EXTENDED REPORT

A prospective study of the effect of a unilateral macular hole on sensory and motor binocular function and recovery following successful surgery

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Aims: To examine the effect of a unilateral full thickness macular hole on sensory and motor binocular function and to study recovery after successful surgical closure.

Methods: Twenty eight consecutive patients undergoing surgery for a unilateral macular hole underwent orthoptic examination, including measurements of Titmus and TNO stereoacuity and motor fusion range before surgery. Twenty three patients had successful anatomical closure. Fifteen of these patients, who had both improved acuity in the operated eye following surgery and were available for further testing, underwent repeat orthoptic assessment 2–7 months after surgery.

Results: In all patients stereoacuity was reduced before surgery, but few patients were subjectively aware of a deficit of depth perception affecting their everyday life. In those patients with improved Snellen acuity after surgery, stereoacuity measured by the Titmus stereotest also improved significantly, but not that measured by the TNO test. Two patients were aware of a subjective improvement in depth perception. Motor fusion was markedly reduced compared to normal before surgery, with only limited recovery after surgery.

Conclusion: A unilateral macular hole notably reduced both stereoacuity and motor fusion. Successful closure improved the deficit in stereoacuity associated with the hole when measured by a stereotest using contoured stimuli. The majority of patients were not subjectively aware of the deficit in stereoacuity or its improvement following surgery.

A full thickness macular hole is a defect of retinal tissue at the anatomical fovea. Since Knapp first described macular holes in 1869,¹ many studies have been published describing their aetiology, pathology, associations, effect on vision in the affected eye, and outcomes following surgery.^{2–10} However little attention has been given to the effect of a unilateral macular hole on binocular visual function or whether this is improved following surgery.^{11–13} Stereoacuity has been found to be reduced by a unilateral macular hole, with some recovery after surgery,^{11–13} but the practical effect of this on the overall visual function of the patient has not been assessed. The role played by motor fusion in these deficits has not previously been investigated.

In normal binocular vision the two foveae are the prime corresponding retinal points and play an important part in both sensory and motor fusion and in stereopsis. In the presence of an abnormality of one fovea it would be expected that the quality of binocular vision would be reduced, but because the defect associated with a macular hole is localised, the changes found may depend on the size and exact nature of the stimuli used in the stereotest. Both sensory and motor binocular function have therefore been assessed in patients with a unilateral macular hole. Two stereotests with distinctly different test stimuli have been used and also the subjective experience of the patient has been ascertained to determine what abnormalities of binocular function are present. Patients with successful closure of the hole and improved acuity were reassessed following surgery to see if binocular function also improved.

PATIENTS AND METHODS

A consecutive cohort of patients with a unilateral, idiopathic, full thickness macular hole who attended for macular hole surgery at Moorfields Eye Hospital between January and

December 2000 inclusive were studied. Patients with bilateral disease, traumatic macular holes, and a small number with significant cataract requiring combined phacoemulsification, lens implantation, and vitrectomy were excluded. Twenty eight patients were eligible; all underwent full ophthalmological and orthoptic examination before surgery. At 2–7 months after surgery 15 patients with successful closure, improved visual acuity in the operated eye, and who were available for testing underwent repeat full orthoptic assessment. This was timed to be after initial settling of the macula, but before significant cataract had developed. Particular note was taken of the stage and duration of the macular hole, lens status, and best corrected Snellen acuity. Patients underwent orthoptic assessment by a single orthoptist before and after surgery, including cover test and ocular motility. Motor fusion was assessed for near and distance using prisms. Stereoacuity was measured using the Titmus and TNO stereotests at the standard viewing distance of 40 cm with appropriate correction. To ensure that patients were not using monocular clues with the Titmus test, responses were checked by inverting the stereotargets and asking the patient if the target appeared in front of or behind the page. A 4 dioptre prism test was performed to detect the presence of a central suppression scotoma. Patients were asked if they had any difficulty in judging distance in daily life—for example, pouring liquid into a glass, or difficulties while driving.

