Assessment of Retinal–Neural Function Before Neodymium:YAG Laser Capsulotomy

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Purpose. The aim of this study was to evaluate a clinical test of hyperacuity in the assessment of retinal–neural function in patients with posterior capsular opacification.

Methods. Neodymium (Nd):YAG laser capsulotomy was performed on 39 subjects (mean age, 76.72 years ± 10.41 years). Measurements of refractive error, logMAR acuity, and displacement threshold hyperacuity (DTH) were made before and 3 weeks after Nd:YAG therapy. The DTH task involved measurement of the smallest detectable displacement of an object relative to two stationary references. In addition, an independent fundus examination was performed before and after therapy to determine the presence of retinal disease. By ophthalmoscopic examination, a blind protocol was adopted for the classification of subjects as normal or as having retinal disease.

Results. Preoperative measures of logMAR visual acuity were of no value in distinguishing between patients with retinal disease and normals (P > 0.1) and were a poor indicator of postoperative logMAR acuity (r² = 0.2). Preoperative DTH could be used to distinguish patients with retinal disease from normals (P < 0.005) and were found to be correlated with measures of postoperative logMAR acuity (r² = 0.4). Preoperative DTH correlated well with postoperative DTH (r² = 0.7), which is consistent with its resistance to optical image degradation.

Conclusion. The results of this study indicate that DTH is of value in the presurgical assessment of visual function in patients with media opacification if adequate fundus examination is not possible. Invest Ophthalmol Vis Sci. 1995;36:1155–1162.

In developed countries, extracapsular cataract extraction is the technique of choice for the removal of senile cataract. The most frequently reported long-term complication of this procedure is posterior capsular opacification; the reported incidence is between 18.4% and 50%.1–4 The prevalence of posterior capsular opacification is higher in studies using extended follow-up periods.

Photodisruption of the posterior capsule using neodymium (Nd):YAG laser therapy has replaced invasive surgery as the most commonly used technique for performing posterior capsulotomy.5–7 Although safer than surgical dissection, Nd:YAG laser capsulotomy is not without its complications, which include raised intraocular pressure,8 damage to or dislocation of the intraocular lens,9 cystoid macular edema,10 and retinal detachment.11 Clinical studies5,12,13 have shown that improved letter acuity is not achieved in 5% to 9.9% of patients, whereas deterioration in letter acuity is incurred in 1% to 5.7% of patients5,12,13 after capsulotomy. Visual acuity fails to improve if there is significant preexisting retinal or neural disease or if the patient sustains a complication of the procedure.

The success of Nd:YAG laser therapy depends on two main factors: the degree of optical degradation produced by the posterior capsular thickening, and the functional capabilities of the retina and its neural system. Presumably, Nd:YAG capsulotomy, a procedure with small but significant risks, would not be used if the degree of optical degradation is extremely small or if retinal function is severely impaired because the procedure then would be of little benefit to the patient. However, assessment of retinal integrity in the
presence of posterior capsular opacification is often problematic because of the absence of an adequate ophthalmoscopic view of the fundus. Clinical assessment of the effect of posterior capsular opacification on vision is highly subjective and unreliable. In addition, the presence of identifiable retinal disease does not preclude improvement in visual acuity after capsulotomy. Several techniques have been developed that attempt to provide the clinician with information on retinal and neural function before surgical intervention.

To assess the functional capability of the macula in the presence of media opacities, a test must be used that does not require the ocular system to produce a high-quality image, that projects an image through the opacity, or that bypasses the optical system of the eye. This can be achieved in a number of ways, such as by using Maxwellian view optical systems to "project" an acuity target through a small, optically clear portion of the opacity. Clinical tests such as the Potential Acuity Meter adopt this approach. Visual function behind an opacity can also be determined using laser interferometric techniques that bypass the eye's optical system and form an image directly on the retina. However, clinical opinion varies regarding the value of these tests in predicting postoperative visual function.

