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*Original Article*

# Analysis of twisted internal carotid arteries in carotid endarterectomy

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## ABSTRACT

**Background:** The twisted carotid artery is a variant, in which the internal carotid artery (ICA) courses medially to the external carotid artery. Due to the sparse descriptions in the literature, we, here, report our experience with cases of carotid endarterectomy (CEA) for twisted carotid artery and its clinical features.

**Methods:** Fifty-seven consecutive CEA-treated patients were evaluated, and the twist angle was measured on the source images of axial slices of computed tomography angiography (CTA).

**Results:** Eight male patients (14.2%) demonstrated a twisted right ICA (mean age, 77.0 ± 2.6 years; and mean stenosis, 66.9% ± 19.9%). The mean twist angle was 30.1° ± 17.9°, while the normal ICA is angled at −23.0° ± 12.3°. No statistical differences in the distribution of coexisting diseases were found between the normal and twisted ICA cases. CEA was successfully performed with the correction of the carotid position in all cases; however, significant position correction was not observed in the postoperative evaluation. Right-side dominancy ($P = 0.045$) and prolonged clamping time ($P = 0.053$) were observed in the twisted cases.

**Conclusion:** Twisted ICA was preferentially found in the right ICA and men. CEA of the twisted ICA was safely performed with appropriate head rotation and wider longitudinal skin incision than usual without a significant increase in the operative time. CTA is useful for preoperative evaluation. This specific variation should be considered by the neurosurgeon involved in the evaluation and treatment of carotid stenoses.

**Keywords:** Carotid endarterectomy, Clinical feature, Surgical feature, Twisted internal carotid artery

## INTRODUCTION

Carotid endarterectomy (CEA) is an established surgical treatment for carotid stenosis in several randomized controlled trials.[1,2,17] Carotid artery stenosis is a major risk factor for ischemic stroke, and randomized trials have demonstrated that carotid CEA reduces the overall stroke risk for both symptomatic and asymptomatic plaques with severe stenosis.[1,2,17] In the actual procedure, neurosurgeons or vascular surgeons should take some anatomical variants into consideration during preoperative planning. Failure to detect these vascular anomalies preoperatively increases the risk of peri- and postoperative complications.[5] Here, we focused on the so-called twisted internal carotid artery (ICA), which runs medially to the external carotid artery (ECA).[3,4,7,10] This anomaly was also called "side-by-side carotid artery," "dorsal/dorsomedial origin of the ICA," or "lateral ECA." [5,12-16,20] Although several series and/or cases have been reported, we clarified the frequency and other clinical features of the twisted ICAs among our CEA-treated cases and

discussed their etiologies and effects on the CEA procedures and operative times and other details.

## MATERIALS AND METHODS

Fifty-seven consecutive CEA-treated cases at our institute between April 2016 and November 2019 were reviewed. Three-dimensional computerized tomographic angiography (3D-CTA) and magnetic resonance imaging (MRI) and angiography (MRA) were performed on all cases before surgery. Cerebral angiography (CAG) was performed in some cases. Postoperative radiological evaluation using 3D-CTA and/or MRI and MRA was performed.

Twisted ICA was defined in accordance with a recent publication.[10] Briefly, the twisted ICA runs medially in the anteroposterior (AP) view [Figure 1a and b] and anterior to the ECA on CTA or CAG. The twist angle was measured on the CTA axial source images as the medially deviated angle from the connected line of centers of the ICA and ECA to the line parallel to the sagittal plane in the center of the ECA [Figure 1c]. A counterclockwise direction in the CT view from the bottom was considered to indicate a positive (medial) twist, whereas a clockwise direction indicated a negative twist.[10] The twist angle was also checked postoperatively in the same manner, but in some cases, we used the MRA [Figure 1d] and its axial source images [Figure 2].

