Turkish Journal of Vascular Surgery 2020;29(3):170-176

DOI: 10.9739/tjvs.2020.710
www.turkishjournalofvascularsurgery.org

Original Article

Evaluation of carotid bifurcation level and diameters with postoperative outcomes in patients undergoing carotid endarterectomy

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ABSTRACT

Objectives: This study aims to investigate the association of common carotid artery bifurcation level, neck length, and carotid artery diameters with postoperative outcomes in patients undergoing carotid endarterectomy (CEA).

Patients and methods: We retrospectively analyzed the computed tomography angiography (CTA) scans of a total of 107 patients (80 males, 27 females; mean age 69.0±9.6 years; range, 48 to 92 years) who underwent CEA between January 2012 and April 2018. The carotid artery bifurcation level was identified according to the cervical vertebrae and compared with the patient's neck length and internal, external, and common carotid arteries.

Results: The mean level of the right carotid artery bifurcation was 3.7±0.54 in females and 4.03±0.74 in males (p=0.019). We found a significant, positive correlation of the female sex and right carotid artery bifurcation level (p=0.042) with both internal carotid artery diameters.

Conclusion: Our study results suggest that a preoperative rigorous examination of CTA scans and planning surgery are essential components to prevent undesirable surgical complications in patients undergoing CEA.

Keywords: Anatomic variation, carotid artery, endarterectomy.

Atherosclerotic plaque formation of the carotid artery is influenced by the vessel anatomy which leads to stenosis and senile changes, mostly in the carotid bifurcation (CB).[1,2] Carotid artery stenosis is one of the main causes of stroke, and carotid endarterectomy (CEA) is the standard treatment method which reduces the risk of stroke. It is recommended for symptomatic and asymptomatic patients who are younger than 75 years old and have more than 70% carotid artery stenosis according to the North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria.[3]

The carotid arterial system has numerous anatomic variations which should be recognized during angiographic imaging and surgery. Preoperative identification of the CB level and choosing the most optimal surgical approach for each individual patient are essential to reduce perioperative morbidity and mortality.[4-7] The CB can vary between the styloid process and the cricoid cartilage, and splits at the superior margin of the thyroid cartilage, which is commonly located between the level of C3-4 and C4-5 vertebra; however, the common carotid artery (CCA) may be absent in some cases.[8,9]

Although there are many studies regarding the CB level and surgical outcomes in the literature, there is a very limited number of studies investigating the anatomy of CB level and diameters. In the present study, therefore, we aimed to examine the association of CCA bifurcation level, neck length, and carotid artery diameters with postoperative outcomes in patients undergoing CEA.

Received: March 23, 2020 *Accepted:* April 23, 2020 *Published online:* June 16, 2020

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Citation:
Deşer SB, Demirağ MK. Evaluation of carotid bifurcation level and diameters with postoperative outcomes in patients undergoing carotid endarterectomy. Turk J Vasc Surg 2020;29(3):170-176

PATIENTS AND METHODS

In this single-center, retrospective study, a total of 120 patients were diagnosed with symptomatic and asymptomatic internal carotid artery (ICA) stenosis and operated in our clinic between January 2012 and April 2018. Of these patients, 107 (80 males, 27 females; mean age 69.0±9.6 years; range, 48 to 92 years) were eligible to be included. Treatment indication for symptomatic and asymptomatic patients was ≥50% stenosis and ≥70% stenosis of the ICA, respectively, according to the NASCET criteria.[3] Patients who underwent simultaneous CEA with a carotid body tumor, patients who were screened at an external center, having redo CEA, and simultaneous CEA with coronary artery bypass grafting were excluded from the study. All demographic and clinical data, and postoperative outcomes of the patients were retrieved from the hospital database. A written informed consent was obtained from each patient. The study protocol was approved by the Ondokuz Mayıs University, Faculty of Medicine Institutional Review Board (OMU KAEK 2018/26). The study was conducted in accordance with the principles of the Declaration of Helsinki.

