

# Spaeth/Richman Contrast Sensitivity in Staging Glaucoma

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**Purpose:** To investigate contrast sensitivity measures in glaucoma eyes with moderate to severe glaucoma.

**Methods:** The study included 50 eyes of 47 pseudophakic patients with moderate or severe glaucoma who were seen at a tertiary center from 2017 to 2020. Assessment of contrast sensitivity using the Spaeth/Richman contrast sensitivity (SPARCS) test and the Pelli–Robson (PR) chart was compared in eyes with mean deviation (MD) < –12 decibels (dB) and > –20 dB (group 1), MD < –20 dB and > –30 dB (group 2), or MD < –30 dB (group 3). Multivariate regression analysis was used to analyze the association of visual field MD with SPARCS/PR scores and various clinical variables, including age, diagnosis, and logMar visual acuity.

**Results:** SPARCS total scores and quadrant-wise scores were significantly different in all of the quadrants, whereas central scores and PR contrast sensitivity were similar across groups. The total SPARCS scores predicted the change in MD ( $\beta = 0.5$ ,  $P < 0.001$ ,  $R^2 = 61.8\%$ ) with minimal association of other quadrant or PR scores. Total SPARCS scores of <45 and <38 predicted severe glaucoma with MD crossing –20 dB (sensitivity, 70.5%; specificity, 80.9%) and –30 dB (sensitivity, 79.3%; specificity, 77.7%), respectively. The logMar visual acuity did not correlate with any contrast sensitivity measure or clinical variables in this study.

**Conclusions:** The total SPARCS score may be used in staging glaucoma severity and to assess visual function in eyes with severe glaucoma.

**Translational Relevance:** The SPARCS test is a useful tool for assessing visual function in advanced glaucoma beyond MD worse than –20 dB or –30 dB.

## Introduction

The visual field remains the gold standard for assessing visual function and estimating disease progression in glaucoma.<sup>1,2</sup> Evaluating the visual field is an important tool for monitoring glaucoma that not only provides quantifiable measures of residual visual function but also helps predict the future course of the disease. Despite the utility of evaluating the visual field in routine clinical practice, limitations for its use among elderly people with field defects include long testing time, effects of fatigue, and requiring attentiveness and an understanding of the test procedure.<sup>3</sup> These limitations pose a problem for patients with advanced field loss, who are elderly, or who have motor instability, poor attention, or dementia. In these situations, there

is a need for alternative tests to monitor the disease and prevent its progression.

Other visual function measures include contrast sensitivity and vision-related quality of life (QOL) assessment.<sup>4–10</sup> Although QOL assessment can be an invaluable tool, QOL measures evaluate the overall status of the patient, in addition to functional impairment of vision-related daily activities; therefore, it has not gained popularity as a tool for clinicians in routine glaucoma care.<sup>4,6</sup> The subjective performance of these QOL questionnaires limits their utility in deciding treatment decisions in glaucoma. Contrast sensitivity, usually measured by the Pelli–Robson (PR) chart, may be decreased even when visual acuity is normal in glaucoma. The PR chart is an effective and easy way of measuring spatial contrast sensitivity in patients with glaucoma and is compatible with routine clinical

settings. The testing time is less than 5 minutes and is reported to be both reproducible and reliable.<sup>5,7,8</sup> This test correlates well with motor vehicle accidents among glaucoma patients with normal central visual acuity<sup>4,5</sup> and has been reported to correlate well with QOL measures and limitation of daily activities.<sup>5</sup> Yet, the PR chart only measures contrast sensitivity in the center, which is an inadequate measure of visual function in a glaucoma patient with peripheral field defects in the arcuate area.<sup>8,9,10-11</sup>

