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ORIGINAL PAPER

Choroidal volume changes following blow-out fracture repair

Kyoung Lae Kim [iD] · **Youn Joo Choi** [iD] · **Seong Hwan Shin** · **Sung Pyo Park** [iD] ·
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Abstract

Purpose To investigate the serial choroidal volume change following orbital blow-out fracture (BOF) repair.

Methods The choroidal volume was measured by optical coherence tomography in patients who underwent BOF repair, preoperatively and postoperatively at 1, 4, 12 and 24 weeks. The orbital volume ratio (OVR) was obtained by dividing the orbital volume of the traumatized orbit by that of the contralateral side using three-dimensional computed tomography imaging. The choroidal volume change was compared between both eyes using a linear mixed model.

Results We analyzed the choroidal volume of 11 patients. Choroidal volume showed a trend of slight increase during the immediate postoperative period, and then, choroidal volume decreased abruptly between postoperative 1 to 4 weeks (β-coefficient − 0.22, $P < 0.001$). Choroidal volume also showed gradual decrease between postoperative 4 to 24 weeks (β-coefficient − 0.02, $P < 0.001$). During the study period, there were no significant differences in choroidal volume change between BOF and contralateral unaffected eyes (β-coefficient − 0.20, $P = 0.711$). The hyperopic refractive errors (β-coefficient 0.27, $P = 0.028$) and the larger preoperative OVR (β-coefficient 10.37, $P = 0.013$) were associated with larger choroidal volume.

Conclusions Choroidal volume showed a similar decreasing change following BOF repair between the BOF and the contralateral unaffected eyes. Moreover, choroidal volume of both eyes was associated with the degree of orbital volume expansion due to BOF, suggesting that choroidal volume change after BOF repair was affected not only by trauma-associated local hemodynamic changes but also by systemic influences such as inflammatory response.

Keywords Orbital fractures · Choroid · Optical coherence tomography

Kyoung Lae Kim and Youn Joo Choi contributed equally to this work as the first author.

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Introduction

Orbital blow-out fracture (BOF) is one of the most common facial injuries in the world [1]. Immediate repair is required if extraocular muscle entrapment occurs or if the orbital space expands and enophthalmos develops [2]. Without proper management, BOF may cause severe ophthalmic complications such as development of diplopia, enophthalmos or sensory changes such as infraorbital hypesthesia [3, 4]. Moreover, orbital damage by BOF can lead to direct damage of blood vessel as well as change in blood flow resistance due to rapid volume change. Grusha et al. found that orbital blood flow decreased and peripheral vascular resistance increased in patients with traumatic orbital deformities, and they suggested that this vascular compromise might be associated with the degree of shift of the eye in the orbit as normalization of the position of the eye during the reconstruction of the orbit can accompanied by an increase in blood flow velocity in retrobulbar vessels and a decrease in peripheral vascular resistance [5].

Choroid is an abundant vascular layer of the eye which is supplied by ophthalmic artery and drained into superior and inferior ophthalmic veins [6]. Thus, it is possible that orbital damage followed by BOF can induce hemodynamic change in choroidal layer. Previous studies reported change in the choroidal layer after ocular blunt trauma. In a study on patients with chorioretinopathy associated with ocular blunt trauma, Ishikawa et al. showed that both choroidal blood flow velocity and thickness decreased in the acute stage of ocular blunt trauma especially at the lesion site and subsequently recovered during the follow-up. The choroidal blood flow measured by mean blur rate on laser speckle flowgraphy was increased by 23–31% at the lesion site and 11–22% at the fovea, and choroidal thickness was increased by 13–17 um at the lesion site and 33–42 um at the fovea during the 6-month follow-up period; however, there were no significant changes in these parameters at the normal retinal site in the affected eye and the fellow eye [7]. In angiographic studies of patients with retinal lesion associated with ocular blunt trauma, and experimental rabbit model, Kohno et al. reported the occurrence of varying degrees of choroidal vascular damage represented as filling delay, leakage or hypofluorescence on indocyanine green angiography [8, 9]. There is also a study showing regionally increasing choroidal thickness following ocular blunt trauma. Lee et al. reported that the choroidal thickness was significantly thicker (13–23%) at the various locations in affected traumatic optic neuropathy eyes than in unaffected fellow eyes, while there was no significant difference in subfoveal choroidal thickness between traumatic optic neuropathy patients and normal control, suggesting impaired blood circulation and vascular remodeling of the optic nerve head and choroid following ocular trauma [10].

