Research Article

Choroidal Thickness and Volume Modifications Induced by Aerobic Exercise in Healthy Young Adults

Choroidal Modifications by Exercise

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Abstract

Introduction

Our aim was to evaluate the changes in choroidal thickness (CT) and volume (CV) following aerobic physical exercise in healthy young adults.

Methods

This study included 72 eyes from healthy volunteers between 22 and 37 years old. Using the International Physical Activity Questionnaire, total physical activity was computed. Measurements using an autorefractometer, ocular biometry, and spectral-domain optical coherence tomography using the Enhanced Depth Imaging protocol were taken. OCT was performed as a baseline measurement and after performing 10 min of dynamic physical exercise (3 and 10 min post-exercise). The choroidal layer was manually segmented, and the CT and CV in different areas from the Early Treatment Diabetic Retinopathy Study grid were obtained.

Results

In healthy adults, at 3 min post-exercise, CT was higher in the subfoveal, the 3-mm nasal, and the 6-mm superior areas. Between 3 and 10 min post-exercise, the CT was reduced in all areas, and in some areas, the values were even smaller than the baseline measurements. The CV values showed changes after exercise similar to those of thickness. The total CV recovery after exercise was related to sex and physical activity level.

Conclusion

Individuals with higher physical activity habits had greater CV at rest than those with lower physical activity levels. During exercise, healthy young people adjust CT and CV. At 3 min post-exercise, CT and CV increase. Women and individuals with greater physical activity levels reduce their total CV more than others during recovery.

Keywords: Exercise; Choroid; Optical coherence tomography; Eye

Introduction

During exercise, the increased O_2 requirement of contracting muscles is satisfied by an increase in blood supply because the heart pumps more blood per minute due to circulatory adaptations and regulation of vessel diameter; these adaptations enable a large part of the bloodstream to reach the muscles rather than the less active tissues. Exercise affects systemic haemodynamics, resulting in increased blood flow, increased arterial systolic pressure, and increased heart frequency.

Ocular blood flow is indispensable for adequate visual performance. The choroid, a vascularized tissue between the sclera and the retina, accounts for 85% of the ocular blood supply. In addition to blood supply, other choroidal functions such as light absorption, thermoregulation via heat dissipation, and the role in the drainage of the aqueous humour from the anterior chamber via the uveoscleral pathway have been considered [1]. Traditionally some authors have claimed that unlike the retina and anterior uvea, the choroid has little or no self-regulation [2]. However, other hypotheses have emerged in which they state that the choroid has the ability to regulate its choroidal blood flow (ChBF) during changes in ocular perfusion pressure (OPP), having a greater ability to adapt to mean arterial pressure (MAP) than to intraocular pressure (IOP) [3, 4].

The introduction of optical coherence tomography (OCT) has had an important effect on the development of methods for studying the choroid [5, 6]. The latest generations of OCT and the introduction of new scanning protocols and visualization have improved the possibility of studying the choroid. This is achievable due to the introduction of the enhanced depth imaging (EDI) technique that inverts the retinal image and has less vitreous resolution but better choroidal images [7]. Spectral-domain OCT (SD-OCT) with the EDI protocol allows visualization of the deeper layers of the retina [8].

Studies report values of choroidal thickness (CT) between 270 and 350 µm [9] and average values of 354 µm [10] in healthy populations. CT may be modified by internal factors. CT has a negative correlation with age [9–15] and axial length (AL) [10]. Another very important factor to consider is the diurnal variation since the choroid decreases in thickness as the hours of the day pass [16–19]. On the other hand, there is a positive relationship between best visual acuity (VA) and central subfoveal thickness in patients older than 50 years [12, 20]. As for the difference by sex, there is controversy, some studies do not find differences, others, despite not being significant, suggest that the thickness is greater in women than in men, and others that choroid is thicker in men than in women [13, 21–24]. In this aspect, it has to be considered that during the menstrual period a woman decreases her CT [25]. CT is also modified by the refractive error [9, 10, 12, 26] and by many diseases that affect the retina, such as age-related macular degeneration (AMD), central serous choroidopathy, macular hole, and pathological myopia [9, 27]. CT may also be modified by other external factors that affect vascular regulation: caffeine causes the CT to decrease in the 4 h following ingestion [28–31]; tobacco produces a decrease in CT following smoking [32–34], although no baseline changes were observed in healthy chronic smokers [35]; and alcohol increases CT between 1 h and 2 h after ingestion [36].

