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Systematic review and meta-analysis of the diagnostic value of computed tomography angiography for severe internal carotid artery stenosis

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Abstract

Background Due to the increasing incidence of ischaemic cerebrovascular diseases, the accurate assessment of internal carotid artery (ICA) stenosis is crucial for the development of treatment plans. This systematic review and meta-analysis aimed to evaluate the diagnostic value of computed tomography angiography (CTA) for severe ICAstenosis, thereby providing support for clinical decision-making and promoting diagnostic updates.

Methods The PubMed, Embase, Cochrane Library, China National Knowledge Infrastructure (CNKI), Wanfang Database, VIP Database for Chinese Technical Periodicals (VIP), and Chinese Biomedical Literature (CBM) electronic databases were searched from inception to March 21, 2024, to identify publicly available research literature on the use of CTA to diagnose severe ICA stenosis. Literature screening, data extraction, and quality assessment were conducted based on the inclusion and exclusion criteria as well as the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) standards. Data analysis was performed using Stata 17.0 and Meta-Disc 1.4 software. The sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, and diagnostic odds ratio of the included studies were calculated using Stata 17.0 software, and forest plots and summary receiver operating characteristic (SROC) curves were generated. The area under the curve (AUC) was calculated, and funnel plots were constructed to assess publication bias.

Results A total of 16 studies with 2368 vascular segments were included. The meta-analysis revealed that the combined sensitivity and specificity of CTA for severe ICA stenosis were 0.93 (95% CI: 0.88 ~ 0.96) and 0.99 (95% CI: 0.96 ~ 1.00), respectively. The combined positive likelihood ratio and negative likelihood ratio were 92.0 (95% CI: 24.2 ~ 349.6) and 0.07 (95% CI: 0.04 ~ 0.13), respectively. The diagnostic odds ratio was 1302 (95% CI: 257 ~ 6606), and the AUC of the SROC curve was 0.98. The Deeks funnel plot suggested no publication bias among the included studies.

Conclusion CTA demonstrated high sensitivity and specificity for diagnosing severe ICA stenosis. Therefore, this study provided important evidence for the accurate diagnosis and treatment of severe ICA stenosis. However, there

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was considerable heterogeneity among the included studies, thus indicating the need for additional high-quality prospective studies to confirm the clinical applicability of CTA.

Keywords CT angiography, Carotid artery stenosis, Meta-analysis

Introduction

In recent years, given the high incidence of ischaemic cerebrovascular diseases, increasing attention has been devoted to the diagnosis and treatment of related diseases [1]. ICA stenosis is a common vascular disease, and the severity of this disease directly affects patients' quality of life and health. As one of the important risk factors for ischaemic cerebrovascular diseases, ICA stenosis has attracted considerable attention [2]. It has been reported that 20 to 25% of ischaemic strokes are related to ICA stenosis. The main treatment methods for this disease currently include medical conservative treatment, surgical procedures, and interventional therapy, with the choice of treatment depending on the patient's clinical symptoms and the degree of ICA stenosis [3, 4]. Therefore, accurate assessment of the degree of ICA stenosis is crucial for developing appropriate treatment plans.

Currently, digital subtraction angiography (DSA) is considered the gold standard for evaluating ICA stenosis. However, its invasive nature, high examination costs, and presence of certain procedural complications limit its widespread use in clinical practice [5]. In contrast, computed tomography angiography (CTA) is a minimally invasive, accurate, and multi–perspective vascular imaging technique that plays an important role in the diagnosis and treatment of ischaemic cerebrovascular diseases. CTA offers advantages such as ease of operation, high resolution, and noninvasiveness, thus making it an alternative approach for evaluating ICA stenosis. However, there is still controversy and uncertainty regarding the accuracy and reliability of CTA in diagnosing severe ICA stenosis [6]. Some studies have reported that CTA has high sensitivity and specificity, thus providing reliable diagnostic information to support clinical treatment decisions [7], whereas others have noted that CTA has a certain misdiagnosis rate and limitations [8], indicating the need for further improvement and validation in evaluating ICA stenosis. In light of these findings, this study aimed to clarify the value of CTA in diagnosing ICA stenosis severity through meta–analysis. By systematically integrating the literature, we objectively evaluated the diagnostic accuracy and clinical prospects of CTA, thus providing a scientific basis and decision support for clinicians. Through comprehensive literature retrieval, screening, and data analysis, we revealed the true performance of CTA in diagnosing severe ICA stenosis, thereby providing reference and guidance for further improvement of diagnostic techniques and optimization of treatment plans.

Methods

Our systematic review follows the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Protocols (PRISMA-P) [9] and has been registered with the identifier INPLASY202440027.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) Population: patients with severe ICA stenosis, defined as 70–99% stenosis [10]; (2) Intervention: use of CTA for the diagnosis of severe ICA stenosis; (3) Comparison: DSA, which is the "gold standard" for diagnosing ICA stenosis; and (4) Outcome: true positive (TP), true negative (TN), false–positive (FP), and false–negative (FN) rates for diagnosing severe ICA stenosis.

The exclusion criteria were as follows: (1) duplicate publications; (2) literature without access to relevant raw data, such as studies where TP, TN, FP, and FN rates cannot be directly or indirectly obtained; and (3) non-Chinese or non-English literature.