The ICA stenosis was initially diagnosed by carotid artery color Doppler ultrasound and then confirmed by computed tomography angiography (CTA) according to the NASCET criteria.[3] The CTA was performed in the standard anteroposterior position using a 16 multi-detector computed tomography scanner (Aquilion™ 16 system, Toshiba Medical Systems Corp., Ottawa, Japan). The CB level was identified according to the cervical vertebrae and neck length. The latter was measured according to mandibular angle and middle of the clavicle on the coronal plane of angiographic views (Figure 1).[10] The variations at the level of bifurcation of the CCA were noted. In addition, the widest diameter of the ICA, external carotid artery (ECA) and CCA were measured bilaterally. Conventional longitudinal endarterectomy with Dacron®/saphenous patch closure or modified eversion endarterectomy techniques were performed in all patients. Standard exposure techniques were used for high and low bifurcation levels.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 21.0 software (IBM Corp., Armonk, NY, USA). Continuous variables were expressed in mean ± standard deviation (SD) or median (min-max), while categorical variables were expressed in number and frequency. The Kolmogorov-Smirnov test was used to analyze normally distributed continuous variables. The independent sample t-test was used to compare the means of dependent groups for the CB level, neck length, and diameters. The categorical data were analyzed using the chi-square test or Fisher's exact test for the carotid artery level, affected side, and sex. The Pearson correlation analysis was used to evaluate possible correlations between variables. A p value of <0.05 was considered statistically significant.

RESULTS

Among the patients, the mean age was 67.6±9.8 (range, 48 to 84) years in females and 69.5±9.6 (range, 48 to 92) years in males, indicating no statistically significant difference (p=0.381). The CB level was distributed between the C3 and C5 vertebrae. No absence of CB was observed in any of the patients (Table 1).

The CB level was most frequently seen at the level of C4 (42%) in the right side and at the level of C4 (52.3%) in the left side, indicating no statistically

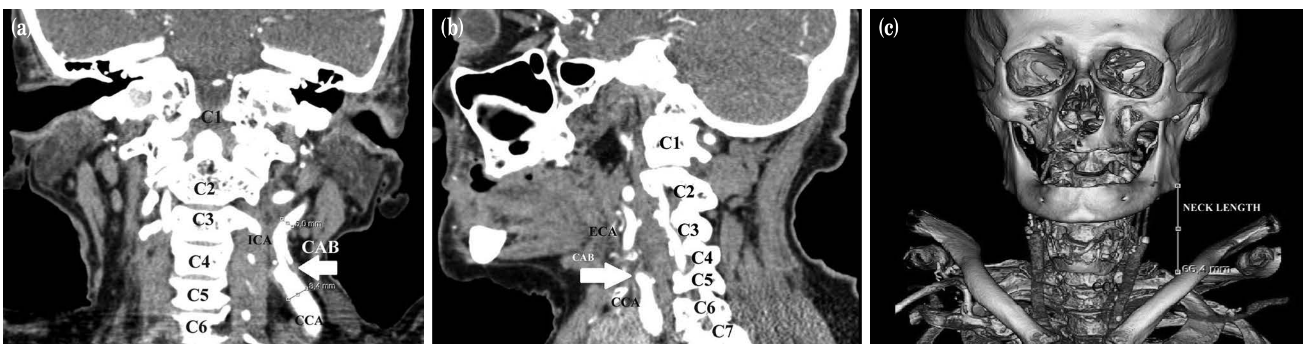

Figure 1. A coronal view of the cervical vertebra and measurement of common carotid artery and internal carotid artery on computed tomography angiography of a patient. **(a)** A sagittal view of the cervical vertebra on computed tomography angiography of another patient. **(b)** Measurement of neck length of a patient. **(c)** External carotid artery.

ICA: Internal carotid artery; CAB: Carotid artery bifurcation; ECA: External carotid artery; CCA: Common carotid artery.

Table 1. Baseline data of patients

	Males (n=80)			Females (n=27)			
	n	%	Mean±SD	n	%	Mean±SD	*p*
Age (year)			69.5±9.6			67.6±9.8	0.381
Right ICA stenosis (%)			49.8±27.9			47.6±36.1	0.843
Left ICA stenosis (%)			52.9±32.1			54.1±27.4	0.832
Stenosis ipsilateral to CEA			85.7±8.6			77.8±5.7	0.362
Operation side (right)	45	56		13	48		0.533
Operation side (bilateral)	5	6.2		2	7.4		1
Preoperative neurologic symptoms	20	25		7	25.9		1
Diabetes mellitus	57	71.2		19	70		1
Hypertension	42	52.5		13	48.1		0.824
Coronary artery disease	43	53.7		14	51.8		1
Chronic obstructive pulmonary disease	9	11.2		3	11.1		1
Peripheral arterial disease	16	20		6	22.2		0.788
Smoke	18	22.5		7	25.9		0.817
Hemoglobin (g/dL)			13.5± 1.56			13.3±1.58	0.51
Hematocrit (%)			43.09±5.9			42.24±4.34	0.27
Creatinin			0.94±0.48			0.94±0.33	0.354
Hyperlipidemia	17	70.8		110	73.8		0.330

