Critical Flicker Frequency as a Potential Vision Technique in the Presence of Cataracts

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PURPOSE. Potential vision testing attempts to predict the visual outcome that might be expected as a result of a cataract operation. This report details the clinical utility of critical flicker frequency (CFF) as a potential vision test (PVT).

METHODS. CFF thresholds were determined in 31 subjects with age-related idiopathic cataract and no other eye disease, 19 subjects with macular disease (MD) and clear ocular media, and 24 age-matched control subjects. In addition, the CFF technique was administered before cataract surgery in 52 patients and compared with the information provided by presurgical case history and ocular examination alone (ophthalmological judgment [OJ]) and results from two commonly used PVTs (the retroilluminated pinhole and the potential acuity meter).

RESULTS. CFF thresholds obtained in the nonsurgical cataract group were unrelated to cataract severity and were similar to those in the control group. In contrast, CFF scores were significantly related to visual acuity (VA) in the MD group. In the pre- and postsurgical studies, OJ predicted postoperative VA very well in patients with moderate cataract and normal fundi and better than all the PVTs. OJ performed less well in patients with comorbid eye disease and dense cataracts, when information from the PVTs would probably have been useful. CFF provided the most accurate predictions of postoperative VA in the small sample of patients with dense cataracts.

CONCLUSIONS. CFF was unaffected by cataract, yet sensitive to MD, and provided useful information about the postoperative visual outcome beyond that obtained through history and ocular examination in patients with dense cataracts. (Invest Ophthalmol Vis Sci. 2005;46:1107–1112) DOI:10.1167/iovs.04-1138

The most important factor leading to relatively poor visual outcome after cataract surgery is ocular comorbidity and particularly age-related macular disease (MD).1–6 For example, the percentage of eyes achieving 6/12 (20/40) after cataract surgery decreases to 89.7% (from 95.5%)6 and to 77% (from 92%)6 if patients with coexisting eye disease are included. Given the annual rate of cataract operation, which is more than 1 million in the United States, these percentages indicate that a significant number of patients obtain poor postoperative visual outcome. The high success rate of cataract surgery is leading to more operations being performed at an earlier stage of visual impairment. This scenario makes the improvement in visual performance critical. Even when a good view of the ocular fundus is possible, the surgeon frequently faces the difficulty of estimating the effect of any macular changes on vision and how much of the vision loss is due to cataract. For example, Schein et al.2 reported that 63% of patients that were predicted to obtain a visual acuity (VA) of 20/40 or worse after surgery (the level at which cataract surgery is typically deemed unsuccessful) by an ophthalmic examination actually attained a VA of 20/30 or better. In contrast, in the presence of dense cataracts an ophthalmoscopic view of the retina can be obscured or impossible to achieve. The success of cataract surgery can therefore be undermined by the unexpected presence after surgery of neuroretinal anomalies. To decide whether a patient would benefit from cataract surgery, a preoperative evaluation of retinal and neural visual function is pertinent. This estimation, referred to as potential vision testing, is used to determine the level of vision that may be expected as a result of cataract surgery and to assist cataract surgeons and their patients in setting realistic expectations.

Several techniques have been proposed to determine the integrity of the visual system behind the cataract and to predict the outcome of cataract surgery, but there is as yet no single test or test battery capable of accurately predicting postoperative outcome.9–16 In particular, there are no potential vision tests (PVTs) that provide an accurate assessment of visual outcome after cataract surgery in patients with dense cataract and VA worse than 20/200.15

The present study discusses the development of critical flicker frequency (CFF) as a PVT. The CFF may be considered the transition point for an intermittent light source, at which the flicker sensation disappears, to be replaced by the sensation of continuous stimulation. The image degradation caused by cataract would be expected to have an adverse effect on the spatial rather than the temporal processing of the visual system, so that CFF thresholds should, in theory, remain relatively unaffected by image degradation. Cataract has been simulated by refractive blurring lenses and diffusing filters, with which the induced optical degradation had relatively little effect on the temporal modulation function.17,18 The temporal modulation function is also resistant to change induced by the presence of transverse chromatic aberration.19 This resistance to optical-degradation-induced change has lead to the conclusion that the measurement of temporal performance may give a reliable clinical test for evaluation of neural visual function. Previous studies have indicated that the CFF is a sensitive indicator for detecting visual dysfunction in patients with early chloroquine retinopathy,20 maculopathies,21 neuropathy,21–25 and glaucoma.24,25

