Systematic review of preoperative carotid duplex ultrasound compared with computed tomography carotid angiography for carotid endarterectomy

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ABSTRACT

INTRODUCTION We reviewed the literature for preoperative computed tomography carotid angiography and/or carotid duplex to determine their respective sensitivity and specificity in assessing the degree of carotid stenosis. We aimed to identify whether one imaging modality can accurately identify critical stenosis in patients presenting with transient ischaemic attack or symptoms of a cerebrovascular accident requiring carotid endarterectomy.

METHODS Systematic search of MEDLINE, Embase, Cochrane database of systematic reviews, all Evidence-Based Medicine Reviews (Cochrane Database of Systematic Reviews, ACP Journal club, Database of Abstracts of Reviews of Effects, Cochrane Clinical Answers, Cochrane Controlled Trials Register, Cochrane Methodology Register, Health Technology Assessment and NHS Economic Evaluation Database) for primary studies relating to computed tomography carotid angiography (CTA) and/or carotid duplex ultrasound (CDU). Studies included were published between 1990 and 2018 and focused on practice in the UK, Europe and North America.

RESULTS The sensitivity and specificity of CTA and CDU are comparable. CDU is safe and readily available in the clinical environment hence its use in the initial preoperative assessment of carotid stenosis. CDU is an adequate imaging modality for determining stenosis greater than 70%; sensitivity and specificity are improved when the criteria for determining greater than 70% stenosis are adjusted. Vascular laboratories opting to use duplex as their sole imaging modality should assess the sensitivity and specificity of their own duplex procedure before altering practice to preoperative single imaging for patients.

CONCLUSIONS The sensitivity and specificity of CTA (90.6% and 93%, respectively) and CDU (92.3% and 89%, respectively) are comparable. Both are dependent on criteria used in vascular laboratories. CDU sensitivity and specificity was improved to 98.7% and 94.1%, respectively, where peak systolic velocity and end diastolic velocity were assessed. Either modality can be used to determine greater than 70% stenosis, although a secondary imaging modality may be required for cases of greater than 50% stenosis.

KEYWORDS

Ultrasonography, doppler, duplex – computed tomography angiography – endarterectomy, carotid – sensitivity and specificity

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Introduction

Carotid endarterectomy, according to the North American Symptomatic Carotid Endarterectomy Trial, (NASCET) benefits patients presenting with transient ischaemic attack or stroke found to have 70–99% stenosis of the internal carotid artery (ICA).¹ The European Carotid Surgery Trial (ECST) found that the risk of major stroke increased dependent on the degree of stenosis and patients with ECST stenosis greater than 80% benefited more from having surgery to decrease the long term risk of stroke.² NASCET and ECST criteria are not equivalent, and it is suggested that an 82% ECST stenosis corresponds to a 70% NASCET stenosis.³ The relationship

between NASCET and ECST criteria was defined based on regression analysis as:³

$$\text{ECTS stenosis (\%)} = 0.6 \times (\text{NASCET \% stenosis}) + 40\%$$

The criteria are summarised in the following equations:^{3,4}

$$\text{NASCET} = \frac{(\text{Diameter of normal ICA lumen distal to bulb} - \text{Diameter of residual lumen in stenosis})}{\text{Diameter of normal ICA lumen distal to the bulb}} \times 100\% \text{ stenosis}$$

Current clinical practice for patients presenting with symptoms of transient ischaemic attack or stroke suggestive of carotid artery stenosis is that they undergo carotid duplex ultrasound (CDU) initially, followed by computed

tomography carotid angiography (CTA) to identify the extent of stenosis, if present. The main objective of this review was to identify whether duplex ultrasound and/or CTA should be used preoperatively to screen patients for the extent and character of their carotid artery stenosis, before undergoing carotid endarterectomy, where required.