Search strategy

The PubMed, Embase, Cochrane Library, CNKI, Wanfang, VIP, and CBM databases were searched from inception to March 21, 2024, to identify publicly available Chinese and English literature on the CTA diagnosis of severe ICA stenosis. A combination of subject headings and free text terms was used for the search. The search terms included CT angiography, CT angiographies, computed tomographic angiography, computed tomography angiographies, carotid stenosis, carotid stenoses, carotid artery narrowing, carotid artery narrowing, carotid artery stenosis, carotid artery stenoses, carotid artery plaque, carotid artery plaques, and carotid artery ulcerating plaque. For example, the search strategy for PubMed was as follows: ((CT angiography[MeSH Terms]) OR (((CT angiographies[Title/Abstract]) OR (computed tomographic angiography[Title/Abstract])) OR (computed tomography angiographies[Title/Abstract]))) AND ((carotid stenosis[MeSH Terms]) OR (((((((carotid stenoses[Title/Abstract]) OR (carotid artery narrowing[Title/Abstract])) OR (carotid artery narrowings[Title/Abstract])) OR (carotid artery stenosis[Title/Abstract])) OR (carotid artery stenoses[Title/Abstract])) OR (carotid artery plaque[Title/Abstract])) OR (carotid artery plaques[Title/Abstract])) OR (carotid artery ulcerating plaque[Title/Abstract]))). Additionally, to identify further relevant studies, the references of the included articles were

also screened to ensure compliance with the inclusion criteria.

Literature screening and data extraction

Two researchers independently screened the literature and extracted information according to the preestablished inclusion and exclusion criteria. Cross-checking was performed to ensure accuracy. Any discrepancies were resolved through discussion or consultation with a third researcher if necessary. The extracted information included the following: (1) general information: first author, publication year, country, sample size, sex, age, number of arteries, and type of CT system; and (2) outcome indicators: TP, FP, FN, and TN rates.

Quality assessment

The quality of the studies included in the meta-analysis was assessed using the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool [11].

Statistical analysis

Data analysis was conducted using Stata 17.0 and Meta-Disc 1.4 software. Cochran's Q test and the I^2 statistic were used to assess heterogeneity among studies. If $P<0.05$ and I2 > 50%, indicating significant heterogeneity, a random effects model was chosen; otherwise, a fixed effects model was used [12]. The combined sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, and diagnostic odds ratio with their 95% confidence intervals (CIs) were calculated for the included studies. Forest plots and SROC curves were generated, and the area under the curve (AUC) was calculated. If heterogeneity was present, the presence of a threshold effect was assessed using the Spearman correlation coefficient in Meta–Disc 1.4 (a strong positive correlation indicates a threshold effect). Additionally, meta–regression analysis was performed to explore the sources of heterogeneity. Subgroup analyses were conducted to explore differences in sensitivity and specificity between subgroups. Deeks' funnel plot was used to assess publication bias using Stata 17.0, and the P value for publication bias was obtained directly from this test, with $P < 0.05$ indicating the presence of publication bias.

Assessment of evidence quality

To assess the certainty of evidence, we employed the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) framework. This method evaluates the quality of evidence across the domains of risk of bias, consistency, directness, precision, and publication bias. Each domain is rated as high, moderate, low, or very low [37].

Results

Literature search results

A total of 4772 articles were initially retrieved from various databases, with 1 article identified through a manual search. After reviewing the titles and abstracts, 1237 duplicate articles were excluded; 3419 articles were excluded due to being unrelated to the research objectives; 98 articles were excluded due to being reviews, conference papers, or experience summaries; and 3 articles were excluded because of the inability to extract TP, TN, FP, or FN rates. Following the aforementioned stepwise screening process, 16 articles [7–8,13-26] were ultimately included, comprising 2368 vascular segments. The detailed screening process is illustrated in Fig. 1. The basic characteristics of the studies are presented in Table 1.

Quality assessment results of the included studies

The risk of bias for each included study was assessed using detailed evaluation criteria (see Table 2). Each study was evaluated across 14 specific criteria. The results indicated that most studies had a high risk of bias, particularly in terms of the interval between the gold standard and the evaluated test and the independence of test interpretation.

Heterogeneity and threshold effect analysis

The I^2 values for the combined sensitivity and specificity of CTA in diagnosing severe ICA stenosis were 81.64% and 95.10%, respectively. The Cochran Q test yielded P values of 0.00 for both sensitivity and specificity, indicating significant heterogeneity among the included studies. Therefore, a threshold effect analysis was conducted. Threshold effect: Using Meta-Disc 1.4 software, the Spearman correlation coefficient was calculated to be -0.338, with a corresponding P value of 0.20, suggesting the presence of nonthreshold effect heterogeneity among the studies. Therefore, a random effects model was employed for estimating the combined effect size.

Meta-analysis results

Forest plots and SROC curves were generated using Stata 17.0. The combined sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, diagnostic odds ratio, and AUC were calculated. The combined sensitivity and specificity were 0.93 (95% CI: 0.88 ~ 0.96) and 0.99 (95% CI: 0.96 ~ 1.00), respectively. The combined positive likelihood ratio and negative likelihood ratio were 92.0 (95% CI: 24.2 ~ 349.6) and 0.07 (95% CI: 0.04 ~ 0.13), respectively. The diagnostic odds ratio was 1302 (95% CI: 257 ~ 6606), and the AUC was 0.98. Forest plots and SROC curves for the diagnosis of severe ICA stenosis based on CTA are shown in Figs. 2 and 3.