However, studies on choroidal layer changes following BOF, one of the most common facial injuries, or serial changes of choroidal volume after ocular blunt trauma are scarce. We wondered whether there was any change in the choroidal layer after BOF which might be in proportion to the degree of trauma, and whether there is any possibility that such changes would persist and lead to permanent impairment. Thus, in this study, we investigated serial choroidal volume change in patients with BOF before and after surgical repair and compared with findings in the unaffected contralateral eye using optical coherence tomography (OCT). We also measured orbital volume ratio (OVR) which represents the degree of orbital expansion after BOF and correlated it with choroidal volume changes.

Methods

Participants

Between March 2016 and February 2017, patients who had medial or inferior BOF and were scheduled to undergo BOF repair were consecutively enrolled. The study was approved by the Institutional Review Board (IRB) of Kandong Sacred Heart Hospital (Seoul, South Korea, IRB No. 2015-12-018). The study was conducted in accordance with the tenets of the Declaration of Helsinki, and written informed consent was obtained from all study participants. Patients who were unable to perform ophthalmologic examination including OCT and those with other retinal or choroidal diseases that might affect choroidal volume (e.g. uveitis, diabetic retinopathy, retinal vein occlusions, and age-related macular degeneration) were excluded from the study.

Surgical procedure

BOF repair was performed within 2 weeks after the injury in the following cases: (1) the presence of diplopia, (2) positive forced duction test which was not improved within 1–2 weeks, (3) the presence of enophthalmos greater than 2 mm. The surgery was performed by one experienced surgeon (Y.J.C.) through a transcaruncular approach in case of medial wall BOF and a transconjunctival approach in case of inferior wall BOF. The extent of fracture site was measured, and barrier Medpore® was cut and inserted into the subperiosteal area of the fracture site. Conjunctiva was closed with 6-0 vicryl after confirming that the entrapped extraocular muscle or associated fascia was removed from the fracture site as confirmed by normality of forced duction testing. Methylprednisolone was injected intravenously pre- and at 6-hour post-surgery. Patients instilled 0.1% fluorometholone eye drops 4 times a day and took oral prednisolone (1 mg/kg per day) which was gradually tapered for 1 month.

Ophthalmologic examination and choroidal volume measurements

Patients underwent thorough ophthalmologic examinations including slit lamp examination, intraocular pressure and fundus examinations. Best corrected visual acuity was measured using Snellen chart and converted to logarithm of minimal angle resolution for statistical evaluations. Choroidal thickness is known to be associated with axial length and refractive errors, and myopic eyes generally show thin choroid compared to emmetropic eyes [11]. However, we were not able to perform A-scan ultrasound on the injured eyes, so we could only measure refractive errors to adjust the choroidal thickness variability. Choroidal volume was measured by using spectral domain OCT (Spectralis OCT, Heidelberg Engineering, Heidelberg, Germany). Two examiners (K.L.K. and Y-K.K.) manually performed choroidal segmentation according to previously described method using built-in software [12, 13]. In brief, 25 horizontal volume scan-enhanced depth images covering $30° \times 20°$ area, centered on the fovea, were obtained from each eye. Masked observers manually moved reference lines of built-in auto-segmentation from the retinal boundaries to the choroidal boundaries. The internal limiting membrane line was moved to the base of the retinal pigment epithelium and the basement membrane line was moved to the chorio-scleral interface. A 6-mm-diameter choroidal volume map, centered on the fovea, was automatically generated by built-in software using the Early Treatment Diabetic Retinopathy Study (ETDRS) grid. Based on the ETDRS grid, macula was divided into the central fovea (1 mm diameter), inner ring (0.5–1.5 mm from the center) and outer ring (1.5–3 mm from the center). The topographic area was divided into 5 parts: center ring (1 mm diameter), superior, inferior, nasal and temporal segments (including both inner and outer ring segments, respectively). Choroidal volume of these parts was used for subsequent analysis (Fig. 1). The choroidal volume was measured preoperatively and at postoperative 1, 4, 12 and 24 weeks, and the average values of the two observers' measurements were used in analyses.