An alternative approach uses tests of visual function that can be performed irrespective of optical image quality, which include electrophysiology and en tropic techniques. Unlike laser interferometry and the Potential Acuity Meter, these techniques do not provide a direct measure of spatial resolution and are subject to a number of drawbacks that have been documented in previous studies. More recent additions to this group are certain hyperacuity tasks. The term "hyperacuity" is used to describe a set of spatial thresholds that exhibit clear superiority over conventional spatial thresholds, such as visual acuity. The precision with which relative localization can be performed is often of the order of 5 seconds of arc and is achieved despite the limitations imposed by visual pathways and aberrations produced by the optical media. Examples of hyperacuity include vernier acuity, stereovision, bisection acuity, and displacement detection.

The resolving capacity of the eye relies on the ability to distinguish two objects as spatially separate. As the retinal image becomes increasingly diffused over a larger retinal area because of hazy optical media or uncorrected refractive error, the two objects merge and the eye becomes unable to resolve them as separate. For this reason, measures of visual acuity are of little value in patients with media opacities because it is impossible to distinguish between reductions in acuity caused by the opacity and those caused by underly ing posterior pole pathology. Because hyperacuity thresholds, such as vernier acuity and displacement thresholds, are extremely resistant to the effects of retinal image degradation produced by media opacities, the threshold obtained should relate directly to the functional capabilities of the retina and neural system.

Most previous studies examining hyperacuity thresholds in the presence of cataract have used vernier acuity. However, this type of hyperacuity may not be the ideal choice because vernier threshold varies as a function of the vertical separation between the stimulus features. A single measure of vernier acuity provides the clinician with little useful information; a range of gap separations must be examined to determine optimum threshold. This leads to an increase in test times and a consequent reduction in the clinical appeal of the test. An alternative is to use displacement thresholds that simply require the patient to detect the motion of an oscillating bright dot stimulus. This technique has previously been used in patients awaiting cataract extraction and has been shown to offer a good indication of the likely quality of vision achieved after surgery.

The aim of this study was to assess the value of a clinical test of hyperacuity, which is robust to optical image degradation, in assessing neural–retinal function in patients with posterior capsular opacification.

METHODS

Thirty-nine consecutive subjects (mean age, 76.72 ± 10.41 years), representing all patients thought to require Nd:YAG consecutive laser over a 6-month period, were referred from the general ophthalmology outpatient clinics of the Southern General Hospital and the Victoria Infirmary in Glasgow. There was no prior selection process, nor were there exclusions from the study. Informed consent was obtained from all patients before experimental testing, and the tenets of the Declaration of Helsinki were followed.

The stimulus for measurement of displacement threshold hyperacuity (DTH) was generated on the monitor (HP, 640 × 480 pixels) of an HP-386 personal computer (Hewlett-Packard). A square patch of light, luminance 187 cd/m², which subtended 20.4 × 20.4 minutes of arc at a viewing distance of 4 m, was made to oscillate in square wave fashion at a temporal frequency of 2 Hz. Two identical flanking squares were placed at 62 minutes of arc on either side of the central target, which acted as references against which movement of the central oscillating target could be judged. The amplitude of oscillation increased linearly as a function of time after a random delay, and threshold was determined by the smallest displacement of the central target that could be just detected.
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A psychophysical method of ascending limits was used, and the subject was required to press a button when the movement of the target was just detectable. This procedure was performed six times under low room illumination (50 lux), and from these measures the mean and standard deviation were calculated to determine the final DTH. Tests usually took 2 to 3 minutes to complete. Before experimental data collection, all subjects were given a practice run to become familiar with the test.

Subjects underwent routine refraction to obtain best optical correction, followed by measurement of logMAR (logarithm of the minimum angle of resolution in minutes of arc) acuity using a Bailey–Lovie chart and determination of DTH. Displacement threshold and logMAR acuities were determined in random order. A blind protocol was adopted for the recording of logMAR acuity, DTH, and fundus examination. The Bailey–Lovie chart was externally illuminated to 480 lux. Nd:YAG laser capsulotomy was then performed using powers of 0.4 to 0.9 mj.

