ORIGINAL ARTICLE

Evaluation of Choroidal Thickness in Non-arteritic Anterior Ischaemic Optic Neuropathy at the Acute and Chronic Stages

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ABSTRACT

The objective of this study was to evaluate the measurements of choroidal thickness (CT) in patients with non-arteritic anterior ischaemic optic neuropathy (NAION) at the acute and chronic stages. This case-control study compares three groups: Group 1 included 23 eyes of 23 patients with chronic NAION, Group 2 consisted of 24 eyes of 24 patients with acute NAION, and Group 3 included 24 eyes of 24 age-matched control subjects. The average CTs for Group 1, Group 2, and Group 3 were 261.24 ± 50.04 , 280.05 ± 74.94 , and 254.74 ± 50.11 μm , respectively. For all measurements, no statistical significance was found between the groups ($p = 0.319$, 0.357 , 0.680 , and 0.178 for the CTs as average, foveal, superior, and inferior, respectively). Similarly, there was no difference between the CT measurements of the affected and unaffected eyes in Group 1 and Group 2 ($p = 0.571$, 0.741 for average, respectively). The amount of time after the onset of the disease ranged from 6.0 to 48 months (23.86 ± 16.70 months) in Group 1 and from 1 to 30 days (7.45 ± 8.86 days) in Group 2. There was no correlation between the CTs and follow-up times in Group 1 ($p = 0.768$ for average) and no association between the CTs and the thicknesses of the retinal nerve fibre layers in Group 2 ($p = 0.453$ for average). CT is not directly influenced by NAION at either the acute or the chronic stage of the disease. These results may also demonstrate that the changes of CT do not increase the risk of experiencing a NAION attack.

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Introduction

Non-arteritic anterior ischaemic optic neuropathy (NAION) is a common cause of acute visual loss. The reported incidence is 2–10 cases per 100,000 in the United States.¹ NAION is a well-established clinical entity characterised by the sudden, painless loss of vision with optic disc oedema.² The optic disc oedema disappears within a few weeks and is generally followed by pallor of the disc.³ The chronic stage of the disease then follows. In this stage, the pallor of the disc increases because of apoptosis of the retinal ganglion cells and ganglion cell loss.⁴

The aetiology of NAION is believed to be multifactorial. However, the exact pathogenic mechanisms of the disease remain unproven. There have been several theories, including a reduction in blood flow caused by a combination of nocturnal hypotension, impaired auto-regulation of the microvascular supply, vasculopathic occlusion, and venous insufficiency.^{5–7} These mechanisms as well as other systemic and local

risk factors result in an acute ischaemia of the laminar or retro-laminar portions of the optic nerve head (ONH).^{2,8} Although the ONH is supplied with blood by several vascular sources such as retinal arterioles, the peri-papillary choroid, short posterior ciliary arteries (PCAs), and the central retinal artery, the main source of blood supply to the ONH is PCA circulation through the peri-papillary choroid and the short PCAs.² Therefore, several studies of the pathogenesis of NAION have focused on the short PCA and choroidal circulation and on factors that might affect them.^{6,9–12} However, it is unclear whether changes of choroidal thickness (CT) make a person more vulnerable to NAION, and whether NAION causes changes of CT. In this study, therefore, we evaluate the measurements of the CT in patients with acute and chronic NAION, comparing the results of the CT with a similar control group and the internal control generated from the unaffected eyes of the NAION patients with unilateral disease.

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Methods

Three groups of cases were enrolled in the study as follows: Group 1 consisted of 23 eyes of 23 consecutive patients who had chronic NAION with pallor of the disc, Group 2 included 24 eyes of 24 consecutive patients who had acute NAION with optic disc oedema, and Group 3 included 24 eyes of 24 age-matched control subjects. The study was performed from July 2014 to November 2015. The protocol of the study adhered to the tenets of the Declaration of Helsinki.

All groups included subjects who had a spherical refraction of less than ± 5.00 dioptres and astigmatism of less than ± 3.00 dioptres. In phakic subjects, the most recently manifested refraction was recorded. The pre-operative manifest refraction was used in patients who had a history of cataract surgery. The exclusion criteria for all groups were patients with diabetes mellitus, diabetic retinopathy or other retinal disease, temporal arteritis or other optic neuropathy, glaucoma, ocular hypertension, cataracts that could affect CT imaging during the optical coherence tomography (OCT) measurements, and a history of coffee addiction, smoking, and vitreo-retinal surgery or retinal laser applications.