The effects of exercise on the IOP, OPP, AL, corneal thickness, depth of the anterior chamber, thickness of the lens, and blood flow in the ophthalmic artery, the central retinal artery, the optic nerve head, the retina, and the choroid have been studied, but the effects of exercise on CT are still controversial [37]. Some authors demonstrate that exercise increases CT [38], but others did not see any changes [37, 39, 40], probably related to methodological differences or differences in the population.

We hypothesized that, due to the great choroidal vascularization, changes in the blood circulation induced by exercise could generate changes at the choroidal vascularization. The aim of our study was to assess with SD-OCT the CT changes after physical exercise. The normalization of a database of choroidal variations before and after exercise in healthy young people would be very useful, so that their results could be extrapolated to help us understand the influence of exercise in the eyes with pathologies involving the choroid.

Materials and Methods

Participants

Seventy-two eyes from healthy individuals (32 men and 40 women) with a mean age of 25 ± 5 years (range from 22 to 37 years) were recruited from among hospital workers and friends in the Ophthalmology Department of the University Clinical Hospital Lozano Blesa, Zaragoza, Spain. The inclusion criteria were age between 20 and 40, best corrected VA measured by Snellen charts of 20/20, no history of ocular or systemic disease, and no treatments. The exclusion criteria were having a refractive error of ≥±6.50 dioptres (D) spherical or ≥±3 D cylindrical.

This study was carried out in accordance with the tenets of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards of Declaration of Helsinki (2013) and was approved by the Clinical Research Ethics Committee of Aragon (project licence PI19/352). Written informed consent was obtained from the subjects who participated in this study; confidentiality and protection of data were ensured by applying international recommendations and current Spanish legislation (Ley de Investigacion Biomedica 14/2007 and LOPD).

Each subject underwent a preliminary ophthalmologic examination to exclude any pre-existing, undiagnosed ocular disease. The ophthalmologic examination included refraction, an evaluation of intrinsic and extrinsic ocular motility, an anterior segment, and central ocular fundus study by biomicroscopy and SD-OCT.

Assessment of the Levels of Physical Activity

Levels of physical activity in a typical week, according to intensity, frequency, and duration, were estimated using the International Physical Activity Questionnaire [41]. One metabolic equivalent (MET) is defined as the amount of oxygen consumed while sitting at rest (3.5 mL O_2/kg/min). Moderate intensity refers to activities that cause small increases in breathing or heart rate. Vigorous intensity refers to activities that require hard physical effort and cause large increases in breathing or heart rate. MET-adjusted minutes (MET-min) of physical activity in the last week were calculated by assigning 4 METs to the time spent in moderate activities and 8 METs to the time spent in vigorous activities.

Protocol for the Examinations and Exercise

Subjects were instructed to refrain from ingesting alcohol and caffeine and from doing exercise in the 24 h prior to the examination. All subjects were examined under the same conditions without mydriatics and by the same investigator. All examinations were obtained during the same time period to avoid diurnal variations (2 p.m.–3 p.m.).

Ocular biometric measures were collected using the IOLMaster biometer (IOLMaster; Carl Zeiss Meditec, Jena, Germany) to determine the AL. The measurement was taken before exercise. Each measurement was performed at least 3 times, and the mean was calculated. Refractometry (KR-7000P; Topcon Medical Systems Inc., Oakland, NJ, USA) was performed, and the measurement was taken before exercise. Each measurement was performed at least 3 times, and the mean was defined as the spherical equivalent. Finally, the CT was measured by SD-OCT with a Spectralis OCT device (software version 5.6b; Heidelberg Engineering, Heidelberg, Germany) with EDI, a fast macular protocol, and 25 frames. The focus system was adjusted to obtain a higher quality image. When taking the images, the Eye-Tracking® system was used to minimize possible eye movements during the scans and to guarantee good image quality, and subjects were warned to look at an internal fixation point. The highest quality scans obtained were chosen for evaluation. Their quality line, rated in the OCT from 0 to 40 dB (decibels), was always higher than 25 dB.

After this baseline measurement, volunteers with their refractive error corrected were required to perform 10 min of exercise. The exercise was going up and down stairs at a moderate pace. An examiner (GI-S) controlled the exercise level to assure that it was similar in all participants. After exercising, 2 more OCT measurements, 3 and 10 min after completing the exercise, were taken following the same protocol as in the baseline measurement.