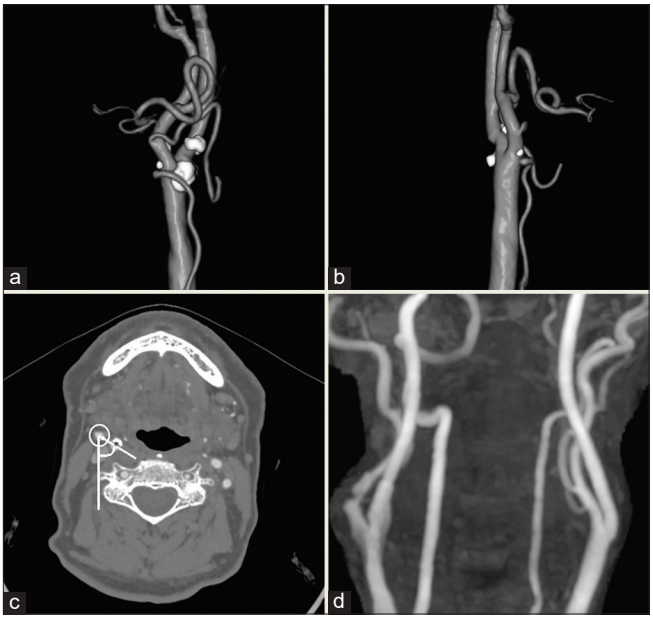


**Figure 1:** Computed tomography angiogram of the representative case 8: right carotid stenosis. (a) Preoperative anterior view showing that the internal carotid artery (ICA) runs medially, and the external carotid artery (ECA) runs laterally. The ECA branches cross-over the ICA. (b) Preoperative right lateral view showing the ICA coursing posteriorly to the ECA. (c) Twist angle measured in the axial view of computed tomography angiography as the medially deviated degree from the connected line (white line) of the centers of the ICA (asterisk) and the ECA (white circle) to the line parallel to the sagittal plane on the center of the ECA (thin white line). The preoperative twisted angle is 48°. (d) Postoperative magnetic resonance angiogram showing the dilated ICA without repositioning.

CEA was performed using the standard technique under general anesthesia. The single antiplatelet agent therapy was not interrupted during the perioperative period. The head and neck were extended, and the latter was rotated approximately 30°–60° toward the contralateral side. A longitudinal skin incision along the anterior margin of the sternocleidomastoid muscle (SCM) was made toward the mastoid tip. The skin, subcutaneous tissue, and the platysma were sharply divided in the same direction. We recommend using the hooks, instead of wound retractors, to lift these layers step-by-step, resulting in easier handling of the carotid bifurcation, ICA, and ECA. The SCM muscles were also retracted by hooks; then, further dissection finds the partial part of internal jugular vein (IJV), common carotid artery, ICA, or ECA. Wider dissection of jugular vein from adjacent carotid sheath than usual makes it easier to rotate these vessels in the following stages of the procedures. The cottonoids-protected IJV was retracted dorsally by hooks, and the carotid sheath was dissected and then was also hooked up. The freed ECA was pulled to the contralateral side by a rubber band with tourniquet further than usual. Cottonoids under the bifurcation and ICA help to lift the ICA to the shallow surgical field. The plaque removal was succeeded conventionally with or without using an internal double-balloon shunt (Inter Medical Co., Ltd., Nagoya, Japan).

The ethics guidelines for clinical studies by the Japanese Health, Labor, and Welfare Ministry (2003) were strictly observed. The study was approved by the Institutional Ethics Review Board.

All continuous data were expressed as mean ± standard deviation. Comparisons between the two groups were performed using the Fisher *t*-test and Chi-square, or Fisher probability test, as appropriate, for continuous and dichotomous variables, respectively. Multivariate logistic regression analysis was used to calculate the odds ratios and 95% confidence intervals after controlling simultaneously

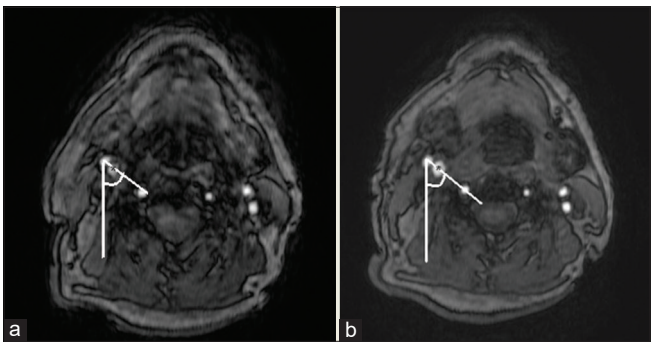


**Figure 2:** Twisted angle measured on magnetic resonance angiography in the same manner as that on computed tomography angiography before (a) and after (b) carotid endarterectomy.

for potential confounders. The continuous and dichotomous variables considered in the model were age and sex, location of the affected ICA (right or left), cofounding clinical backgrounds, lesion characteristics (i.e., symptomatic or asymptomatic; severe or moderate stenosis measured using the North American Symptomatic Carotid Endarterectomy Trial formula; and vulnerable or not), and operative and clamping times, respectively. The significance level was set at $P < 0.05$. Statistical analyses were performed using Excel (EXCEL-TOUKEI 2012R, Social Survey Research Information Co., Ltd., Tokyo, Japan).

