Effects of scleral buckling on the retrobulbar haemodynamic changes

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Abstract

Purpose This study was planned to investigate blood flow changes due to scleral buckling surgery. In addition the effects on these changes of factors related to patient characteristics and operative technique were studied.

Methods Central retinal artery (CRA) and ophthalmic artery (OA) blood flow velocities were studied with colour Doppler ultrasonography after scleral buckling surgery in 25 patients with unilateral rhegmatogenous retinal detachment. The effects of the patient's age, referral time, aetiological factors, operative technique, cryotherapy width and buckling distance on the haemodynamic changes were noted.

Results Buckling surgery reduces the blood flow velocities in the CRA, but affects OA blood flow less. Encircling is found to be responsible and it is greater in patients with anatomical success. Other factors do not have any significant effect on these changes.

Conclusions Good anatomical and functional results can be achieved despite these haemodynamic changes. It must be kept in mind that these changes may cause complications in some patients and the surgery must be minimised.

Key words Central retinal artery, Colour Doppler ultrasonography, Ophthalmic artery, Scleral buckling

Scleral buckling procedures are still the treatment of choice in most centres for rhegmatogenous retinal detachment. Good anatomical and functional results can be achieved with scleral buckling, but complications, although rare, do occur.¹ Post-operative complications such as anterior segment and posterior segment ischaemia, or central retinal artery occlusion, following scleral buckling procedures can be related to ocular circulatory abnormalities.² Although never formally studied, this reduction in posterior segment perfusion may adversely influence visual recovery.³ To determine ocular blood flow

alterations after scleral buckling, many clinical and laboratory studies using different methods have been designed.¹⁻⁶ Colour Doppler imaging is a good method for determining retrobulbar circulation. This technique provides reproducible qualitative and quantitative haemodynamic information, it is non-invasive, it allows for independent analysis of vessels and it is easily performed.^{1,5,7-12}

In this study, the effects of scleral buckling performed in patients with unilateral rhegmatogenous retinal detachment on blood flow velocities in the central retinal and ophthalmic arteries were studied with colour Doppler imaging. The effects of some factors related to patient characteristics and operative techniques on the changes in blood flow velocities were studied.

Patients and methods

We prospectively studied 25 patients with unilateral rhegmatogenous retinal detachment repaired by scleral buckling. No patient had diabetes mellitus, cardiovascular or haematological disorders, and none was using any drugs. Their ages ranged from 18 to 76 years (mean 44.44) years. Fourteen patients were female and 11 male. Pre-operative examination of the eyes included determination of visual acuity, biomicroscopy of the anterior segment and vitreous, binocular indirect ophthalmoscopy and contact lens examination using the Goldmann three-mirror lens. A detailed fundus drawing was performed for each patient.

All patients underwent unilateral scleral buckling surgery by the same surgeon under local anaesthesia using the same anaesthetic agent. The retinal breaks were identified and treated with transscleral cryotherapy. Neither diathermy nor scleral dissection was performed in any patient. Encircling was performed in all patients and additionally local buckling was performed in 14 patients. A Mira # 40 silicone encircling element was used in all patients. Local buckling was used for patients with large breaks under scleral buckling. Subretinal fluid was drained externally when necessary. No intraoperative complications were recorded. At

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the end of the operation, central retinal artery pulsations were controlled and in no patient was the eye thought to be so firm as to compromise the ocular blood flow.

After the operation all patients were given the same topical treatment regimen for standardisation of the measurements. All patients were followed for 11.5 months (minimum 6, maximum 17 months). In none did anterior or posterior segment ischaemia or other complications develop. Anatomical and functional results were assessed by the final results. Anatomical success was retinal reattachment and functional success was visual acuity better than 1/10.

Intraocular pressure (IOP) recorded pre-operatively, on the first post-operative day and prior to each colour Doppler imaging measurement.

For evaluating the retrobulbar circulation, a colour Doppler imaging unit (Toshiba SSH 140A) with a 7.5 MHz linear transducer was used. Examinations were performed with the patient in the supine position; ultrasound gel was applied to the external surface of the eyelids without any pressure on the eye. Measurements were taken on both eyes 12–24 h pre-operatively and on the operated eye 40–48 h post-operatively. Informed consent was obtained from all patients.