In this study, we assessed the effect of cataract and macular disease (MD) on CFF thresholds, and subsequently compared the test with two commonly used PVTs—the retroilluminated pinhole (RPH), and the potential acuity meter (PAM)—in addition to the information provided by case history and ocular examination alone, in a pre- and postoperative study.
METHODS
Optimal VA was determined with a Bailey-Lovie log minimum angle of resolution (logMAR) chart and by-letter scoring system with a chart luminance of 160 cd/m² and a working distance of 4 m. A termination rule of no letters correctly called on one line was used. When no letter was visible at 4 m, the testing distance was reduced and a working-distance lens used as necessary. The CFF stimulus consisted of a red, light-emitting diode (LED) of peak wavelength 635 nm and bandwidth 30 nm. This was chosen because it is compact, robust, silent in operation and reliable, and it emits a constant intensity for several years and will follow an electrically generated, square wave faithfully. The relatively long-wavelength light may assist in encouraging a good performance in the presence of media opacities. The driving unit generated a square wave with an equal light–dark phase (ratio of 1), a modulation depth of 100%, and a frequency range from 1 to 80 Hz (flashes per second). The LED source was arranged at the center of a rectangular board (20 × 13 cm) painted matte white. The apparatus was mounted on a slit lamp with a special attachment. The LED was viewed monocularly at a distance of 38 cm, using the chin rest of the slit lamp to ensure a stable working distance and head position. The size of the CFF target LED subtended a visual angle of 1.5°, as pilot study data had indicated that this was the most useful target size to discriminate between cataract and MD. The LED mean luminance at 50 flashes per second was 450 cd/m² and the surrounding screen was illuminated by portable lamps to a luminance of 15 cd/m². The CFF thresholds were determined with a 3-second presentation facility, to provide an ascending–descending staircase method, changing the frequency by 1 Hz between each presentation. This approach avoids any influence from frequency acceleration or deceleration, which may induce a perceived change when continuous exposure to a CFF target of changing frequency is allowed, and yet the pulse is not too short to become a determinant of CFF. The whole procedure took ~3 to 5 minutes; thus, the effect of fatigue was minimal.

For both experiments, subjects were recruited from the Outpatient Clinic of Ophthalmology at Oftálmico Hospital in Madrid, Spain. Informed consent was obtained in each case, all studies gained approval from the hospital ethics committee, and the tenets of the Declaration of Helsinki were followed. All subjects were inexperienced with regard to the tests.

Experiment 1
CFF thresholds and VA were determined for 31 eyes of 31 subjects with age-related idiopathic cataract and no other eye disease or abnormality (nonsurgical cataract group; mean age, 70.5 ± 6.2 years), 19 subjects with MD and clear ocular media (mean age, 67 ± 4.5 years; 9 with dry age-related MD, 5 with disciform scarring, 2 with myopic maculopathy, 1 with macular pucker, 1 with a macular hole, and 1 with diabetic maculopathy), and 24 age-matched control subjects (mean age, 69.0 ± 5.7 years). Exclusion criteria for all three groups included any other ocular disease or abnormality, as determined by a case history and a full ophthalmic examination; previous ocular surgery; and poor general health or any systemic disease that could affect the results (e.g., diabetes mellitus, hypertension, Parkinson’s disease). All subjects in the MD and control groups had normal ocular media for their age, defined as lens opacification below level 2.0 on the Lens Opacification Classification System (LOCS) III 30 for cortical and nuclear opacity and any posterior subcapsular cataract (PSC). The cataract group had normal maculae defined as less than four drusen in the macular area and only slight pigmentary changes. The ability to observe macular integrity in patients with media opacities depends on the severity of the cataract. For that reason, the cataract sample was restricted to subjects with VA better than 1.0 logMAR (Snellen equivalent, 20/200). The control group all had VA better than 0.1 logMAR (Snellen equivalent, 20/25).

