European Radiology
https://doi.org/10.1007/s00330-021-08417-4

NEURO

Early diffusion-weighted MRI at 3 Tesla detects ischemic changes of the optic nerve in anterior ischemic optic neuropathy

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Received: 21 May 2021 / Revised: 21 September 2021 / Accepted: 15 October 2021

Abstract

Objectives To assess the impact of timing from visual symptoms' onset to diffusion-weighted (DW) 3 T MRI completion to detect ischemic changes of the optic disc and optic nerve in AION patients.

Methods This IRB-approved retrospective single-center study included 3 T MRI data from 126 patients with AION and 111 controls with optic neuritis treated between January 2015 and May 2020. Two radiologists blinded to all data individually analyzed imaging. A senior neuroradiologist resolved any discrepancies by consensus. The primary judgment criterion was the restricted diffusion of the optic disc and/or the optic nerve assessed subjectively on the ADC maps. ADC values were also measured. Spearman rank correlations were used to examine the relationships between timing from visual symptoms' onset to MRI completion and both the restricted diffusion and the ADC values.

Results One hundred twenty-six patients (47/126 [37.3%] women and 79/126 [62.7%] men, mean age 69.1 ± 13.7 years) with AION were included. Restricted diffusion of the optic disc in AION eyes was more frequent in the early MRI group than in the late MRI group: 35/49 (71.4%) eyes versus 3/83 (3.6%) eyes, $p < 0.001$. ADC values of the pathological optic discs and optic nerves were lower in the early MRI group than in the late MRI group: 0.61 [0.52–0.94] × 10^{-3} mm^2/s versus 1.28 [1.01–1.44] × 10^{-3} mm^2/s, $p < 0.001$, and 0.74 [0.61–0.88] × 10^{-3} mm^2/s versus 0.89 [0.72–1.10] × 10^{-3} mm^2/s, $p < 0.001$, respectively.

Conclusions DWI MRI showed good diagnostic performance to detect AION when performed early after the onset of visual symptoms.

Key Points

• *Restricted diffusion of the optic disc in eyes affected by AION was significantly more likely to be observed in patients who had undergone MRI within 5 days after onset of visual symptoms.*

• *ADC values of the pathological optic discs and optic nerves were significantly lower in patients who had undergone MRI within 5 days after onset of visual symptoms of AION: 0.61 × 10^{-3} mm^2/s versus 1.28 × 10^{-3} mm^2/s, $p < 0.001$, and 0.74 × 10^{-3} mm^2/s versus 0.89 × 10^{-3} mm^2/s, $p < 0.001$, respectively.*

• *The optimal threshold for timing from visual symptoms' onset to MRI completion to detect restricted diffusion of the optic disc and/or optic nerve was 5 days, with an AUC of 0.88 ($CI_{95\%}$: 0.82–0.94).*

Keywords Optic neuropathy, ischemic · Diffusion magnetic resonance imaging · Magnetic resonance imaging

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Abbreviations

ADC	Apparent diffusion coefficient
AION	Anterior ischemic optic neuropathy
DWI	Diffusion-weighted imaging
GCA	Giant cell arteritis
MRI	Magnetic resonance imaging
WI	Weighted imaging

Published online: 01 December 2021

Introduction

Anterior ischemic optic neuropathy (AION) is the most common acute optic neuropathy in older patients. Its annual incidence is of 2.3 to 10.2 cases per 100,000 persons over 50 years[1]. AION can be classified into non-arteritic (NA-AION), accounting for 95% of AION cases, and arteritic (A-AION), mainly associated with giant cells arteritis (GCA). AION, which is considered a "stroke of the optic nerve," corresponds to optic nerve head ischemia secondary to infarction of the short posterior ciliary arteries, supplying the anterior portion of the optic nerve head [1]. Early and accurate diagnosis is essential to avoid severe and irreversible complications such as permanent visual loss [1].

Similar to ischemic stroke, a few studies and case reports showed that diffusion-weighted (DW) MRI might detect ischemic changes of the optic nerve in patients with ischemic optic neuropathy [2, 3]. However, diagnosis of AION using DWI remains challenging with no restriction of diffusion detected in some cases of confirmed AION. It might be due to the small size of the optic nerve as well as the presence of kinetic and susceptibility artifacts in the orbit, which impairs the performance of DWI [4–6]. Another explanation might be the timing from visual symptoms' onset to completion of DW-MRI. It is well established that DWI abnormalities are evolutive in ischemic stroke, the lowest apparent diffusion coefficient (ADC) value usually being reached within 24–32 h, then back to normal at 7 to 10 days [7, 8]. Performing an MRI too late after the onset of symptoms could explain the absence of abnormalities. To the best of our knowledge, the impact of timing has not yet been investigated in AION.

