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HEAD AND NECK

Validity of high resolution magnetic resonance imaging in detecting giant cell arteritis: a meta-analysis

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Abstract

Objectives This study was designed to evaluate the performance of high-resolution magnetic resonance imaging (HR-MRI) in detecting giant cell arteritis (GCA), evaluate superficial extracranial artery and other MRI abnormalities, and compare three-dimensional (3D) and two-dimensional (2D) techniques.

Methods PubMed, Web of Science, and Cochrane Library were screened up to March 7, 2021, and further selection was performed according to the eligibility criteria. Quality Assessment of Diagnostic Accuracy Studies-2 was used for quality assessment, and heterogeneity assessment and statistical calculations were also performed.

Results In total, 1851 records were retrieved from online databases, and 15 studies were finally included. Regarding the performance of HR-MRI, the superficial extracranial artery had 75% sensitivity and 89% specificity, respectively, with an area under the receiver operating characteristic curve (AUC) of 0.91. Positive and negative post-test possibilities were 86% and 20%, respectively, with clinical diagnosis as reference. When referenced with temporal artery biopsy, the sensitivity was 91%, specificity was 78%, AUC was 0.92, and positive and negative post-test possibilities were 78% and 10%, respectively. 3D HR-MRI and 2D HR-MRI had 70% and 72% sensitivity, respectively, and 91% and 84% specificity, respectively.

Conclusions HR-MRI is a valuable imaging modality for GCA diagnosis. It provided high accuracy in the diagnosis of GCA and played a potential role in identifying GCA-related ischemic optic neuropathy. 3D HR-MRI had better specificity than 2D HR-MRI.

Key Points

- *HR-MRI helps clinicians to diagnose GCA.*
- *Superficial extracranial arteries and other MRI abnormalities can be assessed with HR-MRI.*
- *HR-MRI can help in assessing GCA-related optic neuropathy.*

Keywords Giant cell arteritis · Magnetic resonance imaging · Optic neuropathy, Ischemic

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Abbreviations

AUC	Area under the receiver operating characteristic curve
CRP	C-reactive protein
GCA	Giant cell arteritis
HR-MRI	High-resolution magnetic resonance imaging
ICA	Internal carotid artery
MRI	Magnetic resonance imaging
TAB	Temporal artery biopsy
VISTA	Volume isotropic turbo spin echo acquisition

Introduction

Giant cell arteritis (GCA) is a common form of systemic vasculitis, mainly affecting Caucasians, and is associated with increased age and female sex [1]. It has a wide range of symptoms, including new-onset headache, scalp tenderness, jaw claudication, fever, fatigue, and malaise. Up to 15% of patients may experience severe complications such as ischemic optic neuropathy and cerebrovascular accidents, causing visual loss [2]. High-dose corticosteroids can relieve symptoms and prevent severe complications [2]. However, corticosteroid treatment can cause adverse effects such as hypertension, hyperglycemia, and pancreatitis [3]. Accurate diagnosis of GCA is crucial for proper administration of corticosteroid treatment.

Clinical diagnosis of GCA is made based on the American College of Rheumatology (ACR) criteria, which require three or more of the following: age older than 50 years, new-onset localized headache, temporal artery tenderness or decreased pulsation, abnormal erythrocyte sedimentation rate, and positive temporal artery biopsy (TAB) [4]. TAB is the "gold standard" for GCA, but is invasive. It has perfect specificity; however, its sensitivity is limited [5], mainly because biopsy samples may not contain affected artery segments; this phenomenon has been described as "skip lesions" [6]. TAB alone may lead to false-negative results. However, symptom-based ACR criteria may lead to false-positives. Harmless and highly accurate techniques should be used to diagnose GCA.

Previous studies have explored imaging modalities aiding GCA diagnosis including ultrasonography, high-resolution magnetic resonance imaging (HR-MRI), and positron emission tomography-computed tomography (PET-CT). The European League Against Rheumatism (EULAR) recommended ultrasound and HR-MRI to detect mural inflammation of extracranial arteries, rather than PET-CT [7]. Ultrasound is inexpensive and more convenient, while HR-MRI can investigate a wider range of arteries, both extracranial and intracranial [7]. In the EULAR-conducted meta-analysis in 2018, HR-MRI was reported to have a sensitivity of 73% and specificity of 88% compared with clinical diagnosis, and sensitivity of 93% and specificity of 81% compared with TAB [8]. Considering TAB is invasive and has limited accuracy, other imaging modalities are needed to compensate for TAB.

However, that meta-analysis only focused on superficial extracranial arteries, and the area under the receiver operating characteristic curve (AUC) and post-test possibility were not calculated [8]. Recently, many studies have reported that three-dimensional (3D) HR-MRI might better evaluate wall thickening and mural enhancement compared with the usual two-dimensional (2D)-MRI [9]. In addition to the superficial cranial arteries, HR-MRI can detect intracranial structures [10, 11] to help identify GCA. MRI abnormalities, such as ophthalmic arteries and posterior ciliary arteries, could also help differentiate GCA-related ischemic optic neuropathy from non-arteritic optic neuropathy.

To prove the validity of HR-MRI in detecting GCA, this study was designed to update the validity of HR-MRI in detecting superficial extracranial arteries in GCA, evaluate the performance of 3D techniques, and evaluate other HR-MRI abnormalities in detecting GCA and GCA-related ischemic optic neuropathy.

Materials and methods

Search strategy and eligibility criteria

The online databases PubMed, Web of Science, and Cochrane Library were screened up to 7 March 2021, with keywords "Giant Cell Arteritis" and "Magnetic Resonance Imaging." Detailed search strategy is depicted in the Supplementary File.

