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Combination 3D TOP with 2D PC MRA Techique for Cerebral Blood Flow Volume Measurement

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Abstract— **Purpose: To demonstrate the discrepancy of cerebral blood flow volume (BFV) estimation with 2D phase-contrast (2D PC) MRA guided with 3D time-of-flight (3D TOF) MR localization by using an "internal" standard. Materials and methods: 20 groups of the common (CCA), internal (ICA), and external (ECA) carotid arteries in 10 healthy subjects were examined with 2D PC MRA guided by 3D TOF MR angiograms. The sum BFV of the internal and external carotid arteries was then compared with the ipsilateral common carotid artery flow. An accurate technique would demonstrate no difference. The difference was therefore a measure of accuracy of the method. Results: 3D TOF MRA localization is presented to allow the determination of a slice orientation to improve the accuracy of 2D PC MRA in estimate the BFV. By using the combined protocols, there was better correlation in BFV estimate between the sum of ICA+ECA with the ipsilateral CCA (R^2 = 0.729, P = 0.000). The inconsistency (mean±SD) was found to be 6.95±5.95% for estimate the BFV in ICA+ECA and ipsilateral CCA. The main inconsistency was contributed to the ECA and its branches. Conclusions: Guided with 3D TOF MRA localization, 2D PC MRA is more accurate in the determination of blood flow volume in the carotid arteries.**

Keyword—**Cerebral Blood Flow, Quantification, Phase Contrast, Three-Dimensional Localization, Magnetic Resonance Imaging.**

I. INTRODUCTION

PHASE-CONTRAST magnetic resonance angiography (PC MRA) flow quantification can non-invasively determine vascular velocities and blood flow volume (BFV) for in vitro and in vivo [1-6]. In addition, this technique can be added to morphologic MRI sequences, offering the option to correlate flow to morphologic based on data generated during one examination [5]. However, using PC MRA, considerable differences in total cerebral blood flow have been found in healthy volunteers [6]. These differences could be whether lack of accuracy and reproducibility of the method or biologic variation probably [5], are still unclear. The major reasons for the difficulty to clarify the differences include the lack of the standard protocol for cerebral blood flow volume measurement resulting in different data from healthy volunteers in the published literature; also that most of the investigations could not overcome the curved-flow effect of the carotid vasculature [5,9]. The aim of this study is to establish a precise method for quantification the carotid arterial flow by combining 3D TOF (as localizers) and PC MRA technique (for quantification of blood flow).

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II. METHODOLOGY

The BFV estimates of 20 groups of extracranial carotid arteries were obtained with 2D PC MRA combining 3D TOF MRA technique in 10 healthy subjects (2 men and 8 women, age range 30 to 50 years old). This study was performed based on the assumption that total BFV of the internal carotid artery (ICA) and external carotid artery (ECA) was equal to that of the common carotid artery (CCA). Any measurement of their difference would then reflect the inconsistency of the imaging technique applied.

MRI technique:

All 3 blood vessels (ie, CCA, ICA, and ECA) of the 20 groups of extracranial carotid arteries were examined on a 1.5T MR whole-body system (Signa cv/I; GE Medical Systems, Milwaukee, Wis) running 8.2.5 software with an optimized 2D cine PC-venc MR sequence and 3D TOF MR arteriogram of cervical arteries with spinal vascular sequence. The MR imaging was performed using a body coil as transmitter and a cervical coil as receiver.

3D TOF MR arteriogram of cervical arteries (pulse sequence: Vasc TOF SPGR; Mode, 3D) was performed in all subjects as localizers. The parameter included: TR/TE, 26/6-9; flip angle, 20^0; bandwidth, 5.63; FOV, 28cm; slice thickness, 2.4mm; overlap, 5mm; matrix, 256x128; Nex, 1.0; locs per slab, 20; acquisition time, 5 min 46 sec. The bilateral CCA, ICA and ECA were shown respectively on 3D TOF images. Subsequently, the positions of PC MRA scan planes were placed at least 2cm lower the bifurcation for bilateral CCA, and 2cm higher bifurcation for bilateral ICA and ECA. Each slice was set carefully perpendicular to the straight, long segments of interest vessels as more as possible to minimize partial volume and displacement artifacts. The 3D TOF MRA imaging should be rotated for localizing the scan plane properly if necessary (Fig.1). The total scan plane slices were 2 to 4 planes depending on whether the vessels of interest were parallel or not.

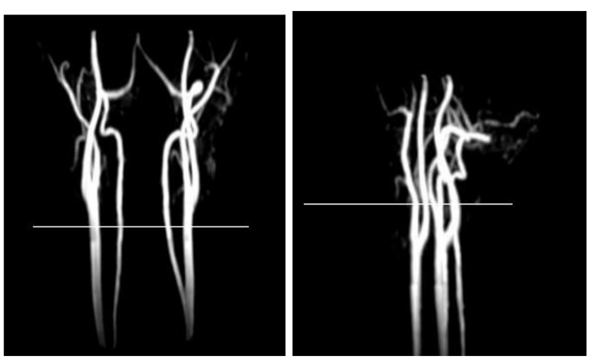


Fig. 1. 3D TOF MRA localizition of cervical vasculature allows rotating to set the 2D PC MRA scan slice perpendicular to the ROI.