TABLE 1. The Proposed Five-Grade OJ System

<table>
<thead>
<tr>
<th>Grade</th>
<th>Characteristics</th>
</tr>
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<tbody>
<tr>
<td>4</td>
<td>Normal retinal and neural system</td>
</tr>
<tr>
<td></td>
<td>Predicted postoperative VA better than 20/50</td>
</tr>
<tr>
<td>3</td>
<td>Slight or mild changes from normal (e.g., small, discrete drusen, or pigment scattered over the macula)</td>
</tr>
<tr>
<td></td>
<td>Predicted postoperative VA better than 20/40</td>
</tr>
<tr>
<td>2</td>
<td>Moderate changes that may require clinical intervention (e.g., confluent drusen, geographic atrophy, or hyperpigmentation)</td>
</tr>
<tr>
<td></td>
<td>Predicted postoperative VA between 20/40 and 20/120</td>
</tr>
<tr>
<td>1</td>
<td>Severe changes that usually require clinical intervention</td>
</tr>
<tr>
<td></td>
<td>Detachment of the retinal pigment epithelium or choroidal neovascularization</td>
</tr>
<tr>
<td>0</td>
<td>Very severe changes</td>
</tr>
<tr>
<td></td>
<td>Predicted postoperative VA between 20/120 and 20/200</td>
</tr>
<tr>
<td></td>
<td>Disciform scarring</td>
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<tr>
<td></td>
<td>Predicted postoperative VA worse than 20/200</td>
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Experiment 2
Fifty-two patients (mean age, 70 ± 7 years) admitted for cataract surgery were examined approximately 2 to 3 weeks before surgical intervention and 6 to 9 weeks after the cataract operation. This group consisted of an approximately equal number of patients with and without comorbid eye disease, recruited from a consecutive series of cataract surgeries with the intention of analyzing the merits of the PVTs, both in the presence and absence of coexisting ocular disease. Surgery consisted of phacoemulsification with intraocular lens implantation and was performed by the same experienced consultant surgeon in all cases.

The examination was performed in two separate visits. In visit 1, refraction and a complete ophthalmic examination were undertaken. VAs were determined as previously described. After measurement of VA, pupils were dilated with tropicamide 1%, and the subjects were screened for ocular disease with slit lamp biomicroscopy and indirect ophthalmoscopy. Cataracts were categorized and graded according to the LOCS III, and mixed cataracts were categorized according to the morphologic type scoring the highest grade. In this first visit, retinal acuities were determined with dilated pupils using the PAM31,32 and the RPH33,34 techniques. Both procedures were performed before the fundus evaluation, to avoid the disturbing effect of glare caused by the intense light of indirect ophthalmoscopy. An RPH VA chart was designed for the present study. Three VA logMAR chart reductions, with different patterns of Sloan letters, were produced on negative photographic paper so that the chart consisted of white letters on a black background. The charts were then placed in a light box, so that the chart could be retroilluminated. A high letter luminance (1200 cd/m²) and short working distance (1 m) were used to overcome the significant reduction in retinal illumination caused by conventional pinhole apertures. The subjects, wearing pinhole spectacles with multiple 1-mm pinholes, were asked to read the lowest line of the chart at a distance of 1 m. The VA measurement procedure was as previously described.