The Spaeth/Richman contrast sensitivity (SPARCS) test is a recently developed online testing strategy that evaluates contrast sensitivity in four peripheral quadrants and one central quadrant.<sup>10-14</sup> The peripheral quadrants correlate to the quadrants of typical glaucomatous visual field defects, thus making the SPARCS test more applicable for use in routine care. It also uses square wave gratings instead of letters and a bracketing technique similar to that used in visual fields for measuring the contrast in each quadrant.<sup>10</sup> The test is easy to understand, as the patient only has to identify the quadrant where the gratings are presented, and the short testing time avoids fatigue effects that could confound results. Earlier studies have shown excellent correlation with visual field parameters and central visual acuity.<sup>13,14</sup> The global SPARCS score (a single measure similar to the Visual Field Index, which is a measure of residual visual function) and PR sensitivity scores have been shown to significantly correlate with subjective measures of QOL measures and vision-related performance.<sup>12,13</sup> Previous studies have used a mixed cohort of phakic and pseudophakic eyes, which may influence central and peripheral contrast sensitivity. Although the Visual Field Index is believed to be minimally affected by media opacities, studies have shown that results may be affected by specific locations of the cataract.<sup>1,3,15</sup> Further, visual fields have to be interpreted with caution in eyes with advanced field defects due to floor effects and greater variability.<sup>3</sup> In eyes with severe glaucoma, we need to determine whether contrast sensitivity could be a useful tool to continually measure visual function. For this purpose, this study evaluated the performance of the SPARCS test and visual field measures in pseudophakic eyes with advanced glaucoma.

## Methods

Consecutive patients with glaucoma who had undergone visual field testing at a tertiary eye center in east India from 2017 to 2020 were screened. Details retrieved from the hospital database included slit-

lamp findings, Goldman applanation intraocular pressure, logMar best-corrected visual acuity (BCVA), gonioscopy, fundus biomicroscopy, and visual field parameters. Because media opacities such as cataract may potentially influence contrast and the visual field, patients who had undergone surgery with intraocular implantation (AcrySof SA60AT single-piece hydrophobic lens only; Alcon, Geneva, Switzerland) were included in the study, but patients with aphakia, other types of lenses (e.g., those with yellow tint), or intraoperative or postoperative complications were excluded. Patients with associated retinal pathologies, high myopes (>6 diopter sphere), cataract of any grade, or neurological conditions that could potentially affect the visual field were also excluded. The study conformed to the tenets of the Declaration of Helsinki and was approved by the institutional review board of LV Prasad Eye Institute, Mithu Tulsu Chanrai Campus, Bhubaneswar, India.

The visual field was evaluated with a Humphrey 750 Visual Field Analyzer (Carl Zeiss Meditec, Dublin, CA) using the Swedish interactive thresholding algorithm and 24-2 test strategy (and 10-2, if needed, for defects involving the center). Visual defects were defined as glaucomatous if they corresponded to disc findings and glaucoma hemifield tests outside normal limits or to pattern standard deviations with probability < 5%; fixation losses < 15% and false positives and false negatives < 30% determining reliability. Only reliable fields were considered for inclusion, and unreliable fields (false-positive and fixation losses > 15%) were excluded. Patients were stratified into groups based on glaucoma severity mean deviation (MD): group 1, MD < -12 dB and > -20 dB; group 2, MD < -20 dB and > -30 dB; and group 3, MD < -30 dB. Eyes with early glaucoma (MD > -12 dB) were excluded.

## Contrast Measurement

The contrast sensitivity for all patients was measured by two independent optometrists blinded to the clinical or visual field details of the patient under the supervision of the clinician. Contrast sensitivity was tested monocularly using the PR test followed by the SPARCS test. The average scores of both tests performed twice for each eye were recorded and used for analysis. The PR contrast sensitivity wall-mounted chart uses eight horizontal lines of large Sloan letters with a stepwise decrease in contrast of 0.15 log units after every three letters to measure contrast in the central region. The patient is asked to read the lowest possible line appreciable from 1 meter from the chart with a luminance set at 85 candelas/m<sup>2</sup>.

The SPARCS test is an Internet-based contrast sensitivity measure (<http://www.sparcscontrastcenter.com>) that is used to test the contrast sensitivity across four different quadrants (superotemporal, superonasal, inferotemporal, and inferonasal) and the central region. The detailed method for conducting the SPARCS test is described elsewhere.<sup>10</sup> The SPARCS test also determines contrast sensitivity in the center across an area spanning 5° horizontally and 3.5° vertically.<sup>10–12</sup> Briefly, the test is administered on a computer screen (22 cm wide by 26.5 cm high, 1064 × 768 resolution, 256 gray levels) after creating a unique identifier on the website and providing full instructions to the patient.<sup>10</sup> The patient is seated at 50 cm which ensures that the test spans 30° horizontally and 23.5° vertically. The patient is asked to fixate at the center and point toward the quadrant where vertical gratings are shown for 0.3 seconds. Failure to identify the gratings at any quadrant is registered as a failed attempt; the log-based scores for each of the five testing regions are scaled from 0 to 20, making the highest possible SPARCS score 100.

