the mean, 95% confidence interval, the standard deviation, range values. The averages have been compared by the Wilcoxon–Mann–Whitney's U-test. The agreement was assessed by calculating quadratically weighted kappa coefficient when there were more than 2 variables to study, Fleiss' Kappa (for multiple readers) or Cohen's Kappa (two observers) [10]: between observers, between two analyzes of the same observer, between 4D and 2D DSA, for each item in the grid. The results were then interpreted as suggested by Landis and Koch [11,12] ($\kappa < 0$: poor agreement; 0.01-0.20: slight agreement; 0.21–0.40: fair agreement; 0.41–0.60: moderate agreement; 0.61–0.80 substantial agreement; 0.81–1: almost perfect agreement). Link between the answers for an item between 4D DSA and 2D DSA was tested with Cochran Q when variables where binary, and differences of repartition of answers in categories between the two modalities for every item was tested by Wilcoxon signed rank test when variables where ordinal. A P value < 0.05 was considered to indicate a significant difference. All statistical analyses were performed using Stata software (STATA/MP 13.0 for Mac StataCorp, Texas).

Results

Comparing responses of observers between the two methods

The study was submitted to the local institutional review board that waived informed consent. All 10 AVMs detected with 2D DSA were identified with 4D DSA. We demonstrated no significant differences between the distribution of responses observers across the two modalities for each item in the classification (nidus size $P = 0.706$, drainage $P = 0.739$, location $P = 0.317$), or for determining the SM grade ($P = 0.638$). We noticed that the readers established the same grade SM in 65% of the cases with the 2D and 4D DSA, and that it was found a disagreement over 1 point only once (Fig. 2). Details of SM grading in 2D DSA according to readers are shown in Table 2. The results of the inter-observer, intra-observer and intermodality agreements for 2D and 4D DSA are detailed in Table 3.

Inter-observer agreement

Reading 2D DSA acquisitions, inter-observer agreement was calculated as slight determining the size of the nidus, and substantial characterizing the draining pattern and the eloquence of the localization. When reading 4D DSA acquisition, inter-observer agreement were either higher or almost equal. Considering SM

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