Candidate studies were retrieved if they met the eligibility criteria. The inclusion and exclusion criteria are depicted in Table 1.

Data extraction and risk of bias assessment

After removing duplicates, two reviewers independently screened retrieved articles with titles and abstracts, and then with full text according to inclusion and exclusion criteria. Cohen's kappa statistic was calculated to evaluate agreement between the two reviewers [12]. Disagreements were resolved through discussion and consensus. Eligible data were then extracted from each included study for meta-analysis. The items for data extraction are depicted in Table 2.

Table 1 Inclusion and exclusion criteria

Inclusion criteria
The main idea of the studies should focus on validity of HR-MRI (1.5T or 3T) in help diagnosis of GCA or GCA optic neuropathy in patients.
Studies should provide enough data for 2 × 2 tables to calculate sensitivity and specificity.
All patients should be suspected of GCA and controls are proved GCA negative.
Exclusion criteria
Articles not written in English, commentaries, editorials, conference abstracts, letters, reviews, case reports, or case series

This table depicted the inclusion and exclusion criteria for the present meta-analysis

HR-MRI high-resolution magnetic resonance imaging, *GCA* giant cell arteritis

Table 2 Characteristics of included studies

MRI abnormalities	Author	Year	Design	MRI parameter	No. patients	Gender (male/female)	Age (mean) [SD]	CRP (mean mg/dL) [SD]		ESR (mean mm/h) [SD]		Reference standard	Sensitivity	Specificity	Tp	Fp	Fn	Tn
								GCA	Control	GCA	Control							
Superfacial extracranial artery	Bley, T. A.	2005	Retrospective	2D-3T-T1WI	21	10/11	70 [10.5]	12.6 [3.7]	9.7 [9.7]	91.9 [21.1]	49.2 [34.3]	CD	88.90%	91.70%	8	1	1	11
												TAB	100.00%	80.00%	5	1	0	4
	Bley, T. A.	2007	Retrospective	1.5T/3T-T1WI	64	33/31	68 [–]	11.2 [7.1]	7.05 [7.3]	76.1 [30.9]	48.8 [32.3]	CD	80.60%	97.00%	25	1	6	32
												TAB	90.50%	72.70%	19	3	2	8
	Bley, T. A.	2008	Retrospective	1.5T/3T-T1WI	59	27/32	71 [8.7]	12 [7.5]	6 [7.9]	84 [30]	46 [23]	CD	69.00%	91.00%	25	2	11	21
												TAB	83.00%	71.00%	20	5	4	12
	Geiger, J.	2010	Retrospective	2D-3T-T1WI	43	13/30	72 [–]	48 [49.4]		55 [24.4]		CD	67.90%	73.30%	19	4	9	11
												TAB	90.90%	50.00%	10	2	1	2
	Klink, T.	2014	Prospective	1.5T/3T-T1WI	185	60/125	71.7 [8.7]	–		–		CD(O1)	83.30%	85.50%	85	12	17	71
												CD(O2)	78.40%	90.40%	80	8	22	75
												TAB(O1)	93.60%	75.00%	58	9	4	27
												TAB(O2)	88.70%	75.00%	55	9	7	27
	Franke, P.	2014	Retrospective	2D-3T-T1WI	23	–	–	–		–		TAB(O1)	92.90%	100.00%	13	0	1	9
												TAB(O2)	85.70%	100.00%	12	0	2	9
	Siemonsen, S.	2015	Prospective	3D-3T-T1WI	25	7/18	74.36 [7.3]	–		–		CD	80.00%	80.00%	16	1	4	4
												TAB	88.90%	100.00%	8	0	1	2
	Rheaume, M.	2017	Prospective	3D-3T-T1WI	171	45/126	70.6 [10.4]	2.67 [38.1]		48.3 [32]		TAB	93.60%	77.90%	29	31	2	109
												CD	64.10%	89.30%	50	9	28	75
	Poillon, G.	2020	Prospective	3D-3T-PDWI	79	42/37	75 [9.5]	72.5 [55.5]*	17 [31]*	71 [12]*	41 [63]*	CD	73.00%	93.00%	37	2	14	26
				2D-3T-PDWI								CD	70.00%	85.00%	36	4	15	24
	Rodriguez-Regent, C.	2020	Prospective	3D-3T-T1WI	32	7/25	70 [12]	148 [150]	23 [40]	–		CD	80.00%	100.00%	8	0	2	22
Intracranial artery(ICA)	Siemonsen, S.	2015	Prospective	3D-3T-T1WI	25	7/18	74.36 [7.3]	–		–		CD	50.00%	100.00%	10	0	10	5
	Gospe, S. M.	2021	Retrospective	T1WI	13	4/9	73.77 [9.2]	–		55.3 [27.4]	28.5 [28.5]	TAB	85.70%	83.30%	6	1	1	5
Posterior ciliary artery	Sommer, N. N.	2018	Prospective	3D-3T-T1WI	27	8/19	71.07 [–]	–		–		CD	92.90%	92.30%	13	1	1	12
	Mohammed-Brahim, N.	2019	Prospective	3D-3T-VISTA	27	14/13	80 [9]*	57 [44]*	9 [15]*	70 [46]*	41 [43]*	CD	82.00%	100.00%	14	0	3	10
Ophthalmic artery	Mohammed-Brahim, N.	2019	Prospective	3D-3T-VISTA	27	14/13	80 [9]*	57 [44]*	9 [15]*	70 [46]*	41 [43]*	CD	100.00%	100.00%	17	0	0	10