Orbital volume measurements

The preoperative computed tomography (CT) scans were acquired within 1 week after trauma using Philips Mx8000 (Philips Healthcare, Cleveland, OH, USA), via continuous 2-mm-thickness axial and coronal slices. The postoperative CT scans were acquired 1 month after the surgery. The orbital volume was measured according to previously described method [14–16]. In brief, the bony orbital area on each section was measured by tracing the orbital walls using Image J (http://imagej.nih.gov/ij, version 1.50i, USA). The orbital volume was calculated by summing the volume between the two scanned sections, which was calculated by averaging area of two adjacent sections and multiplying by section thickness (2 mm). Axial sections were used for calculating orbital volume in patients with medial BOF, and coronal sections were used for calculating orbital volume in patients with inferior BOF [17]. Contralateral orbital volume was also calculated, and OVR was obtained by dividing the orbital volume of the traumatized orbit by that of the contralateral side (Fig. 2).

Statistical analyses

Data are presented as mean ± standard deviation, where applicable. We compared baseline
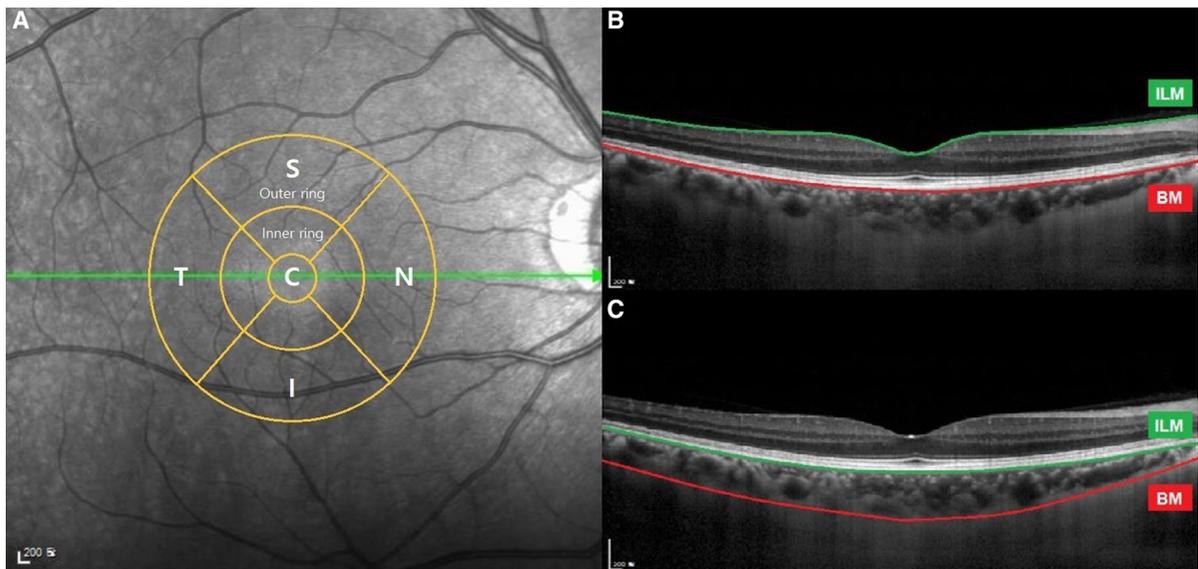
Fig. 1 Choroidal volume measurements. **a** The choroidal volume map was generated automatically by built-in software using the standardized Early Treatment Diabetic Retinopathy Study (ETDRS) grid. Based on the ETDRS grid, macula was divided into the central fovea (1 mm zone), inner ring (1–3 mm zone), and outer ring (3–6 mm zone). Subsequently, the inner ring and outer ring were divided into the superior, inferior, nasal and temporal segments. Instead of using these nine segments, we combined both inner and outer ring region in superior, inferior, nasal and temporal area, and we assessed choroidal volume at five segments: center 1 mm zone, superior, inferior, nasal and temporal area (1 to 6 mm zone). **b, c** The choroidal volume was measured using the built-in software which was originally designed to measure macular retinal volume. The software allows to adjust the segmentation lines. The original lines (**b**) were manually moved inferiorly to the choroidal level (**c**) and choroidal volume is calculated automatically instead of macular volume. C, central; I, inferior; N, nasal; T, temporal; ILM, internal limiting membrane; BM, Bruch's membrane

(preoperative) and postoperative visual acuity, choroidal volumes, and OVR using Wilcoxon signed-rank test. Inter-observer agreement was evaluated using intra-class correlation coefficient (ICC). Serial changes in choroidal volume of each of the ETDRS segments were compared between the BOF and contralateral eyes using linear mixed model. In this model, the refractive errors (represented as spherical equivalent), time, preoperative OVR and BOF eye were fixed effects, and the patient identification number was the categorical random effect. Statistical analyses were performed using statistical software (Stata version 14.0; Stata Corp., College Station, TX, USA), and statistical significance was defined as $P < 0.05$.