Surgery was performed using a standard pars plana vitrectomy (PPV) approach.¹⁴ Following a three port PPV, separation of the posterior vitreous cortex was effected using direct aspiration over the posterior pole with the vitreous cutter. The vitrectomy was then completed and peeling of the internal limiting membrane performed using a disposable

Abbreviations: PPV, pars plana vitrectomy.

pick. A careful examination of the retinal periphery was then made and any breaks treated with endolaser or cryotherapy at that stage. This was followed by a fluid-air exchange and secondary drainage of fluid after 10 minutes with the sclerotomy site closed with plugs. Any fluid accumulated at the posterior pole was removed using a 34 gauge extrusion canula. The procedure was then completed with a gas exchange using perfluoropropane (C₃F₈) 16%. Patients were instructed to posture immediately in the face down position and maintain this for 2 weeks. Postoperative assessment was carried out 1 day, 2 weeks, 6 weeks, and 3 months after primary surgery, with additional visits where indicated.

Thirty normal subjects of a similar age range but with no ocular pathology were recruited, most during attendance at a lacrimal clinic. Control subjects underwent full orthoptic examination by the same orthoptist. Motor fusion was assessed for near and distance using prisms. Stereoacuity was measured using the Titmus and TNO stereotests at the standard viewing distance of 40 cm using appropriate correction.

Stereoacuities were analysed statistically using the Wilcoxon signed rank test for paired values and the Mann-Whitney U test for unpaired values (Statview; SAS Institute Inc, Cary, NC, USA). Motor fusion ranges were analysed using paired *t* tests for comparisons of preoperative and postoperative values and unpaired *t* tests for comparison between patients and the control group (Excel; Microsoft).

The study followed the tenets of the Helsinki accord and was approved by the hospital's ethics committee.

RESULTS

Effect of a unilateral macular hole on binocular function

Clinical details of all 28 patients studied are given in table 1. The interval between diagnosis of a macular hole and surgery ranged from 7–36 months, with a mean of 14.5 months. Sixteen (57%) patients received surgery within one year of onset of symptoms. Using the Gass classification,³ three holes

(11%) were stage 2, 14 (50%) were stage 3, and 11 (39%) were stage 4. Twenty five patients (89%) had noticed a significant reduction in the vision of their affected eye; three were asymptomatic. Thirteen patients (46%) had also noticed distortion, two of whom were aware of a central scotoma. Only one patient reported difficulty in accurately judging distances in everyday life.

Using the Titmus stereotest two patients had no detectable stereopsis whereas 23 of the 28 patients (82%) appreciated only the fly screening plate in depth (3000 seconds of arc at 40 cm). Of the three remaining patients, one had a stereoacuity of 800 and two of 400 seconds of arc. With the TNO stereotest one patient had no detectable stereopsis and 22 patients (73%) could only appreciate the screening plates (1700 seconds of arc); six (27%) had a measurable stereoacuity, three of 480, and three of 240 seconds of arc. The 4 dioptre prism test showed a central scotoma in 26 patients; the results in the other two were inconclusive.

At preoperative orthoptic assessment, the cover test for near fixation elicited a slight exophoria with good recovery in 24 cases (86%), three showed a slight, well compensated esophoria, and one was orthophoric. The distance cover test revealed no deviation in the majority of patients, but in four cases where the visual acuity was worse than 6/60 in the affected eye it was not possible to perform an accurate cover test. Ocular motility was normal and the near point of convergence was 10 cm or better in all cases.

Comparison of binocular function before and after successful closure

Twenty three of the 28 patients (82%) had successful anatomical closure of the macular hole on clinical biomicroscopic assessment and had a negative Watzke-Allen test. Four of these did not attend subsequent follow up appointments because of travel difficulties. Two further patients had a reduced acuity (despite anatomical success) because of increasing nuclear sclerotic cataract and retinal pigment epithelial changes and were excluded from further analysis;