## RESULTS

Of the 57 CEA-treated patients (mean age, 75.0 ± 6.8 years; male-to-female ratio, 51:6; ratio of symptomatic to asymptomatic cases, 30:27; and ratio of the right ICA to left ICA cases, 28:29), 8 (14.2%) demonstrated twisted ICA, and their baseline characteristics are summarized in [Tables 1 and 2]. A representative case is shown in [Figure 1]. All the patients had twisted right ICA and were male, with a mean age of 77.0 ± 2.6 years and mean twist angle of 30.1° ± 17.9°, whereas the normal ICA is angled at −23.0° ± 12.3° [Tables 1 and 2]. No statistical differences were found in the distribution of coexisting clinical features such as diabetes mellitus, hyperlipidemia, hypertension, ischemic heart disease, smoking habit, body mass index, and degree of stenosis between the normal and twisted ICA cases, except for right-side twisted ICA dominancy ($P = 0.045$).

CEA was successfully performed with the correction of the carotid position in all cases. No significant position correction was observed in the postoperative evaluation [Table 2]. An internal shunt was not used in the twisted ICA cases. Although clamping time ($P = 0.053$ in the univariate analysis and $P = 0.043$ in the logistic regression analysis) was prolonged in the twisted cases, no significant difference

**Table 1:** Characteristics of the 57 CEA-treated cases with or without a twisted internal carotid artery.

| | All | Normal | Twisted | Univariate analysis | Logistic regression analysis | | |
|---|---|---|---|---|---|---|---|
| **N** | **57** | **49** | **8 (14.2%)** | ***P* value** | ***P* value** | **OR** | **95% CI** |
| Age (years) | 75.0±6.8 | 74.7±7.2 | 77.0±2.6 | 0.38 | | | |
| Male/female | 51/6 | 43/6 | 8/0 | 0.58 | | | |
| Right/left | 29/28 | 21/28 | 8/0 | 0.0045 | <0.001 | 0.16 | 0.073–0.34 |
| Degree of stenosis (NASCET) | 72.2±19.3 | 73.0±9.3 | 66.9±19.9 | 9 | | | |
| Twisted angle | 15.5±22.9 | -23.0±12.3 | 30.1±17.9 | <0.001 | | | |
| Hypertension | 52 (91.2) | 44 (89.8) | 8 (100) | 1 | | | |
| Diabetes mellitus | 28 (49.1) | 22 (44.9) | 6 (75) | 0.14 | 0.083 | | |
| Hyperlipidemia | 43 (75.4) | 36 (73.5) | 7 (87.5) | 0.66 | | | |
| Ischemic heart diseases | 8 (14.0) | 7 (14.3) | 1 (12.5) | 1 | | | |
| Smoking | 17 (29.8) | 16 (32.6) | 1 (12.5) | 0.41 | | | |
| Body mass index | 22.8±3.3 | 22.7±3.3 | 23.7±2.9 | 0.4 | | | |
| Internal shunt | 8 (14) | 8 (16.3) | 0 | 0.58 | | | |
| Surgery time (min) | 146±42.2 | 144±42.9 | 153±37.2 | 0.57 | | | |
| Clamping time (min) | 55.6±20.1 | 3.5±19.4 | 68.3±20.9 | 0.053 | 0.0436 | 1.037 | 1.00–1.077 |

NASCET: North American Symptomatic Carotid endarterectomy Trial, OR: Odds ratio, CI: Confidence interval, Min: Minutes

**Table 2:** Summary of twisted internal carotid artery cases.

| Case | Age (years) | S/A | Stenosis (%) | Twisted angle | | Coexisting diseases | Plaque pathology | Surgery time (min) | Clamping time (min) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Before | After | | | | |
| 1 | 76 | S | 61 | 18 | 38 | DM, HT | Cal | 125 | 58 |
| 2 | 78 | A | 90 | 32 | 22 | DM, HL, HT | Cal | 165 | 72 |
| 3 | 73 | S | 50 | 54 | 42 | DM, HL, HT | Cal, vul | 209 | 71 |
| 4 | 78 | S | 50 | 24 | 38 | DM, HL, HT | | 106 | 46 |
| 5 | 81 | S | 50 | 14 | 18 | HL, HT | Cal, vul | 147 | 83 |
| 6 | 74 | S | 80 | 6 | 10 | DM, HL, HT | Cal | 205 | 106 |
| 7 | 77 | A | 99 | 48 | 48 | DM, HL, HT, IHD | Cal, vul | 131 | 40 |
| 8 | 79 | A | 55 | 48 | 48 | HL, HT | Cal, vul | 140 | 70 |