The test strategy is similar to the strategy used in visual field testing, with the luminance of the square wave gratings of vertical bars being presented in each quadrant in a staircased manner with reversals. There are 17 potential contrast levels that can be presented at any quadrant, with the range of contrast varying between 0.45% and 100% (log contrast sensitivity, 0.00–2.35). This essentially means, after a correct response, the levels are increased by four levels until an incorrect response occurs and then decreased by two levels to determine the contrast sensitivity threshold after a robust one-level stepwise fine tuning at each quadrant.

### Statistics

All statistical analyses were conducted using Stata (StataCorp, College Station, TX) with statistical significance set at  $P < 0.05$ . Continuous variables are represented as mean ± SD or as median (range), and categorical variables are depicted as proportions. Demographics, clinical variables, and PR contrast/SPARCS test scores were compared among groups using the Kruskal–Wallis test with post hoc Dunn’s test. The association of visual field indices (MD) with SPARCS/PR scores and clinical variables such as age, intraocular pressure, fundus changes, and logMAR visual acuity was analyzed using multivariate linear regression analysis. Receiver operating characteristic (ROC) curves were used to define contrast score cutoffs to adequately stratify glaucoma severity based on MD.

**Table 1.** Demographics of Patients with Advanced Glaucoma ( $N = 50$  Eyes)

Variable	Value
Male:female ( $n$ )	36:11
Right eye:left eye ( $n$ )	28:22
Type of glaucoma ( $n$ )	
POAG	14
PACG	16
PXG	20
Type of visual field defect ( $n$ )	
Superior arcuate only	7
Inferior arcuate only	6
Incomplete biarcuate	14
Complete biarcuate	23
Age (y), mean ± SD	65 ± 7.7
Visual acuity score (logMar), mean ± SD	0.25 ± 0.25
PR chart score, mean ± SD	1 ± 0.3
Central SPARCS test score, mean ± SD	10 ± 2.9

## Results

Of 98 eyes of 102 patients screened during the study period, we excluded 23 patients due to incomplete data, 26 patients who had unreliable fields, and six patients with associated retinal pathologies. We finally included 50 eyes of 47 patients with moderate or severe glaucoma, which included primary open-angle glaucoma (POAG), primary angle-closure glaucoma (PACG), and pseudoexfoliation glaucoma (PXG), with a mean age of 65 ± 7.7 years (Table 1). Complete biarcuate defects were found in 46% of eyes, and defects involving one hemifield in the superior or inferior quadrant were seen in 26% of eyes (Table 1).

Comparing variables in the different groups, age and logMar BCVA were not statistically different among the groups (Table 2). PR scores also were not significantly different among the groups (Table 2, Fig. 1). The SPARCS total and quadrant-wise scores were significantly different in all the quadrants, and the central score was similar across groups (Table 2).

Univariate analysis showed a positive correlation between PR scores and SPARCS central scores ( $r = 0.4$ ,  $P = 0.004$ ), as well as scores for right lower ( $r = 0.5$ ,  $P < 0.001$ ), left upper ( $r = 0.4$ ,  $P = 0.001$ ), and left lower ( $r = 0.6$ ,  $P < 0.001$ ) quadrants and total SPARCS scores ( $r = 0.6$ ,  $P < 0.001$ ). PR scores also correlated significantly with the MD ( $r = 0.4$ ,  $P = 0.004$ ), but no correlation was found with age or BCVA. BCVA correlated negatively with all contrast scores, although none of the correlations reached statistical significance. On multivariate analysis, only total SPARCS scores ( $\beta = 0.5$ ,

**Table 2.** SPARCS Scores, Clinical Variables, and Glaucoma Severity

Variable	Mean ± SD			P <sup>a</sup>
	Group 1 (n = 14)	Group 2 (n = 21)	Group 3 (n = 15)	
Age (y)	65 ± 7.1	67 ± 8.1	60 ± 6.01	NS
PR chart score	1 ± 0.2	1 ± 0.3	1 ± 0.2	NS
SPARCS test score				
Center	11 ± 2.2	9 ± 2.5	9 ± 4.3	NS
Right upper	11 ± 3.02	9 ± 3.6	7 ± 3.6	0.02
Right lower	10 ± 2.8	7 ± 3.7	4 ± 2.4	0.002
Left upper	11 ± 3.4	9 ± 3.4	6 ± 4.5	0.07
Left lower	11 ± 1.7	5 ± 3.3	2 ± 2.1	0.001
Total	56 ± 8.1	40 ± 11.4	29 ± 8.08	0.0002
BCVA (logMar)	0.1 ± 0.1	0.3 ± 0.2	0.1 ± 0.2	NS

NS, not significant.