Results

A total of 11 patients were enrolled during the study period. The mean age was 40.2 ± 13.5 years (range, 24–67 years). Eight patients showed medial wall BOF, and three patients revealed inferior wall BOF. The baseline visual acuity in BOF eyes was 0.05 ± 0.09 (LogMAR, 0.9 Decimal equivalent), which was not significantly changed after BOF surgery. All BOF eyes showed mild-to-moderate level of anterior chamber cell reactions while there were no inflammatory signs observed in unaffected contralateral eyes. Fundus examination revealed normal fundus findings without any significant retinal or choroidal changes in both BOF and contralateral eyes. Inter-observer reproducibility of the choroidal volume measurements was excellent, with ICC (2, 1) values that were 0.989, 0.986, 0.978, 0.984 and 0.981 for baseline, 1-, 4-, 12- and 24-week total choroidal volume, respectively. There were no significant differences between BOF and contralateral eyes in terms of ETDRS 6-mm total zone choroidal volume at preoperatively (BOF eyes, 8.85 ± 1.49 mm³ vs. contralateral eyes, 8.75 ± 1.87 mm³, $P = 0.929$ by Wilcoxon signed-rank test). The restoration of expanded orbital space by medial & inferior wall BOF was observed in postoperative 1-month orbital CT images
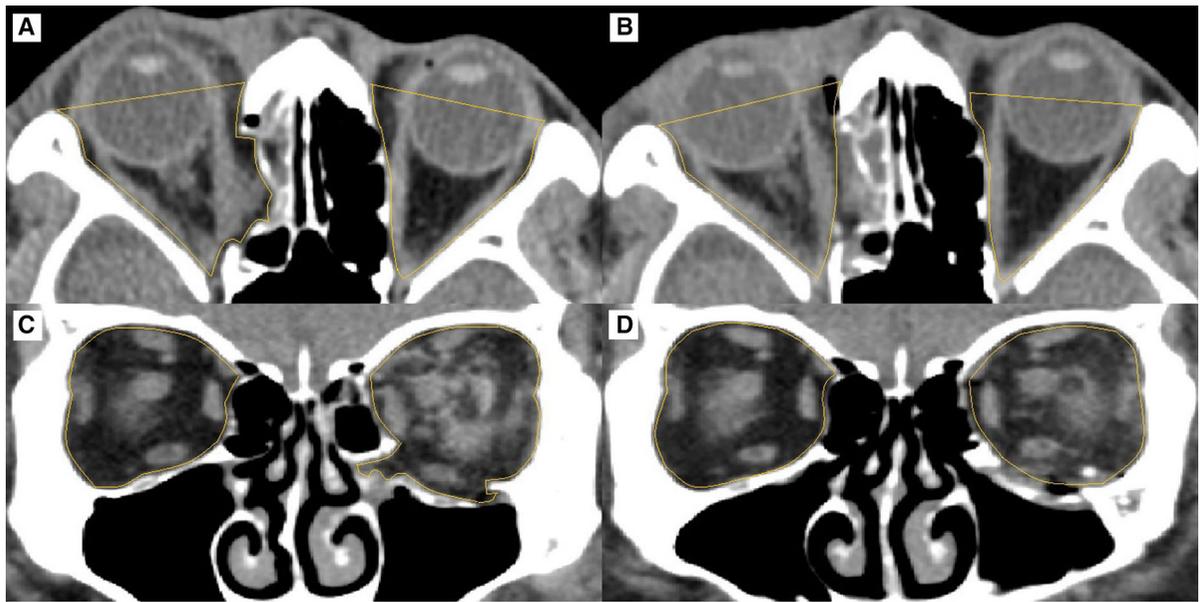
Fig. 2 Preoperative and postoperative orbital CT images of blow-out fracture patients and calculation of orbital volume ratio (**a**, **b**). Preoperative (**a**) and postoperative 1 month (**b**) orbital CT images of a medial wall BOF patient (**c**, **d**). Preoperative (**c**) and postoperative 1 month (**d**) orbital CT images of an inferior wall BOF patient. In these serial 3D CT images, we measured orbital area in each section and summed it throughout the whole orbit. The orbital volume was calculated by summing the volume between the two scanned sections, which was calculated by averaging area of two adjacent sections and multiplying by section thickness (2 mm). Orbital volume ratio was calculated by dividing the orbital volume of the traumatized orbit by that of the contralateral side

(Fig. 2). The OVR significantly decreased following BOF repair (preoperative OVR, 1.11 ± 0.07 vs. postoperative OVR 1.04 ± 0.06, $P = 0.003$ by Wilcoxon signed-rank test, Table 1).