CDU is a cost effective, non-invasive and safe imaging modality that provides expedited imaging of the carotid arteries (carotid bifurcation and ICA).⁵ CDU combines ultrasound technology with doppler, allowing the operator to assess the calibre of the carotid arteries in addition to blood flow and velocities.⁶ NASCET and/or ECST criteria can be used for the determination of carotid stenosis however in clinical practice vascular laboratories base the degree of stenosis on a combination of peak systolic velocity (PSV), end diastolic velocity (EDV) or ratios of the two.⁵

CTA uses ionising radiation and administration of contrast to the patient, creating one-dimensional images which are subsequently reformed into a two-dimensional digital image of the intra- and extracranial parenchyma and vasculature.^{5,6} These images can either be helical/spiral CTA or use new multidetector computed tomography, which provide lower radiation doses and require less contrast media to be given to patients.⁵ The recreation of images

can be further enhanced via computer software allowing for presentation via multiplanar reconstruction, volume-rendering or other means.⁶

The gold standard imaging modality used for determining degree of carotid stenosis is intra-arterial angiography or digital subtraction angiography (DSA);⁵ however, the incidence of angiography-related stroke led to the use of non-invasive imaging modalities discussed here.⁷

Methods

To conduct this review, literature was critically appraised using PRISMA guidelines and focused on the use of preoperative CTA and/or CDU to assess the extent of carotid artery stenosis. The following databases were searched: MEDLINE, Embase, Cochrane Database of Systematic Reviews and all Evidence-Based Medicine Reviews (encompassing Cochrane Database of Systematic Reviews, ACP Journal club, Database of Abstracts of Reviews of Effects, Cochrane Clinical Answers, Cochrane Controlled Trials Register, Cochrane Methodology Register, Health Technology Assessment and NHS Economic Evaluation Database) using the Ovid platform. Limitations were placed on the search to identify only English literature. The timeline of interest was set from 1990 to May 2018.

Only studies published in this time were considered. Two searches were conducted using Ovid, and 309 papers were identified. A manual search through titles and abstracts identified papers for further detailed review.

Search terms used to identify studies which assessed the accuracy of CTA were: 'tomography', 'x-ray' 'computed AND sensitivity and specificity AND carotid stenosis'. This search identified a total of 177 results. When the search was limited to the English language, a total of 162 papers were retained, of which 8 were excluded as duplicates (Fig 1).

Search terms used for the assessment of the accuracy of CDU were: carotid stenosis AND ultrasonography, doppler, duplex AND sensitivity and specificity. This search identified a total of 158 results. When the search was limited to the English language, a total of 147 papers were retained, although 7 were duplicates so only 140 were reviewed further (Fig 2).

The identified papers were assessed individually for their relevance to the systematic review. Exclusion criteria used to eliminate further studies during the review were:

- > studies conducted outside of the area of interest (North America, Europe and the UK)
- > studies where the full-text article was unavailable to the reviewer

- > studies not including both sensitivity and specificity data
- > review articles or meta-analyses.

Results

The database search produced a total of 43 primary studies.

Computed tomography carotid angiography

The data were separated based on the use of NASCET and ECST criteria to determine the degree of stenosis, as shown in Tables 1 and 2. Weighted means for all the studies using NASCET criteria was then calculated (Table 3). The overall sensitivity and specificity of a greater than 70% NASCET stenosis was 90.6% and 93%, respectively, from a total of nine studies, which assessed a total of 1245 carotid arteries, compared with DSA.

Carotid duplex ultrasound

The sensitivity and specificity of the different methods for determining carotid stenosis via CDU were collated (Table 4) and, based on these data, a weighted mean was calculated (Table 5). One study looking at power doppler was excluded, from the analysis as it was the only study

Table 1 Sensitivity and specificity of computed tomography carotid angiography based on North American Symptomatic Carotid Endarterectomy Trial criteria

Stenosis (%)	CT type	Carotid arteries (n)	Sensitivity (%)	Specificity (%)	Reference
> 70	Helical/spiral	56	100	100	Link <i>et al</i> ¹²
	Dual source	80	80	91	Biermann <i>et al</i> ¹³
	Dual source	80	100	84	
	Axial	44	67	96	Leclerc <i>et al</i> ¹⁴
	Axial	236	98.3	100	Moll <i>et al</i> ¹⁵
	Helical/spiral	44	100	100	Randoux <i>et al</i> ¹⁶
	Helical/spiral	59	65	100	Patel <i>et al</i> ¹⁷
	Multi-detector	129	90.9	54.9	Bucek <i>et al</i> ¹⁸
	Multi-detector	268	88.2	92.4	Bartlett <i>et al</i> ¹⁹
	Helical/spiral	73	75	96	Silvennoin <i>et al</i> ²⁰
	Axial	45	90	87	Howard <i>et al</i> ²¹
	Multi-detector	336	95	99	Anzidei <i>et al</i> ²²
	Not known	180	78	93	Marquering <i>et al</i> ²³
	Dual source	80	80	100	Tsiflikas <i>et al</i> ²⁴
	Dual source	80	91	83	
> 60	Axial	48	81.8	100	Gupta <i>et al</i> ²⁵
	Axial	96	87	90	Magarelli <i>et al</i> ²⁶
Occlusion	Axial	236	100	100	Moll <i>et al</i> ¹⁵
> 50	Multi-detector	129	95.8	59.6	Bucek <i>et al</i> ¹⁸
	Multi-detector	268	75	93.8	Bartlett <i>et al</i> ¹⁹
	Helical/spiral	73	88	82	Silvennoin <i>et al</i> ²⁰
	Not known	180	75	98	Marquering <i>et al</i> ²³
	Axial	48	91.7	72.7	Gupta <i>et al</i> ²⁷
	Axial	72	85	83	
< 50	Multi-detector	268	95.2	93.2	Bartlett <i>et al</i> ¹⁹