<sup>a</sup>Kruskal–Wallis with post hoc Dunn test (maximal differences seen between group 1 and group 3 for all variables).

$P < 0.001$ ,  $R^2 = 61.8\%$ ) predicted the change in MD with minimal association of other quadrantic or PR scores (Fig. 2). Because the structure–function relationship becomes complex beyond MD < -20 dB, we also compared the association between eyes with MD < -20 and those with MD > -20 dB (Supplementary Fig. S1). The results were similar in these eyes, with the total SPARCS score significantly predicting the MD crossing -20 dB and no association of any other contrast measure with MD.

To determine whether these results were affected by a correlation between two eyes of the same patient, we repeated the analysis after excluding the better eye when both eyes were included and did not find any significant difference in the results (Supplementary Table S1).

Areas under the curve (AUCs) and ROC curves were plotted for various sensitivities and specificities of SPARCS total scores to classify severe glaucoma (MD < -20 dB). A cutoff for the total SPACRS score of 45 provided the maximum AUC (0.85; 95% confidence interval [CI], 0.73–0.97) with a sensitivity of 70.5% and specificity of 80.9% for predicting severe glaucoma with MD crossing -20 dB. Similarly, we also analyzed a cutoff of <38 for an AUC of 0.82 (95% CI, 0.69–0.95) with sensitivity of 79.3% and specificity of 77.7% to predict MD crossing -30dB (Table 3).