Therefore, the purpose of our study was to assess the impact of timing from the onset of AION to the completion of a DW MRI at 3 Tesla on the detection of ischemic changes of the optic nerve.

Material and methods

Study design

We conducted this retrospective analysis in a tertiary single center specializing in ophthalmic diseases. This study was approved by an institutional review board and adhered to the tenants of the Declaration of Helsinki (IRB CE_20200204_3_ALR, NCT 2,117,130,220). The need for informed consent was waived by the IRB. This study follows the Standards for Reporting of Diagnostic Accuracy Studies (STARD) guidelines[9].

Study population

From January 2015 to May 2020, 158 consecutive patients with AION were included in the study.

Inclusion criteria for this study were as follows: (a) age over 18 years; (b) definite diagnosis of AION made by an expert neuro-ophthalmologist with 20 years of experience (C.V.) based on initial clinical and fundoscopic findings, visual field, retinal angiogram when performed, exclusion of differential diagnoses, response to treatment, and follow-up at 3 months; (c) the completion of a 3 Tesla MRI.

Exclusion criteria were the absence of a DWI sequence or the presence of major artifacts preventing any interpretation of the DWI.

The diagnosis of A-AION was based on a positive temporal artery biopsy or a review of the clinical chart performed by an interdisciplinary panel of rheumatologists, internists, and ophthalmologists not involved in the management of the patient, based on ACR criteria [10]. Selection of patients is shown in Fig. 1.

One hundred eleven consecutive patients with a definitive diagnosis of acute optic neuritis, based on clinical and imaging findings, were included over the same period of time to serve as a control group for assessing the overall diagnostic performance of DWI for detecting AION.

Clinical data

Clinical charts were systematically reviewed, including ophthalmological findings, fundoscopy findings, visual field, retinal angiogram, response to treatment, and follow-up at 3 months. Timing from the onset of AION to the completion of MRI was carefully noted.

MR imaging

All MRIs were performed on a 3 Tesla Philips INGENIA device or on a 3 Tesla Philips ELITION (Philips Medical Systems) device with a 32-channel head coil. The MRI protocol including DWI is displayed in Supplementary Table 1. DWI parameters were two-dimensional axial plane; TR = 3,380 ms; TE = 111 ms; *b*-values = 0, 1000, and 2000s/mm^2; three diffusion gradient directions; number of excitations = 2; slice thickness = 5 mm; acquired voxel size = $1.51 \times 2.17 \times 5 mm^3$; reconstructed voxel size = 1.03×1.03 mm; matrix = 152×106 mm; and field of view = 230×230 mm; ADC maps were generated automatically. Post-contrast imaging was performed after intravenous injection of a single bolus (0.1 mmol/kg) of Gadobutrol (Gadovist; Bayer HealthCare).

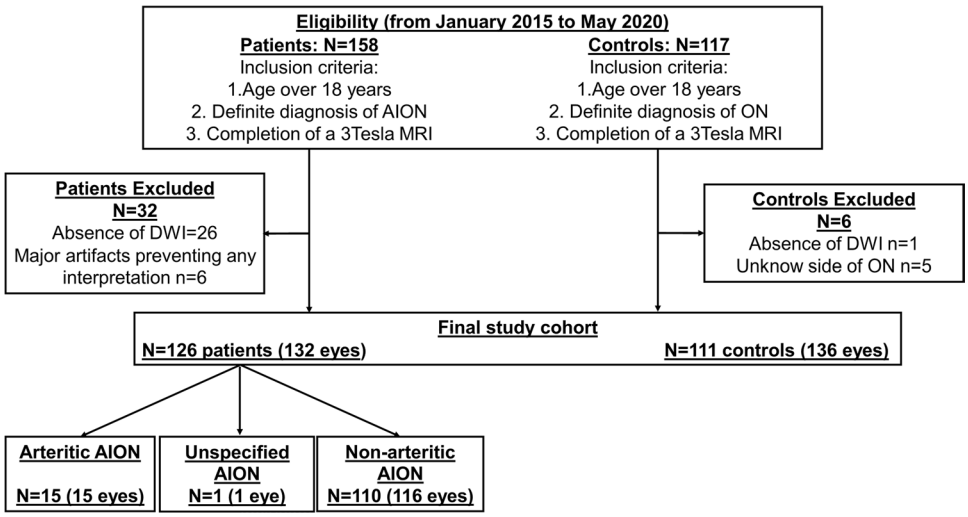

Fig. 1 Flow chart. AION: anterior ischemic optic neuropathy; MRI: magnetic resonance imaging; DWI: diffusion-weighted imaging

Imaging analysis

Two radiologists, blinded to all data, individually read anonymized MR images: one junior radiologist with 8 months' experience in neuroradiology (S.M.), and one neuroradiologist with 12 years' experience (F.C.). Six weeks after the first reading session, a consensus reading session was performed with a third reader, a second senior neuroradiologist specialized in neuro-ophthalmological imaging with 9 years' experience (A.L.), also blinded to all data. This consensus session was used as a reference for analysis. All reading sessions were performed on a dedicated workstation (IntelliSpace Portal, Philips Healthcare).