Central retinal artery (CRA) blood flow was examined at the retrobulbar region, on the optic nerve trace and 10 mm behind the globe. Ophthalmic artery (OA) blood flow was examined 20–30 mm behind the globe. A 50–100 Hz wall filter and low pulse repetition frequency (PRF) values were used to examine CRA blood flow. When the vessels were seen in colour Doppler mode, the Doppler cursor was placed on the lumen. When a signal was detected, a sample volume (1 mm) was used to obtain Doppler spectral wave formation. The Doppler angle of incidence was assigned parallel to the direction of blood flow in the portion of the vessel being studied, and was always less than 60°. With spectral analysis peak systolic, end-diastolic, average blood flow velocities, resistive index and pulsatility index were recorded in the CRA and OA.

The non-operated eyes were taken as the control group pre-operatively. For statistical analysis, Student's *t*-test and Pearson's chi-squared test and Spearman rank correlation was used. For the purposes of the study, statistical significance was accepted if $p < 0.05$.

Results

The aetiological factors were myopia in 11 patients, trauma in 7 patients, trauma and myopia in 2 patients and lattice degeneration in 5 patients. Patients' referral times were 1–15 days for 8 patients, 16–30 days for 8 patients, 31–45 days for 4 patients and more than 46 days for 5 patients. Ocular pathologies associated with retinal detachment were macular pucker (1 patient), choroid coloboma (1 patient) and cataracts (2 patients).

Encircling was performed on all patients, while local buckling in addition to encircling was performed on 14 patients. The distance of scleral buckling from the limbus was 12–13 mm in 7 patients, 13.5–14 mm in 13 patients

and more than 14.5 mm in 5 patients. Cryotherapy was performed in all patients. Cryotherapy width was one to three quadrants in 10 patients and four to five quadrants in 15 patients.

Post-operatively, anatomical success was obtained in 21 patients (84%) and functional success in 17 patients (68%). Pre-operative visual acuities were hand movements (HM) or counting fingers (CF) at 1 m in 16 (64%) patients, at CF 2–5 m in 5 (20%) patients and 0.1–0.4 in 4 (16%) patients, while they were HM or CF at 1 m in 1 (4%) patient, CF at 2–5 m in 7 (28%) patients, 0.1–0.4 in 14 (56%) patients and ≥ 0.5 in 3 (12%) patients post-operatively.

IOP was between 2 and 18 mmHg (mean 10.6 mmHg) pre-operatively. Post-operatively it was between 8 and 18 mmHg (mean 13.8 mmHg). The difference was statistically significant ($p < 0.05$, Student's *t*-test).

Pre-operatively, the fellow eyes were taken as the control group. Eyes with rhegmatogenous retinal detachment (study group) did not have significantly altered CRA or OA blood flow velocities compared with the contralateral eyes (control group $p > 0.05$). Post-operatively, CRA and OA blood flow velocities are compared with those obtained pre-operatively on the same eye.

CRA peak systolic velocity was reduced post-operatively: 9.0 ± 2.739 cm/s versus 5.96 ± 1.620 cm/s ($p < 0.05$). CRA end-diastolic velocity was also reduced post-operatively: 3.240 ± 1.128 cm/s versus 2.32 ± 0.557 cm/s ($p < 0.05$). Mean average blood flow velocity of CRA was also reduced post-operatively: 5.76 ± 2.66 cm/s versus 3.88 ± 1.166 cm/s ($p < 0.05$). Pulsatility index of the CRA was significantly reduced (1.0872 ± 0.297 versus 0.9728 ± 0.239) while the resistive index of the CRA was reduced non-significant (0.6432 ± 0.118 versus 0.6272 ± 0.082) (Figs. 1, 2; Table 1).