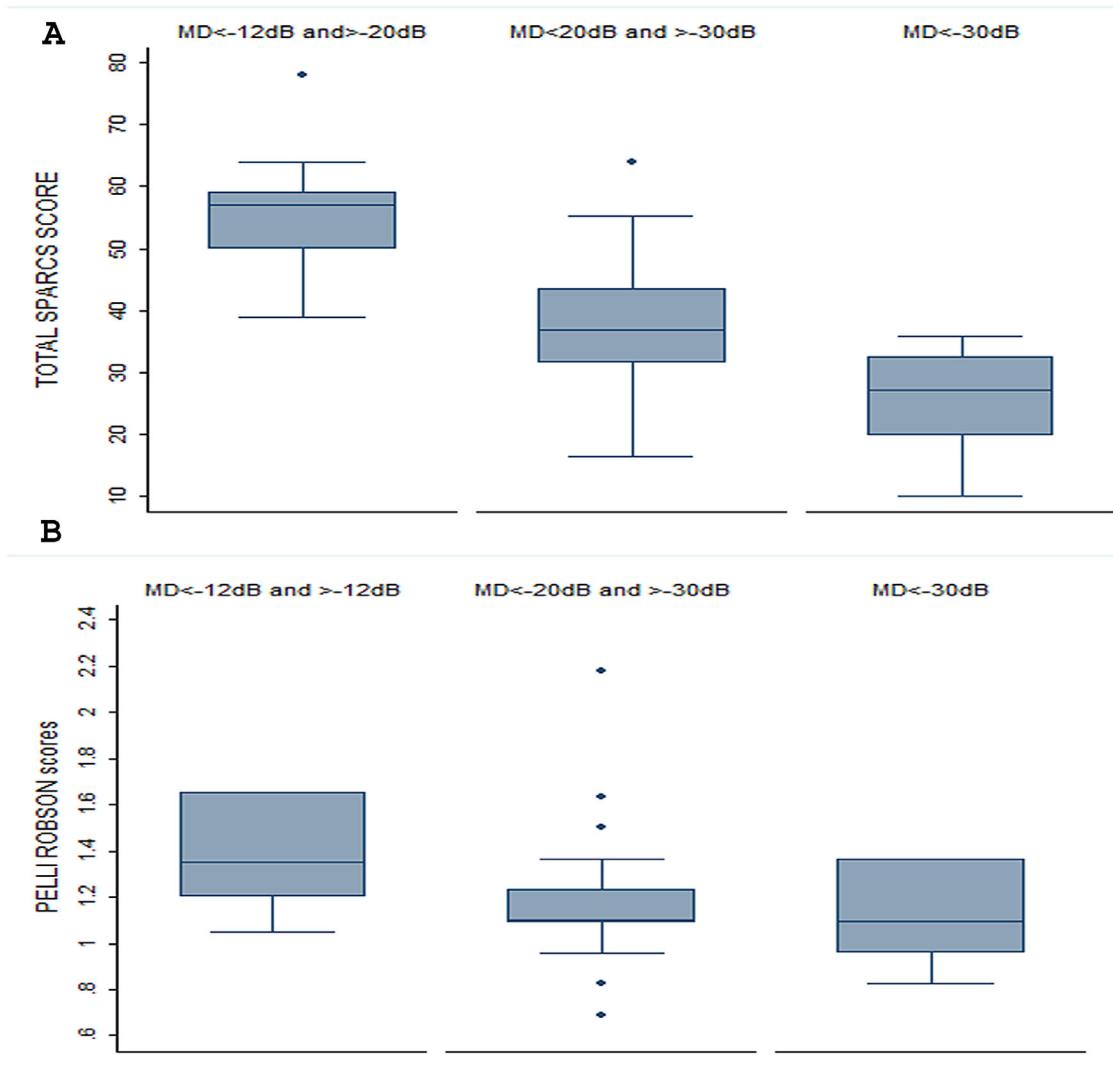
## Discussion

This study identified contrast-based cutoffs for staging visual field MD beyond -20 dB and -30 dB where floor effects cause problems in predicting glaucoma progression. The total SPARCS score

was the only score that significantly influenced the change in MD with minimal association of PR scores or other variables. The logMar visual acuity did not correlate with the contrast functions measured with either SPARCS or PR in this study, which evaluated pseudophakic eyes only. We chose to study only severe glaucoma eyes to investigate utilizing the SPARCS test as a complement to visual fields. The SPARCS test was administered by optometrists blinded to the clinical details of the patient under the doctor’s supervision, which made the process more reliable than patients self-administering the test.

The visual field is the gold standard for monitoring glaucoma progression.<sup>1,2,4</sup> In eyes with severe glaucoma, when floor effects gain prominence in eyes with MD < -20 dB, changes in visual field parameters have to be interpreted with caution.<sup>3</sup> Variability in threshold sensitivity in eyes with severe glaucoma and the different test strategies available has prompted a search for alternative modes of monitoring disease progression in these eyes. Contrast sensitivity is a robust measure of ganglion cell function that directly reflects the state of retinal ganglion cells in eyes with glaucoma. Traditionally, the PR chart has been used for measuring contrast, but it is limited due to its measuring contrast only in the central region.<sup>8,9,13,14</sup> Glaucomatous defects conventionally involve the peripheral arcuate regions and progression is more common in these regions. The PR chart, therefore, has limited utility in assessing the true extent of visual function in glaucoma. The SPARCS test is a new innovative tool for measuring visual function in glaucoma in different quadrants, which is an advantage over the PR chart, which measures only central contrast sensitivity.<sup>10–12,16</sup> The SPARCS test has been shown to be reliable and reproducible across various studies and has demon-





**Figure 1.** Comparison of total SPARCS test scores (A) and PR contrast sensitivity (B) in eyes with varying glaucoma severity.

strated excellent correlation with visual field parameters.<sup>10,12</sup> This study concurred with earlier studies showing good correlation of visual field MDs with PR and SPARCS scores.<sup>13,16–18</sup> Earlier studies have used mixed cohorts of eyes with cataract, which may have influenced the results; the present study included only pseudophakics.