SD: Standard deviation; ICA: Internal carotid artery; CEA: Carotid endarterectomy.

significant difference between the both sides in terms of sex (p=0.162 and p=0.872, respectively). However, females had a higher rate of C3 levels (p=0.013) on both sides. In addition, a significant difference was found between two sexes (p=0.004) at the level of C5 in favor of males on the right side.

The mean level of the right CB was 3.8±1.7 (range, 3 to 5) in all patients. In addition, the mean level of the left CB was 3.7±4.8 in females and 3.8±0.6 in males (p=0.179). The mean level of the right CB was 3.7±0.5 in females and 4.0±0.7 in males (p=0.019) (Table 2).

We also compared the symmetricity of the CB levels between the sexes. The CB was symmetrical at the level of C3 in 25.9% and at the level of C4 in 51.8% of females. The level of CB was symmetrical at the level of C3 in 20%, at the level of C4 in 30%, and at the level of C5 in 10% of males. No significant difference was found in the symmetricity at the level of C3 (p=0.52) between males and females; however,

Table 2. The distribution of the carotid artery bifurcation levels of patients

	Female (n=27)				Male (n=80)				Total (n=107)			
	Left side		Right side		Left side		Right side		Left side		Right side	
	n	%	n	%	n	%	n	%	n	%	n	%
C3	16	59.2	16	59.2	26	32.5	22	27.5	42	39.3	38	35.5
C4	11	40.8	11	40.8	45	56.2	34	42.5	56	52.3	45	42
C5	0	0	0	0	9	11.3	24	30	9	8.4	24	22.5

Table 3. The symmetricity of the carotid bifurcation levels

	Females (n=27)		Males (n=80)		Total (n=107)	
	n	%	n	%	n	%
C3	7	25.9	16	20	24	22.4
C4	14	51.8	24	30	35	32.7
C5	0	0	8	10	8	7.4

we found a significant difference at the level of C4 (p=0.04) in favor of females (Table 3).

The mean length of the neck was 7.8±1 (range, 5.9 to 10.5) cm in all patients. The mean length of the neck was 7.4±1.7 (range, 5.1 to 10.5) cm in females and 8.0±1.5 (range, 5.6 to 10.1) cm in males. The mean length of the neck was shorter in females (p=0.038).

The neck length was positively correlated with both right and left CB level (p=0.042 and p=0.044, respectively) in all patients; however, no significant correlation was found with the age (p=0.593). Nevertheless, we found a significant, positive correlation with the female sex and right CB levels (p=0.042), right ICA diameter (p=0.06), left ICA diameter (p=0.05), right CCA diameter (p=0.012), left CCA diameter (p=0.003), and left ECA diameter (p=0.045). In addition, we found a statistically significant, positive correlation between the right and left CB levels in all patients (p=0.01). A significant, positive correlation was also noted between the right CB level and right CCA and right ICA diameter (p=0.03 and p=0.045, respectively) and between the left CB level and left CCA and left ICA diameter (p=0.03 and p=0.018, respectively). A significant, positive correlation was found between the age and left ICA diameter (p=0.035).

On the other hand, there was no correlation between the neck length and operation side, preoperative symptoms, postoperative death, and bleeding, (p=0.552, p=0.213, p=0.84, and p=0.25, respectively). Postoperative stroke developed in three patients (2.8%); however, no significant correlation was found between the neck length and postoperative stroke (p=0.58). One patient (1.9%) died and we found a significant, positive correlation between right ICA diameter and postoperative death (p=0.048). No significant correlation was found between the operation side and postoperative death (p=0.39). In addition, there was no significant correlation between the higher CB level (C3) and postoperative stroke (p=0.057).

