Bilateral 4D flow geometrical analysis of common carotid arteries in patients selected for endarterectomy

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Authors: G. Corrias¹, L. Barberini², G. Columbano¹, M. E. Laino³, L. Saba¹;
¹Monserrato/IT, ²Cagliari/IT, ³Rome/IT
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Aims and objectives

The aim of our study is to investigate geometry changes of Common Carotid Arteries in patients selected for surgical Endarterectomy, with a 4-dimensional analysis. In particular changes of area and circumference of distal CCA, on a standardized plane (2 cm proximally the bifurcation) have been analyzed. 3D Phase Contrast, time-resolved, Magnetic Resonance imaging with spatial 3-directional velocity encoding, also named 4D Flow, has been used in this study to analyse flow in carotids. 4D flow is a new technique, emerging as an innovative method to analyse flow. However there is a lack of studies which evaluate its clinical and research usefulness especially within Carotid arteries. To our knowledge there are no studies which have analysed flow changes in carotid arteries with a time-resolved technique.
Methods and materials

The institutional review board approval for this study was obtained. This is a prospective single institution pilot study enrolling 11 patients, for a total of 22 carotids, who were scheduled to perform a Neck MR scan of the supra-aortic vessels with a Ingenia 1.5-T superconducting magnet (Philips, Best, The Netherlands). No contrast medium has been delivered prior to the examination.

Patient Population:

The examinations were performed between November 2016 and March 2017 for a total of 22 carotids, 11 patient. The only inclusion criteria was that the patients had to be already selected to undergo an endoarterectomy surgery in our institution at the department of Vascular Surgery. Patients were selected to undergo this type of surgery according to Biller et al guidelines. According to these guidelines there are two main groups of patients who can benefit from endarterectomy: asymptomatic and symptomatic. We considered them as a unique group. All patients had already performed a MDCTA before and an ultrasound examination of carotids as a standardized protocol before to undergo endoarterectomy surgery.

MR Technique

Imaging examinations were performed with a Ingenia 1.5-T superconducting magnet (Philips, Best, The Netherlands) with a head coil. As previously proposed, a 3D Time-of-Flight (TOF) sequence in an axial slab has been performed to check the bifurcation height and to properly orient the axial slabs on 4D flow images. Following parameters for TOF were as follows: flip angle, 20°; TE, 4.7 ms; TR, 22 ms; spatial resolution, 0.9 x 0.9 x 1.1 mm3; slab thickness, 120 mm. 4D flow MR imaging consisted of a prospectively electrocardiogram-gated radio-frequency-spoiled gradient-echo sequence with interleaved 3-directional velocity encoding. Imaging parameters were as follows: flip angle, 8°; TE, 2.2 ms; TR, 4.1 ms; velocity sensitivity (VENC), 200 cm/s; spatial resolution, 2.4 x 2.39 x 2.50 mm3; slab thickness, 50.4 mm; number of sections 55; temporal resolution, 64.9 ms; parallel imaging (SENSE), NSA= 2; average scan time = 10 minutes. The VENC has been chosen of 200 cm/s because all patients were known to have a significative carotid stenosis affecting at least one side (>50% according to NASCET criteria). The data were corrected for concomitant gradient fields for phase wraps and eddy currents automatically on the scanner. Minimum standards for 4D MR flow data, regarding acquisition and post processing parameters are described in more detail in the MR 4D flow consensus statement.