Data Analysis

Following each measurement session, the OCT images were exported from the device. In each OCT profile, we could distinguish the retinal thickness, which was delimited by the internal limiting membrane and the Bruch membrane

(BM), which served as the outer limit. Choroidal sections were obtained with manual segmentation, which exhibited a high degree of intraobserver and interobserver repeatability [26, 42]. In each of the 25 frames, an experienced, masked observer moved the BM line to the choroidal-sclera interface and the internal limiting membrane line to the BM location. After moving the lines, the OCT provided the CT and the CV in the retinal map, specifically in each one of the 9 macular areas of the Early Treatment Diabetic Retinopathy Study (ETDRS) [43].

Data obtained were statistically treated using a licensed version of SPSS 19.0 for Windows (SPSS, Chicago, IL, USA). Descriptive statistics for continuous variables included the mean and standard deviation. For each continuous variable, the Kolmogorov-Smirnov test was applied to check normality.

The CT measures were analysed at baseline and at 3 and 10 min after exercise by the Friedman test, a repeated measure analysis, as the data were not normally distributed. Post hoc analysis of the baseline, 3-min post-exercise, and 10-min post-exercise choroidal values was performed by the Wilcoxon test. Adjustment for multiple comparisons was performed using the Holm-Bonferroni method.

To determine the relationship of age, sex, AL, and physical activity levels with total CV, multivariate linear regression models were analysed using forward stepwise selection. The assumptions of linear regression (normality, linearity, and homoscedasticity of residuals) were tested and examined through the scatter plots of the residuals. The level of significance considered was $p < 0.05$.

Results

Seventy-two healthy eyes (from 32 men and 40 women) with a mean age of 25 ± 5 years (ages 22–37 years) were included in this study. The average ametropy was −1.82 ± 1.82 D (range: −6.25 to +0.75 D), and the AL was 24.05 ± 1.25 mm (range: 20.60–26.01 mm). At baseline, the temporal measurements were significantly higher than the nasal measurements in both CT and CV, both in the perifoveal and parafoveal rings ($p < 0.001$ in all comparisons). However, between the superior and inferior areas, there were no significant differences in the CT or CV of the parafoveal ring ($p = 0.760$ and $p = 0.393$, respectively) or the perifoveal ring ($p = 0.297$ and $p = 0.248$, respectively).

Table 1 shows the multiple linear regression with the explanatory variables sex, age, AL, and physical activity levels with the total CV at rest as the dependent variable. The AL and physical activity level were the best explanatory variables (adjusted $R^2 = 0.366$, $p < 0.001$ for the model). Sex and age were not found to be significant for explaining the total CV at baseline ($p = 0.453$ and 0.255, respectively). The mean CV values were 8.25 ± 2.23 mm^3 and 8.80 ± 1.89 mm^3 for men and women, respectively. For the β-coefficient of the significant explanatory variables, for each 1 mm that AL increased, the total CV diminished 0.94 mm^3, and for each 1 MET-min/week that physical activity level increased, the total CV increased 372 picolitres.

Table 1.

The table layout displayed in this section is not how it will appear in the final version. The representation below is solely purposed for providing corrections to the table.

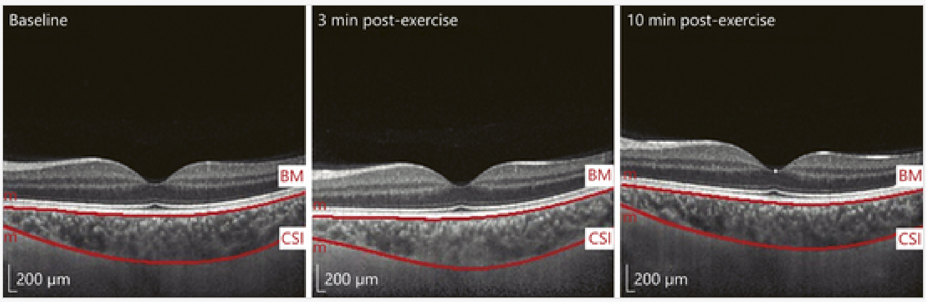
Multiple linear regression models of total choroidal volume