In visit 2, the CFF test was administered monocularly on natural pupils with optimal refractive correction. In addition, an ophthalmological judgment (OJ) assessment, based solely on the information from the patient’s history and routine ocular examination, was made. This included an assessment of the patient’s ocular, medical, and family histories followed by preoperative optimal VA, pupillary testing, binocular vision assessment, and dilated fundus examination with indirect ophthalmoscopy. The OJ was performed by the same consultant ophthalmologist who performed all cataract operations with no input from the potential vision investigation. A quantitative five-point recording system for grading the ophthalmic observations was adopted (Table 1). A score of 4 was allocated when a normal retinal-neural ocular system...
TABLE 2. Test Results

<table>
<thead>
<tr>
<th></th>
<th>Older Normal</th>
<th>Cataract</th>
<th>Macular Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>69.0 ± 5.7</td>
<td>70.5 ± 6.2</td>
<td>67.0 ± 4.5</td>
</tr>
<tr>
<td>CFF (Hz)</td>
<td>39.0 ± 2.4</td>
<td>38.2 ± 2.1</td>
<td>32.5 ± 5.0</td>
</tr>
<tr>
<td>Distance VA (logMAR)</td>
<td>0.00 ± 0.04</td>
<td>0.38 ± 0.14</td>
<td>0.57 ± 0.45</td>
</tr>
</tbody>
</table>

Data are expressed as the mean ± SD. Cataract group, n = 31; macular disease group, n = 19; normal control group, n = 24.

was predicted and a score of 3, 2, 1, or 0 when mild, moderate, severe, and very severe pathologic changes, respectively, were predicted. The scoring system also provided a prediction of the postoperative VA (Table 1).

Three of the 52 patients were excluded from the study: Two did not attend postoperative visits (unknown reasons) and one had surgical complications. Three patients did not attend the fourth visit to the ophthalmic clinic for unknown reasons, and therefore some postoperative potential vision data were not obtained. After the preoperative ophthalmic examination of the surgical eye, the patients were categorized into the following three groups as suggested by the American Agency for Health Care Policy and Research.15 Twenty-two patients with mild to moderate cataract and a normal fundus (mean VA, 0.37 ± 0.14; Snellen, −0/50; range, 0.10–0.64 logMAR), 15 patients with dense cataract (mean VA, 1.13 ± 0.59; Snellen, −20/20; range, 0.42–2.20 logMAR), and 12 patients with mild to moderate cataract and comorbid eye disease (mean VA, 0.61 ± 0.30; Snellen, −20/80; range, 0.20–1.10 logMAR). A dense cataract was classified as a cortical or nuclear opacity greater than or equal to LOCS grade 5.0 or posterior subcapsular cataract greater than or equal to LOCS grade 3. The 12 patients with comorbid eye disease included 9 with age-related MD and 1 each with retinitis pigmentosa, myopic degeneration, and refractive amblyopia.

RESULTS

Experiment 1

The mean ages of the nonsurgical cataract, MD, and control groups (Table 2) were not significantly different (P > 0.1). Regression analysis revealed CFF thresholds to be unrelated to cataract severity as determined by VA (R² = 0.01, P > 0.5). The 95% lower confidence limit for normal CFF thresholds from the native criterion; vertical line: the level for the best discrimi-

nator RPH and PAM values were very similar to postoperative distance VA scores (I₄₅ = 0.90, P > 0.1; I₄₅ = 0.49, P > 0.5; Table 3). The ability of the PVTs to predict postoperative outcome was assessed using the percentage of PVT estimates that fell within 2 and 3 lines of postoperative VA (Table 4). The PVT was considered as giving no useful information when the patient was unable to perform the technique because of a dense cataract. To allow comparison of CFF results with the other VA-based PVTs, preoperative CFF results were converted to estimates of VA using the equation VA (logMAR) = 2.42 – 0.06 CFF determined for subjects with PVT and clear media in experiment 1.

FIGURE 1. Scattergram of VA (logMAR) against CFF (Hz) in 19 subjects with macular disease. Horizontal line: the level for the best discrimi-

native VA; dotted diagonal line: regression line of the points. The four quadrants represent the true positives (TP, TN) and false (FP, FN) predictions.

Experiment 2

Using data from all patients, CFF thresholds were similar before and after surgery (I₄₅ = -0.52; P > 0.5; Table 3). In contrast, the RPH and PAM values showed a significant improvement after cataract surgery, from approximately 0.30 to 0.10 logMAR (Snellen, 20/40–20/25; t > 4.77, P < 0.001; Table 3). Postoperative RPH and PAM values were very similar to postoperative distance VA scores (I₄₅ = 0.90, P > 0.1; I₄₅ = 0.49, P > 0.5; Table 3).