Table 2 (continued)

MRI abnormalities	Author	Year	Design	MRI parameter	No. patients	Gender (male/female)	Age (mean) [SD]	CRP (mean mg/dL) [SD]		ESR (mean mm/h) [SD]		Reference standard	Sensitivity	Specificity	Tp	Fp	Fn	Tn
Optic disc	Remond, P.	2017	Prospective	3D-3T-T1WI	30	22/8	71 [11]	–		–		CD(O1)	100.00%	53.30%	15	7	0	8
												CD(O2)	100.00%	60.00%	15	6	0	9
												CD(O3)	100.00%	60.00%	15	6	0	9
	Mohammed-Brahim, N.	2019	Prospective	3D-3T-VISTA	27	14/13	80 [9]*	57 [44]*	9 [15]*	70 [46]*	41 [43]*	CD	76.00%	60.00%	13	4	4	6
Optic nerve sheath	Mohammed-Brahim, N.	2019	Prospective	3D-3T-VISTA	27	14/13	80 [9]*	57 [44]*	9 [15]*	70 [46]*	41 [43]*	CD	82.00%	100.00%	14	0	3	10
Deep temporal artery	Veldhoen, S.	2014	Prospective	1.5T/3T-T1WI	99	68/31	74 [8.5]	–		–		TAB(O1)	34.40%	84.20%	21	6	40	32
												TAB(O2)	49.20%	94.70%	30	2	31	36
Temporalis muscle	Veldhoen, S.	2014	Prospective	1.5T/3T-T1WI	99	68/31	74 [8.5]	–		–		TAB(O1)	19.70%	92.10%	12	3	49	35
												TAB(O2)	21.30%	97.40%	13	1	48	37

This table depicted characteristics of each study, including author, year of publication, study design information of HR-MRI technique, reference standard, patient demographic information and data for 2 × 2 tables

MRI abnormalities, including the superfacial extracranial artery, intracranial artery, posterior ciliary artery, ophthalmic artery, optic disc, optic nerve, optic nerve sheath, deep temporal artery, and temporalis muscle, were assessed

ICA, internal carotid artery; *MRI*, magnetic resonance imaging; *CRP*, C-reactive protein; *ESR*, erythrocyte sedimentation rate; *SD*, standard deviation; *Tp*, true positive; *Fp*, false positive; *Fn*, false negative; *Tn*, true negative; *GCA*, giant cell arteritis; *CD*, clinical diagnosis; *TAB*, temporal artery biopsy; *O1,2,3*, observer 1,2,3; *T1WI*, T1-weighted imaging; *PDWI*, proton density–weighted; *VISTA*, volume isotropic turbo spin echo acquisition

O1 and O2 suggested two observers independently evaluating the MRI abnormalities

*(median)[interquartile range]

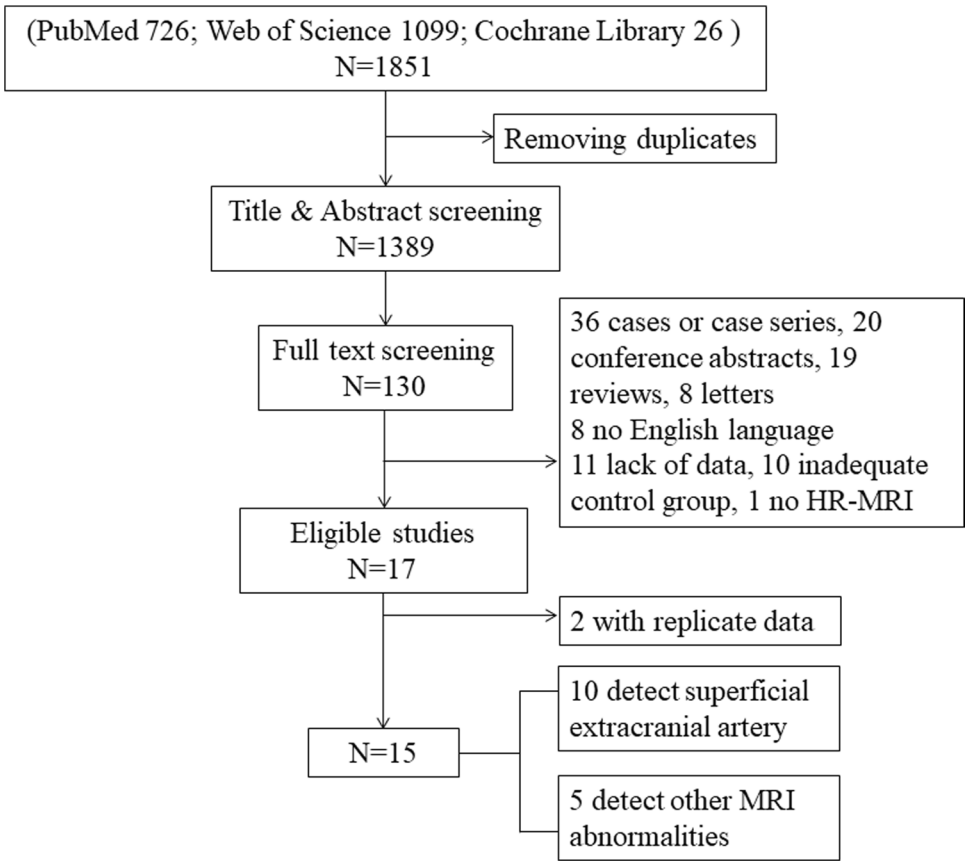


Fig. 1 Flow chart of selection process

Quality assessment was performed using RevMan 5.3 with Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) [13]. Heterogeneity, threshold effects, and publication bias were assessed using STATA 14.0. Details of the risk of bias assessment are depicted in the Supplementary file.