Dependent variable: total choroidal volume (mm^3) at baseline						
independent variable	**unstandardized β-coefficient**	**95% confidence interval for β**		**standardized β-coefficient**	***p* value**	**model summary**
		lower	**upper**			
(Constant)	30.56	22.59	38.54		**<0.001**	**Adjusted R^2 = 0.366 $p < 0.001$**
Physical activity level (MET-min/week)	$372 \cdot 10^{-6}$	$65.4 \cdot 10^{-6}$	$372 \cdot 10^{-6}$	0.240	**0.018**	
Axial length (mm)	−0.941	−1.271	−0.611	−0.563	**<0.001**	
Sex (0-male)	−0.088				0.453	Excluded from the

Age, years	−0.120				0.255	model
Dependent variable: total choroidal volume (mm ^{3}) difference between baseline versus 3 min post-exercise						
independent variable	**unstandardized β-coefficient**	**95% confidence interval for β**		**standardized β-coefficient**	***p* value**	**model summary**
		lower	**upper**			
(Constant)	−1.38				0.506	All variables excluded. No model built
Physical activity level (MET-min/week)	$3.57 \cdot 10^{-6}$				0.955	
Axial length, mm	0.042				0.572	
Sex (0-male)	0.071				0.708	
Age, years	0.015				0.405	
Dependent variable: total choroidal volume (mm ^{3}) difference between 3 min versus 10 min post-exercise						
independent variable	**unstandardized β-coefficient**	**95% confidence interval for β**		**standardized β-coefficient**	***p* value**	**model summary**
		lower	**upper**			
(Constant)	0.15	−0.06	0.36		0.156	**Adjusted R^{2} = 0.141 p = 0.003**
Physical activity level (MET-min/week)	$-126 \cdot 10^{-6}$	$-200 \cdot 10^{-6}$	$-52.0 \cdot 10^{-6}$	−0.411	**0.001**	
Sex (0-male)	−0.203	−0.404	−0.002	−0.244	**0.048**	
Axial length, mm	−0.033				0.803	Excluded from the model
Age, years	0.065				0.579	

Participants were required to go up and down stairs at a moderate pace for 10 min. At 3 min post-exercise, the CT values were higher than those at baseline, although only significant differences were found in the subfoveal CT, the 3-mm nasal, and the 6-mm superior areas (shown in Fig. 1; Table 2).

Fig. 1.



Enhanced depth imaging-optical coherence tomography of the choroid in a healthy adult at the baseline evaluation and 3 and 10 min after finishing 10 min of dynamic exercise. BM, Bruch membrane; CSI, choroidal-sclera interface.

Table 2.

The table layout displayed in this section is not how it will appear in the final version. The representation below is solely purposed for providing corrections to the table.

Choroidal thickness of the 72 healthy eyes at baseline and 3 and 10 min post-exercise

Choroidal	Baseline	3 min	10 min	p value:* baseline	p value:$ baseline	p value:# 3 min

thickness, μm		post-exercise	post-exercise	versus 3 min post-exercise	versus 10 min post-exercise	versus 10 min post-exercise
Subfoveal	331±91*	341±95$^{*,\#}$	333±90$^{\#}$	0.016	0.777	0.001
Inner circle (ETDRS parafoveal region: 3 mm)						
Superior	330±87	337±89$^{\#}$	329±84$^{\#}$	0.183	0.191	0.004
Temporal	328±80	333±81$^{\#}$	327±77$^{\#}$	0.130	0.604	0.003
Nasal	303±90*	310±95$^{*,\#}$	302±89$^{\#}$	0.019	0.830	0.001
Inferior	329±85$^{\$}$	332±89$^{\#}$	325±83$^{\$,\#}$	0.327	0.042	0.001
Outer circle (ETDRS perifoveal region: 6 mm)						
Superior	320±79*	330±83$^{*,\#}$	322±78$^{\#}$	0.023	0.907	0.002
Temporal	309±72$^{\$}$	308±68$^{\#}$	303±66$^{\$,\#}$	0.355	0.027	0.002
Nasal	239±73	241±75$^{\#}$	237±73$^{\#}$	0.584	0.625	0.023
Inferior	315±73$^{\$}$	316±74$^{\#}$	310±72$^{\$,\#}$	0.886	0.048	0.016

ETDRS, Early Treatment Diabetic Retinopathy Study.

* $p < 0.05$, baseline versus 3 min post-exercise.

$ $p < 0.05$, baseline versus 10 min post-exercise.

# $p < 0.05$, 3 min versus 10 min post-exercise (Wilcoxon test).

When comparing 10 min post-exercise with 3 min post-exercise, there was a significant reduction in CT in all areas (Table 2). The 10-min post-exercise values in the 3-mm inferior, 6-mm inferior, and 6-mm temporal areas were even smaller than the baseline values. The CV values showed changes with exercise similar to those of CT (Table 3).