Choroidal volume showed a trend of slight increase during the first postoperative period in both BOF and contralateral eyes; however, the degree was not statistically significant (β-coefficient 0.23, $P = 0.269$). Between postoperative 1- and 4 weeks, choroidal volume showed rapid decrease in both BOF and contralateral eyes and there were no significant differences between two eyes (β-coefficient for visit -0.22, $P < 0.001$, β-coefficient for eye groups -0.16, $P = 0.755$). Between postoperative 4 and

Table 1 Baseline characteristics of patients	Variables	$N = 11$ eyes
	Age (years)	40.2 ± 13.5 (range, 24–67 years)
	Sex (male:female), n	9:2
	Laterality (right:left), n	4:7
	Fracture site (medial:inferior), n	8:3
	Refractive errors in BOF eyes, diopters	-1.88 ± 2.28
	Refractive errors in contralateral eyes, diopters	-2.20 ± 2.39
	Preoperative visual acuity in BOF eyes, LogMAR	0.05 ± 0.09
	Postoperative visual acuity in BOF eyes, LogMAR	0.05 ± 0.05
	Preoperative choroidal volume in BOF eyes (mm^3)	8.85 ± 1.49
BOF blow-out fracture, *LogMAR* logarithm of minimal angle of resolution, *OVR* orbital volume ratio	Preoperative choroidal volume in contralateral eyes (mm^3)	8.75 ± 1.87
	Preoperative OVR (%)	1.11 ± 0.07
	Postoperative 4 weeks OVR (%)	1.04 ± 0.06

24 weeks, there were overall gradual decrease trend in choroidal volume and there were no significant differences between BOF and contralateral eyes (β-coefficient for visit − 0.02, $P = 0.034$, β-coefficient for eye groups − 0.34, $P = 0.544$). During the overall study period, there were no significant differences in choroidal volume change between BOF and contralateral eyes (β-coefficient − 0.20, $P = 0.711$). Hyperopic refractive errors were associated with larger choroidal volume (β-coefficient 0.27, $P = 0.028$) and the larger preoperative OVR, indicating that larger orbital volume expansion after trauma was associated with larger choroidal volume (β-coefficient 10.37, $P = 0.013$). These patterns of choroidal volume changes were similar in each ETDRS segment (Fig. 3, Table 2). There were no significant differences in serial choroidal volume changes following BOF surgery according to the location of BOF (i.e., medial wall BOF or inferior wall BOF, β-coefficient 0.50, $P = 0.500$).

Discussion

In this study, serial choroidal volume was measured in both BOF and contralateral unaffected eyes before and after the BOF repair surgery. Choroidal volume showed a trend of slight increase during the immediate postoperative period; however, choroidal volume abruptly decreased between postoperative 1 and 4 weeks in both BOF and contralateral eyes. There were overall gradual decreases in choroidal volume between postoperative 4 and 24 weeks, and there were no significant differences in terms of serial choroidal volume change between BOF and contralateral eyes. These results contradict our initial expectations that choroidal volume of BOF eye will be different from that of the contralateral eye due to trauma-associated indirect hemodynamics change in BOF eyes or direct injury to the choroidal vessels. In addition, choroidal volume was also associated with degree of refractive errors and preoperative OVR, which is associated with the degree of orbital volume expansion due to BOF.

Previous studies on ocular blunt trauma have reported a decrease in choroidal blood flow and choroidal thickness in affected eyes [7–9]. In cases of traumatic optic neuropathy, the choroid may become thicker locally [10]. Unlike the cases mentioned above, our patients did not have direct intraocular damage such as retinal hemorrhage, retinal Berlin's edema, or optic neuropathy except for blunt orbital trauma such as orbital contusion and BOF. Moreover, our patients showed good initial visual acuity of 0.9 decimal equivalent. Theories of bucking and hydraulic mechanism are reported in relation with development of BOF [18–20]. In buckling mechanism, fracture is caused by direct impact on the orbital wall. Thus, it is thought that in our cases, buckling effect on the orbital rim caused BOF, whereas impact on the eye itself was relatively low; thus, patients maintained good visual acuity and preserved choroidal blood flow.