The ability of the PVTs to predict postoperative outcome was assessed using the percentage of PVT estimates that fell within 2 and 3 lines of postoperative VA (Table 4). The PVT was considered as giving no useful information when the patient was unable to perform the technique because of a dense cataract. To allow comparison of CFF results with the other VA-based PVTs, preoperative CFF results were converted to estimates of VA using the equation VA (logMAR) = 2.42 – 0.06 CFF determined for subjects with PVT and clear media in experiment 1.

DISCUSSION

The CFF technique was shown to be resistant to image degradation caused by cataracts, as CFF thresholds obtained in ex-

TABLE 3. Pre and Postoperative Data for the PVTs and VA

<table>
<thead>
<tr>
<th></th>
<th>Preoperative Mean</th>
<th>Postoperative Mean</th>
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<tbody>
<tr>
<td>RPH (Snellen equivalent, −20/40)</td>
<td>0.29 ± 0.15 logMAR</td>
<td>0.11 ± 0.10 logMAR</td>
</tr>
<tr>
<td>PAM (Snellen equivalent, −20/40)</td>
<td>0.31 ± 0.22 logMAR</td>
<td>0.12 ± 0.13 logMAR</td>
</tr>
<tr>
<td>CFF (Snellen equivalent, −20/40)</td>
<td>38.6 ± 2.9 Hz</td>
<td>38.8 ± 2.5 Hz</td>
</tr>
<tr>
<td>VA (Snellen equivalent, −20/90)</td>
<td>3.61 ± 0.71</td>
<td>—</td>
</tr>
</tbody>
</table>

Data are expressed as the mean ± SD.
performance was not unduly influenced by the presence of the CFF technique was shown to be the only PVT whose compared with the RPH and PAM instruments in experiment 2, those found in the control group (Table 2). Furthermore, when experiment 1 in the nonsurgical cataract group were similar to those found in the control group (Table 2). Furthermore, when compared with the RPH and PAM instruments in experiment 2, the CFF technique was shown to be the only PVT whose performance was not unduly influenced by the presence of dense cataracts (Table 3). The fact that the patient with mature intumescent cataract (VA, 2.20 logMAR, ~20/3000 Snellen) was able to perform the CFF technique correctly before surgery constituted a remarkable finding. This patient was unable to give a response to any of the other PVTs, and an ophthalmoscopic view of her fundus was impossible. It should be noted that, to date, the only available method to investigate the neural integrity in this kind of opacity has been the electrophysiological tests and endotopic phenomena. The CFF technique measures the temporal resolution at a high modulation depth, and this may be the reason it is so resistant to cataract-induced changes that adversely affect the spatial processing system. It is possible that the resistance of CFF to cataract-induced vision loss may also be due to the scattering effects of cataract producing a larger retinal image of the target, which may compensate for any reduction in CFF thresholds due to a reduction of retinal illuminance.

The CFF technique also showed a low variability in thresholds among older subjects with normal visual function and in the nonsurgical cataract group (standard deviations of <10% of thresholds). This obviously helps in the correct identification of normal and abnormal thresholds. In fact, the CFF technique showed an excellent sensitivity for identifying normal visual function and hence for predicting successful postoperative outcome, with a 97% accuracy in the nonsurgical cataract sample. In agreement with previous studies, the CFF technique also appeared to be sensitive to the presence of MD. Although different mechanisms mediate the appreciation of VA (spatial processing) and the detection of CFF (temporal processing), a significant association between VA and CFF was found for results from the MD group (Fig. 1).