Table 3.

The table layout displayed in this section is not how it will appear in the final version. The representation below is solely purposed for providing corrections to the table.

Choroidal volume of the 72 healthy eyes at baseline and 3 and 10 min post-exercise

Choroidal volume, mm^3	Baseline	3 min post-exercise	10 min post-exercise	*p* value*: baseline versus 3 min post-exercise	*p* value:$^{\$}$ baseline versus 10 min post-exercise	*p* value:$^{\#}$ 3 min versus 10 min post-exercise
Subfoveal	0.26±0.07*	0.27±0.07$^{*,\#}$	0.26±0.07$^{\#}$	0.019	0.621	0.003
Inner circle (ETDRS parafoveal region: 3 mm)						
Superior	0.52±0.14	0.53±0.14$^{\#}$	0.52±0.13$^{\#}$	0.255	0.119	0.003
Temporal	0.51±0.12	0.52±0.13$^{\#}$	0.51±0.12$^{\#}$	0.107	0.882	0.002
Nasal	0.48±0.14*	0.49±0.15*,$^{*,\#}$	0.48±0.14$^{\#}$	0.043	0.954	0.010
Inferior	0.51±0.13	0.52±0.14$^{\#}$	0.51±0.13$^{\#}$	0.202	0.087	0.001
Outer circle (ETDRS perifoveal region: 6 mm)						
Superior	1.70±0.42*	1.75±0.45$^{*,\#}$	1.70±0.41$^{\#}$	0.024	0.924	0.002
Temporal	1.64±0.38$^{\$}$	1.63±0.36$^{\#}$	1.61±0.35$^{\$,\#}$	0.295	0.024	0.005
Nasal	1.26±0.40	1.27±0.40	1.26±0.39	0.551	0.817	0.140

Inferior	$1.66 \pm 0.39^{\$}$	$1.68 \pm 0.39^{\#}$	$1.64 \pm 0.37^{\$,\#}$	0.729	0.032	0.004
Total volume	8.56 ± 2.05	$8.64 \pm 2.12^{\#}$	$8.49 \pm 1.99^{\#}$	0.241	0.160	0.000

ETDRS, Early Treatment Diabetic Retinopathy Study.

* $p < 0.05$, baseline versus 3 min post-exercise.

$ $p < 0.05$, baseline versus 10 min post-exercise.

# $p < 0.05$, 3 min versus 10 min post-exercise (Wilcoxon test).

When analysing the significance of the explanatory variables in the total CV differences found between baseline and 3 min post-exercise, no linear regression model could be calculated (Table 1). However, physical activity levels and sex were found to be the best variables to explain the total CV changes between 3 min versus 10 min post-exercise (adjusted $R^2 = 0.141$, $p = 0.003$ for the model). This result suggests that women and individuals with higher physical activity habits had the greatest decreases in total CV during recovery, that is, from 3 to 10 min post-exercise.

Discussion

Choroid is a vascularized layer, and vascular changes have been described related not only to pathological conditions such as central serous chorioretinopathy with a mean CT of 505 µm [5], polypoidal choroidal vasculopathy with a mean CT of 438 µm, and exudative AMD with a CT <171 µm to normal subjects [44] but also to healthy subjects under the influence of different circumstances such as the Valsalva manoeuver with some studies where it may not influence [45] and with other studies where it increased CT [46] and such as the use of mydriatics that decreased CT [47].

When studying the influence of sex on CV, the previous results are variant. In our study, sex was not a significant explanatory variable of the total CV at baseline. These results are in accordance with those of Park et al. [48], which comprised 26 male and 22 female children with a mean age of 7 years. Our results are in accordance too with Sanchez-Cano et al. [26], which comprised 30 men and 65 women with a mean age of 24. In contrast, other authors, including Li et al. [49] who studied 33 males and 60 females with a mean age of 25 years and Barteselli et al. [6] who studied 55 men and 63 women with a mean age of 50 years, found significantly greater CVs in males than in females. Thus, more research and higher subject numbers are necessary to clarify the influence of sex on CV and whether other factors also influence CV.