Data analysis

Sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, and diagnostic odds ratio with 95% confidence interval were calculated. Forest plot and summary receiver operating characteristic curves (SROC) were drafted, and the AUC was calculated. The post-test possibility was calculated and a Fagan plot was drafted. Calculations were performed using STATA 14.0 and Meta-Disc 1.4.

Results

Search results

After removing duplicates from a total of 1851 articles, 1389 were left for title and abstract screening and 130 for full-text screening. Seventeen articles were identified as the candidates. The procedure for article selection is depicted in Figure 1. The kappa statistic was 0.817, suggesting a 96.15% agreement.

Risk of bias assessment

The overall quality of the included studies was high and free of threshold effects and publication bias. Fixed or random effects models were used to assess heterogeneity. The results are shown in the Supplementary file.

Study characteristics

Among the 17 candidates, 12 mainly focused on mural thickness and contrast enhancement of superficial extracranial arteries in the diagnosis of GCA. Two studies were excluded for replicate data [14, 15]; therefore, 10 were included in this meta-analysis [9, 10, 16–23]. All the above studies used 1.5T or 3T HR-MRI with gadolinium-based contrast agents to detect superficial extracranial arteries, which are composed of the frontal and parietal branches of the superficial temporal artery and the occipital artery. Three of them used 3D techniques, three used 2D techniques, one used both techniques, and three not clearly depicted them. With respect to the reference standard, nine used ACR-based clinical

Table 3 Diagnostic validity of the superficial temporal artery on HR-MRI for GCA

Reference standard	Sensitivity	Specificity	AUC	PLR	NLR	DOR
Clinical diagnosis	0.75 (0.70 to 0.79)	0.89 (0.86 to 0.92)	0.91 (0.88 to 0.93)	7.1 (5.3 to 9.5)	0.28 (0.23 to 0.34)	26 (17 to 38)
TAB	0.91 (0.86 to 0.94)	0.78 (0.72 to 0.82)	0.92 (0.89 to 0.94)	4.1 (3.2 to 5.1)	0.12 (0.08 to 0.18)	33 (20 to 55)

This table depicted the diagnostic validity of the superficial temporal artery on HR-MRI for GCA, referenced with clinical diagnosis or TAB (95% confidence interval)

TAB temporal artery biopsy, *AUC* area under the receiver operating characteristic curve, *PLR* positive likelihood ratio, *NLR* negative likelihood ratio, *DOR* diagnostic odds ratio

diagnosis and eight used TAB. A total of 702 patients were included, and their demographic information is depicted in Table 2. Detailed information of MRI parameters is provided in the Supplementary file. The diagnostic validity of superficial temporal artery in HR-MRI was evaluated in this meta-analysis with reference standards of clinical diagnosis and TAB, and further comparisons were made between the validity of 3D and 2D techniques.

Two studies observed contrast enhancement of intracranial arteries in GCA, and one observed deep temporal artery and temporalis muscle [10, 24, 25]. Four studies involved several MRI abnormalities such as enhancement of ophthalmic artery and posterior ciliary artery, which could be helpful in identifying GCA-related ischemic optic neuropathy [24, 26–28]. Other different MRI abnormalities in GCA were evaluated in this study, including the intracranial internal carotid artery, ophthalmic artery, posterior ciliary artery, optic nerve sheath, optic disc, deep temporal artery, and temporalis muscle.

Outcome of meta-analysis

Superficial extracranial artery

A total of 10 studies were pooled for the meta-analysis. Nine studies referenced ACR-based clinical diagnosis and eight referenced TAB. One study had two sets of data to make a comparison between 2D and 3D HR-MRI, both of which were included [9]. Another two studies included two sets of data with two reviewers evaluating MRI abnormalities individually, all of which were included [9, 18]. Finally, 11 sets of data were acquired based on ACR, and 10 were referenced to TAB. The diagnostic validity of the superficial temporal artery on HR-MRI for GCA is shown in Table 3 and forest plots are depicted in Figure 2. SROC curves are shown in the Supplementary File.

GCA accounted for the diagnosis in 47% of the included patients, with 332 GCA positive and 370 GCA negative; 47% was regarded as a pre-test possibility. Positive and negative post-test possibilities were 86% and 20%, respectively, compared with the clinical diagnosis. Positive and negative