Table 1 Preoperative data for all patients with unilateral macular hole

Patient	Age (years)	Sex	Eye	Stage of hole	Duration of symptoms (months)	Snellen acuity	
						Affected eye	Fellow eye
1	74	F	R	3	8	6/60	6/6
2	72	F	R	3	36	6/36	6/12
3	69	M	R	3	12	6/18	6/9
4	72	F	R	3	12	6/60	6/9
5	66	F	L	3	11	6/36	6/6
6	59	M	R	4	8	6/36	6/6
7	64	F	R	3	12	6/60	6/6
8	67	F	R	3	15	6/60	6/5
9	59	F	R	3	9	6/36	6/6
10	70	F	L	3	32	6/60	6/6
11	68	F	R	4	24	6/60	6/4
12	70	F	L	2	15	6/60	6/6
13	58	F	L	4	12	6/36	6/6
14	72	F	L	2	7	1/60	6/9
15	66	F	L	3	32	6/36	6/5
16	65	F	R	4	27	3/60	6/9
17	72	F	L	3	10	6/60	6/6
18	69	F	R	4	9	6/36	6/6
19	65	F	R	2	10	6/18	6/4
20	63	M	R	3	8	6/60	6/6
21	73	M	R	4	13	2/60	6/6
22	68	M	R	4	10	2/60	6/5
23	54	F	L	4	9	6/60	6/4
24	76	F	L	3	15	6/36	6/9
25	74	M	R	4	7	6/24	6/4
26	73	M	L	4	14	6/36	6/7.5
27	68	F	L	4	15	2/60	6/9
28	68	F	L	3	16	6/36	6/12

F, female; M, male; R, right; L, left.

in a further two patients acuity was unchanged. The remaining 15 patients had an improved best corrected acuity in the operated eye following surgery and these underwent a repeat orthoptic examination. The mean follow up was 3.9 months (range 2–7 months). All these patients had complained of visual symptoms of reduced visual acuity and/or distorted vision in the affected eye before surgery, but only one patient was aware of difficulty in accurately judging distances in everyday life.

Postoperatively, 12 of the 15 patients (80%) had no visual symptoms, the remaining three complained of some distortion. The visual acuity in the affected eye had improved to between 6/60 and 6/9 (table 2). Preoperative stereoacuity was markedly reduced in these patients compared with normal (table 2). Following surgery, stereoacuity as measured by the Titmus test improved in seven patients to a best level of 100 sec of arc and was unchanged in eight patients (table 2), the overall improvement being significant ($p < 0.02$: Wilcoxon signed rank test). No overall improvement in stereoacuity was seen with the TNO test (table 2). Two patients reported a subjective improvement in distance judgement, including the one patient who had noted some difficulty preoperatively. Both these patients had a substantial improvement in their visual acuity and stereoacuity.

Motor fusion ranges measured at both 6 metres and $\frac{1}{2}$ metre were notably reduced in patients with a macular hole before surgery compared with the normal control group (table 3). Following surgery there were small increases in the mean prism fusion ranges, but only the increase in the base-in range at $\frac{1}{2}$ metre was statistically significant and motor fusion remained substantially subnormal (table 3). The three patients where the fusion range was not measurable preoperatively showed improvement. The results of the 4 dioptre prism test were unchanged. Following surgery there was no significant change in cover test, ocular motility, or convergence.

DISCUSSION

This study has shown that patients with a unilateral macular hole have markedly reduced stereoacuties compared with controls of a similar age. This would be expected from their lack of bifoveal visual function. Following successful surgery,

stereoacuity as measured by the Titmus stereotest using a contoured stimulus improved substantially, but there was no improvement in random dot (TNO) stereopsis. This raises some interesting questions, both with respect to the part played by the nature of the stimulus and the role of motor fusion in measurements of stereoacuity.

Stereoacuties were substantially poorer in relation to the acuity of the worse eye than the reductions found in normal subjects when the acuity in one eye is artificially reduced by lens induced blur.^{15 16} This may simply be because, for a given reduction in acuity, the retinal pathology associated with a macular hole is more disruptive of binocular function than is induced blur, but in view of the interval between the onset of the macular hole and surgery it could also indicate a continuing central deterioration in stereoacuity as described in patients with longstanding unilateral blur.^{17 18}