The readers assessed the following characteristics of patients' MRIs for each eye separately.

The primary judgment criterion was the presence of a restricted diffusion of the optic disc and/or the optic nerve assessed subjectively on the ADC maps. A restricted diffusion was defined by a signal inferior to that of the normal-appearing white matter in the temporal lobe used as reference.

The secondary judgment criteria were as follows:

- The presence of a high signal of the optic disc and/or the optic nerve on DWI, using the normal-appearing white matter in the temporal lobe as a reference.
- The presence of an enhancement of the optic disc.
- Self-confidence in reading was evaluated as follows: a score of 1 for low confidence, 2 for moderate confidence, and 3 for excellent confidence.

Subsequently, ADC values of the optic disc and the optic nerve on the pathological eyes were measured by placing two regions of interest (ROIs): the first one in the optic disc and the second one in the intra-orbital optic nerve segment presenting the lowest signal on ADC maps.

Statistical analysis

Quantitative variables were presented as mean (standard deviation or SD) or median (interquartile range or IQR) as appropriate, and categorical variables as percentages.

We used Spearman's correlation analysis to determine the correlation between the timing from the onset of AION to the completion of MRI and both the restricted diffusion and the ADC values. Optimal thresholds for the timing were calculated from receiver operating characteristic (ROC) curves using the Youden index. Based on these ROC curves, two groups of patients were defined and compared: the early MRI group when the MRI was performed within 5 days after the onset of visual symptoms, versus the late MRI group when the MRI was performed after more than 5 days from onset of visual symptoms.

Normality was assessed for continuous variables using the Shapiro–Wilk test. Categorical variables were compared using Fisher's exact test or generalized estimating equation (GEE) as appropriate to take into account correlation between eyes of same subject, while continuous variables were compared using a *t*-test or Mann–Whitney *U* test as appropriate. A Benjamini–Hochberg correction was used to take into account multiple testing. Accuracy, sensitivity, specificity, positive predictive values (PPVs), and negative predictive values (NPVs) were calculated.

Inter- and intra-observer agreement for MRI reading was assessed using non-weighted Cohen kappa statistics and interpreted as follows: 0.0 to 0.2, poor correlation; 0.21 to 0.4, fair correlation; 0.41 to 0.6, moderate correlation; 0.61 to 0.8, good correlation; and 0.81 to 1, almost perfect correlation [11]. A *p*-value below 0.05 was considered statistically significant. Data were analyzed using the R software package version 3.6.1 [12].

Results

Demographic and clinical characteristics

AION group

One hundred and twenty-six patients (47/126 [37.3%] women and 79/126 [62.7%] men, median age 71.0 years IQR [60.0–77.0] years) were included from January 2015 to May 2020. Six patients (4.8%) presented with a bilateral AION. Fifteen patients (11.9%) had a final diagnosis of A-AION, and 110 (88.1%) patients had a final diagnosis of NA-AION. The arteritic or non-arteritic origin of the AION could not be specified definitively for one patient.

Control group (optic neuritis)

One hundred eleven patients (65/111 [58.6%] women and 46/111 [41.4%] men, median age 36.0 years IQR [27.8–55.2] years) with optic neuritis were included from December 2015 to May 2020. Twenty-five patients (22.5%) presented with bilateral optic neuritis. Seventy-two of 111 (65%) were idiopathic, 24/111 (22%) associated with multiple sclerosis, 15/111 (13%) with neuromyelitis optica.

Overall diagnostic performance of DWI for detecting AION

Restricted diffusion of the optic disc was observed in 38/132 (28.8%) eyes and restricted diffusion of the optic nerve in 7/132 (5.3%) eyes with AION, respectively.

Accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of restricted diffusion of the optic disc on DWI MRI to detect AION were 0.63, 0.29, 0.97, 0.93, 0.57.

Accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of restricted diffusion of the optic nerve on DWI MRI to detect AION were 0.52, 0.05, 0.99, 0.88 and 0.51. Detailed MRI results are displayed in Supplementary Table 2.

Impact of the timing from the onset of AION to the completion of MRI for detecting AION

The optimal threshold for the timing from the onset of AION to the completion of MRI to detect restricted diffusion of the optic disc and/or optic nerve was 5 days, with an AUC of 0.88 ($CI_{95\%}$: 0.82–0.94).