Age could also influence choroidal flow regulation. Several studies have found lower CT values with ages ranging from 12 to 80 years [14]; from 19 to 60 years [15]; from 19 to 85 years; and from 23 to 80 years [9, 11]. Ding et al. [12] noted that choroidal weight loss occurs after 60 years of age. Ikuno et al. [10] found that the decrease in CT was 14 µm with each decade. Similarly, Sardi Correa et al. [13] found that for each increase in one year of age, the average CT decreases 2.27 µm. Our age range (from 22 to 37 years old) may be small (all healthy young); thus, differences related to age were not found. Similarly, Kinoshita et al. [37], who studied 38 eyes with a mean age of 39 years, found no significant differences in the OCT parameters of young and middle-aged subjects.

In ametropia, although other factors, such as curvature of the cornea or lens, may influence their relationship, AL and refractive error are often related, and we found a reduction effect on CV when increasing AL. Our results reinforce those found by Sanchez-Cano et al. [26], who found that emmetropic eyes tended to have thicker choroids and greater CVs than did myopic eyes. Ikuno et al. [10] also showed a relationship between the foveal CT and the AL; however, the regression was low.

In the regression model, we found that physical activity level was also an explanatory variable for total CV at baseline, indicating that the more physical activity performed, the greater the CV of the individuals at rest. First, this finding is truly important when standard databases are made because physical activity level should also be considered. Second, this result may reflect a beneficial effect of continued exercise on choroidal flow. These data were obtained using the

International Physical Activity Questionnaire, and perhaps knowing other factors, such as the body mass index, or assessing cardiovascular capacity would give us a more objective view.

Previously, the beneficial effect of training has been studied in IOP, where despite being transiently reduced by dynamic exercise, for the great majority of patients, exercise is beneficial to the eyes by reducing the risk of central retinal vein occlusion and neovascular AMD and by improving the control of systemic hypertension and diabetes [50, 51]. Therefore, more research is needed to determine whether exercise also has an influence on other parts of the eye or may have other benefits, as it is well known that the physiological effects that occur in the long term in people who do physical activity are changeable. We can discuss the change that occurs in energy expenditure: exercise increases the resting metabolic rate and thermogenesis, and it can also modify the body composition favourably by decreasing fat mass and increasing lean mass. It can also reduce resting blood pressure and increase the capacity to carry blood in the coronary arteries, and there are beneficial changes in the lining of blood vessels that help direct the appropriate distribution of blood in the body. Exercise has beneficial effects on the body's capacity for forming and breaking down blood clots and produces favourable changes in the plasma lipid profile. It improves blood glucose handling and is also associated with beneficial immunological and neurological changes (review in [52]).

Looking at the CT values between different EDTRS areas at baseline, our results showed that temporal measurements were significantly higher than nasal ones but that there were no significant differences between the superior and inferior areas. This is consistent with Park et al. [48] who showed that in children, the temporal choroid was significantly thicker than the nasal choroid but that no significant difference was detected between superior and inferior CT. Additionally, other authors found that the choroid was thickest in the superior areas [10, 26, 53]. When the healthy volunteers in our study performed exercise, we found that the 3-min post-exercise choroidal values, both CT and CV, were increased. At 10 min post-exercise, CT and CV decreased, and even in some areas, these values were below the baseline values. This supports the finding that in young people with no pathological conditions, choroidal flow after exercise is modified. The same findings were found after performing exercise with other ocular-related values, such as IOP [40], AL [54], systolic and diastolic blood pressures, heart rate, mean ocular perfusion pressure, and the mean blur rate [37], in which these values were modified after exercise. However, not all authors found similar changes, as IOP [38], diastolic blood pressure [39], AL, previous anterior chamber depth, lens thickness, and vitreous length [40] values were not found to be different after exercise. Previous studies in a small series on changes in CT after physical exercise also showed opposite results. Alwassia and colleagues, in a sample of 15 patients with a mean age of 61 years, concluded that there was no variation in CT after performing physical exercise [39]. This lack of variation in CT after exercise in the Alwassia study could depend on the age of the studied participants, not only because of the presence of choroidal diminution but also because of their cardiac condition.

However, the same conclusion was shown by Hong, in a study of 25 subjects with a mean age of 25.4 years [40], and by Kinoshita, in a study of 38 subjects with a mean of 39 years [37]. However, Sayin et al. [38] studied 19 subjects with a mean age of 27 years and found similar results to our study: a small time after finishing the exercise (3 min in our study and 5 min in Sayin's work), they found a CT increase, and then there was a diminution after a later timepoint (10 in our study and 15 in Sayin's one). In the study by Sayin et al. [38], the CT values 15 min post-exercise did not differ significantly from the baseline.