The diagnosis of acute or chronic NAION was based on a history of sudden onset of visual loss with an absence of other ocular and neurological disorders that might explain the patient's visual symptoms, disc oedema, and haemorrhage on the fundus examination. All patients had normal levels of erythrocyte sedimentation rate and C-reactive protein. None of the patients had signs or symptoms of giant cell arteritis. The diagnosis of chronic NAION was also based on a history of resolution of the disc oedema within 3 months.¹³ Patients with pallor of the disc were included in Group 1 as chronic NAION patients. Subjects with optic disc oedema that had occurred in a time period of less than 1 month were placed in Group 2 as acute NAION patients, since early retinal ganglion cell damage and dysfunction can arise at 1 month of the disease.^{14–16}

Following a complete ophthalmic examination, Spectralis OCT (Heidelberg Engineering, Heidelberg, Germany) was performed in all subjects. Enhanced depth imaging (EDI)-OCT was used for choroidal imaging. Twenty-five sections were acquired in a

5.8×5.8 mm area of the macula by centring the fovea. The CTs were determined in horizontal sections, which were taken through the centre of the fovea and 1250 μm superior and inferior to the fovea. They were also measured at the centre (foveal meridian) and at 1500 μm in the nasal and temporal directions.¹⁷ Each horizontal section included three CT measurements for a total of nine CT measurements acquired from each eye. Three were located at 1500 μm nasal to the foveal meridian at these three horizontal sections. These three points were used for measurements of the foveal, superior, and inferior peri-papillary CTs. The distance from these three points to the optic disc margin was about 2000–2500 μm closer to the optic disc than the other six points. On the OCT images, two ophthalmologists took the CT measurements manually perpendicularly from the outer edge of the hyper-reflective retinal pigment epithelium (RPE) to the choroid-sclera junction (Figure 1). The average of these two measurements was used for all measurements in the study. The measurements included the CTs as foveal, superior, and inferior, which were obtained from three horizontal sections using the average values of three measurements in these sections, and the average CT. All OCT imaging were performed between 1:00 and 3:00 PM to reduce the effects of the diurnal variation on CT.¹⁸

Three patients in Group 1 and 2 patients in Group 2 had bilateral disease; therefore, only one of these patients' eyes was analysed. In addition, four patients in Group 1 and six patients in Group 2 had epi-retinal membrane or cataract in their unaffected eyes. As a result, the affected eyes of seven patients in Group 1 and eight patients in Group 2 were not suitable for comparison with their contralateral, unaffected eyes. Therefore, the affected eyes of 16 patients in each group were used for comparison with their contralateral eyes. The right eyes of all of the control subjects were selected for analysis.

Statistical analysis was performed using SPSS for Windows 16.0 (SPSS, Chicago, IL, USA). The descriptive statistics were shown as mean $\pm$ standard deviation. The Kolmogorov-Smirnov goodness-of-fit and the Levene tests were used to check normality and homogeneity of CT measurements for assumptions of analysis of variance (ANOVA), respectively. All CT measurements were observed as normally

Figure 1. CT measurements, which were evaluated on three horizontal sections of the macula at nine points. The choroid was measured manually perpendicularly from the outer edge of the hyper-reflective retinal pigment epithelium to the choroid-sclera junction. Choroidal thickness measurements were made centrally (at the foveal meridian) and at 1500 μm in the nasal and temporal directions.

distributed, and all groups satisfied the homogeneity of variances in terms of CT measurements. One-way ANOVA was used to compare the mean CT measurements between groups. Paired *t* test was used to compare the results of all measurements between the affected eye and the contralateral, unaffected eye of each of the NAION patients who had unilateral disease in Groups 1 and 2. The correlation between the CTs and the follow-up times was evaluated by Spearman's rank correlation test as well. This test was also used to assess correlations between the measurements of the CTs and the retinal nerve fibre layers (RNFLs). A *p* value of less than 0.05 was accepted as statistically significant.

Results

The mean age of Group 1 (10 females and 13 males) was 62.17 ± 7.01 years (range: 50–78 years), whereas that of Group 2 (11 females and 13 males) and Group 3 (11 females and 13 males) was 61.62 ± 6.99 years (range: 50–74 years). No statistical significance was found in terms of age and gender between the groups (*p* = 0.953 and 0.956, respectively).