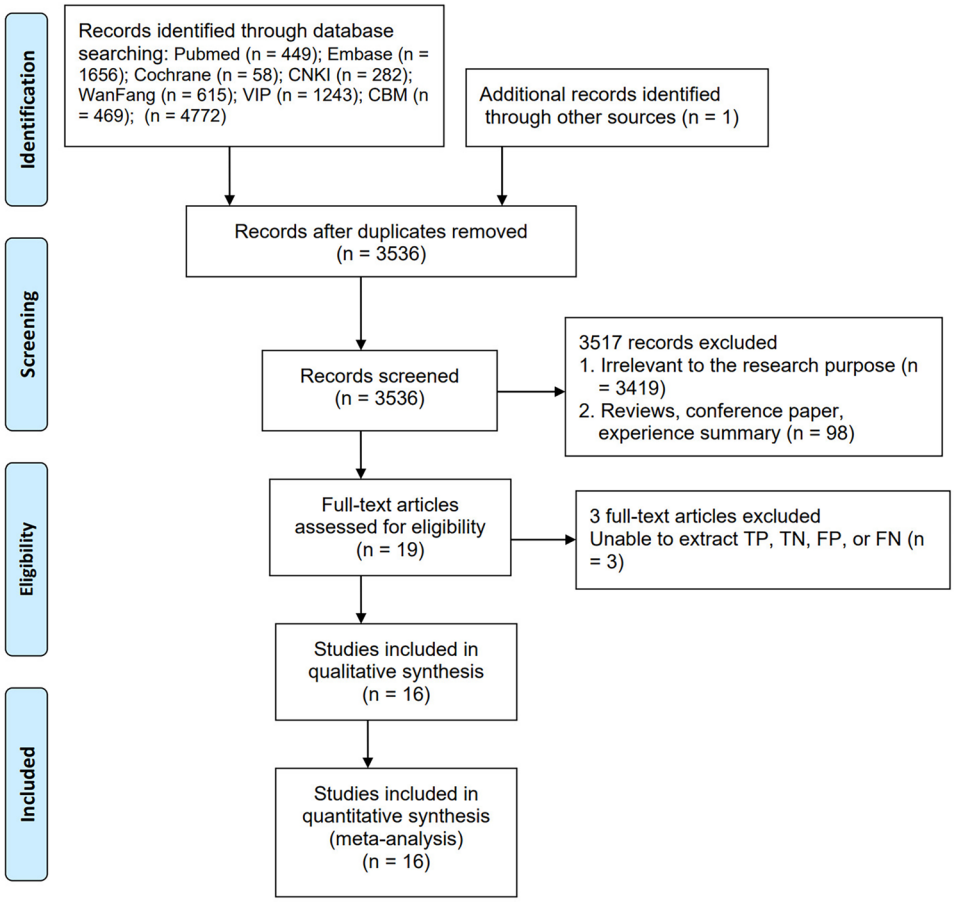

Fig. 1 Study selection process

Publication bias

A Deeks funnel plot was generated to assess publication bias in the diagnosis of severe ICA stenosis using CTA. The plot exhibited basic symmetry, with a p value of 0.85, indicating a relatively low likelihood of publication bias, as shown in Fig. 4.

GRADE evidence quality assessment

The GRADE assessment indicated that the quality of evidence for the diagnostic accuracy of CTA in detecting severe ICA stenosis was low for all evaluated outcomes, including sensitivity, specificity, positive likelihood ratio, and negative likelihood ratio, as presented in Table 3.

Meta-regression and subgroup analysis

Heterogeneity due to threshold effects was excluded. Consequently, single-factor meta-regression analyses were conducted on the basis of country, publication year, sample size, type of CT system, and blinding method. The results revealed that the type of CT system was the primary factor contributing to heterogeneity in sensitivity, whereas country, publication year, and sample size were the main contributors to heterogeneity in specificity. The subgroup analysis results are presented in Table 4.

Discussion

This meta-analysis demonstrated that CTA has high accuracy and reliability in diagnosing severe ICA stenosis. Our findings indicate that CTA has high diagnostic accuracy in detecting severe ICA stenosis, with a sensitivity of 93% (95% CI: 0.88 ~ 0.96) and a specificity of 99% (95% CI: 0.96 ~ 1.00). A the global population continues to age, the incidence of ischaemic cerebrovascular diseases has significantly increased, which seriously affects the quality of life of patients and increases the social medical burden [27, 28]. Clinical studies have shown that the degree of ICA stenosis and the nature of plaques are closely related to the occurrence of ischaemic cerebrovascular diseases [29, 30]. Therefore, early clarification of the degree of ICA stenosis is highly important for the effective prevention of ischaemic cerebrovascular diseases. Colour Doppler ultrasound (CDU) is the preferred method for initial screening and evaluation of carotid artery stenosis because it is noninvasive, easy to use, and widely employed. However, CDU has limitations in terms