Restricted diffusion of the optic disc in eyes affected by AION was significantly more likely to be observed in the early MRI group than in the late MRI group: 35/49 (71.4%) eyes versus 3/83 (3.6%) eyes, $p < 0.001$.

Restricted diffusion of the optic nerve in eyes affected by AION was significantly more likely to be observed in the early MRI group than in the late MRI group: 7/49 (14.3%) eyes versus 0/83 (0%) eyes, $p < 0.001$. Detailed MRI results are displayed in Table 1.

Accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of restricted diffusion on DWI MRI to detect AION in the early MRI group were 0.87, 0.92, 0.85, 0.71, and 0.96 for the optic disc and 0.68, 0.14, 1, 1, and 0.66 for the optic nerve, respectively.

The median timing from the onset of AION to the completion of MRI was significantly shorter in patients

Table 1 Detailed MRI characteristics of patients presenting with anterior ischemic optic neuropathy (AION) divided into an early MRI group (MRI performed within 5 days after the onset of visual symptoms) and a late MRI group (MRI performed more than 5 days after the onset of visual symptoms)

	Early MRI group ($n = 49$ eyes)	Late MRI group ($n = 83$ eyes)	*p*
Restricted diffusion of the optic disc	35/49 (71.4%)	3/83 (3.6%)	***< 0.001****
Restricted diffusion of the optic nerve	7/49 (14.3%)	0/83 (0%)	***< 0.001****
High signal of the optic disc on DWI	13/49 (26.5%)	9/83 (10.8%)	*0.04*
High signal of the optic nerve on DWI	4/49 (8.2%)	0/83 (0%)	*0.02*
Enhancement of the optic disc on post-contrast T1-WI	3/22[§] (13.6%)	1/33[§] (3.0%)	*0.1*
Self-confidence > 1	37/49 (75.5%)	56/83 (67.5%)	*0.5*
ADC of the optic disc on pathological eyes (10^{-3} mm^2/s) [IQR]	0.61 [0.52–0.94]	1.28 [1.01–1.44]	***< 0.001****
ADC of the optic nerve on pathological eyes (10^{-3} mm^2/s) [IQR]	0.74 [0.61–0.88]	0.89 [0.72–1.10]	***< 0.001****

DWI diffusion-weighted imaging, *WI* weighted imaging, *ADC* apparent diffusion coefficient, *IQR* interquartile range

The results in parenthesis are percentages

*Bold characters represent a statistically significant difference between both groups

§22/49 (45%) eyes in the early MRI group and 33/83 (40%) eyes in the late MRI group were explored with post-contrast MRI sequences covering the optic disc

presenting with a restricted diffusion of the optic disc and/or optic nerve: 3 days (IQR 2–3) versus 23 days (9–138), $p < 0.001$.

Calculation of optimal ADC thresholds to detect AION

ADC values of the pathological optic discs and optic nerves were significantly lower in the early MRI group than in the late MRI group: 0.61 [0.52–0.94] $\times 10^{-3}$ mm^2/s versus 1.28 [1.01–1.44] $\times 10^{-3}$ mm^2/s, $p < 0.001$, and 0.74 [0.61–0.88] $\times 10^{-3}$ mm^2/s versus 0.89 [0.72–1.10] $\times 10^{-3}$ mm^2/s, $p < 0.001$, respectively (Fig. 2). Based on the ROC curves, the optimal ADC thresholds to detect AION were 0.63 for the optic disc and 0.79 for the optic nerve, yielding a specificity of 95% and 55%, respectively (Supplementary Fig. 1).

There was a significant correlation between the ADC values of both the optic disc and the optic nerve and the timing from the onset of AION to the completion of MRI with a Spearman's correlation coefficient of 0.54 ($p < 0.001$) and 0.26 ($p = 0.004$), respectively (Fig. 3).

Diagnostic performance of DWI for distinguishing A-AION and NA-AION

Restricted diffusion of the optic disc was more likely to be seen in A-AION versus NA-AION: 8/15 (53.3%) versus 30/116 (25.9%), $p = 0.04$ (Fig. 4). No significant differences were found between A-AION and NA-AION for the restricted diffusion of the optic nerve.

Accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of a restricted diffusion of the optic disc to distinguish A-AION from NA-AION were 0.72, 0.53, 0.74, 0.21, and 0.92 respectively.

ADC values measured in the optic disc and in the optic nerve were significantly lower in A-AION versus NA-AION: 0.75 [0.61–1.25] $\times 10^{-3}$ mm^2/s versus 1.1 [0.9–1.4] $\times 10^{-3}$ mm^2/s, $p = 0.01$, and 0.65 [0.61–0.81] $\times 10^{-3}$ mm^2/s versus 0.8 [0.7–1.0] $\times 10^{-3}$ mm^2/s, $p = 0.03$, respectively. Detailed MRI results are displayed in Table 2.