Choroidal volume increased with hyperopic refractive errors, in agreement with previous reports [21]. In addition, choroidal volume also increased in proportion to preoperative OVR. The OVR is a quantitative and useful value compared to the conventional exophthalmometer to evaluate orbital volume changes before and after the BOF surgery [14]. Average preoperative OVR was 1.11, which indicated that the orbital space of the BOF eye was 11% larger on average than that of contralateral eye, and this value decreased to 1.04 after surgery. Since orbital damage is expected to be greater when there is a larger orbital volume change following trauma, we may interpret our result as choroidal volume was increased in proportion to the degree of orbital volume expansion following orbital trauma which may represent the degree of orbital damage. Interestingly, this finding was observed not only to the BOF eyes but also to the contralateral unaffected eyes.

Collectively, these results suggest that the observed change in choroidal volume after BOF surgery may be influenced by other mechanism rather than local effect associated with BOF trauma itself. It is likely that inflammation associated with trauma may have affected the BOF eye as well as choroidal volume in the opposite eye. Several studies described inflammation after trauma [22, 23], and inflammatory cytokines such as MCP-1 are reported to increase in the aqueous humor of the contralateral eye in patients undergoing cataract surgery [24]. It is plausible that inflammation may occur in the opposite eye by systemic and/or sympathetic ophthalmic-type uveitis after orbital trauma. In particular, our results indicated that choroidal volume showed a trend of increase during the first postoperative period then rapidly decreased from postoperative 1 to 4 weeks. Early trend of increase in choroidal volume may be due to acute
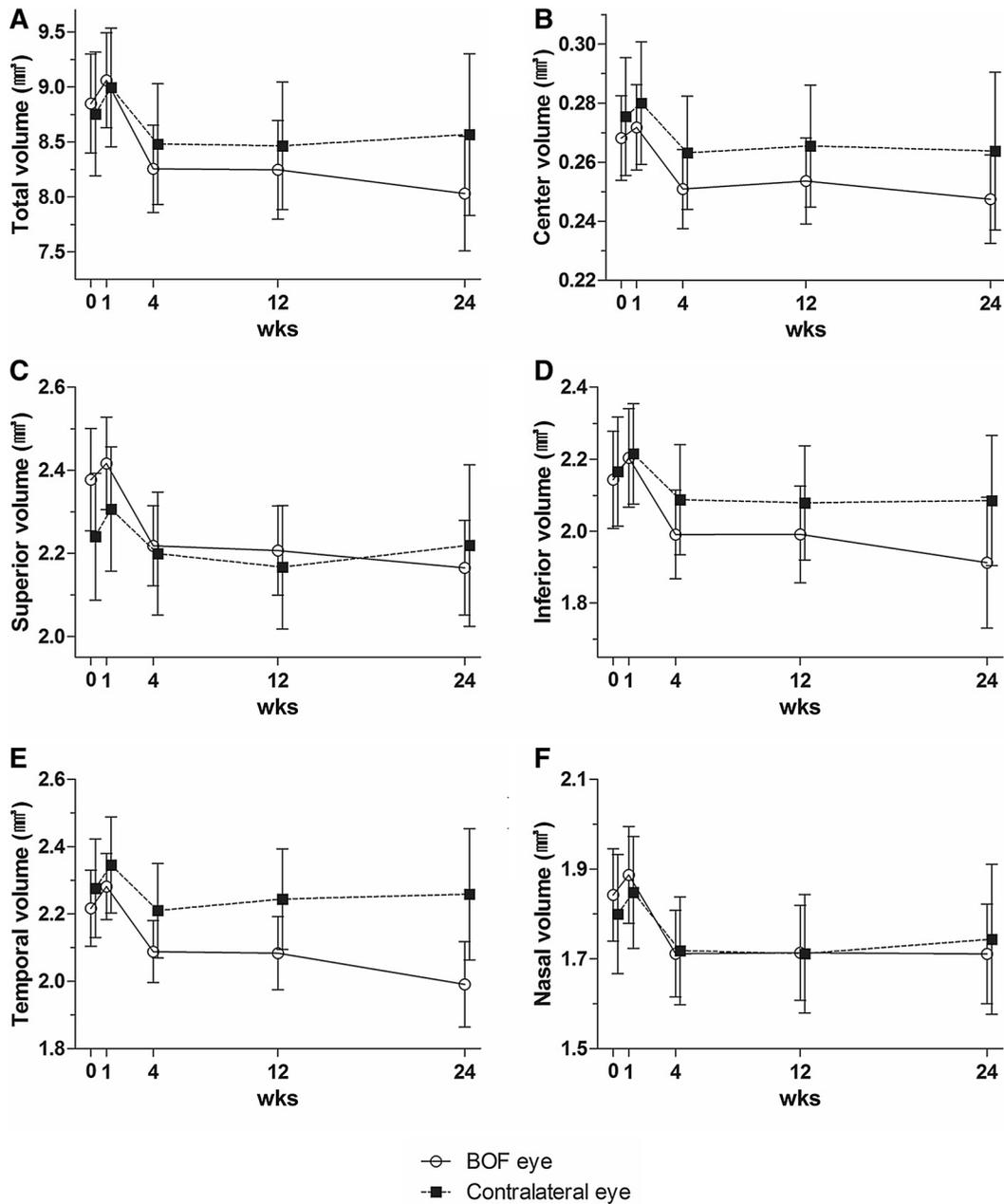
Fig. 3 Serial changes of choroidal volume in blow-out fracture eyes and contralateral unaffected eyes of 11 patients within postoperative 24-week follow-up. **a** Serial changes of choroidal volume in total ETDRS 6 mm zone. Both BOF and contralateral eyes showed slight increase in choroidal volume during the first postoperative week, although it was statistically not significant. Choroidal volume rapidly decreased between postoperative 1 and 4 weeks in both eyes. Choroidal volume remained stable in contralateral eyes and showed gradual decrease in BOF eyes; however, linear mixed model analysis revealed no significant differences in serial choroidal volume change between two eye groups. These patterns were also observed in center 1-mm ETDRS zone (**b**), superior zone (**c**), inferior zone (**d**), temporal zone (**e**), and nasal zone (**f**). BOF, blow-out fracture; ETDRS, early treatment diabetic retinopathy study; wks, weeks