All 39 subjects were reexamined 3 weeks after surgery. They were refracted, and measures of DTH and logMAR acuity were obtained in random order. Patients’ eyes were then dilated, and fundus examinations were performed. Based on this examination and documented fundus examinations performed before capsulotomy, patients were allocated to a normal group or to a group with pathology for analysis. Included in the group with pathology were patients with age-related macular degeneration (n = 4), lamellar macular hole (n = 1), diabetic retinopathy (n = 1), amblyopia (n = 4), retinitis pigmentosa (n = 1), and glaucoma (n = 4).

RESULTS

The mean preoperative logMAR acuity of the 39 subjects was 0.67 ± 0.32 log units (approximately 6/30 Snellen equivalent). Figure 1 shows the relationships between preoperative and postoperative logMAR acuity for the normal group and the group with pathology. Preoperative and postoperative logMAR acuity measures were found to be correlated in subjects with retinal pathology ($r^2 = 0.53$; $P = 0.0021$). This is perhaps to be expected because the major factor limiting logMAR acuity in this group is retinal–neural function rather than the optical degradation imposed by the capsular opacification. However, regression analysis of the data for normal subjects demonstrates a lack of correlation between these two measures ($r^2 = 0.06; P = 0.24$), indicating that when the image-degrading effects of the opacity are removed, visual acuity improves significantly. A one-factor analysis of variance revealed that preoperative measures of logMAR acuity in patients with retinal disease were not significantly different from that in normals ($F = 1.122; P > 0.1$). This indicates that preoperative measures of visual acuity cannot be used to differentiate between reduced acuity from capsular opacification and that from underlying posterior segment disease.

Approximately 90% of the subjects experienced a significant improvement in visual acuity after Nd:YAG laser therapy. Significant improvement in visual acuity was not achieved in only four patients (approximately 10%), confirming previous reports2-15 (95% confidence limits for a significant change in logMAR acuity were set at ±0.1 log unit30). Regression analysis of the combined data revealed a weak but significant correlation ($r^2 = 0.20; P = 0.007$) between these two measures, indicating that preoperative logMAR visual acuity is a poor predictor of postoperative logMAR acuity.

The relationships between preoperative and postoperative DTH for the normal group and the group with pathology are shown in Figure 2. Similar correlations are found for normals ($r^2 = 0.62; P = 0.0001$) and for subjects with retinal disease ($r^2 = 0.54; P = 0.0018$). Preoperative measures of DTH were significantly higher in patients with retinal disease than in normals (one-factor analysis of variance, $F = 17.64; P < 0.005$). Regression analysis of preoperative DTH against postoperative DTH for the combined data of...
FIGURE 2. Preoperative DTH is plotted against postoperative DTH for the normal group (●) and the group with pathology (●). Similar correlations are found for normals (y = 0.3 + 0.8 × r² = 0.62) and subjects with retinal disease (y = 0.95 + 0.5 × r² = 0.54). DTH = displacement threshold hyperacuity.

The two groups show these two measures to be well correlated (r² = 0.70; P = 0.0001).

The relationship between preoperative DTH measurements and postoperative logMAR acuity is shown in Figure 3. Regression analysis demonstrates that the two measures are correlated (r² = 0.40; P = 0.0001).

The optimal preoperative DTH cutoff value that allows subjects with retinal disease to be distinguished from normals can be determined by generating a receiver–operator characteristic (ROC) function (Fig. 4). If a patient has capsular opacification, the clinician must weigh the risks of Nd:YAG capsulotomy (perhaps retinal detachment) against potential improvement in visual function. Assessment of these factors allows an optimal criterion to be determined for the relevant psychophysical test using equation 1.