S: Symptomatic, A: Asymptomatic, DM: Diabetes mellitus, HT: Hypertension, Cal: Calcification, HL: Hyperlipidemia; vul: Vulnerable plaque, IHD: Ischemic heart disease. Sex and side were originally deleted because all the twisted cases occurred in men and were right-sided lesions. All cases were treated in the corrected position. In case 3, intraoperative further head tilting was performed.

was observed in the total operative times ($P = 0.57$). Surgical procedures could be successfully accomplished in all cases, and the postoperative courses were uneventful.

## DISCUSSION

The incidence of twisted ICA has been reported to range from 4% to 16%, which is relatively not as rare as expected.[4-7,10,16] However, the diagnostic criteria and epidemiological features have not been well understood.[6,7,10,16,20] In this study, we defined "twisted" as just twisted, that is, twisted carotid bifurcation with the ECA lying posterolaterally to the ICA and excluding overlapping of the ECA and ICA cases from the AP view of CTA to simplify the classification.[5,7,10] Twisted ICA is a result of excessive mediolateral migration of the ECA during embryogenesis or age-related elongation and tortuosity of the carotid arteries due to atherosclerosis.[5,7,10,16] In our cases, all twisted cases were observed significantly in the right carotid bifurcation compared to the normal cases reported previously and showed male dominancy.[5,7,10,11] Structural differences such as the presence of an anomic artery on the right side might be associated with an imbalance in the distribution of twisted ICA cases between the two sides.[14,16]

Sex-related differences in the twisted ICA cases remain controversial because male dominancy of carotid artery stenosis is obvious; and as a result, male dominancy has been reported.[5,7,10] However, female dominancy or the absence of sex-related differences in twisted ICA cases and ethnic differences in the carotid bifurcation anatomy have also been reported.[10,18-20] Male sexuality itself or menopausal transition in women might have some effect on the congenital or acquired factors of twisting; thus, this matter should be elucidated. The restricted number of CEA-treated patients led to the right-side twisted ICA and male dominancy in this study.

Considering the effects of acquired diseases, Katano *et al.* reported that patients with twisted ICA have diabetes mellitus and hypertension, with statistical significance, although this was not observed in the present study and other reported cases [Table 3].[7,10] Although 75% and 100% of the twisted cases had diabetes mellitus and hypertension, respectively, these diseases also showed a high prevalence in 57 CEA cases (49.1% and 91.2%, respectively). Thus, the significance could not be determined. The social or clinical background in each study might have affected the disease effect on twisted ICA.

During surgery, we pulled out the ICA to correct the twist [Figure 2]. In one case (Case 3), we first performed CEA in the twisted position, as some authors described previously.[3,7,10] However, in the actual surgery, CEA seemed difficult to perform without sacrificing the overlying ECA branches. In addition, we were not familiar with the technique, so we repositioned the head by turning it more toward the contralateral side, which resulted in the smooth correction of the twisted ICA. Fortunately, our cases showed milder twists than the reported cases.[3,5,10] Thus, wider longitudinal exposure and radical turning of the head to the contralateral side, at an angle of up to 60°, as mentioned before and recommended by Loftus with caution to avoid overlying of the SCM on the operative field, were enough to perform CEA in the usual manner.[5,12-14] We usually perform CEA with the neck rotated by approximately 30°. Thus, in our twisted ICA cases, the neck rotation angle was between 30° and 60°, without any obstruction of the operative field. In the case of vulnerable plaque, some studies have recommended CEA without twist correction to prevent artery-to-artery embolism.[5,7,10] Thus, gentle retraction of the ECA and carotid sheath, the elevation of the carotid bifurcation with cottonoids, and drawing out the ICA to the shallow surgical field could prevent the disastrous complication.[5,10]

In twisted cases, the distal end of the ICA seems running toward inner direction with sharper angle than usual. Hence, more meticulous dissection and capture of this distal end enable satisfactory hemostasis and are key to complete CEA safely in this specific anomaly as usual cases. On the other hand, several reports have indicated the left-side dominancy of