Inter-reader agreement

Inter-reader agreement was good for detecting a restricted diffusion of the optic disc or the optic nerve: kappa = 0.75 [0.57—0.85] and 0.79 [0.59–0.87], respectively. It was excellent when measuring the ADC of the optic nerve: ICC = 0.83

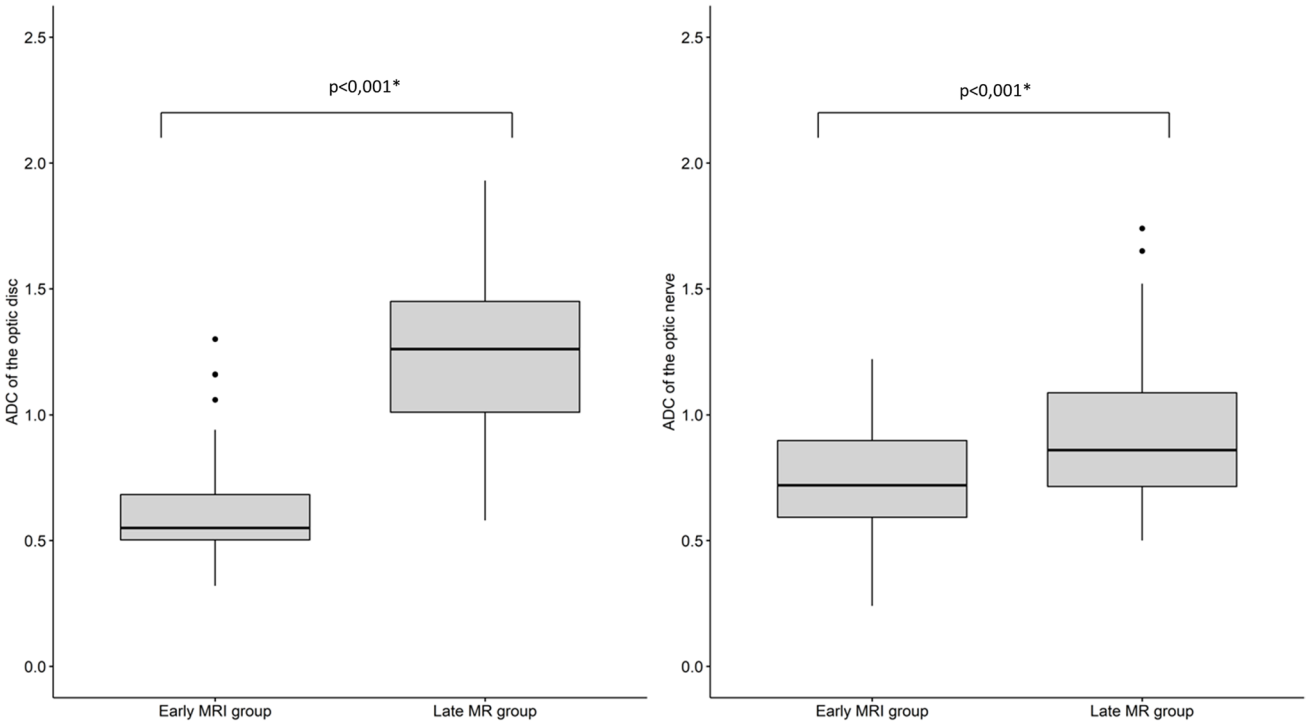

Fig. 2 Box plots showing the apparent diffusion coefficient (ADC) values of the optic disc (left) and the optic nerve (right) in the early MRI group (MRI performed within 5 days after the onset of visual symptoms) versus the late MRI group (MRI performed more than 5 days after the onset of visual symptoms)