The optimum cutoff point is the point on the ROC curve at which the slope of the tangent to the curve is:

\[
\beta_{\text{opt}} = \frac{\text{value (correct rejection)}}{\text{value (hit) - cost (miss)}} - \text{cost (false alarm)}
\]

where \( P(D+) \) and \( P(D-) \) are the probabilities of disease either present or absent, respectively, in the population studied. The value of a hit and correct rejection are the relative weights assigned to identify correctly a subject with or without disease. The cost of a false alarm is the relative weight attached to incorrectly identifying someone as having retinal–neural

FIGURE 3. Preoperative displacement threshold versus postoperative logMAR acuity. This plot shows the ability of preoperative displacement threshold measures to predict postoperative logMAR acuity. The equation of the regression line fitted to the data is \( y = -1.4 + 0.8 \times r^2 = 0.40 \).

FIGURE 4. Receiver–operator characteristic function. This plot indicates the relative sensitivities and specificities for a range of preoperative displacement threshold hyperacuities. The cutoffs associated with the values derived for \( \beta \) (●) and \( \beta_{\text{opt}} \) (●) for distinguishing between patients with underlying retinal disease and normals are indicated.
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dysfunction, whereas the cost of a miss is the relative weight attached to incorrectly identifying a subject as normal when there is reduced retinal–neural function.

When test scores are measured on a continuous scale, the frequency distributions derived from the normal group and group with pathology commonly overlap. If \( \beta_{\text{opt}} = 1 \), the optimum cutoff point is the intersection of these two distributions or the point on the ROC curve farthest from the indecision line (for the current study, this is 102 seconds of arc). If the costs and benefits of a false alarm and a correct rejection balance the cost and benefits of a miss and a hit, then \( \beta_{\text{opt}} \) is defined by the point on the ROC curve at which the slope of the tangent to the curve is the ratio of \( P(D-) \) to \( P(D+) \). This point is indicated on Figure 4 (\( \beta \)). Because the sample size of this study is relatively small and may not be representative of the incidence of retinal disease in the population studied, values for \( P(D+) \) and \( P(D-) \) for the appropriate age group have been obtained from a more detailed source.32

The location of the optimal cutoff point is influenced by the relative values of the designated payoff conditions. For example, the results of this and previous studies5,12,13 indicate that between 5% and 10% of patients undergoing Nd:YAG laser capsulotomy do not experience improvement in letter acuity. Therefore, if a strict criterion is adopted, the value of a correct rejection can be taken as 0.9, and the value of a hit as 0.1. Similarly, because the surgical risks are small (in 1% to 6% of patients there is deterioration in letter acuity5,12,13) in relation to the value of improved visual function, the cost of a miss can be taken as 0.06 and the cost of a false alarm as 0.94, again adopting a strict criterion. This allows equation 1 to be used to calculate a value for \( \beta_{\text{opt}} \):

\[
\beta_{\text{opt}} = \frac{0.73 (0.9) - (-0.94)}{0.27 (0.1) - (-0.06)}
\]

\( \beta_{\text{opt}} \) is, therefore, the point on the ROC curve at which the slope of the tangent to the curve is 31.05. This point is indicated on Figure 4 (\( \beta_{\text{opt}} \)) and is found to be 251 seconds of arc. Figure 4 illustrates how the optimal criterion is modulated by the relative premiums assigned to the various payoff conditions. Because the relative weighting is such that the cost of depriving an individual of potential improvement in visual function is high in relation to the risks of Nd:YAG laser capsulotomy, the optimum criterion is shifted toward a higher cutoff value.

Because the sensitivity and specificity of the test and the probability of retinal disease32 are known, it is possible to calculate the conditional probabilities.35

\[
P(D+/T+) = \frac{P(D+) \cdot P(T+/D+)}{P(D+) \cdot P(T+/D+) + P(D-) \cdot P(T+/D-)}
\]

\( P(\text{D+}/\text{T+}) \) is the probability of retinal disease given a DTH of higher than 251 seconds of arc and can be calculated using equation 2.