In the presence of moderate cataract and a normal fundus, OJ was able to predict postoperative VA better than the PVTs (Table 4), which suggests that there is no benefit in using PVTs in patients with moderate cataract and a normal fundus. However, in the presence of moderate cataracts and comorbid eye disease, all the PVTs showed higher percentages of correctly predicted postoperative VA than those obtained by OJ (Table 4). Although OJ provided a limited performance in predicting postoperative VA in dense cataract, with only 9 (60%) of the 15 patients’ VA predicted to within 3 lines, this was still superior to the performance of the RPH and PAM at 40% (Table 4). CFF provided the best predictive performance in dense cataract. This comparative assessment of OJ is obviously limited by the relatively small number of patients in each group and the fact that OJ was provided by one consultant ophthalmologist whose skill may not be representative. The results from OJ in this study are, however, similar to the OJ results from 75 ophthalmologists reported by Schein et al. They indicated that 65% of patients predicted to achieve a VA of 20/40 or worse after surgery, attained 20/30 or better acuity. In the present study, OJ only predicted a postoperative VA of 20/40 or worse in five patients. Three of them (60%) achieved a postoperative VA of 20/30 or better. These three predictions were incorrect by 4.5, 5.5, and 9 lines. One patient had moderate cataract (LOCS III grade, P2.8) and MD, the second had dense cataract (LOCS III grade, P5.0; C, NC, and NO, all 4.0) with MD, and the third was a patient with dense cataract (LOCS III grade, P5.0; NC and NO, both 2.5) and exotropia who obtained 0.08 logMAR VA (~20/25 Snellen) after surgery in his exotropic eye. In addition, OJ predicted VAs that were >3 lines better than achieved after surgery (FPs) for three patients. All three patients had moderate cataract, with two also having MD and the third, retinitis pigmentosa.

The detrimental effect of cataracts on the RPH and PAM values appears to be due to the inability of both instruments to bypass media opacities as the cataract becomes denser. The mean differences between predicted and postoperative VA were 0.12 ± 0.15 logMAR (PAM) and 0.14 ± 0.14 logMAR (RPH), using the data from patients with moderate cataract, but 0.38 ± 0.27 logMAR (PAM) and 0.31 ± 0.18 logMAR (RPH) in the patients with dense cataract. This fact has been previously reported for both techniques. It was somewhat surprising that the PAM showed a similar ability to bypass media opacities as the RPH, considering that the PAM uses a 1.0-mm pinhole positioned approximately 15-mm from the cornea. However, it has been reported that the image of the letter chart produced by the PAM is a much larger, crosslike diffraction pattern than the 0.15-mm point source image claimed. Melki et al. reported a better predictive ability of their potential acuity pinhole test compared with the PAM in 56 patients undergoing cataract surgery, although predictive ability for both tests deteriorated with increased cataract density. This result may be due to differences between their potential acuity pinhole and the RPH and differences in sample population.

CFF has been shown to be higher in the periphery than in the fovea in some experimental conditions. Therefore, the possibility exists that patients with cataract and coincident foveal dysfunction, usually macular degeneration, can achieve better preoperative CFF thresholds through the use of extrafoveal areas and still exhibit poor postoperative outcome. This may lead to false-positive predictions (i.e., the technique suggests normal visual function, but after surgery abnormal VA is discovered). This is the worst situation when predicting the postoperative outcome in cataract patients, with subsequent disappointment for both patient and surgeon. No evidence exists to suggest that this occurred in the present study. On the contrary, two patients from the PVT group who in fact re-

### Table 4. Percentages of PVT Results Accurate to within 2 and 3 Lines of Postoperative Visual Acuity

<table>
<thead>
<tr>
<th></th>
<th>Moderate Cataract and Normal Fundi (n = 22)</th>
<th>Moderate Cataract and Comorbid Disease (n = 12)</th>
<th>Dense Cataract (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Within 2 Lines</td>
<td>Within 3 Lines</td>
<td>Within 2 Lines</td>
</tr>
<tr>
<td>OJ</td>
<td>95</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>PAM</td>
<td>70</td>
<td>90</td>
<td>83</td>
</tr>
<tr>
<td>RPH</td>
<td>73</td>
<td>86</td>
<td>83</td>
</tr>
<tr>
<td>CFF</td>
<td>77</td>
<td>95</td>
<td>58</td>
</tr>
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</table>
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