Single-slice triggered 2D-PC MRA of bilateral CCA, ICA, and ECA were performed using the following parameters: TR, 40ms; TE, 7.496ms; flip angle, 15^0; Nex, 1.0; receiver bandwidth, 15.63; FOV, 16-18cm; matrix, 128×256; slice thickness, 4mm. The velocity enconding (Venc) was 80 cm/sec, which was referenced our previous study [9]. Gating was performed retrospectively with a peripheral pulse unit. The acquisition time for each slice was 3 min to 3 min 40 sec depending on the subject's heart rate. A total of 30 phases were resolved over the cardiac cycle on the triggered acquisition.

Flow and velocity measurements were analyzed using CV Flow software on a GE Advantage Windows Workstation (4.0). In this analysis a ROI was manually drawn around the vessel of magnitude image in all heart phases to be sure that the analysis program allowed ROI shape and position to be more adapted for each phase of the cardiac cycle. The blood flow volume of the left and right CCA, ICA, and ECA for all subjects were obtained.

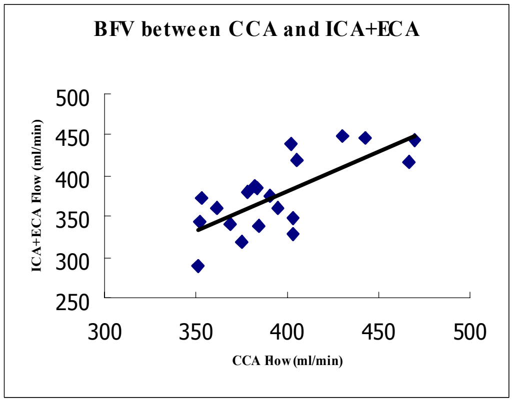
The sum of BFV of ICA and ECA on each side was compared with that of the ipsilateral CCA. The inconsistency was expressed as the percent difference between the sum of ICA and ECA BFV estimates and that of the CCA. It was calculated by subtracting the total ICA and ECA blood flow by the ipsilateral CCA flow. The absolute difference was then divided by the CCA flow and expressed as a percentage. The paired ***t*** test was used to compare the correlation between CCA flow and sum of flow in ICA+ECA, ICA, and ECA, respectively. The significance level was taken at $\boldsymbol{P}<0.01$. The ratio of ICA to CCA flow was also counted.

III. RESULTS

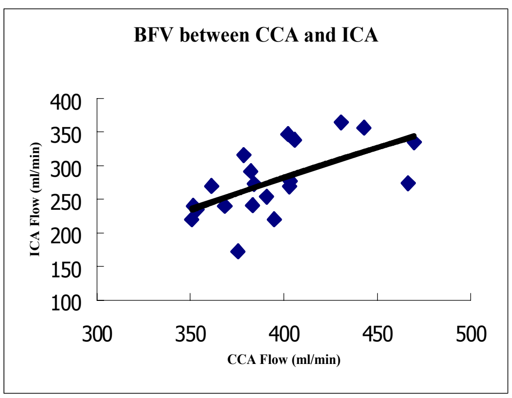
The BFV estimates of 20 groups of carotid arteries were successfully obtained from 10 healthy subjects with PC MRA guided by 3D TOP MRA localizations. In total, BVF of 73 arteries (including 13 ECA branches (ECAb) were measured by PC MR protocol. In 3D TOF MRA localizers, 9 ECAb were found in all of the 20 groups of adown to opposite direction of the ECA stems. The percent inconsistency of the BFV between CCA and its branches(ICA+ECA) was no significant (t=1.405, $P = 0.168$). There was better correlation for BFV between the CCA with the sum of ICA and ECA ($R^2=0.729$, $P = 0.000$) (Fig 2 A, B, C).

IV. DISCUSSION

In the current study, a 3D TOF localization technique was developed to determine optimal arterial segments and slice orientations for cervical vasculature. This technique constructed the cervical arterial tree automatically based on MRA images. This 3D TOF structure was used to identify and facilitate perpendicular cuts during scanning and to



A



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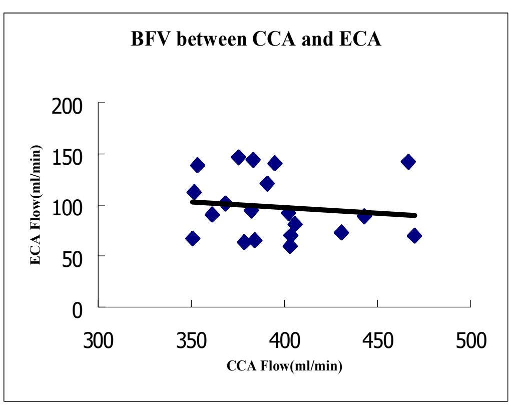