CT, computed tomography.

using this method and the sample size was too small for inclusion independently.⁸

Discussion

Overall, our review established a sensitivity and specificity of CTA compared with CDU for identifying greater than 70% stenosis as 90.6% and 93%, and 92.3% and 89% respectively (Table 6), compared with DSA. This suggests that CTA and CDU are comparable in their ability to identify patients with greater than 70% stenosis and exclude patients with less than 70% stenosis who may not benefit from carotid endarterectomy. The sensitivity and specificity of CDU improved in three studies when the criteria for reporting the degree of stenosis was altered. When CDU criteria included both EDV and PSV to identify stenosis greater than 70%, the sensitivity and specificity increased

to 98.7% and 94.1%, respectively, greater than that found with CTA.

After identifying CDU sensitivities and specificities, we further categorised the data as consensus compliant and non-compliant. Focusing on those studies that adhered to the consensus PSV criteria (greater than 250 cm/s) a weighted mean analysis identified a sensitivity and specificity of 92.3% and 89%, respectively. Inclusion of studies using narrowed consensus criteria (range from greater than 250 cm/s to 285 cm/s) decreased the sensitivity and specificity to 86.5% and 87.8%, respectively. All studies analysed used DSA as the gold standard comparator.

The sensitivity and specificity of both imaging modalities decreased when the degree of stenosis was greater than 50%; the results were 81.7% and 85.6% for CTA respectively, and 85.1% and 86.4% for CDU, respectively. This decrease could prove problematic where vascular centres

Table 2 Sensitivity and Specificity of computed tomography carotid angiography based on European Carotid Surgery Trial criteria

Stenosis (%)	CT type	Carotid arteries (n)	Sensitivity (%)	Specificity (%)	Reference
> 70	Multi-detector	129	94.7	46.3	Bucek <i>et al</i> ¹⁸
> 50	Multi-detector	129	96.4	42.5	Bucek <i>et al</i> ¹⁸

CT, computed tomography.

Table 3 Weighted mean analysis of computed tomography carotid angiography sensitivity and specificity results

Stenosis (%) CTA NASCET	Weighted mean sensitivity (%)	Weighted mean specificity (%)	Studies (n)	Carotids (n)
> 70	88.9	92.4	17	1882
> 70 ^a	90.6	93	9	1245
> 50	81.7	85.6	6	770

^aGold standard.

CTA, computed tomography carotid angiography; NASCET, North American Symptomatic Carotid Endarterectomy Trial.

begin to consider patients with a greater than 50% stenosis, as per 2018 European Society for Vascular Surgery (ESVS) guidelines.⁷ Where stenosis is measured as less than 70%, a second imaging modality may be used to ensure the accuracy of the first investigation. In this situation, another CDU scan may be ordered or an alternative non-invasive imaging modality such as CTA or magnetic resonance angiography may be used to determine whether the extent of the stenosis is less than that required for surgical intervention (greater than 70%).⁷

CDU is recognised for its ability to identify plaque morphology more easily than CTA.⁵ However, this ability is hindered where the plaque is significantly calcified, there is operator inexperience or a lack of strict reporting criteria.⁶ It is suggested that CTA may be better suited for analysing heavily calcified plaques, in addition to providing a more objective and reproducible assessment of plaque morphology than CDU, as images can be reviewed.⁵ CTA is limited by factors such as the use of ionising radiation and intravenous iodinated contrast media, which are contraindicated for certain patients, such as those with renal dysfunction or those taking metformin. Iodinated contrast agents carry the rare risk of reactions in patients (1/3000). Patients may suffer from circulatory collapse, arrhythmias or bronchospasm, in addition to the risk of nephropathy as a direct result of contrast administration.⁶ Thus, the use of CTA for imaging of the carotid arteries is not without its risks and limitations compared with CDU.