Our results provide new findings because when analysing the data only 10 min after the end of the exercise, the CT values were lower than those at baseline in some areas. Although we could differentiate between isometric activities (with continuous muscle contractions) and dynamic activities (contraction and relaxation phases), the practice of exercise involves an increase in heart rate as well as cardiac output and generates redistribution of blood flow.

On the other hand, variations in blood flow, systolic blood pressure, ventilation, and hormonal changes occur [55]. Also note that during isometric exercises, blood pressure in the ophthalmic and brachial arteries increased, and the same occurred with choroidal vascular resistance [56].

Regarding the regulation of choroidal blood flow during isometric exercise at different levels of IOP, Popa-Cherecheanu said that the regulation of choroidal blood flow during changes in ocular perfusion pressure is controlled by complex mechanisms in humans and has less capacity to adapt to IOP elevation than to MAP elevation [57]. Choroidal changes after exercise, smoking, caffeine drinking, or other external factors need to be described not only in healthy and young subjects but also in patients with retinal diseases. These findings could be a recommendation to avoid the pathological influence of external factors in pachychoroid diseases, AMD, or other vascular retinal diseases where choroidal flow may be crucial.

For example, in patients with primary open-angle glaucoma and ocular hypertension, the baseline ChBF response to isometric exercise indicates less active regulatory capacity [58]. We should also keep in mind that aerobic exercise decreases IOP while isometric exercise can cause a temporary elevation in IOP that can aggravate the problem. In pseudoexfoliative glaucoma, patients who performed at least 30 min of exercise per week had less progression in the visual field defect than those who did not exercise [59].

When we talk about AMD, some studies in dry AMD said that there were no differences between the ChBF changes observed in control subjects and those observed in patients with AMD during the isometric exercise phase and after exercise [48]. However, Pournaras CJ et al. [49] found that in response to an acute, moderate increase in OPP induced by isometric exercise, there were no changes in ChBF. In contrast, in patients with neovascular AMD, this flow increases, indicating an altered regulation in response to the increase in OPP.

To prescribe exercise to patients with eye diseases, more research is needed to determine if they have alterations that do not allow them to recover properly after acute exercise. On the other hand, chronic exercise, as in other haemodynamic variables [4], could also produce adaptations in the choroidal flow, which could be beneficial for these patients. Therefore, more studies are needed to determine whether training improves their choroidal condition. For all this, an exercise protocol during an ophthalmologic examination could be useful to obtain an early diagnosis in ocular diseases because our results show that physical activity level and sex have an effect on total CV.

The present study has several limitations that need to be addressed. The lack of objective ocular and systemic measures is still a problem in choroidal measurements. Independent measurements have been made by 2 experienced evaluators to minimize subjectivity. The intensity of the exercise has not been controlled with an ergometer, but it must be considered that the objective is to carry out these measurements in a simple way in the ophthalmologic room. However, a step and a timer are easy to achieve in the consultation and allow controlling the amount of exercise performed. So, in this simple way, the measures after exercise provide much more information than the simple basal measurement at rest. In this study, the majority of examined eyes were myopic. This is the result of the narrow age range of the sample (22–37 years), and that most of them were university students, but it is necessary to take this into account because myopia could influence the final CT differently than in emmetropic or other ametropic subjects.

We can conclude that in our sample of healthy young adults, individuals with higher physical activity levels had greater CV at rest than those with lower physical activity levels. Moreover, the average values of CT and CV were affected by the performance of acute exercise.

Within a few minutes of completing a dynamic physical exercise, the CT and CV increased, and after a short period of time, they recovered, although some area values were even lower than the baseline measurements. Thus, we can conclude that healthy young people are able to adjust CT during exercise. Additionally, women and individuals with greater physical activity levels reduce their total CV more during recovery after exercise than others.

Statement of Ethics

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (Clinical Research Ethics Committee of Aragón, project licence PI19/352) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Written informed consent was obtained from all individual participants included in the study.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

G.I.S. and I.P.L. conceived of and designed the experiments; G.I.S. performed the experiments; G.I.S. and L.F.B. analysed the data; all authors contributed to the interpretation of the data; the first draft was written by G.I.S.; and all authors provided critical input and revisions. All authors read and approved the final manuscript.

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The corrections made in this section will be reviewed by journal production editor.

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