**Figure 5. Preoperative displacement threshold hyperacuity measurements and postoperative logMAR acuity for the group with pathology (•) and the normal group (○), with the cutoff values selected from the receiver–operator characteristic.**

The conditional probability of \( (P(\text{D-}/T-)) \) is found to be 1, or 100%.

Similarly, the probability that a patient does not have retinal disease given a DTH of less than 251 seconds of arc can be calculated using equation 3.

\[
P(D-/T-) = \frac{P(D-) \cdot P(T-/D-)}{P(D-) \cdot P(T-/D-) + P(D+) \cdot P(T-/D+)}
\]

The conditional probability of \( (P(\text{D+}/T-)) \) is 0.774, or 77.4%.

Figure 5 shows preoperative DTH measurements and postoperative logMAR acuity for the group with pathology and the normal group, with the cutoff values associated with \( \beta \) and \( \beta_{\text{opt}} \) selected from the ROC. The shift in cutoff value toward a higher test score, produced by the relative weights attached to the costs
and benefits associated with the outcome of a decision, is clearly illustrated.

**DISCUSSION**

The results of this study demonstrate that measurement of displacement threshold hyperacuity provides a means of distinguishing between reduced visual acuity caused by optical degradation and a reduction caused by retinal pathology.

Preoperative measures of logMAR acuity provide the clinician with little useful information with regard to postoperative visual performance. The problem of predicting postoperative visual performance is confounded by the fact that preoperative visual acuity measures are affected by image degradation imposed by capsular opacification and the presence of retinal-neural dysfunction. Consequently, a subject with poor preoperative logMAR acuity cannot be identified as either having or not having acuity-limiting retinal disease. This is demonstrated in Figure 1, which depicts subjects separated into a normal group and a group with pathology on the basis of preoperative and postoperative fundus examination. In the group with pathology limited by retinal-neural factors, there was considerable correlation between preoperative and postoperative logMAR acuity, as expected, because the major factor limiting visual performance was not removed. However, normal subjects displayed a lack of correlation between these two measures because the factor limiting visual acuity was removed by Nd:YAG laser therapy.

In contrast, preoperative measures of DTH remain relatively unaffected by image degradation in the normal group and the group with pathology (Fig. 2). The finding that preoperative DTH is highly correlated with postoperative DTH demonstrates that these measures are highly resistant to the image-degrading effects of posterior capsular opacification. This has been demonstrated in studies of patients with cataract and simulated cataract. The fact that the group with pathology had significantly higher DTH than the normal group and the group with pathology indicates that the test is sensitive to abnormal retinal-neural function. Preoperative DTH measures can be used to help distinguish between patients with retinal disease and normals, and they provide a better prediction of postoperative logMAR acuity than preoperative logMAR acuity.

A patient with dense opacification, visual acuity of 3/60 (1.3 logMAR), and displacement threshold of 400 seconds of arc is unlikely to have visual loss caused solely by the image-degrading effects of the capsular opacification. Based on the results of this study, such a displacement threshold indicates a postoperative acuity of approximately 0.8 logMAR (Snellen equivalent of 6/38). Although postoperative visual acuity may be restricted, it remains a substantial improvement over the preoperative acuity level, and, in this respect, the capsulotomy is beneficial. The information provided by the DTH task may allow the clinician to determine a guarded prognosis about the level of postoperative vision. Conversely, a patient with a low DTH (30 seconds of arc) probably does not have retinal disease that will restrict vision after surgery. The idea of separating patients with retinal disease from normals becomes problematic near the cutoff area of 2.01 log units (102 seconds of arc). In this region, DTH does not provide a conclusive answer but does provide additional information with which the clinician can advise the patient.