Postoperative cranial nerve paralysis was seen in six patients (5.6%) and we found a significant, positive correlation between the higher CB level (C3) and postoperative cranial nerve damage (p=0.033). The mean duration of operation was also longer in the patients with a higher CB level (C3) than the others (105.3±14.8 vs. 91.4±11.3 min, respectively; p=0.01).

DISCUSSION

The main objective of this study was to investigate the CB level and the carotid artery diameters and to identify its association with postoperative outcomes. In the present study, we found that a higher CB level (C3) was correlated with postoperative cranial nerve damage. The neck length was also correlated with both right and left CB level. The mean duration of operation was also longer in patients with a higher CB level (C3). The CB level was most frequently found at the level of C4, and females had a higher rate of C3 level. On the other hand, no significant correlation was found between the neck length and postoperative stroke, between the operation side and postoperative death and, between the higher the CB level (C3) and postoperative stroke.

The knowledge of the variations of vascular structures is extremely important to reduce the risk of complications. Despite numerous studies over many years, the anatomy of vascular structures is still to be researched. The significant variability of the shaping of the venous and arterial systems determines the constant need for reliable morphological studies in this field. In our study, we believe that such expectations were met, since we analyzed the issue of variations of carotid arteries and their association with postoperative outcomes in patients who underwent CEA. To the best of our knowledge, this is the first study to evaluate the relationship between the CB level, neck length and carotid artery diameters in terms of postoperative outcomes in patients who underwent CEA.

The level of CB is essential during CEA or neck surgery and, therefore, surgeons should be aware of the level of CB before surgery to prevent inadvertent devastating vascular injuries or cranial nerve injury.[9-12]

The level of CB was previously reported between C1 and T2.[13] The CCA and the proximal part of the ICA developed at the level of the third aortic arch, and the rest of the ICA developed from the cranial part of the dorsal aorta. Most authors have demonstrated that the CCA bifurcation is usually (58% of patients) located at the level of the superior border of thyroid cartilage, which is approximately the same level as the C4 vertebra.[9,14] Additionally, Gray[15] and Dilenge and Heon[16] reported that the CB was usually anatomically located at the level of C3-C4 vertebrae and angiographically C4 vertebrae. Our findings are consistent with this previous study reporting that CB was most frequently seen at the level of C4 in both males and females.

The alterations of the CB level have been usually reported in cadaver studies, carotid artery angiographic studies, some case reports or have been incidentally detected during neck and carotid surgery.[17] Zümre et al.[4] showed that CB was located in 55% of the fetus at the level of C3, 35% at the C4 level and 10% at the C5 level on the right side and 60% at the level of C3, 40% at the level of C4 on the left side. In addition, they observed no CB at the level of C5 on the left side.[4] Mcaffe et al.[18] dissected 140 cadavers and found no CB below the level of C3-C5.

In addition, some cadaver studies demonstrated that CB was located more superiorly due to several hypotheses. Those are the status of the patient's neck during death, post-mortem changes, and difficulty of the natural neck posture.[19,20] In this context, it would be more suitable to compare these studies with each other. In addition, the CB level is important during surgery for the exploration of the disease-free segment of the ICA for cross-clamping and arteriotomy. Thus, we consider that angiographic measurements in humans would yield more accurate results.

In a study, Toyota et al.[11] compared 147 Japanese patients versus 490 Hungarian patients and found that CB was more frequently seen at the level of C3 vertebrae in the Japanese cohort, whereas it was more frequently seen at the level of C4 vertebrae in the Hungarian population. Consistently, Hayashi et al.[21] reported that the level of CB was usually located at the level of C3 vertebra in the Japanese population which supports the previous study.

On the contrary, in a study including 100 patients, Kurkcuoglu et al.[10] found no CB at the level of C3, but it was mostly located at the level of C4 in 26% of patients on the left side and located at the level of C4-C5 in 29% of patients on the right side. For the overall study population in our study, we found that CB was most frequently seen at the level of C4 in all patients, while it was more frequently seen at the level of C3 in females on both sides (p=0.013) and the level of C5 in males on both sides (p=0.004). Our findings are similar to previous studies conducted in Turkey and Europe, while the CB level was lower than that of the Far Eastern populations. In addition, we found no significant difference in the symmetricity at the level of C3 between males and females; however, there was a significant difference at the level of C4 in favor of females.

