ORIGINAL ARTICLE

Imaging–anatomic Measurements of Carotid Artery Bifurcation

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ABSTRACT

Objective: *To have anatomic measurements of carotid artery bifurcation (CAB) with 64-spiral computed tomography angiography (64-SCTA), and provide anatomic basis for related research.*

Methods: *Imaging data of 92 subjects (45 males, 47 females, the age range 20–82 years and mean age 48.4 ± 6.1 years) without pathology of CAB, who underwent 64-SCTA in head and neck from June 1, 2008 to June 30, 2010, were selected from the Picture Archiving and Communication Systems in Zhongshan Hospital of Xiamen University, Fujian, China. On the 3D images, the angle and size of CAB were measured, and the statistical comparisons of measurements were made between the bilateral, sex and age groups.*

Results: *The measurements of CAB were divided into young (≤ 40 years) and older (> 40 years) groups: bifurcation angle is 36.206° ± 10.210° and 49.343° ± 16.489°, respectively; the inner diameter of common carotid artery (CCA) is 6.820 ± 0.635 and 6.845 ± 0.838 mm, respectively; the proximal inner diameter of internal carotid artery (ICA) is 7.143 ± 0.992 and 7.476 ± 1.630 mm, of the enlargement is 7.568 ± 1.069 and 8.554 ± 1.733 mm, of the distal is 4.897 ± 0.508 and 5.123 ± 0.699 mm, respectively; the inner diameter of external carotid artery (ECA) is 4.324 ± 0.580 and 4.104 ± 0.638 mm, respectively. There were statistically significant differences in all the measurements between male and female groups, in the bifurcation angle, inner diameters of ICA and ECA between young and older groups, and in the bifurcation angle between the left and right ($p < 0.05$).*

Conclusion: *A 64-SCTA with 3D image post-processing technique can clearly observe and show the CAB. All CAB measurements will provide the objective basis for applied anatomy, imaging diagnosis and surgery treatment.*

Keywords: Carotid artery bifurcation, imaging anatomy, measurement, three-dimensional computed tomography.

INTRODUCTION

Blood supply to the brain originates from the internal carotid artery (ICA) and vertebral artery, of which the ICAs mainly supply to the anterior 2/3 of brain hemisphere and part of the diencephalon. Studies found that carotid artery bifurcation (CAB) is the predilection site for many diseases, such as carotid atherosclerosis, carotid artery aneurysm, carotid body tumour and so on. Its structure or morphology is easy to be affected by the local neurogenic tumour or lymphadenopathy and to directly influence the local blood flow of brain (1–3). Therefore, this study is to measure the CAB with the 64-slice spiral computed tomography (CT) angiography (64-SCTA), and the anatomic data will provide the objective basis for further basic and clinical study on the CAB.

MATERIALS AND METHODS

General information

A total of 92 subjects (45 males, 47 females; age range 20–82 years, mean 48.4 ± 2.5 years), who performed the 64-SCTA (the CAB without vascular lesion or pushing, impinging by other pathological changes of surrounding structures), were selected from the *Picture Archiving*

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and Communication Systems in Zhongshan Hospital of Xiamen University, Fujian, China, between June 1, 2008 and June 31, 2010. The two groups were divided, including 40 cases in the ≤ 40 years and 52 cases in the > 40 years. Their scanning data were used to form the 3D images again for the CAB measurements.

Equipment and technique

Sixty-four-slice spiral CT (GE LightSpeed VCT, Beijing, GE Healthcare in China), contrast medium (Omnipaque 300 mgI/ml, Shanghai Affiliate Corporation of GE) and high-pressure syringe (MCT-plus, PGH. or Stellant, USA) were used. Examination process includes the following steps:

(1) **Ascertainment of delayed scan time:** CT pre-scan with low-dose (120 KVp, 30 mA) was automatically started after Omnipaque 20 ml (A tube) + normal saline (NS) 10 ml (B tube) were injected into anterior elbow vein with the rate of 4.0 ml/sec for 8–10 seconds. By using the scan data, the time–density curve of intravascular contrast medium at the ICA and peak time were obtained. The peak time plus 4–6 seconds is the delayed scan time.

(2) **Scanning parameters and technique:** Scanning sequences ranged from carotid artery root (including part of aortic arch) to the top of skull (including the superior sagittal sinus). The parameters included tube voltage of 120 KVp, tube current of 250 mA, pitch of 0.984 or 1.375 and slice thickness of 0.625 mm. Omnipaque 80–90 ml + NS 20 ml were injected into anterior elbow vein with the high-pressure syringe with 4.0 ml/s, then the two-phase CTA scan was started according to the delayed scan time.

