Authors' objectives
To determine the diagnostic accuracy of computed tomographic (CT) angiography, magnetic resonance (MR) angiography, and transcranial Doppler ultrasonography (TCD) compared with that of intraarterial digital subtraction angiography (DSA) in depicting intracranial aneurysms. A secondary objective was to determine whether accuracy was influenced by aneurysm prevalence, sample size, or aneurysm site or size in the populations studied.

Searching
MEDLINE and EMBASE were searched for studies published in any language between January 1988 and December 1998. The search terms were provided in the paper. In addition, the references of identified studies were checked and relevant journals not indexed in either of the databases were handsearched. The authors validated the search strategy through further handsearches of the RSNA Index to Imaging Literature and the journals Neurosurgery, Journal of Neurosurgery, and Stroke. All the references that were located had also been identified through the electronic searches. Only articles published in full were eligible for inclusion.

Study selection
Study designs of evaluations included in the review
Diagnostic accuracy studies that included at least 10 participants were eligible for inclusion.

Specific interventions included in the review
Studies in which the diagnostic accuracy of a noninvasive imaging examination was compared with that of intraarterial DSA performed contemporaneously were eligible for inclusion in the review. The included studies compared CT angiography with angiography (14 studies), MR angiography with angiography (18 studies), both MR angiography and CT angiography with angiography (2 studies), and TCD with angiography (4 studies). The reference standard test was intraarterial DSA.

Reference standard test against which the new test was compared
The reference standard test was intraarterial DSA.

Participants included in the review
Studies on patients with suspected aneurysms of any size were eligible for inclusion. However, studies that assessed children were excluded. The patient populations assessed varied between the different imaging modalities and were as follows.

CT angiography: 3 studies were performed in patients who were not known to have an aneurysm or recent subarachnoid haemorrhage, (SAH) but had symptoms that could be attributed to an underlying aneurysm; 7 studies were performed in a population in which predominantly all of the patients were know to have an intracranial aneurysm or recent SAH; 6 studies were performed in a population that consisted of a mixture of these groups.

MR angiography: 3 studies were performed in patients who were not known to have an aneurysm or recent SAH, but had symptoms that could be attributed to an underlying aneurysm; 11 studies were performed in a population in which predominantly all of the patients were know to have an intracranial aneurysm or recent SAH; 5 studies were performed in a population that consisted of a mixture of these groups; and 1 study was performed in an asymptomatic population at increased risk of an aneurysm.

TCD: all of the studies were performed in patients known to have an aneurysm or recent SAH.

Outcomes assessed in the review
The primary outcomes of interest appear to have been the true positive (rate for the noninvasive examination versus
angiography), and data required to calculate the sensitivity and specificity (i.e. the true-negative rate, false-positive rate and false-negative rate both per patient and per aneurysm). The eligibility criteria (based on quality assessment) permitted studies, which did not provide results from which these data could be extracted per patient and per aneurysm, to be included provided that the weighted assessment score was greater than 5. These studies were, however, excluded from further analysis because the necessary data could not be extracted.

How were decisions on the relevance of primary studies made?
The authors did not state how the papers were selected for the review, or how many reviewers performed the selection.

Assessment of study quality
The validity of the studies was assessed using a predetermined weighted quality criteria form, which contained 26 items relevant to studies of diagnostic accuracy. The items were grouped into three main categories: study design and examination methodology, image review process, and presentation of result data. A score on a scale of 0 to 3 was assigned for each of the three main categories, with an additional mark given for the overall impression of the article. A general score of greater than 5 was deemed to be necessary for inclusion in the meta-analysis. Two reviewers independently assessed study validity, with any differences being resolved by consensus review.

Data extraction
Two reviewers independently extracted the data from the identified studies. The following data were extracted from each article.

Study design and examination methodology: the number of patients in the study who underwent DSA for comparison; study population adequately defined; study population; radiologist in authorship; equipment used; imaging parameters adequately described; contrast material usage; complications assessed; complication rate; full anatomic coverage of all potential intracranial aneurysm sites; clear and adequate description of image reconstruction techniques used; exclusion criteria stated.

Image review process: exclusion criteria stated; the number of patients excluded from the study clearly stated; blinding of the readers explicitly stated; details of image data available for review; the number of independent readers; inter-observer variability assessed; inter-observer variability rate. Presentation of result data: prevalence of aneurysms at DSA; distribution of aneurysms; the number of true-positive cases at noninvasive examination; the number of false-positive cases; the number of false-negative cases; the number of true-negative cases.

Methods of synthesis
How were the studies combined?
The true- and false-positive rates and negative rates per aneurysm and per patient were tabulated into 2x2 tables for each modality, and the sensitivity, specificity, predictive and accuracy values were calculated. To combine independent studies of the same diagnostic examination, the method of Moses et al. was used (see Other Publications of Related Interest) and receiver operating characteristics (ROC) curves were plotted.