OA peak systolic velocity was reduced post-operatively: 40.0 ± 7.569 cm/s versus 37.4 ± 7.071 cm/s ($p > 0.05$). OA end-diastolic velocity was increased post-operatively: 9.72 ± 3.021 cm/s versus 11.2 ± 3.464 cm/s ($p > 0.05$). Mean diastolic velocity of the OA was also increased post-operatively: 21.92 ± 6.204 cm/s versus 22.64 ± 5.484 cm/s ($p > 0.05$). Pulsatility index of the OA was significantly reduced (1.3544 ± 0.249 versus 1.1224 ± 0.264), while the resistive index of the OA was increased non-significantly (0.7572 ± 0.077 versus 0.8012 ± 0.234) (Figs. 3, 4; Table 2).

The effects of patient's age, referral time and aetiological factors on the changes in blood flow velocities post-operatively were studied with Pearson's chi-squared test. Blood flow velocity changes in the OA and CRA did not differ among different age groups. Only the decrease in CRA pulsatility index was higher in patients over 60 years of age than in younger patients. Patient referral time was found to have no effect on either blood flow velocity, though there was a non-significant decrease in the patients who had been referred earlier. The aetiological factors causing retinal detachment had no effect on CRA and OA blood flow velocity changes post-operatively ($p > 0.05$).

Fig. 1. Pre-operative pulse waveform of the central retinal artery recorded by colour Doppler imaging. Peak systolic velocity = 9.2 cm/s; end-diastolic velocity = 4.0 cm/s; average velocity = 5.8 cm/s; pulsatility index = 0.89; resistive index = 0.56.

Fig. 2. Post-operative pulse waveform of the central retinal artery recorded by colour Doppler imaging. Peak systolic velocity = 7.8 cm/s; end-diastolic velocity = 3.6 cm/s; average velocity = 5.4 cm/s; pulsatility index = 0.77; resistive index = 0.53.

Fig. 3. Pre-operative pulse waveform of the ophthalmic artery recorded by colour Doppler imaging. Peak systolic velocity = 36.3 cm/s; end-diastolic velocity = 10.6 cm/s; average velocity = 20.2 cm/s; pulsatility index = 1.27; resistive index = 0.70.

Fig. 4. Post-operative pulse waveform of the ophthalmic artery recorded by colour Doppler imaging. Peak systolic velocity = 33.6 cm/s; end-diastolic velocity = 11.1 cm/s; average velocity = 18.3 cm/s; pulsatility index = 1.23; resistive index = 0.67.

Effects of operative procedure, cryotherapy width and the distance of encircling from the limbus on the changes in blood flow velocities were also studied with Pearson's chi-squared test. CRA and OA blood flow velocity changes did not differ between the patients who had undergone scleral buckling with encircling and those who had undergone buckling with encircling and local implants ($p > 0.05$).

The post-operative decreases in CRA peak systolic, end-diastolic and mean average velocities and the OA peak systolic and mean average velocities were higher in patients in whom cryotherapy had been performed in more than four quadrants. The difference was not statistically significant ($p > 0.05$).

Post-operative changes in CRA and OA blood flow velocities were not correlated with different distances of encircling. However, with an encircling distance of

13.5–14 mm, all CRA blood flow velocities and indices and OA pulsatility and resistive indices, decreased more than with other encircling distances.

Blood flow velocities in patients with anatomical success and velocities in patients without anatomical success were compared with Pearson's chi-squared test. In the former group, CRA blood flow velocities decreased by 91–94%, but by only 6–9% in the latter group. OA peak systolic velocity decreased by 82% in the former and 18% in the latter group. OA pulsatility index decreased by 83% in the former and 17% in the latter group. However, these results are not reliable because there were 21 patients in the former group and 4 patients in the latter.