Standardisation of CDU reporting criteria was not addressed until 2002 when a panel of experts published standard criteria to determine the degree of carotid stenosis.⁹ The consensus report criteria suggestive of 70–99% stenosis in the ICA are as follows:⁹

- > PSV > 250 cm/s
- > EDV > 100 cm/s
- > ICA/common carotid artery (CCA) PSV ratio > 4.0

- > PSV of > 125–250 cm/s is consistent with > 50–69% stenosis.

Although these criteria were introduced over 10 years ago, they have not necessarily been followed and we can see from our data that different vascular laboratories have developed their own criteria.¹⁰ Reporting of CDU is heterogeneous, which the analysis in this paper considered, therefore the weighted mean is categorised based on the conformance to the consensus criteria. Operator variability is one of the biggest weaknesses of CDU as an imaging modality, as a range of factors can affect the result, such as the angle of probe approach, or even the gain set on the scanner.^{6,8}

UK Health Technology Assessment determined that CDU should remain the preferred imaging modality for identifying patients with 70–99% stenosis, primarily due to the cost effectiveness and the sensitivity of the test in detecting stenosis greater than 70%.¹¹ However, the decreased accuracy in diagnosing stenosis of less than 70% is a cause for concern and a criticism acknowledged by the report,¹¹ a point that our data supports.

Our analysis suggests that the imaging modality most able to adapt its criteria to improve the sensitivity and specificity is CDU. On this basis, our findings correlate with the recommendations of the UK working group⁴ and ESVS guidelines.⁷ They suggest the following criteria to determine stenosis greater than 70%:

- > ICA PSV > 250 cm/s
- > ICA EDV > 100 cm/s
- > Ratio of ICA PSV in centimetres/second to CCA PSV – (ICAPSV : CCAPSV) > 4.0
- > Operators must record the PSV and EDV in both the ICA and CCA, used to calculate the above ratios.

Our data suggest that a combination of the PSV and EDV consensus criteria should be used for CDU assessment of stenosis to sufficiently provide diagnostic confidence.⁴ It is

Table 4 Sensitivity and specificity of duplex ultrasound

Degree of stenosis (%)	Method of measurement	Carotid arteries (n)	Sensitivity (%)	Specificity (%)	Reference
> 80	PSV + EDV	67	85	71	Patel <i>et al</i> ¹⁷
	PSV	2186	87	90	Shaalaa <i>et al</i> ²⁸
	EDV	2186	84	91	
> 70	PSV	120	96	86	Neale <i>et al</i> ²⁹
	EDV	120	91	93	
	PSV + EDV	120	96	91	
	Not known	137	93	92	Young <i>et al</i> ³⁰
	PSV	156	79	86	Patel <i>et al</i> ³¹
	Adjusted PSV	156	94	83	
	PSV	56	87	98	Link <i>et al</i> ¹²
	PSV	174	93	86	Alexandrov <i>et al</i> ³²
	PSV	154	96.2	67.4	Curley <i>et al</i> ³³
	PSV	154	37	96	
	PSV + EDV	92	79	96.3	Belsky <i>et al</i> ³⁴
	PSV	236	87.7	99.2	Moll <i>et al</i> ¹⁵
	ECST – PSV	134	88	86	Jogestrand <i>et al</i> ³⁵
	PSV	313	87.5	75.7	Nederkoorn <i>et al</i> ³⁶
	PSV	65	94	86	Knudsen <i>et al</i> ³⁷
	PSV	326	81.5	95.6	Konstantinos <i>et al</i> ³⁸
	NASCET – PSV	158	88	67	Staikov <i>et al</i> ³⁹
	NASCET – EDV	158	88	63	
	ECST – PSV	158	97	65	
	ECST – EDV	158	96	65	
	PSV	71	92.9	81.9	Borisch <i>et al</i> ⁴⁰
	PSV + EDV	978	98.8	95.5	Leonardo <i>et al</i> ⁴¹
	NASCET – PSV	52	86.4	100	Clevert <i>et al</i> ⁸
	PSV	68	100	78	Korteweg <i>et al</i> ⁴²
	PSV + EDV	147	100	87.1	Shakhnovich <i>et al</i> ⁴³
	PSV	397	99	86	AbuRahma <i>et al</i> ¹⁰
	NASCET – PSV	45	94	67	Howard <i>et al</i> ²¹
	NASCET – PSV	336	67	87	Anzidei <i>et al</i> ²²
> 50	PSV	18	95	50	Boyle <i>et al</i> ⁴⁴
	Not known	328	90	76	Srinivasan <i>et al</i> ⁴⁵
	PSV	326	88	97.2	Konstantinos <i>et al</i> ³⁸
	PSV	2186	82	88	Shaalaa <i>et al</i> ²⁸
	PSV + EDV	147	100	87.8	Shakhnovich <i>et al</i> ⁴³
	PSV	397	93	68	AbuRahma <i>et al</i> ¹⁰
	PSV	65	80	100	Preiss <i>et al</i> ⁴⁶
	EDV	65	100	71	
	PSV + EDV	65	80	100	