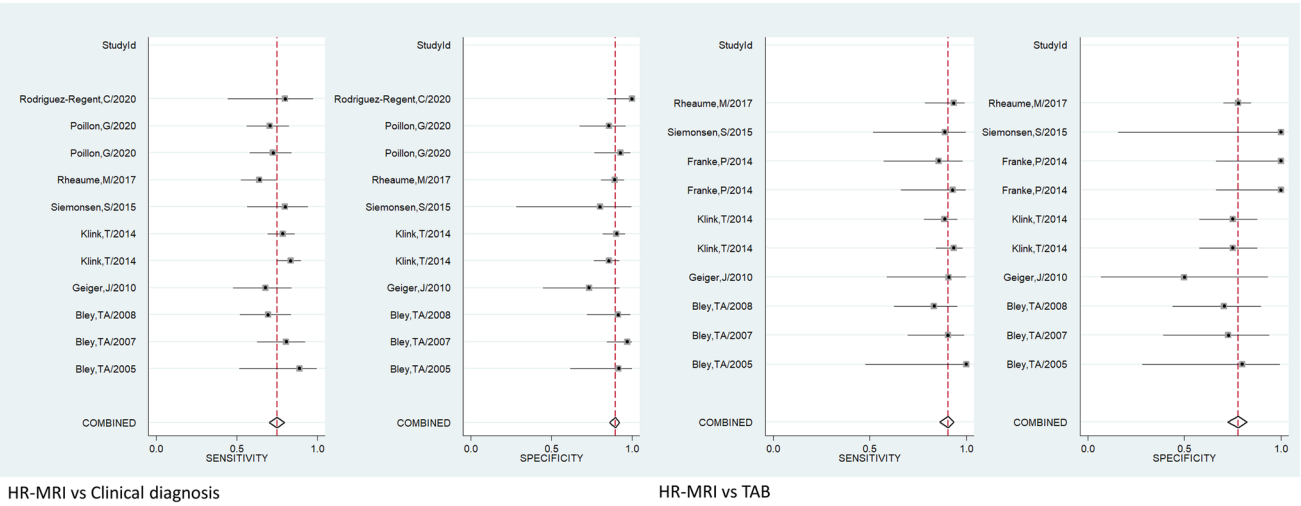


Fig. 2 Forest plots for HR-MRI compared to clinical diagnosis or TAB, with abnormalities in the superficial extracranial arteries. HR-MRI, high-resolution magnetic resonance imaging; TAB, temporal artery biopsy

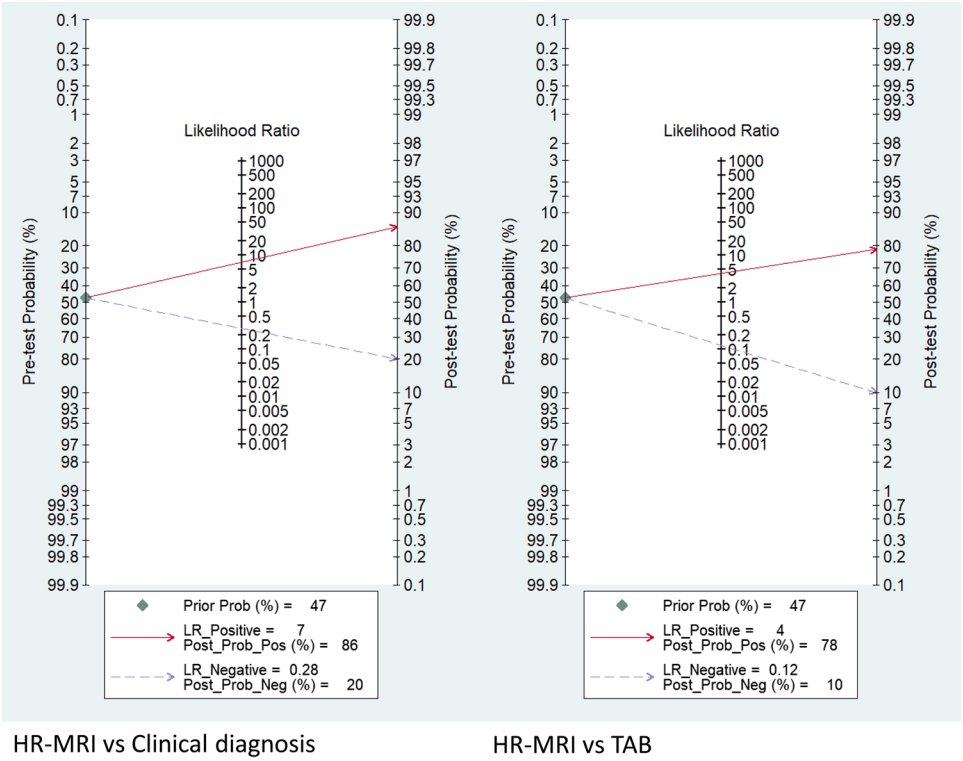


Fig. 3 Fagan plots for HR-MRI compared to clinical diagnosis or TAB. The positive and negative post-test possibility of HR-MRI compared to clinical diagnosis or TAB, with abnormalities in superficial extracranial arteries. HR-MRI, high-resolution magnetic resonance imaging; TAB, temporal artery biopsy

Table 4 Diagnostic validity between 2D and 3D MRI

	Reference standard	Sensitivity	Specificity	PLR	NLR	DOR
2D MRI	Clinical diagnosis	0.72 (0.61 to 0.81)	0.84 (0.71 to 0.92)	4.0 (2.0 to 7.8)	0.36 (0.25 to 0.51)	13 (4 to 39)
3D MRI	Clinical diagnosis	0.70 (0.62 to 0.77)	0.91 (0.85 to 0.95)	6.7 (3.9 to 11.5)	0.35 (0.28 to 0.45)	20 (10 to 39)

This table depicted the diagnostic validity of 2D and 3D MRI in detecting superficial extracranial arteries

(95% confidence interval)

PLR positive likelihood ratio, *NLR* negative likelihood ratio, *DOR* diagnostic odds ratio

post-test possibilities were 78% and 10%, respectively, compared with TAB. The Fagan plots are shown in Figure 3.

Regarding clinical diagnosis as the reference standard, the diagnostic validity of 3D HR-MRI and 2D HR-MRI was compared, as shown in Table 4.