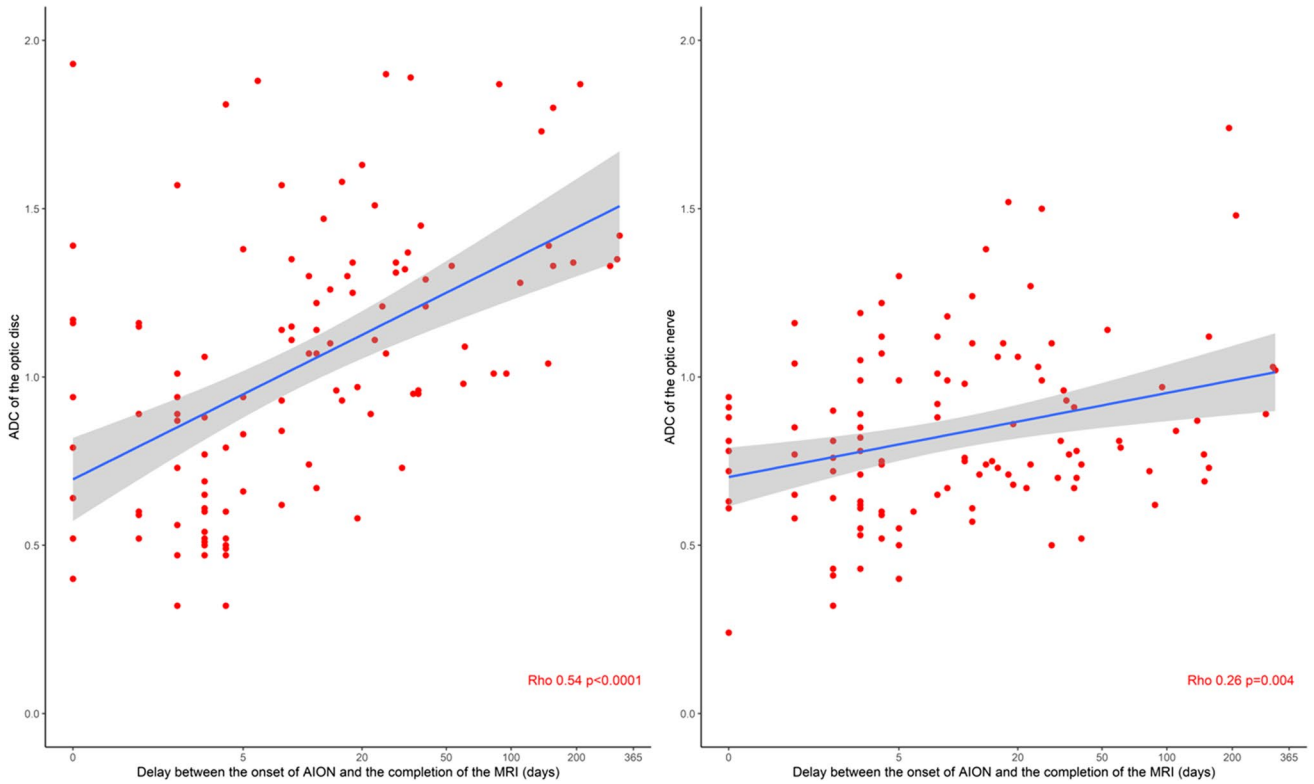

Fig. 3 Graphical representation showing the correlation between ADC values (*y* axis) of the optic disc (left) and the optic nerve (right) in patients with anterior ischemic optic neuropathy and the timing from the onset of AION to the completion of MRI (*x* axis). Spearman's correlation coefficient is of 0.54 ($p < 0.001$) and 0.26 ($p = 0.004$) for the optic disc and optic nerve, respectively

[0.78–0.87] and good for the optic disc: ICC = 0.63 [0.54–0.71].

Discussion

To the best of our knowledge, our study is the first one to show a correlation between successfully detecting ischemic changes in AION and the timing from the onset of AION to the completion of MRI. Restricted diffusion of the optic disc was observed in a majority of eyes with AION in the early MRI group, but only rarely in the late MRI group. It highlights the need to perform an MRI as soon as possible to be able to detect ischemic changes of the optic disc or optic nerve in patients with a suspected diagnosis of AION.

We showed that a threshold of 5 days was optimal to detect ischemic changes of the optic disc or optic nerve in AION. This timing is relatively similar to the 7 days before normalization of the ADC reported in previous studies on acute stroke [7, 13]. However, very little is currently known about the time course of the ADC abnormality in optic nerves. Our study suggests that the ADC evolution in AION could be similar to the time course in brain tissue. AION is supposed to be related to ischemic impairment of the optic nerve secondary to infarction of the short posterior ciliary arteries. Restricted diffusion is supposed to be related to cytotoxic edema and the disruption of the sodium–potassium transmembrane pump function [14, 15].

Our study is in line with previous studies showing that DWI could detect acute ischemic changes of the optic nerve in patients presenting with ischemic optic neuropathy [3, 5, 6, 16–18, 18–21]. Most of these studies were either case reports or small series mixing AION imaged at an early and late stage. Moreover, DWI of the optic nerve remains challenging and some studies did not have specific DWI protocols to explore the optic nerve, which might explain the relatively low incidence of restricted diffusion in the optic disc and/or the optic nerve reported in the literature so far [5]. By including 126 patients with AION, our study provides valuable data regarding the diagnostic performance of DWI in AION. In our study, ADC values of the pathological optic discs and optic nerves were significantly lower in the early MRI group than in the late MRI group in our study: 0.61×10^{-3} mm^2/s versus 1.28×10^{-3} mm^2/s. This is which is very similar to the results reported by Bender et al. with an average ADC being 0.55×10^{-3} mm^2/s in patients with ischemic optic neuropathy as compared with 1.32×10^{-3} mm^2/s in a control group [5].

