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# Three-dimensional Computed Tomographic Reconstruction of the Carotid Artery: Identifying High Bifurcation

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**WHAT THIS PAPER ADDS**

The distance of carotid bifurcation from the base of skull is a potentially useful measurement that has not been previously described. This measurement has been compared with several other methods of quantifying carotid bifurcation height. It is demonstrated that bifurcations within 5 cm of the mastoid process are likely to be in the highest quartile of carotid bifurcations. This measurement could alert vascular surgeons to carotid endarterectomy cases that are more likely to be technically challenging.

**Objective:** To investigate variability in the level of bifurcation relative to other anatomical landmarks on computed tomography (CT) and to develop an objective and reproducible technique for identifying patients with a high carotid bifurcation who might therefore be at greater risk of operative complications.

**Methods:** This was a retrospective cross-sectional, imaging study. A series of 86 nonselected consecutive CT carotid angiograms (172 arteries) were analysed. Using three-dimensional reconstructive software, the curved length (CL) of the internal carotid artery (ICA) and the straight-line distance (SLD) from the bifurcation to the base of skull was measured for 140 carotid arteries. The tortuosity index (TI) of each ICA was calculated by dividing CL by SLD. The relationship of the bifurcation to eight anatomical landmarks in the neck was assessed in order to identify a landmark that could act as a surrogate marker of high carotid bifurcation. The landmarks examined were the angle of mandible, greater horn of hyoid, body of hyoid, upper margin of thyroid cartilage, cervical vertebrae, mastoid process, sternoclavicular joint, and sternal notch.

**Results:** The median curved length of the ICA was 80.4 mm (range 58.0–129.0 mm). The median distance of bifurcation from the base of the skull was 72.7 mm (range 58.1–98.1 mm). There was excellent interobserver agreement in measuring SLD, with an intraclass correlation coefficient of 0.993 ($p = .00$). The median tortuosity index was 1.12 (range 1.01–1.64). Distance from the mastoid process had the greatest correlation with high bifurcation; Pearson's correlation coefficient of 0.894 (two-tailed $p = .00$). Bifurcations within 5 cm of the mastoid process are likely to be in the highest quartile (82.9% sensitive, 80.1% specific).

**Conclusions:** Measuring the distance of carotid bifurcation from the base of the skull (SLD), a measure previously not well defined, may be useful in predicting difficult neck dissection and endarterectomy. A distance from mastoid of $\leq$ 5 cm may also alert the surgeon to potential difficulties.



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## INTRODUCTION

The carotid bifurcation is classically described as lying at the level of the superior border of thyroid cartilage, in line with the C3–C4 intervertebral space.[1–3] Studies examining the clinical anatomy of the carotid arteries have shown a high rate of variation from the "normal" position.[1,2]

A study of cranial nerve injury in patients who underwent carotid endarterectomy (CEA) in the European Carotid Surgery Trial demonstrated an incidence of 5.1%, with hypoglossal nerve injury being the most common.[4] A higher incidence of cranial nerve injury has been demonstrated in patients with a high carotid bifurcation.[1,5–8] At present there is no standardised method of measuring the bifurcation position, relative to the base of skull, preoperatively. An accurate predictor of a high bifurcation may be beneficial in planning surgery and predicting technical challenges. Adjunctive measures that may be considered include nasotracheal intubation, division of the digastric muscle, resection of the styloid process, anterior subluxation of the mandible, or endovascular stenting.[5,9,10]

This study aims to examine the anatomy of the carotid arteries using three-dimensional (3D) reconstruction computed tomography (CT) analysis, and to define the

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degree of anatomical variation in a clinically relevant patient cohort. The study aims to define a method for clinicians to identify those patients in whom a high bifurcation is present, allowing for prediction of intraoperative technical challenges.

## MATERIALS AND METHODS

### Study design

This was a retrospective, cross-sectional imaging study carried out on archived 0.65-mm slice CT angiograms in Cork University Hospital. The main indication for CT carotid angiogram at the institution was the work-up of confirmed or suspected carotid atheromatous disease, making findings from this database of images more applicable to the population of patients in whom CEA is being considered. Thin-slice CT ensured optimal accuracy for the purposes of this study in precisely describing the anatomy of the carotid bifurcation. The measures of bifurcation height can easily be applied in clinical practice to the more widely utilised 3-mm slice CT scans.