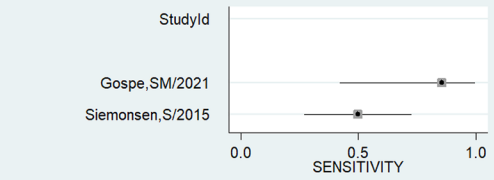
Other MRI abnormalities in GCA

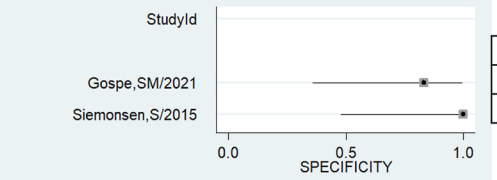
In two studies [10, 24], HR-MRI contrast enhancement of the intracranial internal carotid artery in the diagnosis of GCA was evaluated, which suggested a sensitivity of 50% and 85.7%, and specificity of 100% and 83.3%, respectively. The deep temporal artery and temporalis muscle were evaluated in another study [25], and mural contrast enhancement of the vessel wall and hyperenhancement of the temporalis muscle were observed. The validity of the deep temporal artery and temporalis muscle in the diagnosis of GCA is depicted in Figure 4.

MRI abnormalities in GCA-related ischemic optic neuropathy

MRI abnormalities, including contrast enhancement of the ophthalmic artery, posterior ciliary artery, optic nerve sheath, and optic disc were evaluated. Mural thickness and contrast enhancement of the involved arteries, optic nerve sheath, and relative structure enhancement suggest inflammation could be observed. The sensitivity of above MRI abnormalities ranged from 76 to 100% and specificity ranged from 53.3 to 100%. Detailed information on the diagnostic validity of each abnormality is depicted in Figure 4.

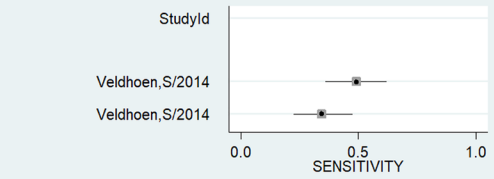
Intracranial artery

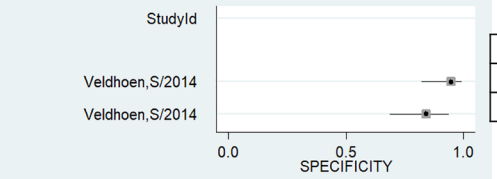




	Sensitivity	Specificity
Gospe,SM	86.7%	83.3%
Siemonsen,S	50%	100%

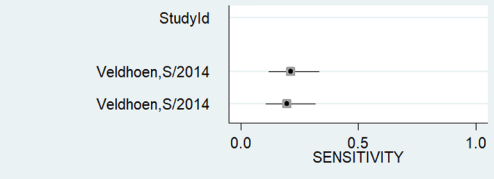
Deep temporal artery

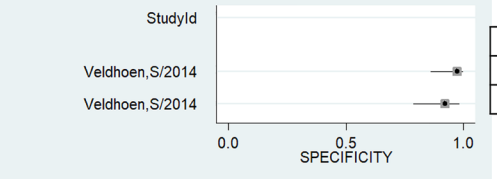




	Sensitivity	Specificity
Veldhoen,S	49.2%	94.7%
Veldhoen,S	34.4%	84.2%

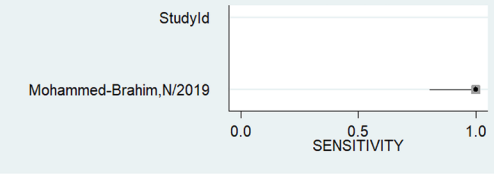
Temporalis muscle

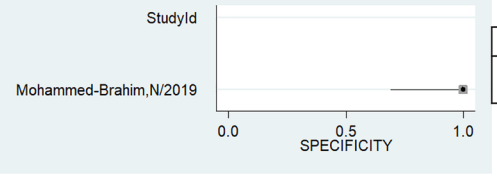




	Sensitivity	Specificity
Veldhoen,S	21.3%	97.4%
Veldhoen,S	19.7%	92.1%

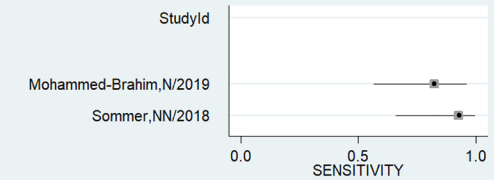
Ophthalmic artery

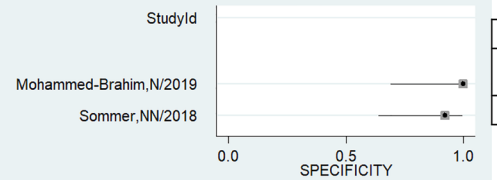




	Sensitivity	Specificity
Mohammed-Brahim,N	100%	100%

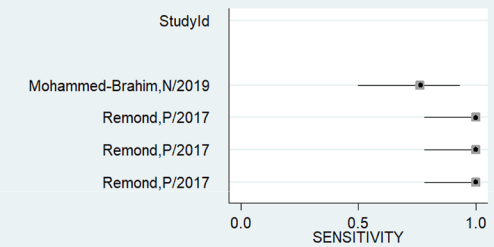
Posterior ciliary artery

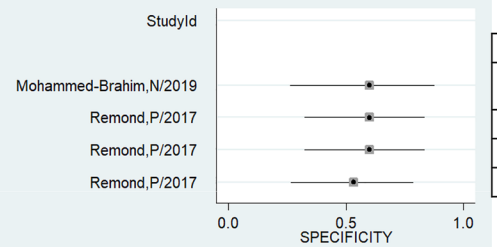




	Sensitivity	Specificity
Mohammed-Brahim,N	82%	100%
Sommer,NN	92.9%	92.3%

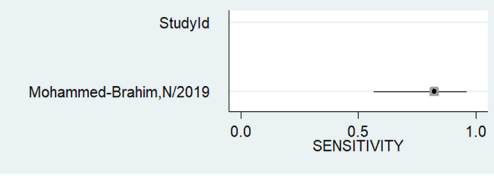
Optic disc

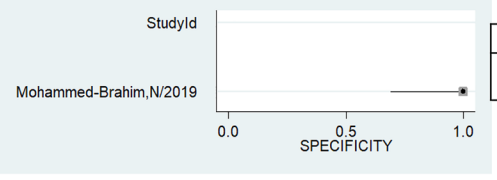




	Sensitivity	Specificity
Mohammed-Brahim,N	76%	60%
Remond,P	100%	60%
Remond,P	100%	60%
Remond,P	100%	53.3%