inflammation associated with the surgery, and subsequent rapid decrease may be due to reduced inflammation through topical and systemic steroid treatment

during postoperative period. Choroidal thickness is reported to increase in various inflammatory diseases and decrease when inflammation subsides [25, 26].

Table 2 Linear mixed model analysis of serial changes of choroidal volume

	Baseline ~ Postoperative 24 wks			Postoperative 1 wk ~ 4 wks			Postoperative 4 wks ~ 24 wks		
	β-coefficient	95% CI	P value	β-coefficient	95% CI	P value	β-coefficient	95% CI	P value
Total volume									
BOF eye	− 0.20	− 1.25 to 0.85	0.711	− 0.16	− 1.20 to 0.87	0.755	− 0.34	− 1.42 to 0.75	0.544
Visit (weeks)	− 0.03	− 0.05 to − 0.02	< 0.001	− 0.22	− 0.30 to − 0.14	< 0.001	− 0.02	− 0.03 to −0.001	0.034
Ref (diopters)	0.27	0.03 to 0.50	0.028	0.26	0.03 to 0.49	0.030	0.26	0.02 to 0.51	0.035
OVR	10.37	2.18 to 18.56	0.013	9.78	1.72 to 17.85	0.017	11.24	2.81 to 19.68	0.009
Central volume									
BOF eye	− 0.01	− 0.05 to 0.02	0.468	− 0.01	− 0.05 to 0.02	0.463	− 0.01	− 0.05 to 0.02	0.429
Visit (weeks)	− 0.001	− 0.002 to − 0.001	< 0.001	− 0.01	− 0.01 to − 0.003	< 0.001	− 0.001	− 0.001 to − 0.00003	0.038
Ref (diopters)	0.01	0.002 to 0.02	0.013	0.01	0.002 to 0.02	0.015	0.01	0.002 to 0.02	0.019
OVR	0.34	0.06 to 0.62	0.018	0.34	0.06 to 0.63	0.017	0.38	0.10 to 0.67	0.008
Inferior volume									
BOF eye	− 0.09	− 0.40 to 0.21	0.557	− 0.08	− 0.38 to 0.22	0.613	− 0.13	− 0.45 to 0.19	0.432
Visit (weeks)	− 0.01	− 0.01 to − 0.005	< 0.001	− 0.06	− 0.08 to − 0.03	< 0.001	− 0.004	− 0.01 to − 0.0002	0.040
Ref (diopters)	0.07	0.01 to 0.14	0.033	0.07	0.004 to 0.14	0.035	0.07	0.003 to 0.15	0.042
OVR	2.81	0.43 to 5.20	0.020	2.67	0.33 to 5.02	0.025	2.99	0.52 to 5.46	0.018
Superior volume									
BOF eye	0.05	− 0.25 to 0.34	0.758	0.05	− 0.25 to 0.34	0.765	0.003	− 0.29 to 0.29	0.982
Visit (weeks)	− 0.01	− 0.01 to − 0.006	< 0.001	− 0.05	− 0.07 to − 0.03	< 0.001	− 0.005	− 0.01 to − 0.001	0.012
Ref (diopters)	0.06	− 0.004 to 0.13	0.066	0.06	− 0.01 to 0.12	0.085	0.06	− 0.005 to 0.13	0.069
OVR	2.24	− 0.02 to 4.50	0.052	2.04	− 0.26 to 4.34	0.082	2.52	0.27 to 4.77	0.028
Nasal volume									
BOF eye	− 0.01	− 0.24 to 0.22	0.921	− 0.01	− 0.24 to 0.23	0.962	− 0.03	− 0.27 to 0.21	0.790
Visit (weeks)	− 0.01	− 0.01 to− 0.004	< 0.001	− 0.05	− 0.07 to − 0.03	< 0.001	− 0.003	− 0.01 to 0.001	0.145
Ref (diopters)	0.07	0.02 to 0.12	0.012	0.07	0.01 to 0.12	0.013	0.07	0.01 to 0.12	0.015
OVR	2.30	0.47 to 4.13	0.014	2.27	0.44 to 4.10	0.015	2.42	0.55 to 4.29	0.011
Temporal volume									
BOF eye	− 0.13	− 0.41 to 0.15	0.370	− 0.11	− 0.38 to 0.16	0.429	− 0.16	− 0.44 to 0.12	0.252
Visit (weeks)	− 0.01	− 0.01 to − 0.004	< 0.001	− 0.05	− 0.07 to − 0.04	< 0.001	− 0.003	− 0.01 to 0.001	0.101
Ref (diopters)	0.05	− 0.01 to 0.11	0.119	0.05	− 0.01 to 0.11	0.113	0.05	− 0.01 to 0.11	0.115