Table 1 Basic characteristics of included studies

Study	City, Country	Study type	Cut-off value	Sample size (M/F)	Age (years)	Number of arteries	Interval between the CTA and DSA	Interventions prior to CTA	Type of CT system	TP	FP	FN	TN
Alvarez-Linera 2003 [13]	Madrid and Mo´stoles, Spain	Prosp	70–99%	34/6	61.5 (42–80)	80	2 days	Injected 150 mL of iopromide at 3 mL/s into the antecubital vein, followed by a 20 mL saline flush.	HiSpeed Advantage CT scanner (GE Medical Systems)	26	1	9	44
Anzidei 2012 [14]	Rome and Monserrato, Italy	Prosp	70–99%	108/62	69 ± 6.5	336	Within 2 weeks	Injected 0.03 mmol/kg of gadofosveset trisodium into the right arm's antecubital vein at 1 ml/s, followed by 15 ml of saline.	Multislice system (Sensation Cardiac 64, Siemens Medical System)	132	6	8	190
Bucek 2007 [8]	Vienna, Austria	Retro	70–99%	34/12	73.5*	87	Na	Administered 100 to 120 mL of Optiray 320 via an 18-gauge cannula at 4 mL/second, followed by a 40 mL saline flush.	Somatom Plus 4 Volume Zoom scanner (Siemens AG)	24	19	0	44
Fu 2022 [15]	Panzhihua, China	Prosp	70–99%	59/38	65.8 ± 8.9	194	Within 2 weeks	Iodixanol 1.0 ~ 1.5 ml/kg at 4 ~ 5 mL/s, followed by 30 mL saline	Na	51	0	4	139
Gao 2006 [16]	Beijing, China	Retro	70–99%	27/13	53 ± 8	80	Na	Injected non-ionic contrast (370 mg I/ml) at a flow rate of 4 ml/s through the antecubital vein, totaling 100 ml.	64-slice spiral CT (GE LightSpeed VCT)	28	2	1	49
Hirai 2001 [17]	Hondo and Kumamoto, Japan	Prosp	70–99%	17/4	68 (52–82)	42	Within 10 days	Injected 100 mL of nonionic contrast material into the antecubital vein at a flow rate of 3.0 mL/sec using a power injector.	Helical CT scanner (W3000 AD; Hitachi)	4	3	0	35
Hu 2007 [18]	Nanjing, China	Retro	70–99%	27/14	61 ± 10	82	Within 2 weeks	Using a high-pressure injector, 60 mL of non-ionic contrast agent (iodixanol) was injected at a rate of 4 ml/s into the antecubital vein.	Siemens Dual-Source CT	14	0	1	67
Jia 2020 [19]	Xinxiang, China	Retro	70–99%	65/40	68.2 ± 6.1	105	Na	Injected 50 ml of iodinated contrast agent, iopromide, for enhanced scanning.	PHILIPS Brilliance iCT	25	6	9	65
Li 2019 [20]	Sanya, China	Retro	70–99%	46/25	63.81 ± 6.96	71	Na	Injected 100 mL of iodixanol contrast agent at a flow rate of 3.5 to 4.5 mL/s.	64-row CT (GE system)	22	4	5	40
Randoux 2001 [21]	Paris, France	Prosp	70–99%	Na/Na	70 (59–83)	44	Within 2 weeks	Using a power injector, 140 mL of non-ionic contrast agent (iobitridol) was injected into the antecubital vein at a rate of 2.5 mL/s, immediately followed by a 20 mL saline flush.	CT scanner (HiSpeed system; GE Medical Systems)	13	0	0	31
Shen 2013 [22]	Yangzhou, China	Prosp	70–99%	38/30	61.0 ± 8.1	272#	Within 1 week	Iopamidol was injected into the median cubital vein at 1-1.5 mL/kg and 4–5 mL/s, followed by a 30 mL saline flush.	Lightspeed 64-row CT (GE system)	40	6	8	218
Silvennoinen 2007 [7]	Helsinki, Finland	Prosp	70–99%	19/18	67**	73	Within 2 weeks	Injected 100 mL of nonionic contrast medium (Omnipaque, 300 mg of iodine/mL) with a power injector into an antecubital vein at a rate of 4 mL/s.	GE Medical Systems	18	0	2	53
Tu 2020 [23]	Chengdu, China	Retro	70–99%	49/31	60.6 ± 12.7	80	Within 2 weeks	Iopamidol was injected into the antecubital vein at high pressure, dosing 1-1.5 ml/kg, at an injection rate of 4–5 ml/s, followed by flushing the catheter with 30 ml of saline.	Philips 256-layer Brilliance iCT	42	0	3	35
Wang 2021 [24]	Mianyang, China	Retro	70–99%.	178/143	68.5 ± 2.5	321	Na	Injected non-ionic contrast agent iopamidol into the antecubital vein at a rate of 3–4 ml/s.	64-row 128-layer spiral CT scanner (Siemens)	25	1	1	294

Table 1 (continued)