Optic nerve sheath





	Sensitivity	Specificity
Mohammed-Brahim,N	82%	100%

◂**Fig. 4** Results of other MRI abnormalities in detecting GCA or GCA-related ischemic optic neuropathy. MRI: magnetic resonance imaging; GCA: giant cell arteritis

Discussion

TAB as the "gold standard" had perfect specificity but limited sensitivity for the diagnosis of GCA [5]. This might be because TAB only sampled segmental temporal arteries up to several centimeters, while the inflammation tended to be discontinuously distributed [29, 30]. On the other hand, symmetrical and simultaneous inflammation of superficial extracranial artery segments was considered to be the typical pattern of GCA [6, 14, 30]; however, a non-typical pattern can be observed in clinical scenarios, similar to solitary involvement of the occipital artery [14]. Histopathologic signs of vasculitis may be missed in specimens because of skip lesions or the involvement of other arterial segments than those sampled [6]. False-negative results and overestimated sensitivity might be caused by TAB as solitary reference standard.

Considering that TAB is invasive and has limited accuracy, imaging modalities such as ultrasound or HR-MRI could compensate for TAB. Previous studies have reported similar diagnostic accuracies between HR-MRI and ultrasound [1, 8]. Ultrasound was recommended as the first imaging modality for GCA, mainly because it is inexpensive and easily generalized [7]. Despite its high cost, HR-MRI has several advantages. HR-MRI can obtain a large field of view at one acquisition; frontal and parietal branches of the superficial temporal artery and occipital artery can be evaluated bilaterally, and intracranial arteries together with other relevant structures can also be evaluated. With all mural contrast-enhanced arteries in the same imaging, it is easy to make a comparison. One study reported 64.1% sensitivity and 89.3% specificity for HR-MRI, 39.7% sensitivity, and 100% specificity for TAB compared with clinical diagnosis [19]. A better coincidence between HR-MRI and the final clinical diagnosis was observed. HR-MRI could greatly avoid skip lesions and reduce false-negative results, and may help in localizing the most inflamed segment of the superficial extracranial artery and guide TAB to improve diagnostic accuracy [14, 21]. HR-MRI could be helpful in the diagnosis of GCA with irreplaceable advantages and compensate for TAB.

Many studies have proven the validity of HR-MRI in diagnosing GCA with mural thickness and contrast enhancement of the superficial extracranial artery [9, 10, 16–23]. We pooled their data to perform a meta-analysis and found a sensitivity of 75%, specificity of 89%, and AUC of 0.91 compared with clinical diagnosis, and sensitivity 91%, specificity 78%, and AUC 0.92 compared with TAB. The results were also consistent with a previous meta-analysis (sensitivity 73%, specificity 88% compared with clinical diagnosis, and sensitivity 93%, specificity 81% compared with TAB) [8]. Additionally, we first reported excellent post-test possibilities of HR-MRI compared with clinical diagnosis or TAB. HR-MRI abnormalities in superficial extracranial arteries are dependable for establishing GCA diagnosis.

We further evaluated 3D HR-MRI and 2D-HR-MRI and attempted to make a comparison. 3D techniques allow for improved through-plane resolution and permit multiplanar reformations with isotropic acquisitions [31]. They could minimize overestimation of wall thickness and volume-averaging effects, and rely less on individual localized scans compared to ordinary 2D techniques [31, 32]. In the present study, we found that 3D HR-MRI could perform better than 2D HR-MRI in GCA. The sensitivity for 3D techniques was 70%, and the specificity was 91% compared with clinical diagnosis. Sensitivity for 2D techniques was 72% and specificity was 84%, also compared with clinical diagnosis. The sensitivities were similar, while the 3D techniques significantly improved the specificity. This might be because 3D techniques provide an overall view with an oblique sagittal plane to align and analyze involved arteries, making it easier to observe and compare distal or focal inflammation of superficial extracranial arteries in GCA [9]. It seems that 3D HR-MRI could indeed increase the diagnostic accuracy in GCA; however, 3D HR-MR is much more expensive than ordinary 2D HR-MRI and depends on precise facilities, which restricts its use to advanced medical institutions.

Considering other MRI parameters, higher field strength could contribute to higher signal-to-noise ratio and spatial resolution [31]. The higher field strength may be a better choice. In most medical institutions, 1.5T or 3T HR-MRI is used; 3T HR-MRI should be preferred [16, 33]. An increased number of coil elements can also lead to an increased signal-to-noise ratio and spatial resolution [34]. A study compared 32-channel and 12-channel HR-MRI in patients with GCA. Similar diagnostic sensitivity suggested that 12-channel HR-MRI was sufficient for the diagnosis of GCA [23]. The number of coil elements does not seem to significantly affect the accuracy of the GCA diagnosis. All involved studies depicting superficial extracranial arteries, applied fat suppression techniques, and fat saturation or inversion recovery techniques were used. Considering that HR-MRI is normally performed with a high-strength field, fat saturation techniques could be preferred to suppress signals from adipose tissue and acquire contrast material–enhanced imaging [35].