The effect of post-operative IOP on the CRA and OA blood flow velocity changes was analysed with Pearson's chi-squared test. It was found IOP had no effect on

Table 1. Central retinal artery blood flow velocities before and after the operation

	Pre-operative	Post-operative	<i>p</i> value
Peak systolic velocity (cm/s)	9.0 ± 2.739	5.96 ± 1.620	< 0.05
End-diastolic velocity (cm/s)	3.240 ± 1.128	2.32 ± 0.557	< 0.05
Mean average velocity (cm/s)	5.76 ± 0.297	3.88 ± 1.166	< 0.05
Pulsatility index	1.0872 ± 0.297	0.9728 ± 0.239	< 0.05
Resistive index	0.6432 ± 0.118	0.6272 ± 0.082	> 0.05

Table 2. Ophthalmic artery blood flow velocities before and after the operation

	Pre-operative	Post-operative	p value
Peak systolic velocity (cm/s)	40.0 ± 7.659	37.4 ± 7.071	< 0.05
End-diastolic velocity (cm/s)	9.72 ± 3.021	11.2 ± 3.464	< 0.05
Mean average velocity (cm/s)	21.92 ± 6.204	22.64 ± 5.484	< 0.05
Pulsatility index	1.3544 ± 0.249	1.1224 ± 0.264	< 0.05
Resistive index	0.7572 ± 0.077	0.8012 ± 0.234	> 0.05

any of the OA blood flow changes or on the CRA peak systolic, end-diastolic and mean average velocities and resistive index ($p > 0.05$). But the decrease in CRA pulsatility index differed among groups with different post-operative IOP measurements (Table 3). The effects of a difference in pre-operative and post-operative IOP on the CRA velocities and indices was also analysed using Spearman rank correlation. A difference in IOP was found to have no statistically significant effect on CRA peak systolic, end-diastolic or mean average velocities or on the resistive index ($p = -0.242$, $p = 0.244$), $p = -0.77$ ($p = 0.396$), $p = -0.326$ ($p = 0.111$), $p = -0.185$ ($p = 0.375$, respectively). It did have a statistically significant effect on CRA pulsatility index ($p = -0.413$, $p = 0.040 < 0.05$).

Discussion

Scleral buckling surgery is used for the treatment of uncomplicated rhegmatogenous retinal detachment in several centres.¹ In our series, we had an anatomical success rate of 84% and visual success rate of 68%, which are both in accordance with the rates reported in the current literature.¹³⁻¹⁹

Unlike other reports, we performed additional studies to identify the blood flow changes in the posterior segment that are related to scleral buckling surgery. Peak systolic, end-diastolic and average velocities and the resistive and pulsatility indices of the CRA decreased post-operatively. Peak systolic velocity of the OA and its pulsatility index both decreased, whereas end-diastolic velocity, average velocity and resistive index increased post-operatively.

The blood flow changes in the posterior segment that are related to scleral buckling surgery were first described by Diddie and Ernest.⁴ They found a significant decrease in the radioactivity uptake of the anterior and posterior segments after an operation with

encircling elements had been performed. Yoshida *et al.*³ and Ogasawara *et al.*² reported decreased arterial blood flow rates with laser Doppler technique in patients who had undergone scleral buckling surgery. These observations show that scleral buckling surgery causes a decrease in the retinal arterial blood flow velocity, and this might be responsible for the severe post-operative complications such as visual field defects and vision loss.

In the study by Dobbie,²⁰ changes in ocular rigidity, pulse amplitude and ocular pressure after the operation were all attributed to encircling but not cryotherapy.

In our study, in addition to scleral buckling, cryotherapy was applied to all patients. The patients treated with a cryotherapy width of four quadrants or more showed a non-significant decrease in the blood flow rates of CRA and OA. Inflammatory substances released from the cryotherapy site might have influenced the blood flow rates of the neighbouring vessels. However, as none of our patients had cryotherapy without undergoing scleral buckling surgery, and as we did not carry out a long-term follow-up, it is impossible to relate all the velocity changes to this reason.

Yoshida *et al.*⁶ added OA pressure readings to the parameters of Dobbie's study. They reported a decrease in all readings after scleral buckling surgery and found them to be directly correlated to the increase in the area affected by surgery.

In our study there was no difference between the blood flow rates of the patients who had only encircling and those who had both encircling and local buckling surgery. As stated by Dobbie and by Diddie and Ernest earlier, we think that encircling is responsible for the blood flow changes and that local buckling does not have any effect on blood flow changes. We also found that buckling distance from the limbus did not affect the blood flow velocity changes.