		Study	Cut-off	Sample		Number of	Interval between					
Study	**City, Country**	**type**	**value**	**size (M/F)**	**Age (years)**	**arteries**	**the CTA and DSA**	**Interventions prior to CTA**	**Type of CT system**	**TP**	**FP**	**FN**	**TN**
Xu 2023 [25]	Lin'an, China	Prosp	70–99%	68/52	50.2 ± 6.4	240	Na	Administered iodixanol via the right antecubital vein at a flow rate of 5 ml/s, dosing 1.0 to 3.0 ml/kg.	64-row CT (GE system)	31	0	0	209
Yan 2021 [26]	Shaoguan, China	Prosp	70–99%	32/36	62.4 ± 4.3	261[#]	Within 1 week	Injected 36–45 mL of non-ionic iodinated contrast agent intravenously using a dual-barrel high-pressure injector at a flow rate of 4.5-5 mL/s.	64-row 128-layer spiral CT scanner (Siemens)	20	0	0	241

*: median age; **: average age of; #: These two studies diagnosed the carotid artery into two segments, namely, the cervical internal carotid artery and the extracranial segment of the cervical internal carotid artery

Abbreviation CT computed tomography; *CTA* computed tomography angiography; *DSA* digital subtraction angiography; *F* Female; *FN* false negatives; *FP* false positives;*GE* general electric; *M* Male; *Na* not available; *Prosp* Prospective; *Retro* Retrospective; *TN* true negatives; *TP* true positives

of resolution and the assessment of deep vascular lesions, particularly in accurately determining the composition of plaques and details of the vascular wall, which may not be as precise as other imaging techniques [31]. DSA, despite being invasive, remains the preferred method for detailed evaluation of ICA stenosis because it effectively reflects changes in ICA morphology and haemodynamic parameters. However, DSA is invasive, technically challenging, and carries risks of complications such as vascular spasm and thrombosis, with certain limitations [3, 32]. CTA is an emerging imaging technology that plays an important role in the clinical diagnosis of various cerebrovascular diseases. Compared with DSA, CTA has fewer restrictions on vascular conditions. CTA is characterized by enhanced scanning of the carotid arteries, and it utilizes differences in enhanced blood flow and contrast agent concentration to display the morphology and characteristics of diseased vessels from multiple angles, thereby reducing vascular overlap interference. In particular, CTA can clearly display the three–dimensional anatomical spatial relationship of large vessels in the cranio–cervical region and intravascular calcified plaques, thereby obtaining accurate diagnostic information [6, 33, 34].

This meta-analysis included 16 studies, comprising a total of 2368 vascular segments. The results demonstrated that CTA has high accuracy and reliability in diagnosing severe ICA stenosis, with a sensitivity of 0.93 and specificity of 0.99. This implies that among patients with the disease, 93% can be accurately diagnosed by CTA, whereas among those without the disease, 99% can be accurately ruled out by CTA. Moreover, the combined sensitivity and specificity of CTA for severe ICA stenosis, with 95% CI of 0.88 to 0.96 and 0.96 to 1.00 respectively, further confirm the statistical significance and robustness of our findings. Although detailed comparisons with other diagnostic methods were not conducted, the high sensitivity and specificity of CTA relative to commonly used methods such as DSA make it a powerful diagnostic tool. CTA has a combined positive likelihood ratio of 92.0 and a combined negative likelihood ratio of 0.07 for severe ICA stenosis, indicating a greater likelihood of a positive test result in individuals with the disease and a greater likelihood of a negative test result in those without the disease. Furthermore, the diagnostic odds ratio was 1302, further emphasizing the high accuracy and reliability of CTA in diagnosing severe ICA stenosis. The area under the SROC curve in the present study was 0.98, indicating the superior performance of CTA as a diagnostic tool. This provides robust support for clinicians to make accurate diagnostic and treatment decisions and promotes their widespread clinical application. Although our study demonstrated the high diagnostic accuracy of CTA, it is important to note the existence of potential misdiagnoses and limitations. This may be attributed

Table 2 Quality assessment results of included studies

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14
Alvarez-Linera 2003 [13]	√	√	√	√	√	√	√	√	√	√	√	√	?	×
Anzidei 2012 [14]	√	√	√	√	√	√	√	√	√	√	√	√	√	×
Bucek 2007 [8]	√	×	√	?	√	√	√	√	√	√	√	√	?	×
Fu 2022 [15]	√	√	√	?	√	√	√	√	√	√	√	√	?	×
Gao 2006 [16]	√	×	√	?	√	√	√	√	√	√	√	√	?	×
Hirai 2001 [17]	√	√	√	√	√	√	√	√	√	√	√	√	?	√
Hu 2007 [18]	√	×	√	√	√	√	√	√	√	?	?	√	?	×
Jia 2020 [19]	√	×	√	?	√	√	√	√	√	?	?	√	?	×
Li 2019 [20]	√	√	√	?	√	√	√	√	√	?	?	√	?	×
Randoux 2001 [21]	√	√	√	√	√	√	√	√	√	√	√	√	?	√
Shen 2013 [22]	√	×	√	√	√	√	√	√	×	?	?	√	?	×
Silvennoinen 2007 [7]	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Tu 2020 [23]	√	√	√	√	√	√	√	√	√	√	√	√	?	×
Wang 2021 [24]	√	√	√	?	√	√	√	√	√	?	?	√	?	×
Xu 2023 [25]	√	√	√	?	√	√	√	√	√	√	√	√	?	×
Yan 2021 [26]	√	√	√	√	√	√	√	√	√	?	?	√	?	×

Note √ Yes; × No; *?* Uncertain

Evaluation Criteria:

1: Does the case spectrum include various cases and cases of confusing diseases?