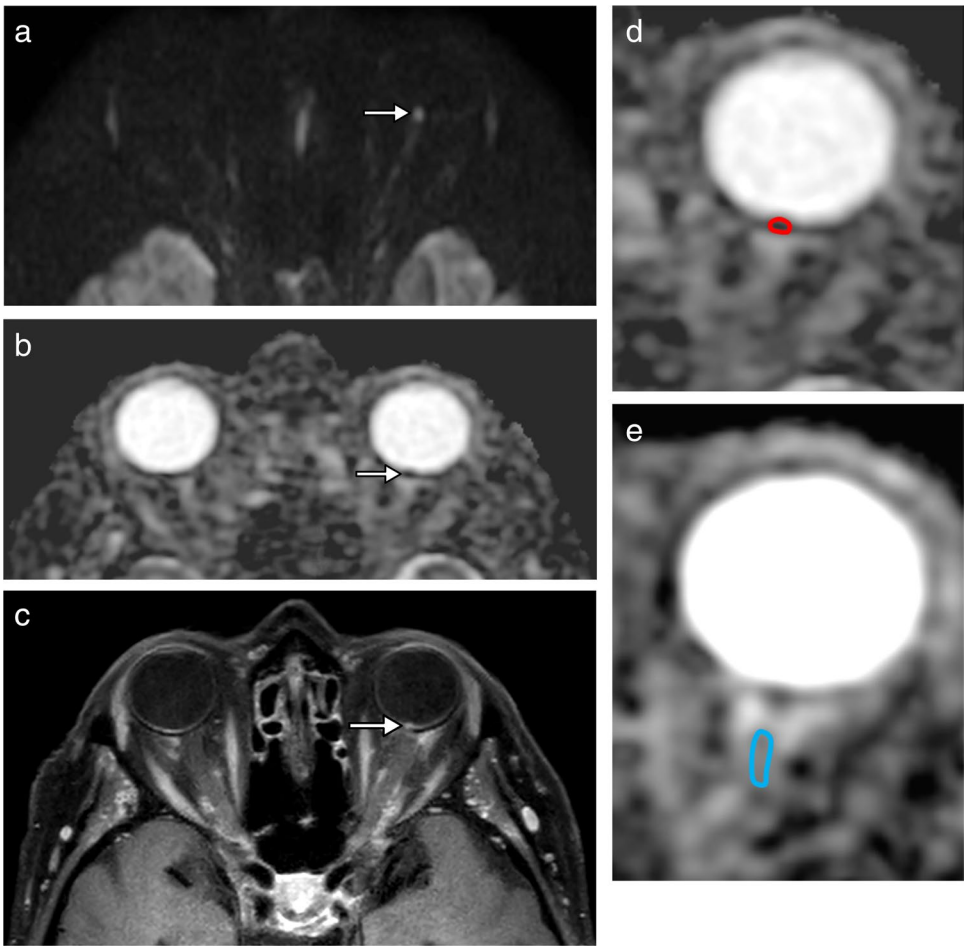

Fig. 4 MR image of an 86-year-old woman presenting to the emergency department for acute visual loss of the left eye. MRI was performed 3 days after the onset of visual symptoms. In the left optic disc (arrow), diffusion-weighted MRI (**a**) shows high signal intensity and apparent diffusion coefficient map (**b**) shows reduced ADC value as sign of restricted diffusion. Post-contrast T1-weighted imaging (**c**) showing enhancement of the left optic disc (arrow). ROI placement in the optic disc (red) and the optic nerve (blue) is shown in **d** and **e**, respectively. A diagnosis of arteritic anterior ischemic optic neuropathy of the left eye was confirmed

Table 2 Detailed MRI characteristics of patients presenting with arteritic anterior ischemic optic neuropathy (AION) versus non-arteritic AION

	Arteritic AION ($n = 15$ eyes)	Non-arteritic AION ($n = 116$ eyes)	p
Restricted diffusion of the optic disc	8/15 (53.3%)	30/116 (25.9%)	*0.04*
Restricted diffusion of the optic nerve	0 (0%)	7/116 (6%)	*> 0.99*
High signal of the optic disc on DWI	8/15 (53.3%)	14/116 (12.1%)	***< 0.001****
High signal of the optic nerve on DWI	2/15 (13.3%)	2/116 (1.7%)	*0.06*
Enhancement of the optic disc on post-contrast T1-WI	1/5[§] (20.0%)	3/49[§] (6.1%)	*0.4*
Self-confidence > 1	11/15 (73.3%)	83/116 (71.6%)	*0.5*
ADC of the optic disc on pathological eyes (10^{-3} mm^2/s) [IQR]	0.75 [0.61–1.25]	1.1 [0.9–1.4]	***0.01****
ADC of the optic nerve on pathological eyes (10^{-3} mm^2/s) [IQR]	0.65 [0.61–0.81]	0.8 [0.7–1.0]	***0.03****