(3) **Image process:** Above scanning data were transferred to AW4.2 workstation, then 3D images were obtained with 3D imaging of separating, fusing, opacifying and false-colouring volume rendering (SFOF-VR), multiple planar reconstruction (MPR), and maximum intensity projection (MIP). Finally, the anatomic measurements of CAB were done on the VR, MPR and MIP, and their mean act as our measurement (4).

(4) **Measurement parameters and statistics:** Measurements of CAB (Fig. 1)： the angle of CAB (α) is the biggest angle of the centre line between ICA and external carotid artery (ECA). The diameter of common carotid artery (CCA) is the location at 1.5 cm below bifurcation (A). The diameters of ICA include that of the proximal (B), the enlargement (C) and the distal (D). The diameter of ECA is the location at 1.5 cm above bifurcation (E). Statistical comparisons were carried out using the *t* test with SPSS 16.0 software.

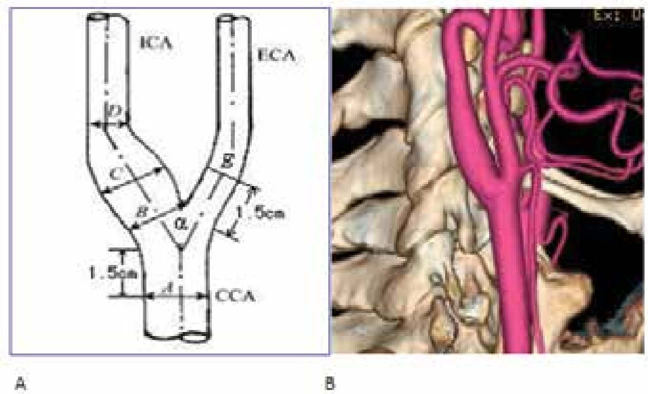

Fig. 1 (A) Measurement of CAB. α: the angle of carotid bifurcation; CCA: common carotid artery; ICA: internal carotid artery; ECA: external carotid artery; A: diameter of CCA (about 1.5 cm below bifurcation); B proximal diameter of ICA; C: width of ICA enlargement; D: distal diameter of ICA; E: diameter of ECA (about 1.5 cm above bifurcation). (B) SFOF-VR image displaying the CAB structure and relation between CAB and surrounding structures.

RESULTS

Technique assessment

All the examination parameters were integrated, and the subjects' blood vessels were filled very well by the contrast medium. Three-dimensional spiral CT images clearly showed the structures of CAB and surrounding structure without obvious artefact, and then magnetic resonance angiography (MRA) or digital subtraction angiography (DSA) images with some shortage (Figs. 2–4).

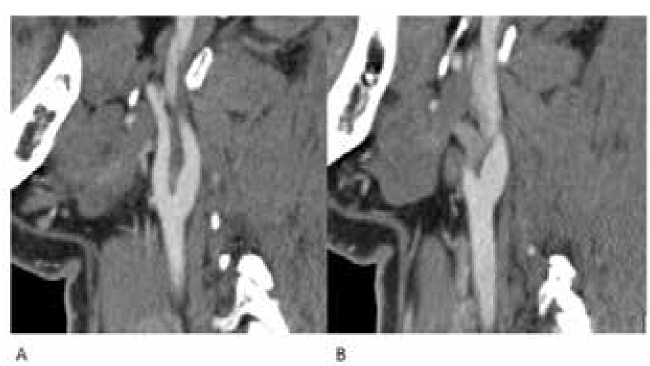

Fig. 2: MPR images clearly displaying the CAB structure and the measuring locations: (A) measured the ICA and ECA; (B) measured the CCA.

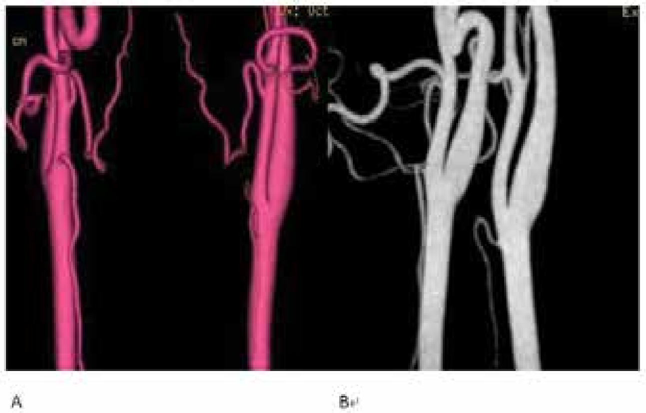

Fig. 3: SFOF-VR image can independently delineate carotid bifurcation anatomy, without the interference of surrounding structures (A). SFOF-MIP image can clearly and directly delineate the calcification of vascular wall (B).