2: Is the selection of study subjects accurately and clearly defined in terms of inclusion and exclusion criteria?

3: Can the gold standard accurately distinguish between diseased and non-diseased states?

4: Is the interval between the gold standard and the evaluated test short enough to avoid changes in the disease condition?

5: Did all samples or randomly selected samples undergo the gold standard test?

6: Did all cases undergo the same gold standard test regardless of the results of the evaluated test?

7: Is the gold standard test independent of the evaluated test (i.e., the evaluated test is not included in the gold standard)?

8: Is the operation of the evaluated test described clearly enough and replicable?

9: Is the operation of the gold standard test described clearly enough and replicable?

10: Was the interpretation of the results of the evaluated test performed without knowing the results of the gold standard test?

11: Was the interpretation of the results of the gold standard test performed without knowing the results of the evaluated test?

12: Are the clinical data available for interpretation of the test results consistent with the clinical data available in actual practice?

13: Are difficult to interpret / intermediate test results reported?

14: Are explanations provided for cases that dropped out of the study?

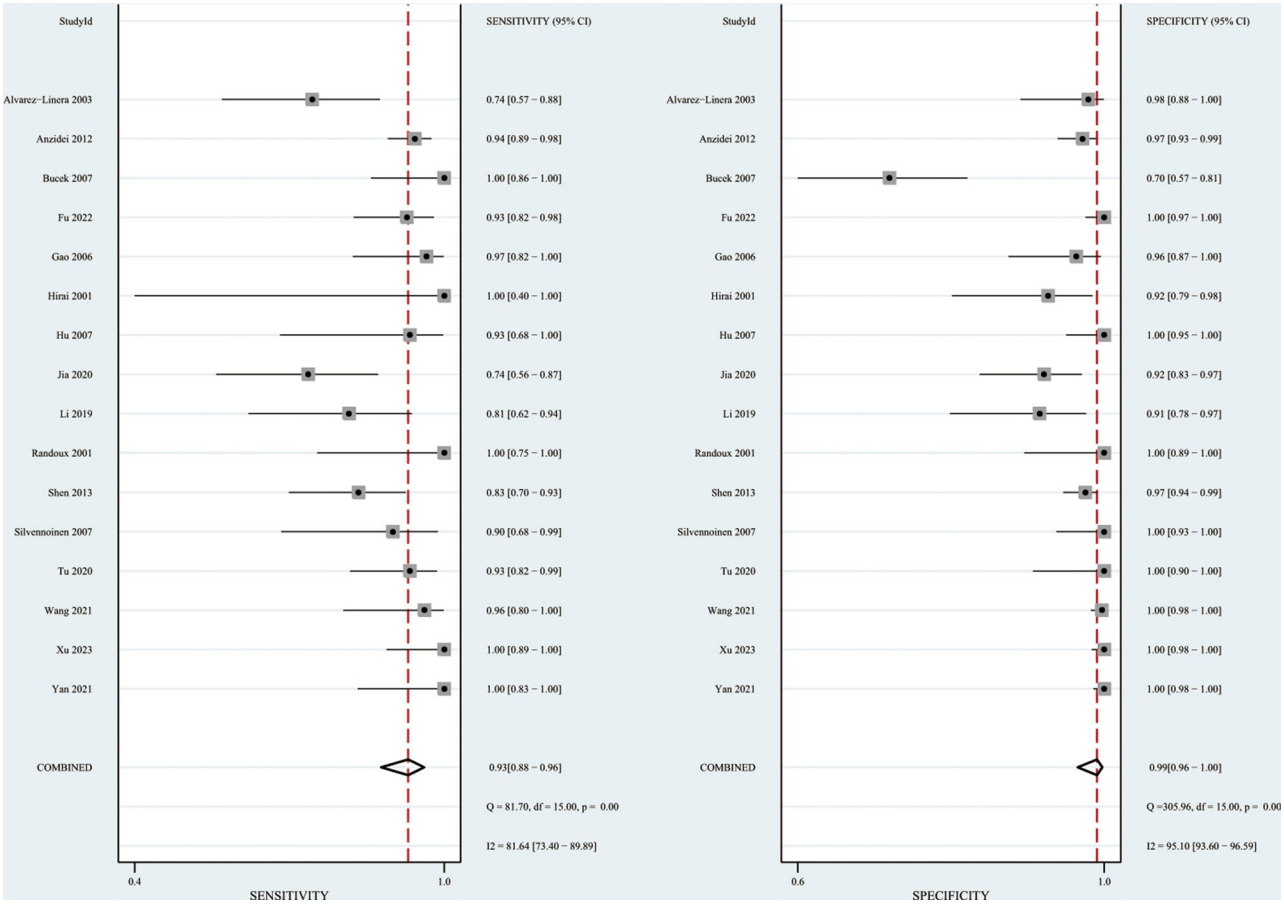

Fig. 2 Forest plot of sensitivity and specificity for CTA diagnosis of severe stenosis in ICA