How were differences between studies investigated?
Differences between the tests were assessed by comparing the proportion of points above and below the best fit line on the summary ROC curve using a standard chi-squares test. Also examined were the effect of aneurysm prevalence in the study population, study sample size, recent versus older study, and aneurysm site (i.e. anterior versus posterior circulation and aneurysm size).

Results of the review
Thirty-eight diagnostic accuracy studies (total n=1,765) were included.

CT angiography per patient had a sensitivity of 92% (95% confidence interval, CI: 89, 95), a specificity of 94% (95% CI: 88, 99) and an accuracy of 93% (95% CI: 90, 95). The positive predictive value (PPV) was 98% (95% CI: 96, 99)
and the likelihood ratio (LR) was 15.84. Per aneurysm, the sensitivity was 90% (95% CI: 88, 92), the specificity 86% (95% CI: 79, 91) and the accuracy 89% (95% CI: 87, 91). The PPV was 97% (95% CI: 95, 98) and the LR was 6.32.

MR angiography per patient had a sensitivity of 87% (95% CI: 84, 90), a specificity of 92% (95% CI: 88, 94) and an accuracy of 89% (95% CI: 87, 91). The PPV was 93% (95% CI: 90, 95) and the LR was 10.28. Per aneurysm, the sensitivity was 87% (95% CI: 84, 90), the specificity 95% (95% CI: 91, 97) and the accuracy 90% (95% CI: 87, 92). The PPV was 97% (95% CI: 95, 99) and the LR was 16.62.

TCD: there was insufficient data for an analysis to be undertaken on a per-patient basis. The data per aneurysm were scanty but indicated a sensitivity of 82% (95% CI: 67, 92), a specificity of 70% (95% CI: 35, 93) and an accuracy of 80% (95% CI: 66, 89). The PPV was 92% (95% CI: 79, 98) and the LR was 2.73.

CT angiography and MR angiography: it was not possible to make direct comparisons between the two techniques of CT and MR, as most of the patients examined using CT angiography were not examined using MR angiography. Both CT angiography and MR angiography were marginally more accurate at depicting posterior circulation aneurysms than at depicting anterior circulation ones, but the difference was small. For CT angiography, the accuracy was 92% (95% CI: 89, 94) for the detection of all anterior circulation aneurysms combined, and 95% (95% CI: 90, 98) for posterior circulation aneurysms. For MR angiography, the corresponding accuracy values were 91% (95% CI: 89, 93) and 95% (95% CI: 92, 98), respectively. The sensitivities for the detection of posterior circulation aneurysms were slightly lower than those for the detection of anterior circulation aneurysms: 88% (95% CI: 76, 95) versus 92% (95% CI: 89, 94) for CT angiography, and 82% (95% CI: 70, 91) versus 90% (95% CI: 87, 93) for MR angiography.

Aneurysm size: there were adequate data from 12 CT angiography and 12 MR angiography studies for an analysis of sensitivity according to aneurysm size. The results showed that the sensitivity of CT angiography was 61% (95% CI: 51, 70) for the detection of aneurysms less or equal to 3 mm, 96% (95% CI: 94, 98) for all aneurysms greater than 3 mm, 93% (95% CI: 88, 96) for aneurysms between 3 and 10 mm, and 100% (95% CI: 96, 100) for aneurysms greater than 10 mm. The corresponding sensitivities for MR angiography were 38% (95% CI: 25, 53), 94% (95% CI: 90, 97), 92% (95% CI: 88, 96) and 99% (95% CI: 93, 100), respectively.

Authors' conclusions
CT angiography and MR angiography depicted aneurysms with an accuracy of about 95%. Most of the studies were performed in populations with high aneurysm prevalence, which may have introduced bias towards noninvasive examinations.

CRD commentary
The authors addressed a clear review question, which was well-defined in terms of the participants, the diagnostic tests (both index and reference standard), the study designs and the outcome measures to be assessed. The literature search was thorough but, since it was restricted to published studies, other unpublished studies could have been missed. In addition, publication bias was not assessed. The authors did not state how the studies were selected for inclusion in the review, and bias may have been introduced into this process if it was not undertaken systematically. Two independent reviewers systematically assessed the validity of the primary studies, thus minimising any bias in this process. The statistical analysis undertaken was appropriate and the authors thoroughly explored how differences in the characteristics of the primary studies (in terms of patient characteristics, year of publication and sample size) may have influenced the results obtained.

Overall, whilst a few biases could have been introduced into the review process, this was a well-conducted and reported review. The authors' results appear to be consistent with the evidence base reviewed and the conclusions follow logically from the results obtained.

Implications of the review for practice and research
Practice: The authors stated that there was very limited information about the accuracy of noninvasive imaging in the kind of patient likely to be screened, and it would be incorrect to assume that the accuracy will be equal to that achieved in studies with a high prevalence of aneurysms and involving symptomatic patients who have an SAH.
Research: The authors stated that large, prospective, blinded studies of noninvasive imaging in patients undergoing angiography, but without a recent acute SAH, are needed to clarify the efficacy of both imaging modalities.

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