A series of 86 nonselected consecutive CT angiograms from the Picture Archive Communication System archive in Cork University Hospital were analysed. Arteries demonstrating occlusion of the ICA were excluded from the study, as the vessel distal to the point of occlusion cannot be visualised sufficiently to allow the required variables to be measured. Twelve arteries were excluded owing to vessel occlusion. Angiograms were also excluded if patient posture deviated significantly from the anatomical position, such that our measured variables would be unduly altered. Anatomic positional exclusion criteria were lateral angulation of the skull $>5$ degrees, rotation $>10$ degrees, and flexion or extension $>15$ degrees. Ten angiograms (20 arteries) were excluded owing to abnormal posturing.

A total of 140 carotid arteries, from 76 patients, were included in the study. Seventy-six of the arteries were from men, 64 were from women. Seventy-two of the arteries were right carotid arteries, 68 were left carotid arteries. Median patient age was 68.0 $\pm$ 16.6 years (range 20.0—90.0 years).

The incidence and degree of carotid artery disease described in radiologists' reports for the included cases were analysed in order to assess the applicability of the study findings to our patient population of interest. Of the 76 CT angiograms included in the study, 60 demonstrated carotid artery disease. Fifty-five of these patients had bilateral disease. Thirty patients had either moderate or severe disease (50—100% stenosis), with 12 patients having one completely occluded ICA. Only 16 patients were free from arterial disease. These included patients with trauma or with suspected acute dissection.

For each artery, centre-line vessel analysis, multiplanar reconstruction, and 3D reconstruction of the radiological images were performed, using a dedicated 3D vascular workstation (TeraRecon, Santa Monica, CA, USA). The study was granted ethical approval by the clinical research ethics committee of the Cork teaching hospitals.

### Study measures

For each case, patient age and sex were recorded. Aside from these demographics, 12 variables were measured for each carotid system. These variables are described below as four separate groups of variables. The four groups of variables are summarised in Table 1. Aside from the three "artery characteristics", the remaining nine variables studied are a variety of methods for describing carotid bifurcation height. This list of nine measures was compiled following a literature search of articles discussing carotid bifurcation height,[1,2,6,11—16] and each of these measures was compared to assess their accuracy in identifying those bifurcations which are close to the base of skull.

**Artery characteristics.** This group included the curved length (CL) of the internal carotid artery (ICA); the straight-line distance (SLD) of the carotid bifurcation from the base of skull; and the tortuosity index (TI) of the ICA. For all measurements, the point of carotid bifurcation was taken as the most cranial point of communication between the internal and external carotid arteries.

3D reconstruction software is capable of measuring the CL of artery spanning between two markers, placed at the carotid bifurcation and the point of entry through the base of skull, respectively. This produced the measure of CL of the ICA.

While commercially available software can measure the length of the curved centre line between the two markers, it is not capable of joining these two markers with a single straight line. This limitation is owing to the fact that both markers lie in separate coronal, sagittal, and transverse planes. In both multiplanar and 3D reconstruction, measurement lines can only be drawn within a single plane of view. Therefore, single-planar measurements had to be

**Table 1.** The 12 measured variables summarised in their four distinct groups.

| | |
|---|---|
| **Artery characteristics** | |
| 1 | Curved length of internal carotid artery |
| 2 | Straight-line distance of carotid bifurcation from base of skull |
| 3 | Tortuosity index of internal carotid artery |
| **Qualitative variables** | |
| | Whether the carotid bifurcation lies above/at/below the: |
| 4 | Angle of mandible |
| 5 | Greater horn of hyoid |
| 6 | Body of hyoid |
| 7 | Upper margin of thyroid cartilage |
| **Semiquantitative variables** | |
| 8 | Vertebral level |
| **Quantitative variables** | |
| | Distance of carotid bifurcation from: |
| 9 | Mastoid process |
| 10 | Angle of mandible |
| 11 | Sterno-clavicular joint |
| 12 | Sternal notch |