Table 3. Effects of post-operative IOP values on the post-operative central retinal artery blood flow velocity changes

Post-operative IOP (mmHg)	Patient no.	Peak systolic velocity		End-diastolic velocity		Average velocity		Pulsatility index			Resistive index		
		No change (%)	Decrease (%)	No change (%)	Decrease (%)	No change (%)	Decrease (%)	Increase (%)	No change (%)	Decrease ^a (%)	Increase (%)	No change (%)	Decrease (%)
8-10	5	50	17	36	7	17	18	0	0	33	11	20	27
11-13	6	0	26	9	36	17	29	75	0	20	56	0	9
14-16	8	50	31	27.5	36	33	29	25	50	26	11	40	46
17-18	6	0	26	27.5	21	33	24	0	50	20	22	40	18

^aStatistically significant correlation.

Colour Doppler imaging was first used by Regillo *et al.*¹ for evaluating the blood flow changes related to scleral buckling surgery. He found a decrease of up to 53% in CRA average blood flow in the early post-operative period, but no change in the blood flow of the OA. Santos *et al.*⁵ reported a decrease of 31% in the average blood flow rate of the OA following surgery. This decrease was related to the surgical procedure and post-operative periocular oedema.

In our study, after surgical interventions for retinal detachment, the blood flow rates of the CRA showed a decrease to a great extent, while the changes in OA blood flow rates following surgery were not statistically significant.

Unlike other reports, in our study we tried to identify a relationship between the time of referral for surgery and the severity of the blood flow changes. There was a statistically non-significant decrease in blood flow changes in the patients who had an early referral time and who were operated on immediately. At the early stages of retinal detachment the barriers have been disrupted. Vasoconstrictor substances that affect the pressure might reach retinal tissue at this stage and diminish the circulation.

The mechanism by which scleral buckling disturbs the retinal and choroidal circulation remains to be explained. Scleral buckling creates pressure on the choroid and sclera, which in turn increases vascular resistance and might cause a decrease in the blood flow.^{4,6,20} However, Ogasawara *et al.*² said that scleral buckling or encircling did not lead to direct pressure on either the retinal vein or artery. The decrease in blood flow was rather attributed to the negative effects of the indentations on the peripheral retinal circulation. In another effort to explain possible mechanisms, direct and indirect effects of scleral surgery were investigated. Direct effects of the encircling elements are seen as chorioretinal pressure which causes distal retinal arteriolar resistance. The indirect effect is related to the increase in the secretion of local vasoconstrictor substances.¹

We hypothesise that the increase in the peripheral resistance due to the effects of encircling on the peripheral retinal circulation is reflected in the CRA as a decrease in the blood flow rate. We found that there is a very significant decrease in the peak systolic velocity of the CRA. End-diastolic velocity and average velocity are moderately affected. As the CRA faces a severe resistance during the systolic period, in order to compensate for this effect it increases vascular compliance during the diastolic period in an effort to increase blood flow. Vascular compliance (= increase in volume/increase in pressure) is explained as an increase in volume in any circulatory area in response to an increase in the pressure.²¹

As a result of the increase in compliance during diastole, end-diastolic velocity and average velocity were less significantly affected when compared with peak systolic velocity. The difference between peak systolic velocity and end-diastolic velocity, and the difference between peak systolic velocity and average velocity, both

decreased. This in turn showed itself as decreases in the resistive and pulsatility indices ($RI = (\text{peak systolic velocity} - \text{end-diastolic velocity}) / \text{peak systolic velocity}$).

In our study, the decrease in the CRA pulsatility index was statistically significant when compared with the decrease in the resistive index ($PI = (\text{peak systolic velocity} - \text{end-diastolic velocity}) / \text{average velocity}$). This proves to us that average velocity is an important factor.