**Table 3:** Summary of the reported series of twisted internal carotid artery cases.

| Case | n (%) | Age (years) | M/F | R/L | S/A | Stenosis | DM | HL | HT | Twist evaluation | TA normal/twisted/after | IP corrected |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kamide | 7/58 (12.4) | 74.6±4.8 | 6/1 | 7/0 | 3/4 | -* | 2(28.9) | 3(42.9) | 6(85.7) | CA | - | 3/7 |
| Katano | 7/75 (9.3) | 70.4±7.3 | 3/4 | 6/1 | 5/2 | 78.7±10.5 | 6(85.7) | - | 5(71.4) | CA/CTA | -7.4±7.7/80.0±17.6/56.4±4.6 | 6/7 |
| Ito | 11/198 (5.3) | 74.0±6.2 | 9/2 | 10/1 | 6/5 | - | - | - | - | CTA | 9.5±9.2/-21±9.5/-12±10 | 11/11 |
| Present cases | 8/57 (14.2) | 77.0±2.6 | 8/0 | 8/0 | 3/5 | 66.9±19.9 | 6(75) | 7(87.5) | 8(100) | CTA/MRI | 23.0±12.3/-30.1±17.9/-33±14.4 | 8/8 |

M: Male; F: Female; R: Right, L: Left; S: Symptomatic, A: Asymptomatic; DM: Diabetes mellitus, HL: Hyperlipidemia, HT: Hypertension, IHD: Ischemic heart disease, TA: Twisted angle, IP: Intraoperative position, CA: Conventional angiography, CTA: Computed tomography angiography, MRI: Magnetic resonance imaging. *Evaluated as severe or moderate.

plaque formation and its vulnerability or ethnic differences in the carotid bifurcation geometry.[10,11,19] Therefore, the right-side twisted ICA dominancy observed in the present and previous reported series might lead to less artery-to-artery embolism, even though half of our cases had vulnerable plaques.

CEA in the twisted position also has the danger of superior laryngeal and vagus nerve injuries or tracheal and esophageal injuries because their usual locations are also twisted.[3,7] To avoid mistaking the ECA for the ICA, surgeons must use a micro-Doppler probe in addition to the visual distinction of the superior thyroid artery from the ECA.[10]

Although we preferred to mobilize the ICA in this series, repositioning was uncommon in postoperative evaluations. Retaining the position might be safe for carotid bifurcation structures. If repositioning seems suitable without any torsion on the distal ICA during surgery, it may be performed. If the ICA returns automatically to its twisted position after the completion of the CEA, the twisted position might be preferred to prevent kinking or occlusion.[5] As we could not make a conclusion regarding repositioning, further observation is needed.

In the comparison of the operative and clamping times, the latter showed a significant delay (around 15 min) and the former a nonsignificant delay (around 9 min). None of the reported cases showed these time sequences, except one.[3,5,7,10] Although we never experienced serious complications, the small number and right-sidedness of the lesions might have resulted in the uneventful postoperative course-mentioned earlier.

We speculated that the twisted ICA itself never delayed the operative time because the preoperative evaluation resulted in a strict unconscious manipulation during surgery, which did not prolong the operative time. During clamping of the twisted ICA, we believe that trimming of the distal end of the plaque might consume a slightly longer time than usual, thereby prolonging the operative time. The distal part of the ICA might be anchored deeper despite the correction of the twisted ICA. Further accumulation of twisted ICA cases might provide crucial findings.

Recently, CTA has become the gold standard of carotid artery evaluation, instead of CAG, due to its less invasiveness.[5,8-10] We also recommend MRI and MRA for the evaluation of the twisted ICA and its twisted angle from the perspective of less invasiveness; however, further accumulation of cases will be needed to standardize this method [Figures 1d and 2].

In the case of twisted but high-positioned lesions, stenting may be preferred. We plan to evaluate twisted ICA cases by stenting and compare their results with those of CEA cases and clarify the clinical aspects of this unique but common disease soon.

## CONCLUSION

The incidence of twisted ICA was 14.2% in our single-center study. The predominant right-side twisted ICA location and male sex in the atherosclerotic population resulted from the congenital variations or anomalies accelerated by the acquired clinical conditions. A slight modification in the usual CEA techniques enabled safe CEA in the present series. The risk of artery-to-artery embolism resulting from arterial manipulations should be kept in mind. The possibility of twisted ICA should be considered by all neurosurgeons involved in the evaluation and treatment of carotid stenoses, especially in the right-side lesions.

### Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

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