to factors such as vascular wall calcification, calcified plaques, and arteriosclerosis, which can affect the assessment of vascular stenosis using CTA, leading to diagnostic bias. Therefore, in clinical practice, clinicians should still consider the patient's clinical symptoms, imaging findings, and other auxiliary examination results for comprehensive analysis and judgement to avoid inaccurate diagnostic and treatment decisions based solely on a single examination result. Through single-factor meta-regression analysis, we further explored the possible reasons for the heterogeneity in sensitivity and specificity. The results indicated that the type of CT system was the primary factor contributing to the heterogeneity in sensitivity, whereas country, publication year, and sample size were the main factors contributing to the heterogeneity in specificity. These findings emphasize the potential differences in diagnostic tool selection and operating standards across different countries, study periods, and sample sizes, leading to variations in results. Additionally, differences in the CT system may also affect the consistency of the results. Therefore, when evaluating the diagnostic accuracy of CTA for severe ICA stenosis, it is necessary to consider the impact of these factors. These results suggest the importance of paying more attention to and standardizing the selection and use of diagnostic tools in future research and clinical practice to ensure the reliability and consistency of the results.

In this study, we confirmed the high sensitivity and specificity of CTA in diagnosing severe ICA stenosis. With the development of advanced technologies such as deep learning, the future application of CTA looks promising. This technology can enhance image quality and optimize the diagnostic process while also supporting personalized treatment. In the future, combining CTA with emerging technologies such as VR and automated image analysis tools will open new paths for the diagnosis and treatment of ICA disease. Therefore, future research should focus on how to integrate these technologies into CTA to continuously improve diagnostic accuracy and clinical utility [35, 36].

This study has several limitations: (1) There was high heterogeneity among different studies, which may affect the stability and consistency of the results; (2) some studies did not describe whether blinding was used for the interpretation of the gold standard, which may introduce interpretation bias; (3) only Chinese and English studies