The correlation between preoperative DTH and postoperative logMAR acuity could perhaps be improved on by using a more sophisticated psychophysical technique, such as a two-alternative, forced-choice procedure that is not criterion dependent. This would eliminate the bias introduced by allowing a patient to set his or her own threshold; subjects who are cautious in their responses record higher thresholds than do confident subjects. If a psychophysical test such as DTH is to be applied to an elderly population in a busy clinical environment, relevant information must be collected as rapidly as possible, which often precludes the use of sophisticated psychophysical procedures.

In this study, the quality of visual function after surgery has been defined in terms of postoperative visual acuity. However, it should be noted that the choice of visual acuity as a "gold standard" is an arbitrary one based only on clinical convenience and general acceptance. Displacement threshold hyperacuity reflects an alternative but equally valid aspect of visual function. Perhaps it is surprising that these two tasks correlate at all because they measure very different aspects of visual function. A more appropriate gold standard for postoperative visual function might be the measurement of contrast perception near the peak of the contrast sensitivity function. Reports have suggested that low and medium spatial frequency information play a vital role in our perception of the normal visual environment. Therefore, to measure only the highest resolvable spatial frequency, as we do in determining logMAR acuity, does not reflect fully the tasks subjects are faced with daily after surgery.

Theory of signal detection can be used to assess the ability of different tests to discriminate between normal and abnormal retinal-neural function. The value $d'$ (an index of discrimination) is equal to the difference between the mean preoperative test scores of the pathologic and normal distributions expressed in standard deviation units of the normal distribution.

This form of analysis has been applied to pre-
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TABLE 1. Results

<table>
<thead>
<tr>
<th>Method</th>
<th>P (hit)</th>
<th>P (false alarm)</th>
<th>d'</th>
<th>n</th>
</tr>
</thead>
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<tr>
<td>DTH</td>
<td>0.87</td>
<td>0.17</td>
<td>2.08</td>
<td>39</td>
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<tr>
<td>IF</td>
<td>0.50</td>
<td>0.16</td>
<td>0.99</td>
<td>59</td>
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<tr>
<td>PAM</td>
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<td>0.55</td>
<td>1.51</td>
<td>47</td>
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<td>BFE</td>
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<td>0.18</td>
<td>2.96</td>
<td>61</td>
</tr>
<tr>
<td>PVS (T-SE)</td>
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<td>0.01</td>
<td>1.71</td>
<td>159</td>
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<tr>
<td>FGP (T-SE)</td>
<td>0.96</td>
<td>0.14</td>
<td>2.83</td>
<td>159</td>
</tr>
</tbody>
</table>

DTH = displacement threshold hyperacuity; IF = interferometry; PAM = Potential Acuity Meter; BFE = blue-field entoptoscopy; PVS = perception of Purkinje vessel shadows using a transcleral entoptic technique; FGP = foveal granular pattern; T-SE = transscleral entoptic perception.

The following techniques were chosen for comparison: interferometry (IF); Potential Acuity Meter (PAM); transscleral entoptic perception (T-SE).

and blue-field entoptoscopy (BFE). A value for d' has been calculated for the perception of Purkinje vessel shadows (PVS) and the foveal granular pattern (FGP) in the transscleral entoptic test.

Results are summarized in Table 1 and represented by graph in Figure 6. The data at the top left-hand corner of the graph (Fig. 6) indicate that the test can discriminate well between normal and abnormal populations. From this analysis, macular entoptic techniques and DTH appear to be better discriminators of normal and anomalous retinal–neural function than other reported procedures such as PAM, IF, and PVS.

In considering the above comparison, we must recognize the different subject samples, the distribution of these samples, and the severity of the retinal diseases. Ideally, to obtain a true index of discrimination for each of the tests, d' should be calculated for each method on the same population.

In conclusion, the results of this study indicate that preoperative measures of displacement threshold will not only afford the clinician a good indication of the level of postoperative vision, it also will provide a benchmark to assess the likelihood of coexisting retinal disease.

Key Words
capsular opacification, hyperacuity, retinal–neural function

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References