DWI diffusion-weighted imaging, *WI* weighted imaging, *ADC* apparent diffusion coefficient, *IQR* interquartile range

The results in parenthesis are percentages

*Bold characters represent a statistically significant difference between both groups

§5/15 (33%) eyes in the arteritic AION group and 49/116 (42%) eyes in the non-arteritic AION group were explored with post-contrast MRI sequences covering the optic disc

Our study highlights the importance of using the ADC map to avoid any misinterpretation of the DWI. A substantial number of eyes had restricted diffusion of the optic disc or the optic nerve without any visible high signal on DWI. This might be due partly to the "T2 shine-through" effect [22]. Indeed, the ADC map provides information regarding water

molecules' diffusion independent of the T2 signal, showing the "true" diffusion. Based on our results, as a simple visual evaluation of ADC map might be challenging and subjective, ADC measurement should be systematically performed to confirm a restricted diffusion of the optic nerve or optic disc. Based on our ROC curves, we provided an optimal ADC threshold of 0.63 for the optic disc to detect AION, yielding a specificity of 95%. This threshold might be used easily in clinical practice.

Interestingly, the restricted diffusion of the optic disc was more likely to be seen in A-AION as compared to NA-AION, which might be due to the presence of more severe ischemic changes related to arteritis in A-AION. Post-contrast high-resolution vessel wall MRI of the orbit already showed high accuracy when distinguishing A-AION from NA-AION, as reported in recent studies in the literature [14, 23, 24]. Combining both DWI and post-contrast high-resolution vessel wall MRI might further increase diagnostic accuracy. DWI might also be used alone in patients with contra-indications to contrast injection.

Our results have the potential to modify the management of patients with a suspected diagnosis of AION. We showed that MRI should be performed as soon as possible after the onset of visual symptoms to accurately detect ischemic changes of the optic disc and/or optic nerve. Fast-track pathways including emergency access to an MRI examination should be considered for diagnosing patients with a suspected diagnosis of AION. AION remains clinically challenging to diagnose and its final diagnosis is made after a 3-month follow-up based on initial clinical and fundoscopic findings, visual field, and the response to treatment. By showing restricted diffusion of the optic disc or optic nerve, MRI enables the positive diagnosis of AION without delay. Moreover, a combination of DWI and high-resolution contrast-enhanced MRI of the orbit might support diagnosing AION and determining its cause (arteritic or non-arteritic) at the same time, thus improving management and treatment overall. Such fast-track pathways should benefit from the collaboration of a multi-disciplinary team of neuroradiologists, neuro-ophthalmologists, and internists. Indeed, restricted diffusion in the optic nerve is not unique to AION and has been described in atypical optic neuritis, lymphomatous optic neuropathy, or traumatic optic neuropathy, highlighting the need for experts in neuro-ophthalmology to rule out these rare differential diagnoses [20, 25, 26].

Our study presents some limitations: firstly, the overall number of patients remains small in a single center. Secondly, this study has been conducted in a tertiary referral center specialized in ophthalmological diseases, which might have led to a selection bias, by recruiting more severe patients. Thirdly, all MRIs were completed on a 3-Tesla MRI device, which might not be practical across all medical centers worldwide and therefore limit the generalization of our results. Fourthly, DWI of the optic nerve remains challenging because of the small size of the optic nerve and the optic disc, and the presence of partial volume effect as well as the presence of susceptibility and kinetic artifacts [5, 6, 27]. The DWI sequence we performed was not a high-resolution DWI sequence; thus, our results might underestimate the diagnostic performance of DWI when detecting AION. Further larger prospective studies including 3D high-resolution DWI are needed to provide more accurate data.

Our study showed that DWI MRI had good diagnostic performance to detect ischemic changes of the optic disc and optic nerve in patients with AION when performed early after the onset of visual symptoms, with an optimal threshold of 5 days.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00330-021-08417-4.

Acknowledgements Laura McMaster provided professional English-language medical editing of this article.

Kevin Zuber performed the statistical analysis of the data.

Funding The authors state that this work has not received any funding.

Declarations

Guarantor The scientific guarantor of this publication is Dr. Augustin Lecler.

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 Kevin Zuber and Jessica Guillaume kindly provided statistical advice for this manuscript.

Informed consent Written informed consent was obtained from all subjects (patients) in this study.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- retrospective
- case–control study/diagnostic study/observational
- performed at one institution

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