The effects of a macular hole on binocular visual function are complex and involve changes in both sensory and motor function. Both the localised nature of the lesion and the nature of the stereotest used have an important influence on the results obtained. The size of the test stimulus used in relation to the size of the macular hole and the presence of contours in the stereotest are of particular importance (fig 1). The normal fovea is 1500 μm in diameter and the foveola 350 μm ¹⁹ and they subtend visual angles of approximately 5° and 1.2° respectively. A macular hole is 200–500 μm in diameter, with a surrounding cuff of subretinal fluid which gives rise to the symptoms of relative scotoma and metamorphopsia.^{20 21} There is an outward radial displacement of retinal tissue in the region surrounding a macular hole and psychophysical evidence shows an associated displacement of points in the retinal image in this cuff region compared with the fellow eye.²² At the standard examination distance, the circles of the Titmus stereotest subtend an angle of only 0.7° at the fovea and will usually fall within the area affected by the hole (fig 1) and so it is not surprising that all except one patient failed this stereotest preoperatively. The Titmus fly used for coarse stereopsis has a much larger projection, which will include normal parafoveal regions, and was still perceived stereoscopically by almost all patients (fig 1).

The stimulus used for fine stereopsis by the TNO stereotest is much larger than the Titmus circles and is comparable to

Table 2 Preoperative and postoperative Snellen acuity and stereopsis for patients with successful surgery

Patient	Snellen acuity of affected eye		TNO stereoacuity (seconds of arc)		Titmus stereoacuity (seconds of arc)	
	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative
1	6/60	6/18	1700	1700	3000	400
2	6/36	6/24	1700	1700	3000	800
3	6/60	6/18	1700	1700	3000	3000
4	6/36	6/18	1700	1700	3000	400
5	6/60	6/18	1700	1700	3000	100
6	6/60	6/24	240	240	400	400
7	6/60	6/12	1700	1700	3000	3000
8	6/60	6/24	1700	1700	3000	3000
9	6/60	6/24	480	240	3000	100
10	6/36	6/24	1700	1700	3000	3000
11	1/60	6/60	1700	1700	3000	3000
12	6/36	6/9	240	1700	3000	3000
13	3/60	6/36	1700	480	3000	3000
14	6/60	6/18	1700	480	3000	400
15	6/36	6/18	1700	1700	3000	100
Median			1700	1700	3000	800
Normal median (n = 30)			120	120	40	40
p Value for preoperative v postoperative*			–	0.71	–	0.016
p Value†			<0.0001	<0.0001	<0.0001	<0.0001

*Wilcoxon signed rank test.

†Compared with normal; Mann-Whitney U test.

Table 3 Preoperative and postoperative motor fusion ranges for patients with successful surgery

Patient	Prism fusion range at 1/3 metre						Prism fusion range at 6 metres					
	Preoperative			Postoperative			Preoperative			Postoperative		
	Base out	Base in	Total	Base out	Base in	Total	Base out	Base in	Total	Base out	Base in	Total
1	0	0	0	12	14	26	0	0	0	0	8	8
2	35	18	53	25	16	41	0	0	0	6	6	12
3	0	0	0	1	0	1	0	0	0	2	2	4
4	14	14	28	14	14	28	16	4	20	12	6	18
5	45	16	61	45	20	65	16	12	28	20	12	32
6	14	12	26	6	12	18	6	4	10	4	6	10
7	20	16	36	16	20	36	4	8	12	12	10	22
8	30	10	40	20	14	34	4	6	10	0	0	0
9	45	20	65	45	18	63	20	12	32	20	10	30
10	45	16	61	45	16	61	16	8	24	20	8	28
11	25	14	39	35	10	45	0	0	0	10	2	12
12	20	6	26	25	14	39	14	4	18	2	0	2
13	0	0	0	40	6	46	0	0	0	25	2	27
14	20	8	28	4	10	14	14	2	16	10	4	14
15	45	10	55	30	16	46	20	0	20	0	0	0
Mean	23.9	10.7	34.5	24.2	13.3*	37.5	8.7	4.0	12.7	9.5	5.1	14.6
Normal mean (SD)	35.1	14.6	49.7	35.1	14.6	49.7	17.2	6.3	23.5	17.2	6.3	23.5
	(11.8)	(3.8)	(12.2)	(11.8)	(3.8)	(12.2)	(9.7)	(4.9)	(12.0)	(9.7)	(4.9)	(12.0)
% difference from normal	-31.9	-26.9	-30.5	-31.0	-8.7	-24.4	-49.7	-36.2	-46.1	-44.7	-19.1	-37.9
p Value†	0.012	0.015	0.005	0.012	0.363	0.011	0.005	0.139	0.005	0.012	0.420	0.021