The mean best-corrected visual acuities measured with the Snellen chart were 0.38 ± 0.06 in Group 1, 0.41 ± 0.37 in Group 2, and 0.93 ± 0.08 in Group 3. Statistical significance was found between the three groups in terms of visual acuity (*p* < 0.001). However, there was no significant difference

between Group 1 and Group 2 (*p* = 0.740). The means of the spherical equivalents were -0.20 ± 0.96 dioptres (range: -2.00 to $+2.00$ dioptres) in Group 1, 0.04 ± 0.83 dioptres (range: -1.50 to $+1.75$ dioptres) in Group 2, and -0.11 ± 0.90 dioptres (range: -1.75 to $+2.00$ dioptres) in Group 3. No statistical significance was found between the groups in terms of spherical equivalents (*p* = 0.637). The amount of time after the ischaemic attack ranged from 6.0 to 48 months (mean: 23.86 ± 16.70 months) in Group 1 and from 1 to 30 days (mean: 7.45 ± 8.86 days) in Group 2. In Group 1, 11 eyes showed inferior hemifield defects, 9 revealed inferior and superior (diffuse) visual field (VF) loss, 2 showed superior hemifield defects, and 1 had centrocecal scotoma.

Table 1 summarises the CTs of Group 1, Group 2, and the control group. A comparison of all the CT measurements showed no significant difference between the groups (*p* = 0.319, 0.357, 0.680, and 0.178 for the CT as average, foveal, superior, and inferior, respectively) (Table 1). When Group 2 was divided into two subgroups based on the duration of the disease as 10 days or less and 11–30 days, there was no difference in terms of the CTs between these subgroups, Group 1, and the control group (*p* = 0.409, 0.376, 0.515, and 0.360 for the CT as average, foveal, superior, and inferior, respectively).

Tables 2 and 3 show all the values of the affected and the unaffected eyes of the NAION patients in

Table 1. CT assessment in the three groups.

Measurement	Group 1 (n = 23)	Group 2 (n = 24)	Control (n = 24)	p value*
CT Average Mean $\pm$ SD	261.24 $\pm$ 50.04	280.05 $\pm$ 74.94	254.74 $\pm$ 50.11	0.319
CT Foveal Mean $\pm$ SD	268.58 $\pm$ 55.25	283.73 $\pm$ 74.23	257.98 $\pm$ 54.03	0.357
CT Superior Mean $\pm$ SD	270.53 $\pm$ 66.78	277.66 $\pm$ 84.43	260.51 $\pm$ 46.51	0.680
CT Inferior Mean $\pm$ SD	257.66 $\pm$ 56.43	278.77 $\pm$ 70.83	245.75 $\pm$ 55.491	0.178

Note. CT = choroidal thickness.

*One-way ANOVA.

Table 2. Comparison of affected and unaffected eyes in patients with chronic NAION in Group 1.

Measurement (μ m)	Affected eye (n = 16)	Unaffected eye (n = 16)	p value*
CT Average Mean $\pm$ SD	262.81 $\pm$ 59.22	266.34 $\pm$ 66.33	0.455
CT Foveal Mean $\pm$ SD	265.68 $\pm$ 61.48	270.30 $\pm$ 67.41	0.393
CT Superior Mean $\pm$ SD	265.14 $\pm$ 76.72	271.66 $\pm$ 70.37	0.953
CT Inferior Mean $\pm$ SD	257.62 $\pm$ 46.61	257.08 $\pm$ 66.57	0.571

Note. CT = choroidal thickness.

*Paired t test.

Table 3. Comparison of affected and unaffected eyes in patients with acute NAION in Group 2.

Measurement (μ m)	Affected eye (n = 16)	Unaffected eye (n = 16)	p value*
CT Average Mean $\pm$ SD	290.97 $\pm$ 75.46	283.71 $\pm$ 90.12	0.741
CT Foveal Mean $\pm$ SD	290.97 $\pm$ 75.46	289.55 $\pm$ 87.58	0.861
CT Superior Mean $\pm$ SD	284.87 $\pm$ 91.19	282.40 $\pm$ 96.61	0.816
CT Inferior Mean $\pm$ SD	282.22 $\pm$ 74.41	279.18 $\pm$ 90.46	0.747

Note. CT = choroidal thickness.