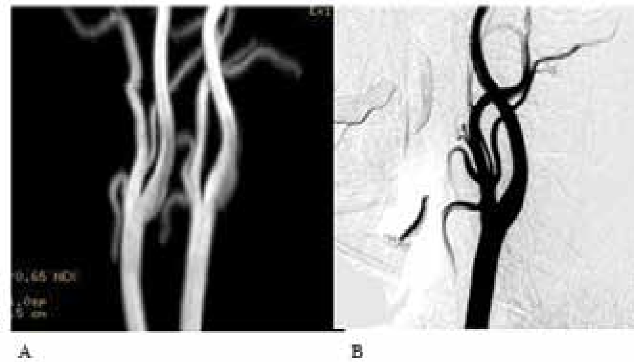

Fig. 4: Three-dimensional time of flight-MRA image can only display CAB anatomy itself, not displaying its surrounding structures, and flow-related signal loss easily lead to the distortion of local anatomy (A). As two-dimensional angiography, DSA can only show vessels themselves, and cannot show three-dimensional relationship between vessels and their surrounding structures (B).

The measurements about CAB

The bifurcation angle ranges from 21.3° to 87.6°, and the inner diameter of CCA from 4.9 to 9.3 mm. The proximal inner diameter of ICA ranges from 4.5 to 13.5 mm, that of the enlargement from 5.3 to 13.5 mm and that of the distal from 3.6 to 7.4 mm. The inner diameter of ECA ranges from 2.7 to 5.6 mm. Measurement data and comparisons are shown in Tables 1–3.

Statistical results

There were significant differences in all the measurements between males and females, in the bifurcation angle, inner diameters of ICA and ECA between young and older groups, and in the bifurcation angle between the left and right ($p < 0.05$).

Table 1: Comparison of measurements between young (40 cases) and older (52 cases) groups

Measurement parameters	a (˚)	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)
≤ 40	36.2 ± 10.2	6.82 ± 0.64	7.14 ± 0.99	7.57 ± 1.07	4.90 ± 0.51	4.32 ± 0.58
＞40	49.3 ± 16.5	6.85 ± 0.84	7.48 ± 1.63	8.55 ± 1.73	5.12 ± 0.70	4.10 ± 0.64
t	6.260	0.224	1.430	4.474	1.676	2.407
p	< 0.05	> 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Table 2: Comparison of measurements between male (45 cases) and female (47 cases) groups

Measurement parameters	a (˚)	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)
Male	46.1 ± 15.9	6.98 ± 0.83	7.77 ± 1.48	8.51 ± 1.42	5.19 ± 0.67	4.35 ± 0.67
Female	41.3 ± 14.9	6.70 ± 0.65	6.81 ± 1.11	7.75 ± 1.60	4.86 ± 0.55	4.06 ± 0.54
t	2.144	2.561	4.996	3.404	3.645	3.271
p	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Table 3: Comparison of 92 cases measurements between the left and the right

Measurement parameters	a (˚)	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)
Left	47.4 ± 16.79	6.79 ± 0.74	7.40 ± 1.52	8.33 ± 1.59	5.05 ± 0.68	4.22 ± 0.64
Right	39.83 ± 13.3	6.88 ± 0.77	7.16 ± 1.23	7.92 ± 1.51	4.99 ± 0.59	4.18 ± 0.60
t	3.420	0.751	1.182	1.781	0.558	0.485
p	< 0.05	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05

DISCUSSION

Research significance

There are some reports of studies on the regional anatomy of CAB by DSA, MRI and ultrasound (US), and these observations and measuring results have been broadly applied (3, 6). Though the measurements can provide good value for basic research or clinical application, there are some differences among the measurements that influence from technique. In this paper, we used the 64-SCTA scan and 3D post-processing techniques to study the CAB in vivo: first, it can act as a new means for anatomic research, and the next the anatomic measurements can reflect the physiological condition of CAB and possess the characteristic of objectivity. If the measurements of the patient were done before operation, the obtained measurements are individual. While doing the anatomic measurements on the cadaver specimens, we found that there are some deficiencies, which are due to conditionality of the cadaver specimens, and the measurements cannot reflect the physiological function of CAB. At the same time, there is some impact on the accuracy of measurements for the anatomic technique and objective factors of the cadaver specimen (7–9). With the images of 64-SCTA, it clearly demonstrates the CAB and the surrounding anatomy bone structure, vein and soft tissues. Obtained measurements can objectively reflect the structure of CAB and the 3D relation to the surrounding structures, and make up for a lack of the other imaging technology. In view of the above advantages, the 3D imaging anatomic measurements can provide reliable basis for disease diagnosis and surgical plan.