During embryological development, the more the origin of the ECA gets closer to the aortic sac, the more the level of CB emerges low. However, the more ECA originates closer to the third aortic arch, the more CB locates in higher levels. Therefore, the level of CB depends on the origin level of the ECA.[13] Due to the unilateral or bilateral absence of ECA in some cases, no CB was found due to the intracranial path and no clinical signs predicting the level of the CB.[10,19,20,22]

In previous studies, Kurkcuoglu et al.,[10] Klosek and Rungruang,[12] and Ito et al.[23] reported that males had a lower level of CB compared to females, regardless of the affected side. Our findings are partially consistent with the previous studies that the mean level of right CB was lower in males compared to the left side. Females were found to have a higher level of C3 rather than males which makes surgery difficult, prolongs the operation time, and increases the rate of the cranial nerve damage due to technical difficulties. In addition, Ito et al.[23] reported no significant difference in terms of the CB level between the right and left side. However, they found that the left side was a slightly higher than the right side. Our findings are also consistent with these findings.

Furthermore, Kurcuoglu et al.[10] reported that the mean length of the neck was 77.6±13.6 (range, 57 to 114) mm in females and 76.2±12.2 (range, 45 to 108) mm in males (p=0.982). In addition, no significant correlation was found between the length of the neck and level of CB and on both sides. However, the mean length of the neck was shorter in females and the neck length was correlated with both right and left CB level in all patients in our study, although there was no significant correlation with the age. On the other hand, we found a significant correlation with the female sex and right CB level, right/left ICA diameter, right/left CCA diameter, and left ECA diameter. We also found a positive correlation between advanced age with the left ICA diameter and a significant correlation between the right ICA diameter and postoperative death.

In their study, Toyota et al.[11] reported that the mean diameter of the CCA was 7.47 mm in male and 7.07 mm in female Japanese patients; however, it was 9.24 mm in male and 7.80 mm in female Hungarian patients. The mean diameter of the ICA in the Japanese patients was 4.96 mm in males and 4.83 in females, while it was 8.56 mm in male and 7.66 mm in female Hungarian patients. In our study, the mean diameter of the CCA was 7.25 mm in males and 6.52 mm in females. In addition, the mean diameter of the ICA was 4.39 mm in males and 3.86 mm in females. The CCA and ICA diameters were larger in favor of males in both Japanese and Hungarian populations.[11] Our findings are consistent with the previous study, showing that the right CCA, right ICA, and left ICA diameters were narrower in females. However, we found smaller carotid artery diameters unlike the previous study, which makes surgery difficult and reduces the success rate. In addition, Koch et al.[24] reported that the diameter of the ICA was larger and the ECA was smaller in Whites and Caribbean Hispanics rather than Afro-Americans.

Moreover, Toyota et al.[11] reported a significant correlation between the CCA diameter and age ($p<0.002$). Similarly, Markert et al.[25] showed a significant, positive correlation between the age and greater carotid artery diameter in Hispanics. Of note, our findings were partially consistent with previous studies that a significant, positive correlation was found between the age and left ICA diameter.

The higher CB level prolongs the operation time and increases the rate of the cranial nerve damage due to technical difficulties. A significant correlation was noted between the right CB level and right CCA diameter and right ICA diameter, and between the left CB level and left CCA diameter and left ICA diameter. In addition, Tsantilas et al.[26] found no evidence between the higher CB level and cranial nerve damage after CEA; however, we found a significant correlation between the higher CB level (C3) and postoperative cranial nerve damage.

Nonetheless, this study has some limitations. First, the number of patients in our study is relatively small. Second, data were non-randomized and retrospectively collected. Third, the power of some outcomes may have been reduced due to the single-center design of the study. We recommend further large-scale, prospective studies to draw a definite conclusion.

In conclusion, our study highlights the importance of recognizing the CB level before CEA and neck surgery. A preoperative rigorous examination of CTA scans and planning surgery are essential components to prevent undesirable surgical complications in patients undergoing CEA. Therefore, surgeons should be aware of the high level of CB to prevent inadvertent devastating vascular injuries and cranial nerve injury in such patients. Despite its limitations, we believe that this study provides an additional information to the body of knowledge in this field.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

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