C

Fig 2. The correlation of BFV between CCA with ICA+ECA (A), CCA with ICA (B), and CCA with ECA (C). A showed relatively correlation well between CCA with ICA+ECA (R^2=0.729, P=0.000); B showed a better correlation between CCA with ICA (R^2=0.6623, P=0.002); and C showed no correlation of BFV between CCA with ECA (R^2=0.3457, P=0.147). (Fig. 2A). There was also correlation in BFV between CCA and ICA (R^2=0.6623, P = 0.002) (Fig. 2B). However, there was no correlation in BFV between the CCA with ECA (R^2=0.3457, P = 0.147) (Fig. 2C).

distinguish specific arterial branches during flow quantification. 3D TOF localization of the vascular tree for the external carotid vasculature yields a 2D PC MR image with the vessel of interest becoming simple to identify. A technician can easily and accurately identify the vessel of interest and set the slice of orientation from the 3D vasculature image. Combining 3D TOF MRA protocol with 2D PC MR images, in the current study, the average inconsistency of BFV between CCA and its branches (ICA+ECA) was about 7% (mean ± SD, 6.95 ± 5.95%). Compared with previous Doppler ultrasonographic study [8], in which the inconsistency of BFV between CCA and ICA+ECA was found to be 10.6±8.3% for CVI and 27.9± 14.3% for SDI, our results in this study by 2D PC MR with guided 3D TOF localization techniques were more precise. The well-documented limitations of Doppler ultrasound include its operator dependency and overestimation of total blood flow in a given vessel due to the fact that only the highest flow in the center of the vessel is assessed with erroneous diameter measurement [1, 8]. Furthermore, only the BFV in ICA and ECA was estimated within 2cm above the bifurcation by Doppler US in the previous study [8]. The branches of ECA proximate to the bifurcation were ignored. In the current PC MRA study, we found 13 (65%) of the total 20 ECAs had branches within 2cm above the bifurcation. Our results were consistent with recent study of cadavers, in which the superior thyroid artery arose from the anterior wall of the ECA close to the bifurcation in 70% of specimens [13].

(a) Limitations

The accuracy of MR phase contrast volume flow measurements in small blood vessels is expected to be smaller than in large vessels, because of partial volume effects at the vessel boundary [2]. In this study, the main reasons of the inconsistency for estimating the BVF between CCA and sum of ICA+ECA were contributed to ECAs with branches and their variances (Fig3 A, B, C).

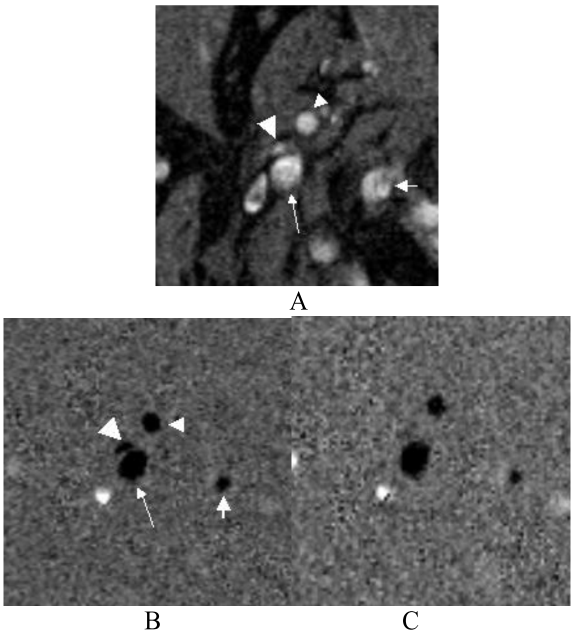

Fig 3 The magnitude (A) and the corresponding phase (B,C) images showed right side of cervical vessels at the 2 cm above bifurcation in subject 10 (long arrow, ICA; short arrow, VA; small arrowhead, ECA, and large arrowhead, ECAb). During the systolic phase (B), the ECAb was clearly visualized as a elliptical dark spot, indicated the scan slice was not perpendicular to ECAb. After systolic phase (C), the ECAb was not visible due to low velocity of blood flow in this ECAb.

V. CONCLUSION

Despite the limitations mentioned above, by combining 3D TOF MRA and 2D PC MRA technique, there was not significant difference of BFV estimate between CCA and its branches. Furthermore, the BFV in (ICA+ECA) was strongly correlated with BFV in CCA. The average inconsistency of BFV in CCA and its branches (ICA+ECA) was about 7% in this study. The protocols in the current study are inadaptable to BFV estimates in ECA and its branches due to partial volume (small vessel), slow flow, and anatomic variances. The BFV in CCA was predominantly determined by ICA (mean $\pm$ SD, 69.97$\pm$10.30%). The protocol combining 2D PC MRA flow volumetric estimate with 3D TOF MRA localization may be a preferred technique for blood flow measurements in cerebrovascular diseases.

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