*Paired t test.

Groups 1 and 2. The results of comparing all the CT measurements of the affected and unaffected eyes in these groups were similar to the outcomes obtained by comparing all the CT measurements of the patient groups and the control group.

Table 4 summarises the peri-papillary CT measurements of the affected and unaffected eyes of the acute NAION patients. In Group 2, a comparison of all of the peri-papillary CT measurements showed that there was no significant difference between the affected and unaffected eyes in patients with acute NAION ($p = 0.931, 0.926, 0.568$, and 0.582 for the peri-papillary CT as average, foveal, superior, and inferior, respectively) (Table 4).

Table 4. Comparison of peri-papillary CT measurements of the affected and unaffected eyes in patients with acute NAION in Group 2.

Measurement (μ m)	Affected eye (n = 16)	Unaffected eye (n = 16)	p value*
CT Average Mean $\pm$ SD	266.43 $\pm$ 93.40	267.14 $\pm$ 104.20	0.931
CT Foveal (μ m) Mean $\pm$ SD	268.81 $\pm$ 97.40	269.93 $\pm$ 104.98	0.926
CT Superior (μ m) Mean $\pm$ SD	266.43 $\pm$ 97.16	272.62 $\pm$ 106.72	0.568
CT Inferior (μ m) Mean $\pm$ SD	264.06 $\pm$ 93.88	258.87 $\pm$ 104.76	0.582

Note. CT = choroidal thickness.

*Paired t test.

Figure 2. Poor correlation between choroidal thickness and follow-up time in chronic NAION.

There were no significant correlations between the follow-up times and any CT measurements in patients with chronic NAION ($r = 0.022, p = 0.921$ for the average CTs) (Figure 2) and in patients with acute NAION ($r = 0.168, p = 0.433$ for the average CTs). No significant correlations were found between the CT averages and the NFL averages in patients with chronic NAION ($r = 0.223, p = 0.296$).

Figure 3. Poor correlation between choroidal thickness and nerve fibre layer thickness in acute NAION.

and in patients with acute NAION (Group 2) ($r = 0.209$, $p = 0.338$) (Figure 3).

Discussion

This study investigated the association between NAION and CT in patients who had acute and chronic NAION. It has been reported that choroidal changes may be involved in retinal and optic nerve diseases such as chronic NAION because the choroid plays a vital role in supplying oxygen and nutrition to the outer layers of the retina, or RPE, and to the pre-laminar portion of the ONH.^{2,17} However, one study has investigated this relationship between NAION and CT in patients who have acute NAION.¹⁹ Our study results demonstrate that the groups of patients with acute and chronic NAION have no significant difference in terms of CTs compared with the control group and the internal control generated from the unaffected eyes of these NAION patients with unilateral disease.

It has been shown that compromised peri-papillary choroidal filling is not a consistent feature of acute NAION using fluorescein and indocyanine green angiography.^{9–11} Also, in accordance with the literature, our study found that both the peri-papillary and macular CTs of the eyes of patients with acute NAION did not differ significantly from the CTs of the control subjects' eyes or the unaffected eyes of patients who had acute NAION.^{9,11,20} In addition, the study found no correlation between the CT measurements and follow-up times in patients with acute NAION. These findings were

in accordance with each other. On the other hand, Schuster et al. have recently reported different findings in their case-control study.¹⁹ They investigated the macular CT measurements in 20 patients with NAION at the acute stage and reported that the eyes of patients who had acute NAION and their contralateral, unaffected eyes showed significantly thinner macular CTs than the eyes of healthy subjects. There have been several methodological differences between this study and our study. First, they used one horizontal section passing through the centre of the fovea for the CT measurements, which were evaluated on this section at seven points, and separately compared these between the groups. However, taking OCT measurements at one selected point and comparing them with each other is not the most precise method for determining CTs, since these measurements, which are performed manually, may be affected by local irregularities of the choroid-scleral boundary.^{17,21,22} Therefore, to reduce the risk of mistakes caused by this, we used three horizontal sections for the CT measurements, which were evaluated on these sections at three points, and used the average of these three measurements for comparisons. Also, the development of automatic software for CT measurements will, in the future, help to improve the accuracy of these measurements.^{21,22} In addition, CT measurements may be affected by several factors such as age, gender, spherical equivalent, diurnal variation, smoking, coffee addiction, and some conditions such as diabetes mellitus and age-related macular degeneration.^{18,21,23–26} To eliminate these potentially confusing factors, the authors have statistically adjusted some of them for comparisons; however, these have not included all the factors mentioned above. However, our study has excluded all of these confusing factors. Also, in their study, although there was a significant difference in terms of the CTs between the acute NAION patients and the healthy subjects, there were no significant differences between the CT measurements of the affected and unaffected eyes in patients with acute NAION and between affected and previously affected eyes. This might support the assertion that the study by Schuster et al.¹⁹ could have been influenced by these confusing factors. As a result, these methodological distinctions may explain the difference between the two studies.