In the post-operative period, peak systolic velocity of the OA decreases, whereas end-diastolic velocity and average velocity increase. This could again be related to the increase in the compliance during the diastolic period in an effort to respond to the resistance and increase the blood flow. As the decrease in the peak systolic velocity is less significant, the resistive index of the OA increases in the post-operative period. However, the pulsatility index decreases to a great extent. This is related to the fact that end-diastolic velocity increases more than the average velocity and the difference between peak systolic velocity and average velocity is less than the difference between peak systolic velocity and end-diastolic velocity for the OA. However, our results for OA could not be standardised; therefore, it is possible to obtain the images either before or after the artery has divided into its peripheral branches. As a result the reliability of the related findings decreases.

The decrease in the pulsatility index of the CRA is less significant in the older age group. As age increases, the vascular compliance decreases due to atherosclerosis. The mechanism that works for increasing the compliance in young patients could not show the same effect in older individuals. The decrease in end-diastolic velocity and average velocity is more significant in older patients due to the fact that vascular volume could not be increased. As a result of this, the difference between peak systolic velocity and average velocity increases, which is reflected to the pulsatility index as a decrease. In the older age group this decrease is less significant than in the younger individuals.

Exclusion of encircling elements might result in an amelioration of choroidal and retinal blood flow velocities.²⁻⁴ However, in neither of our patients was the material extracted. In patients with anatomical failure, the blood flow velocities did not show any change related to surgical procedure. As a result, we think that by causing a pressure effect encircling may increase peripheral resistance. If we take the encircling band away, we exclude this pressure effect and the blood flow might return to normal. But no change in the blood flow velocities in patients with non-successful outcomes is relatively meaningless unless it has a clinical role.

The increase in intraocular pressure during buckling surgery can be expected to cause changes in optic nerve and retinal vascular structures.²² But we think that the blood flow velocity changes in our study are not directly related to intraocular pressure changes from the pre-operative to post-operative situation. We found a relative increase in the intraocular pressure in the post-operative period. None of the patients had a reading above 18 mmHg. There was no optic nerve pathology or retinal

arterial obstruction. As intraocular pressure was normal during Doppler imaging, we do not think that this parameter primarily had any effect on blood flow studies of the CRA and OA. In addition to these clinical observations, statistical studies also showed that the IOP increase in the post-operative period does not primarily affect the blood flow velocities.

In our study, in the patient group with higher IOPs in the post-operative period, the decrease in CRA blood flow velocities was slightly greater than the patient group with lower IOPs in the post-operative period. But these results were all statistically non-significant with Pearson's chi-squared test and Spearman rank correlation. The only significant correlation was the decrease in the CRA pulsatility index in the patient group who had lower but not higher IOPs in the post-operative period.

As discussed before, the increase in the peripheral resistance due to the effects of encircling on the peripheral circulation causes a decrease in CRA peak systolic velocity. In order to compensate for this effect and regulate blood flow, end-diastolic velocity tends to increase, but it cannot be successful because of peripheral pressure. As a result, we expect to see a decrease in the pulsatility and resistive indices.

We found that the decrease in the CRA pulsatility index was more significant in the patient group who had lower intraocular pressures in the post-operative period. When peak systolic velocity decreases, in patients who had lower IOPs, end-diastolic velocity increases more than in the patients who had higher IOPs because factors that influence vascular resistance such as intraocular pressure have a more significant effect on diastolic pressure than systolic pressure. As a result a decrease in the pulsatility and resistive indices is expected to be greater in the group with lower IOPs.

The relationship between IOP, perfusion and blood flow is as follows:²³

Perfusion pressure = average arterial blood pressure – intraocular pressure

Blood flow = perfusion pressure / peripheral vascular resistance.

As a result of the decrease in the intraocular pressure and constant blood flow, perfusion pressure, average velocity and blood flow increase in order to compensate for the effect, which causes a decrease in blood flow and systolic velocity. In addition the resistive and pulsatility indices decrease as was found in our study.

These explanations show us that another factor apart from the increase in IOP can cause a decrease in CRA blood flow velocities. Moreover, the decrease in IOP seems to have a compensatory effect in regulating blood flow.

Although encircling and drainage are classical surgical approaches for retinal detachments, minimal surgery is to be preferred if the complications and haemodynamic changes that have been reported by our group are taken into account. We wish to emphasise the role of minimal surgery by stating that 'less is best'.

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