Structures and shape of CAB

Internal carotid artery is the main vessel to sustain the blood supply of brain. There are few studies about the relation between CAB structure and function (10–16), which include the study on CAB anatomic structure and measurement with multi-imaging techniques, blood fluid dynamics change, and to answer why CAB is easy to form the atherosclerosis and to cause secondary vascular stenosis resulting in ischemic cerebrovascular disease, and so on. Our results indicated that there were statistically significant differences in the measurements of CAB between males and females, young and older groups, which is in accordance with other previous reports (3, 7, 14); when it comes to the CAB bifurcation angle difference between those under the age of 40 years and those aged more than 40 years group, the former is smaller than the latter, this could be due to arterial expansion, which is tortuous, and the changes of vessel elasticity and wall thickness that occur with the advancing age. Regarding male and female subjects, the differences in anatomic parameters measurement values were statistically significant ($p < 0.05$), and males are bigger than females in anatomic measurements and this may be attributed to the male's body type being larger than that of the female's. In addition, there was significant difference in the left and right CAB bifurcation angle and the left is greater than the right; therefore, the reason should be explored further. However, it will provide an objective basis for the future clinical research or application about the CAB. At the same time, when doing the therapeutic or functional simulation, the anatomy of individual differences must be taken into account. In addition, there is larger variability of CAB angle, the upper limit is 87.6° and the lower limit 21.3°. Therefore, it will cause a false positive for us to simply rely on the bifurcation angle expansion to judge the CAB lesion, so radiology must be combined with the cross section of the original image and have a comprehensive analysis in order to improve the diagnostic rate and reduce the rate of misdiagnosis when diagnosing the CAB lesions.

Comparison of imaging techniques

There are many imaging methods in clinical application on diagnosis of the CAB diseases, such as DSA, MRA, CTA and US. Digital subtraction angiography examination is the gold standard and has high specificity and sensitivity; however, it is expensive, invasive, time-consuming and is associated with possible complications. Moreover, DSA images just show vascular cavity structure, not vascular wall and surrounding structure, which may result in certain limitations for diagnosing the diseases of the wall or out of the wall. Ultrasound examination is a very cheap technique on vascular lesion and has widely been applied on the CAB; it can be used to make the anatomical morphology observations and blood flow measurement in real time. However, there are some deficiencies of low resolution image, affected by doctor's manipulation and patient's bloodstream (8–10). Magnetic resonance angiography is extensively used to diagnose the diseases of the CAB, but it is sensitive to the regional flow and cause signal loss for the region of swirl or slow flow. The imaging technique of 64-SCTSA has the characteristics of high specificity, sensitivity and quality of image. With the development of 3D imaging, the separation of target vascular or bone with different colours can be accomplished and their fusion is also possible to have the observation or measurement from any angle, which can provide further detailed anatomic data for clinical surgery. There are some reports that indicated diagnostic accuracy of 64-SCTA is similar to that of DSA in diagnosing the vascular diseases and 64-SCTA is confirmed broadly by clinical physician (8–10).

Clinical application and disadvantages

64-SCTA is a new valuable imaging technique to assess the CAB anatomic structure. It is non-invasive with the objective and individual characteristics which not only shows vascular cavity structure, but also the changes of vascular wall and surrounding structures. 64-SCTA is very helpful in evaluating CAB stenosis degree and plaque stability, and providing more messages for clinical diagnosing and treating，such as plaque rupture, haemorrhage, thrombosis，calcification，reg ional aneurysms, and so on. Moreover, 64-SCTA can define the lesion from the vascular wall or from pressuring of outside structures, which can give basis for differential diagnosis on the CAB lesions and identify the increasing causes of bifurcation angle with combined cross-sectional original image information and multidirectional observation. By measuring the CAB or showing the 3D relation between CAB and lesions, or the carotid artery contour and fat space, we can judge if the mass impinges on carotid artery and provides basis for designing the vascular stent or surgery plan (17–20). There are some shortcomings in this research; for example, we did not consider the bifurcation structure changes due to the influence of blood lipids, blood pressure, blood glucose, smoking, drinking and other. In addition, the sample size of study subjects is small, and it is necessary to conduct multicentre studies with larger sample sizes and statistics to reveal the anatomic features of Chinese normal CAB.

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