Table 4 (*Continued*)

>60%	PSV	210	96	86	Carpenter <i>et al</i> ^{A7}
	EDV	210	97	52	
	PSV + EDV	210	100	100	

ECST, European Carotid Surgery Trial; EDV, end diastolic velocity; NASCET, North American Symptomatic Carotid Endarterectomy Trial; PSV, peak systolic velocity.

Table 5 Weighted mean analysis of duplex ultrasound

Criteria	Weighted mean		Studies (n)	Carotids (n)
	Sensitivity (%)	Specificity (%)		
Duplex – PSV > 50% stenosis	85.1	86.4	8	3271
Duplex – PSV >70% stenosis	85.8	84.5	20	3329
Duplex – PSV >70% stenosis (Consensus ONLY)	92.4	87.9	5	902
Duplex – PSV > 70% stenosis (narrowed consensus ONLY)	82.8	87	8	1366
Duplex – EDV > 70% stenosis	91.7	72	3	436
Duplex – EDV + PSV > 70% stenosis	97.3	94.2	4	1337
Duplex – > 60% stenosis	97.7	79.3	3	630
Duplex – >80% stenosis	85.5	90.2	3	4439

EDV, end diastolic velocity; PSV, peak systolic velocity.

Table 6 Comparison of computed tomography carotid angiography compared with duplex ultrasound – sensitivity and specificity

Criteria	Weighted mean (%)		Studies (n)	Carotids (n)
	Sensitivity	Specificity		
CTA – NASCET > 70% stenosis	88.9	92.4	17	1882
CTA – NASCET > 70% stenosis ^a	90.6	93	9	1245
CTA – NASCET > 50% stenosis	81.7	85.6	6	770
Duplex – PSV > 50% stenosis	85.1	86.4	8	3271
Duplex – PSV > 70% stenosis	85.8	84.5	20	3329
Duplex – PSV > 70% stenosis ^b	86.5	87.8	12	2223
Duplex – PSV > 70% stenosis ^{a,c}	92.3	89	4	857
Duplex – EDV > 70% stenosis	91.7	72	3	436
Duplex – EDV + PSV > 70% stenosis	97.3	94.2	4	1337
Duplex – EDV + PSV > 70% stenosis ^a	98.7	94.1	3	1245

^a Gold standard.
^b Non-consensus and consensus.
^c Consensus only.

EDV, end diastolic velocity; NASCET, North American Symptomatic Carotid Endarterectomy Trial; PSV, peak systolic velocity.

therefore suggested that, where vascular centres use both CDU and CTA to assess patients, only CDU may be used provided criteria are audited to ensure its accuracy in determining stenosis greater than 70%.

Limitations

The search method for this study is stated clearly, allowing the reader to recreate the search carried out to identify the papers included and excluded from this review. We have

indexed the details of each study collected and the results of these studies as reported by the authors; the data are collated where possible to determine the overall sensitivity and specificities of the two imaging modalities focused on as part of the review.

This study did however have its limitations. The literature search identified studies to May 2018 and it therefore may fail to include studies published after this date, as pending abstracts were not part of the database search. Reliance was placed on the original paper's authors reporting of their results and their methodology, and thus the original raw data could not be accessed to assess the quality of statistical calculation and the data extraction methods. The weighted means were restricted to studies which reported the sensitivity and specificity data, and thus excluded other studies which failed to report this data.

We sought to diminish publication bias where possible by including all the data in the original article rather than selecting the optimal criteria and data points set out by the author.

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