Data Processing and Flow Quantification

All the dataset were analyzed with a third-part software: CAAS (PIE Medical Imaging, Maastricht, The Nederland). CAAS MR 4D Flow is aimed at analyzing the blood flow in
large vessels. Flow volume and retrograde flow quantification in 4D Flow CMR is similar to that used in conventional 2D cine PC-CMR with some important changes between the two techniques. If all the acquisition data and the preprocess reconstructions have been performed correctly on the scan system, then the software would automatically sort the 4D flow images in 4 views: -Magnitude view for magnitude image set, -X-directional PC view for X-directional phase contrast image set; -Y-directional PC view for Y-directional phase contrast image set; - Z-directional PC view for Z-directional phase contrast image set. At this point velocity direction are checked and if needed corrected along the three axis. Afterwards, it is checked whether velocity correction are needed, for instance aliasing correction, or offset correction (to correct offsets in velocity components). When the magnitude image, 3-directional phase contrast images and the phase inversions are set, an automatic segmentation of the 3D vessel structure is performed by the software. The main centerline of the vessel of interest is found after having given a start and end point on the 3D reconstruction, and the vessel walls are corrected in a longitudinal or cross sectional view or the vessel. At this point the software provides the functionality to visualize or quantify blood flow using 2D analysis planes which are retrospectively reformatted and positioned in the vessel of interest along the centerline. Six analysis planes have been selected as reference planes for this study in a similar way of what has been previously done. The plane number 1 has been put caudally to the carotid bifurcation at about 2 cm from it. Plane number 2 was positioned at the diversion point of flow between ICA and ECA, perpendicularly to the ICA. Planes number 3-4-5 has been positioned on the main stenosis level, generally on the ICA, based on the MDCTA images examination and on the 3d surface rendering of the 4D flow. The last plane (number 6) has been positioned on the distal ICA level, before its entrance on the skull. Once these 6 planes have been selected the software performed all the visual and quantification analysis on these 6 levels. For this specific study only the plane number 1 have been taken into account, bilaterally. With the 2D Flow analysis standard 2D flow parameters, such as flow velocity, forward and backward flow have been calculated. Additionally, a measure for extreme eccentric flow in one plane is calculated. Every single plane has been corrected by the reader with regards of vessel boundaries rappresentation, in every single cardiac phase time frame (the selected temporal resolution was 64.9 ms), either in the magnitude images or in the velocity images reconstructions. The software has calculated area and circumference values and changes in every single time frame analyzed.

Statistical Analysis

Statistical analysis was performed with the SPSS 13.0 statistical package (SPSS Inc., Chicago, IL). It has been taken into account the staistical association of positive flow and negative flow with two main geometrical charateristics, time resolved during the cardiac cycle: circumference and area. Three main flux patterns have been found: positive flux, total flux and negative flux. It was the analyzed the plane number 1 (see previous paragraph), in the CCA at about 2 cm caudally the carotid bifurcation. Correlations
between selected variables were estimated with the Pearson correlation coefficient. A significance level of 1.5% was set.
Fig. 1: wall shear stress right carotid, at 6 levels

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Fig. 2: wall shear stress left carotid

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Results

Among the 11 patients analyzed there were some problems in reconstructing and post processing the data on 3 patients, mainly because of a really low Signal-to-Noise-Ratio (SNR). In total 8 patients, 16 carotids have been taken into account. Among these 8 patient there was a significative stenosis only on the left side in 5 patients, only on the right side in 1 patient, and 2 patient had a bilateral stenosis. Of these patient all cardiac phases have been taken into account for a total analysis of 40 flux and geometrical values for negative flux, 40 values for total flux and 40 for positive flux. Only negative flow values showed a stastically significative (p<0.02) correlation with area (Correlation coefficient r -0.3884, Significance level P=0.0133, 95% Confidence interval for r -0.6244 to -0.08749) and circumference (Correlation coefficient r -0.4069, Significance level P=0.0092, 95% Confidence interval for r -0.6376 to -0.1092). Positive flow values showed no correlation with either area (Correlation coefficient r 0.1282, Significance level P=0.4306, 95% Confidence interval for r -0.1910 to 0.4228) or circumference changes (Correlation coefficient r 0.2338, Significance level P=0.1464, 95% Confidence interval for r -0.08379 to 0.5083) during the cardiac cycle; Total flow values showed no correlation with either area (Correlation coefficient r 0.09732, Significance level P=0.5502, 95% Confidence interval for r -0.2209 to 0.3968) or circumference (Correlation coefficient r 0.2061, Significance level P=0.2021, 95% Confidence interval for r -0.1127 to 0.4864).
Fig. 3: Relationship between flux and vessel circumference

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Conclusion

There is a correlation between the analyzed geometrical values changes during a cardiac cycle and negative flow. No correlation has been found between total flow and positive flow.

CLINICAL CORRELATIONS

This study correlates the importance of analyzing flow with different methods and confirms all the basic knowledge of pathology of flux in carotids artery stenotic disease. These preliminary results highlight the importance of 4D flow analysis on different anatomical sites. Really few studies have been performed on districts other than heart. More patients need to be analysed in order to determine a strong pattern, also in other sites such as proximal Internal Carotid Arteries. Anyway, it is significative also in such a small number of patients how only the negative flow correlates with the analyzed geometrical values, implying factors other than flow in progression of blood in stenotic patients, such as a cardiac diastolic contribution.
Fig. 2: wall shear stress left carotid

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References