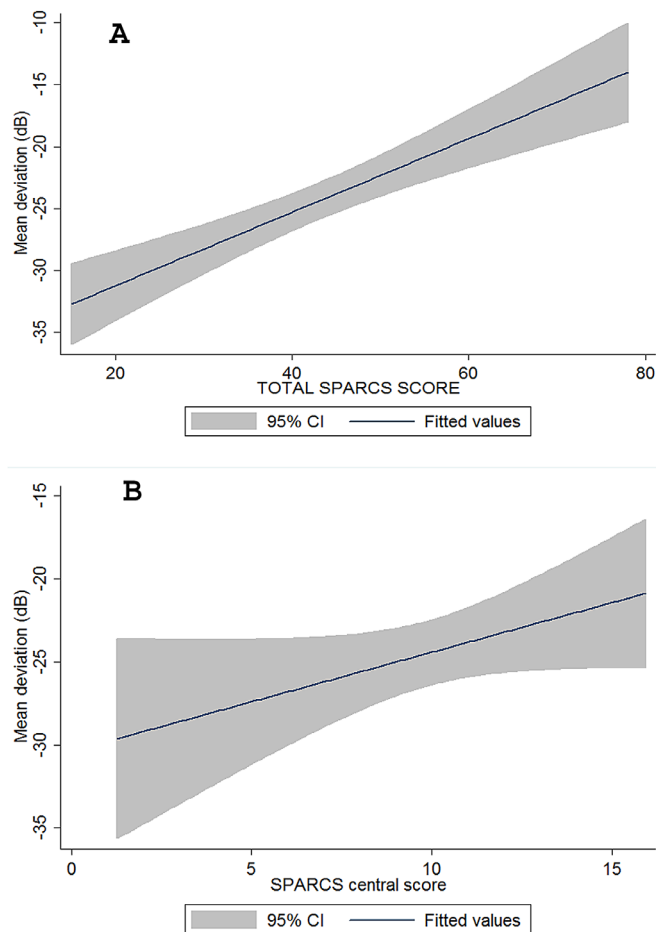
The PR chart has been traditionally used for contrast sensitivity assessment for glaucoma and other ocular disease. Not only is it a quick and easy test, but it has also been found to correlate well with visual acuity and visual functions such as driving.<sup>5,7</sup> Our study, however, did not find any correlation with logMar visual acuity.<sup>5,7–9</sup> This can be attributed to the inclusion of pseudophakics in this study, which removed bias arising from a cataract-induced reduction in contrast threshold sensitivities. Although studies have reported good reliability of the PR chart in

glaucoma, no study has evaluated the performance of the PR chart in different stages of glaucoma. The comparison of PR scores for the different severities of glaucoma in this study reflects the limitations of the PR chart with regard to measuring global contrast sensitivity function, which is minimally affected by disease progression. It may be argued that this study does not represent a routine clinical setting where patients with cataract are common; yet, the results of this study highlight the benefits of using the SPARCS test compared to the PR chart for glaucoma patients.

Contrast sensitivity has not gained wide acceptance among clinics as a routine measure of visual function, although the decline of contrast sensitivity with increasing glaucoma severity is well known. Limitations on daily activities related to vision and QOL measures are commonly used measures of vision-related problems in glaucoma<sup>6,7,19–23</sup>; however, there

**Table 3.** Estimated Range of Total SPARCS Scores and AUCs for Predicting MDs Crossing -20 dB or -30 dB

MD (dB)	Range of SPARCS Total Scores	AUC	Standard Error	95% CI
< -20	44–78	0.852	0.06	0.73–0.97
< -30	15–38	0.823	0.06	0.69–0.95



**Figure 2.** Quadrantic fit plots of MD on visual fields versus SPARCS total score (A) and central score (B).

is considerable variability in QOL responses among patients with similar severity of disease. It is also known that changes in various aspects of QOL may not manifest until the central vision is affected in very advanced glaucoma, although defects affecting central vision may affect QOL very early, thus limiting its role in monitoring eyes with glaucoma.<sup>21,22</sup> Further, QOL responses may also be affected by other factors, such as the presence of cataract-like visual field indices, thus requiring a simple, quantitative measure of visual function in glaucoma.<sup>24–28</sup> SPARCS test scores have been shown to correlate with other measures of visual function and structural changes such as retinal nerve fiber layer thickness. Our study results indicate that SPARCS testing for visual function assessment in severe glaucoma provides more accurate results than

PR scores, suggesting that the SPARCS test could serve as a surrogate measure of visual function in routine glaucoma practice.<sup>23</sup>

Central visual acuity is least affected, even in advanced glaucoma, but central PR and central SPARCS score correlate well with central visual acuity and visual field parameters.<sup>9,11,13</sup> This study found no correlation between logMar visual acuity and any contrast sensitivity measure, which contrasts with earlier studies. The reason may be attributed to inclusion of pseudophakic eyes and the exclusion of eyes with cataract or media opacities, thus inducing potential bias.

We did not evaluate QOL, as subjective improvement of vision in pseudophakia could confound results. We did not include eyes with early glaucoma, because the need for alternative measures of visual function assumes importance only in eyes with advanced defects. We believe that a longitudinal study comparing contrast sensitivity and visual fields in stable and progressing eyes may confirm the advantages of routine use of the SPARCS test for monitoring disease progression. Nevertheless, this study suggests that contrast-based glaucoma staging may be of value in evaluating elderly patients and could serve as a complement to visual field testing of patients with severe defects or motor instability.

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AR conceived of and designed the study; AR, AP, and SM acquired, analyzed, and interpreted the data; AR drafted the manuscript; and AR, AP, and SM gave final approval of the manuscript.

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