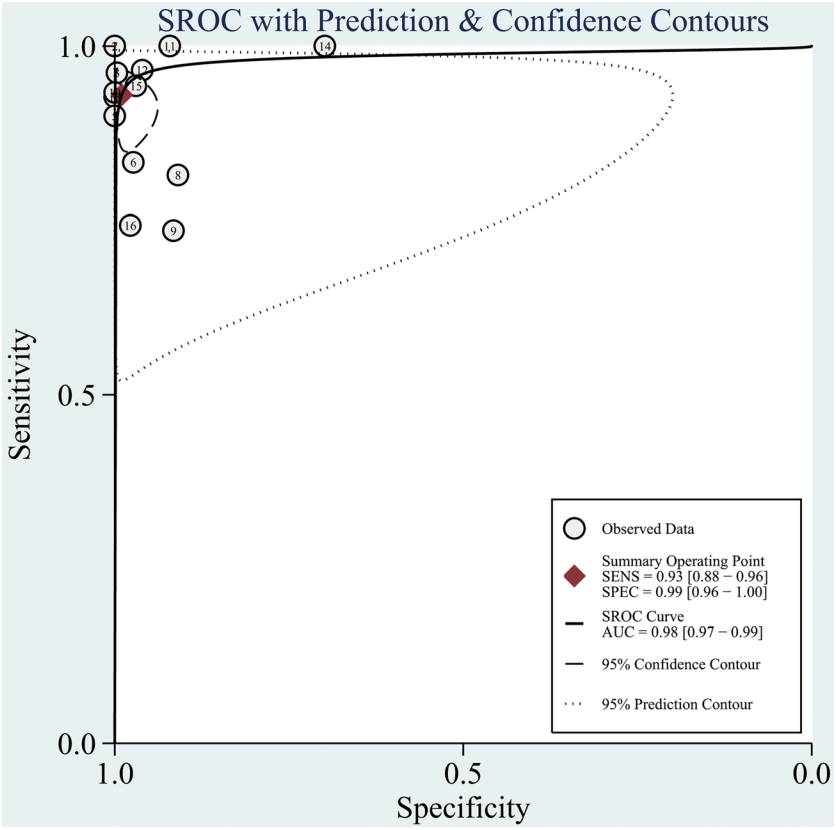

Fig. 3 ROC curve for CTA diagnosis of severe stenosis in ICA

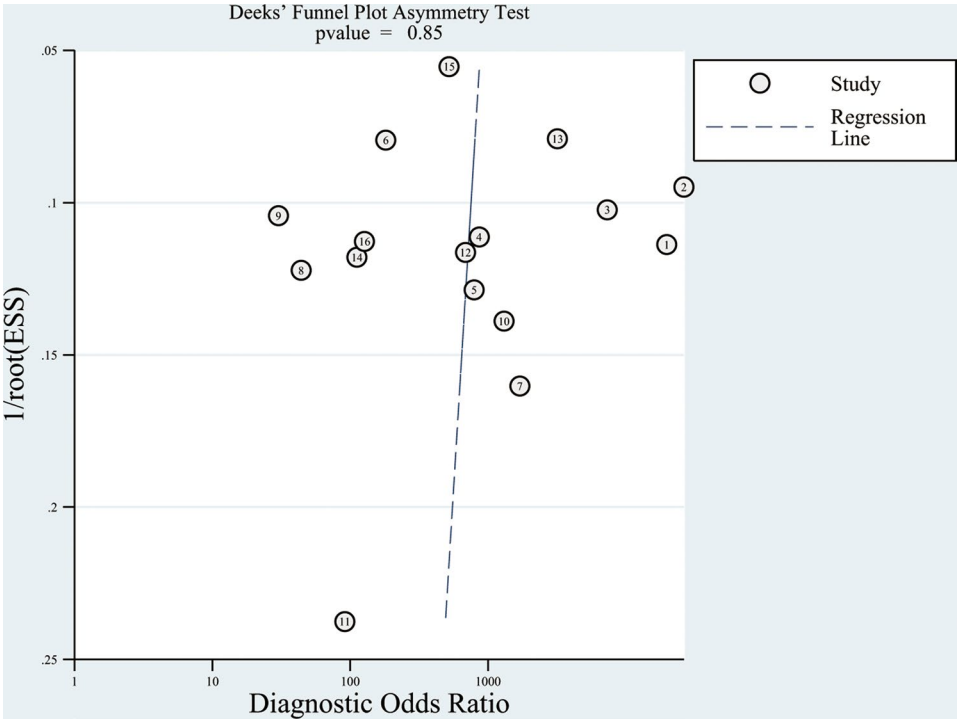

Fig. 4 Deeks funnel plot

Table 3 Grade assessment of outcome measures

Outcome Measure	No. of Studies	Study Design	Limitations (No. of studies with unclear risk of bias / Total)	Indirectness (Patients, Outcomes)	Inconsistency	Imprecision	Risk of Publication Bias	AUROC (Range)	Quality of Evidence
Sensitivity	16	Cohort studies	High risk (15/16)	None	High	None	None	0.88 ~ 0.96	⨂⨂⊖⊖ Low
Specificity	16	Cohort studies	High risk (15/16)	None	High	None	None	0.96 ~ 1.00	⨂⨂⊖⊖ Low
Positive Likelihood Ratio	16	Cohort studies	High risk (15/16)	None	High	None	None	24.2 ~ 349.6	⨂⨂⊖⊖ Low
Negative Likelihood Ratio	16	Cohort studies	High risk (15/16)	None	High	None	None	0.04 ~ 0.13	⨂⨂⊖⊖ Low

Table 4 Subgroup analysis results of included studies

Factor	Subgroup	Number of studies	Sensitivity (95% CI)	*P*-value	Specificity (95% CI)	*P*-value
Number of arteries	≥ 200	5	0.96 (0.92 ~ 1.00)	0.58	1.00 (0.99 ~ 1.00)	0.01
	<200	11	0.91 (0.85 ~ 0.96)		0.98 (0.96 ~ 1.00)	
Country	China	10	0.93(0.88 ~ 0.98)	0.11	0.99 (0.99 ~ 1.00)	0.03
	Non-China	6	0.93 (0.87 ~ 0.99)		0.97 (0.92 ~ 1.00)	
Publication year	Last 10 years	7	0.93 (0.88 ~ 0.99)	0.1	1.00 (0.99 ~ 1.00)	0.01
	More than 10 years ago	9	0.93 (0.87 ~ 0.98)		0.98 (0.95 ~ 1.00)	
Type of CT system	GE system	7	0.91 (0.84 ~ 0.98)	0.01	0.99 (0.98 ~ 1.00)	0.18
	Non-GE system	9	0.94 (0.90 ~ 0.98)		0.99 (0.97 ~ 1.00)	
Blinding	Yes	10	0.94 (0.90 ~ 0.98)	0.29	0.99 (0.97 ~ 1.00)	0.36
	No	6	0.90 (0.82 ~ 0.97)		0.99 (0.97 ~ 1.00)	

GE general electric; *CI* confidence interval

were included, potentially leading to publication bias to some extent; (4) the majority of the authors and cases were from China, which may introduce certain biases; (5) this study only evaluated the diagnostic value of CTA and did not assess safety aspects; and (6) this meta-analysis focused mainly on assessing the degree of ICA stenosis via CTA and did not involve the stability or vulnerability of plaques. The vulnerability of plaques is closely related to the risk of ischaemic stroke, and their stability is a crucial factor in determining the treatment plan and prognosis for patients. These factors may decrease the reliability of the study results, and future large-scale, standardized prospective studies are still needed to confirm the diagnostic value of CTA for severe ICA stenosis.

Conclusion

In summary, CTA has high diagnostic efficacy for severe ICA stenosis, providing clinicians with an effective diagnostic tool. This technique assists in the early detection of diseases and the formulation of appropriate treatment plans, with the expectation of improving patient treatment outcomes and survival rates.

Supplementary Information

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Supplementary Material 1

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None.

Author contributions
Han-Lin Zeng and Fu-Qiang Shao designed the study. Han-Lin Zeng ran the search strategy. Xian-Feng Peng and Chun-Yu Lei collected the data. Han-Lin Zeng reviewed the data. Han-Lin Zeng and Fu-Qiang Shao performed the analyses, and Xian-Feng Peng checked the analyses. Xian-Feng Peng and Chun-Yu Lei assessed the quality of the studies, and Fu-Qiang Shao confirmed the quality of the studies. Han-Lin Zeng wrote the manuscript, and Fu-Qiang Shao edited the manuscript. All listed authors reviewed and revised the manuscript.

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Data availability
The data from this study can be obtained from the corresponding author upon a reasonable request.

Declarations

Ethics approval and consent to participate
An ethics statement is not applicable because this study is based exclusively on published literature.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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