OVR	2.68	0.51 to 4.85	0.016	2.45	0.35 to 4.55	0.022	2.92	0.75 to 5.10	0.008

The refractive errors (represented as spherical equivalent), visit time, preoperative OVR and BOF eye were fixed effects, and the patient identification number was the categorical random effect

CI confidence interval, *BOF* blow-out facture, *Ref* refractive error, *OVR* orbital volume ratio, *wk* week

Considering the similar choroidal volume changes of the contralateral eyes in our results, further investigation is needed to determine whether choroidal volume is a useful indicator of ocular as well as systemic inflammation.

Our results showed sustained decrease in choroidal volume for up to 24 weeks, although rate of decrease diminished after 4 weeks. We were unable to determine the exact duration of choroidal thinning, but because there were no significant differences in the rate of choroidal volume change between BOF and contralateral eyes during the period, choroidal thinning is unlikely to lead to significant choroidal flow compromise such as choroidal atrophy. It is thought that thickened choroid is normalized rather than choroid becomes pathologically thin, and further study is needed to clarify this issue.

Our study has some limitations. First, it included small numbers of cases, non-homogenous location of BOF cases (medial or inferior wall BOF) with short follow-up period. Second, we were unable to directly measure choroidal blood flow, but indirectly evaluated choroidal vascular status based on choroidal volume using OCT. Third, we did not include normal healthy control in this study. However, we believe that choroidal volume change observed in our study is beyond the physiologic extent of circadian choroidal volume change observed in healthy person [27]. Fourth, the results suggested that systemic factor such as systemic inflammation may be related to choroidal volume change after BOF surgery; however, systemic inflammatory indices such as C-reactive protein were not measured. Further study including large number of patients with long-term follow-up is needed.

In conclusion, in BOF patients with fair visual acuity and without specific intraocular damages, choroidal volume showed rapid decrease between postoperative 1 and 4 weeks and gradual decrease between postoperative 4 and 24 weeks in both BOF and contralateral unaffected eyes. It seems that this is a normalization of thickened choroid rather than a pathologic choroidal thinning. Moreover, choroidal volume of both eyes was associated with the degree of orbital volume expansion due to BOF. These suggest that choroidal volume change after BOF repair was affected not only by local hemodynamic changes due to trauma but also by systemic influences such as inflammatory response.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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