*Significantly better than corresponding preoperative value; ($p < 0.05$) paired t test.
†Unpaired t test compared with the 30 normal control subjects.

that for the TNO screening test. Both subtend approximately 8.5° of visual angle at the standard viewing distance and so the TNO tests stimulate an area of retina which extends well beyond the area affected by a macular hole (fig 1). However the TNO test uses random dot stimuli and is more dissociative than the Titmus test. In addition to the direct effect of the hole, the radial displacement of the region of retina surrounding the macular hole will impair the matching of corresponding random dots used for disparity recognition over the area of displaced retina; this is likely to have more effect on the smaller disparities of the fine stereotest. However there is still a substantial area of retina beyond the cuff of fluid which is likely to contribute substantially to the gross stereopsis measured by the TNO screening test. There are two possible explanations as to why this area does not support fine stereopsis with the TNO test. The first is that stereoacuity falls off with eccentricity and this area may simply be insufficiently sensitive to the fine disparities involved.²³ However it also seems likely that the impaired motor fusion, as evidenced by the reduced motor fusion ranges, also leads to imprecise motor alignment in the

absence of stimulus contours and that this impairs random dot matching for fine disparities.

Following successful surgery the macular hole was closed and the cuff of fluid resolved, with an associated improvement in subjective metamorphopsia. Although recovery was not complete, and most patients were still aware of a small degree of metamorphopsia, about half of the patients were able to compensate for the metamorphopsia and combine the images from the two eyes to obtain improved stereopsis with the Titmus test after closure of the macular hole. It is likely that the contours present in the Titmus circles were important in this, in assisting both accurate motor alignment and stimulus matching between eyes during the test. Careful precautions were taken to ensure that genuine depth was being perceived and that monocular cues were not being used. The failure of most patients to achieve more than screening levels on the Titmus test before surgery also indicates that they were not using monocular cues. However, although it improved, motor fusion remained substantially subnormal and it seems likely that it is this, together with residual retinal distortion, which continued to prevent fine TNO random dot stereopsis.

Although their stereoacuities were substantially reduced and the patients were aware of other visual symptoms such as distortion, the majority of patients with a unilateral macular hole were subjectively unaware of problems with depth perception in everyday life; only one patient complained of difficulty judging distances before surgery. This apparent discrepancy between the effect of the macular hole on stereoacuity and its impact on everyday binocular function is of interest. The interval between the onset of symptoms and surgery was quite long and it is possible that some patients had simply adapted to their stereoacuity deficit. However the more likely explanation is that most everyday tasks do not require more than gross stereopsis, at least in this age group of patients. Following successful surgery, with closure of the macular hole and improvement of acuity in their affected eye, eight out of 17 patients showed an improvement in stereoacuity as measured by the Titmus stereotest. Most appreciated an improvement in visual symptoms generally, but only two of these patients were aware of a subjective improvement in depth perception.

Figure 1 Schematic diagram showing approximate relative sizes of the macular hole and associated fluid and the projected images of the stereoscopic stimuli used.

These findings contrast with the substantial benefit to overall visual function seen following second eye cataract surgery^{24–26} and suggest that much of the functional benefit following cataract surgery comes from the restoration of gross rather than fine stereopsis. Restoration of global stereopsis may in part explain the benefit to overall visual function obtained from cataract surgery in the presence of age related macular degeneration.²⁷

In this study, recovery of binocular function was assessed at 2–7 months after surgery. This was timed to allow initial recovery of the macula, but to precede the development of significant nuclear sclerosis. Recovery of visual acuity following macular hole surgery has been shown to be biphasic, with an initial peak at around 3 months, followed by a decline as cataract develops in the majority of patients.¹⁴ The final best acuity is attained after cataract surgery, when further macular recovery has also occurred.¹⁴ It will be of interest to reassess the present cohort of patients after this long term recovery of acuity has occurred, to see if binocular function also shows further improvement in the long term. This study has shown that patients with a unilateral macular hole have a marked reduction in stereoacuity and a reduced motor fusion range. Although most had visual symptoms, they were surprisingly unaware of problems with depth perception in everyday life. Stereoacuity as measured by a contoured stereotest improved in about half of the patients who had successful surgical closure of the hole.

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