Post-contrast HR-MRI is mostly performed with T1-weighted imaging, which can reliably assess vascular inflammatory changes of the superficial extracranial artery with sub-millimeter resolution [10, 16, 20]. A study used T2-weighted imaging to diagnose GCA with the superficial extracranial artery and found that limited spatial resolution might contribute to reduced sensitivity of T2-weighted

imaging [22]. Another study used post-contrast proton density-weighted imaging, and the diagnostic accuracy for GCA was acceptable [9]. HR-MRI with 3D T1-weighted imaging and high field strength were suitable for observing inflammation of the superficial extracranial artery in GCA. Proton density–weighted imaging could be feasible, which remains to be confirmed by further studies and compared with T1-weighted imaging in GCA.

Other MRI abnormalities for the diagnosis of GCA were also evaluated. Contrast enhancement of the intracranial segment of the internal carotid artery (ICA) or vertebral artery can be observed unilaterally or bilaterally [10, 24]. With respect to ICA, one study reported 85.7% sensitivity and 83.3% specificity based on clinical diagnosis [24], while another study reported 50% sensitivity and 100% specificity referenced with TAB; the sensitivity was discrepant. Considering the limitations of TAB, the clinical diagnosis referenced results might better describe the accuracy of ICA. Considering that intracranial arteries are not commonly affected in GCA as superficial extracranial arteries [10], the limited sensitivity of the intracranial artery was accessible. Inflammation of the deep temporal and temporalis muscles was feasible to evaluate with HR-MRI; however, its sensitivity was unlikely to be sufficient to establish the diagnosis of GCA. Indeed, it provided imaging evidence of potential causation of jaw claudication, and a moderate correlation between deep temporal vasculitis and jaw claudication has been reported [25].

Postmortem studies have reported that the temporal artery was mainly affected with 100% incidence, and the ophthalmic artery can also be affected, with 75% incidence [36]. Contrast enhancement of the ophthalmic artery and its branches as posterior ciliary arteries can be observed on HR-MRI [4, 26, 37]. Contrast enhancement of the ophthalmic artery or posterior ciliary arteries might have potential validity in differentiating GCA-related ischemic optic neuropathy from non-arteritis optic neuropathy. One study reported 100% sensitivity and specificity for the ophthalmic artery, 82% sensitivity and 100% specificity for the posterior ciliary artery [28]. Another study reported 92.9% sensitivity and 92.3% specificity for the posterior ciliary artery [26]. MRI abnormalities of the optic nerve, such as the optic disc or optic nerve sheath, were also evaluated [24, 27, 28]. Among the above MRI abnormalities, the ophthalmic artery and its branches as the posterior ciliary artery had the best performance. On the one hand, inflammation of the ophthalmic artery and its branches with HR-MRI can help identify GCA-related ischemic optic neuropathy or other arteritis optic neuropathy from non-arteritis optic neuropathy, providing imaging evidence for corticosteroid decision [28], and reduce false-positive patients who might withstand adverse effects from unnecessary corticosteroid treatment. On the other hand, inflammation involvement of the ophthalmic artery and its branches can be observed with HR-MRI in patients with GCA, which can help evaluate the severity of GCA and identify the risk for developing contralateral optic neuropathy or dreaded complications such as irreversible visual loss [26, 28, 38].

There are several limitations to this meta-analysis. First, both prospective and retrospective studies were included, and the sample size of each study was small. Rigorous standards and methods were used to reduce the bias and heterogeneity. Second, not all included patients underwent TAB, and positive patients might have been excluded. Considering the limitations of TAB, we also included an ACR-based clinical diagnosis as a reference standard. Third, MRI protocols of pooled studies were not totally accordant as 1.5T or 3T MRI was used. However, all studies used post-contrast HR-MRI to detect inflammation changes in GCA. The present study reflects the value of HR-MRI in detecting GCA. Future studies are recommended to make a comparison between 1.5T and 3T MRI in GCA. Fourth, corticosteroid treatment was administered, which might have impacted the evaluation of inflammation. HR-MRI should be performed at GCA onset or as early as possible, so that the impact of corticosteroid treatment can be minimized.

The present meta-analysis further confirmed the validity of HR-MRI for detecting GCA. HR-MRI detecting contrast enhancement of superficial extracranial arteries showed good performance with excellent AUC and post-test possibilities. The 3D techniques were revealed to have better performance than ordinary 2D techniques. Other MRI abnormalities such as signs of GCA-related ischemic optic neuropathy and contrast enhancement of the deep temporal artery could also be visualized with HR-MRI. The ophthalmic artery and its branches had the best performance in differentiating GCA-related ischemic optic neuropathy from non-arteritis optic neuropathy. In summary, HR-MRI is a valuable technique for detecting GCA, and its use should be encouraged in suspected GCA. Although HR-MRI is expensive and facility-dependent, it should be used in clinical scenarios.

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Declarations

Guarantor The scientific guarantor of this publication is Dr Yi Yang.

Conflict of interest The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.

Statistics and biometry One of the authors has significant statistical expertise.

Informed consent Approval and informed consent was not required because this meta-analysis does not involve human or animal subjects.

Ethical approval Approval and Informed consent was not required because this meta-analysis does not involve human or animal subjects.

Methodology
• Meta-analysis

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