NAION is caused by vascular insufficiency within the ONH; however, the exact mechanism and location of this vasculopathy remain unclear.⁶ In addition, it has been reported that the vasculopathy in NAION occurs in the deeper parts of the ONH that are supplied with blood by PCA circulation.²⁷ However, the peri-papillary choroid provides the blood supply for the pre-laminar region of the ONH.⁶ Our study also found that the changes in choroidal thickness do not occur in patients with acute NAION, which demonstrates the level of vasculopathy within the distribution of the para-optic branches of the PCAs after their choroidal branches. The study also demonstrates that there is a poor correlation between CT and NFL thicknesses, which is a quantitative indicator of the optical disc oedema in patients who had acute NAION. Considering the level of vasculopathy that our study implied in patients with acute NAION, this result will be found to be reasonable.

Our study found that no changes in the CTs in patients with both acute and chronic NAION, as well as no correlation between the CTs and follow-up times, were in accordance with each other. However, Dias-Santos et al. have reported that the mean CT is significantly higher in patients with chronic NAION as a marker of the local dysfunction of the vascular auto-regulation mechanisms.¹⁷ These authors have also hypothesised that dysfunction of the vascular auto-regulation might be present before an ischaemic attack, and that this can make a person more vulnerable to experiencing an ischaemic event. However, our results have not supported this hypothesis, since there are no changes in the CTs of patients with acute NAION and no differences in the CTs in the contralateral eyes of patients who had both acute and chronic NAION in our study. Dias-Santos et al. have also reported that the macular tissue, which is decreased in patients with chronic NAION, might be associated with the increase in CT.¹⁷ They have hypothesised that the decrease in macular thickness reduces the metabolic activity of the decreased retinal tissue, and since this could interfere with the choroidal vascular auto-regulation in that area, CT increases in patients with chronic NAION. However, it is not clear whether the choroid has appreciable vascular auto-regulation.² Also, it has been reported that the decrease in macular thickness is caused by the decrease in the ganglion cell complex (GCC) because

there is ganglion cell loss in patients with chronic NAION.^{13,28} As the ganglion cells die as a result of the NAION, the GCC and macular thicknesses become thinner. GCC is composed of three layers in the inner part of the retina, including the retinal nerve fibre layer, the ganglion cell layer, and the inner-plexiform layer. All three layers are supplied with blood by the retinal circulation through the central retinal artery, but not supplied by the choroid. In chronic NAION, therefore, the decrease in metabolic activity due to ganglion cell loss in the inner part of the retina may not be able to affect the choroid vascular regulation and CT, even if the choroid has vascular auto-regulation. In accordance with this, Dias-Santos et al. found no correlation between retinal thickness and CT in patients with chronic NAION because CT is not directly influenced by the changes in the inner part of the retina. We also found no correlation between the CT and NFL thickness in chronic NAION in our study.

As mentioned above, CT measurements may be affected by a number of factors. To eliminate these potentially confusing factors from our study, we generated a second control group that included the unaffected eyes of the both acute and chronic NAION patients. The results obtained from comparing all the CT variables of the affected and unaffected eyes were similar to the outcomes obtained by comparing all the CT variables of the acute and chronic NAION groups and the control group. This ensures that the study has not been affected by these confusing factors. Since the study by Dias-Santos et al. did not include the unaffected eyes of the chronic NAION patients who had unilateral disease, it might have been influenced by these confusing factors, and this may explain the difference between the two studies.

In conclusion, this study found no changes in the CTs, no correlation between the CTs and follow-up times, and no association between the CT and NFL thickness measurements in patients with both acute and chronic NAION. These results may also demonstrate that the changes of CT do not increase the risk of experiencing an ischaemic event in the optic nerve head.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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