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ORIGINAL RESEARCH

STRUCTURED MULTIMODAL OPHTHALMIC EXAMINATION WITH STANDARD AUTOMATED PERIMETRY FOR THE DETECTION, STAGING AND MANAGEMENT OF GLAUCOMA

Tejasree Jakka[1], **Pallavi P**[2], **Shreya Reddy** [3*]

[1] *Assistant Professor, Department of Ophthalmology, Ayaan Institute of Medical Sciences, Hyderabad, Telangana*
[2] *Associate Professor, Department of Ophthalmology, Ayaan Institute of Medical Sciences, Hyderabad, Telangana*
[3] *Associate Professor, Department of Ophthalmology, Ayaan Institute of Medical Sciences, Hyderabad, Telangana*

*Correspondence: Shreya Reddy <bshreyareddy@gmail.com>

ABSTRACT

Background: Glaucoma is the leading cause of irreversible blindness and typically remains symptomless until substantial optic-nerve damage has occurred. Because no single test is sufficient for diagnosis, a structured examination combining tonometry, gonioscopy, optic-disc assessment, optical coherence tomography (OCT) and standard automated perimetry (SAP) is recommended. This study describes the diagnostic yield, severity distribution and treatment outcomes of such a pathway in an Indian tertiary care setting. **Methods:** In this prospective observational study, 196 consecutive patients with suspected or established glaucoma underwent a standardized evaluation comprising best-corrected visual acuity, slit-lamp examination, Goldmann applanation tonometry, gonioscopy, pachymetry where available, dilated stereoscopic optic-disc assessment, OCT of the retinal nerve fibre layer (RNFL) and macular ganglion-cell complex, and SAP. Patients were classified by mechanism and staged by the Hodapp–Parrish–Anderson criteria, managed individually with medical, laser or surgical treatment, and followed with repeat tonometry, OCT and perimetry. **Results:** Mean age was 58.4 ± 11.7 years and 124 patients (63.3%) were men. Established glaucoma was present in 144 (73.5%) primary open-angle in 91 (46.4%), primary angle-closure in 31 (15.8%), secondary in 14 (7.1%) and normal-tension in 8 (4.1%) while 36 (18.4%) were glaucoma suspects and 16 (8.2%) had ocular hypertension. OCT detected RNFL abnormality in 151 (77.0%), against reproducible field defects in 144 (73.5%); structure–function correspondence was present in 132 (67.3%). Of the established cases, 54 (37.5%) were early, 48 (33.3%) moderate and 42 (29.2%) severe; RNFL thickness correlated with mean deviation ($r = 0.68$) and visual field index ($r = 0.64$; both $p < 0.001$). Initial management was medical in 103 (71.5%), laser in 21 (14.6%) and surgical in 20 (13.9%). Mean IOP fell from 23.8 ± 6.4 to 15.9 ± 3.1 mmHg (33.2%; $p < 0.001$); at final assessment 132 (91.7%) had IOP ≤ 18 mmHg, 126 (87.5%) had stable or improved fields and 18 (12.5%) showed progression. **Conclusion:** A structured multimodal pathway detected structural damage somewhat more often than functional loss, staged disease reliably, and achieved target pressure in over 90% of treated patients. Nearly a third of patients nonetheless presented with severe disease, underlining the need for earlier case-finding in the Indian population.

Keywords: Glaucoma; Standard automated perimetry; Optical coherence tomography; Retinal nerve fibre layer; Gonioscopy; Intraocular pressure; Hodapp-Parrish-Anderson

INTRODUCTION

Glaucoma is a chronic progressive optic neuropathy in which loss of retinal ganglion cells produces characteristic excavation of the optic nerve head, thinning of the retinal nerve fibre layer (RNFL) and corresponding visual-field defects. It is the leading cause of irreversible blindness worldwide: a pooled analysis of fifty population-based studies estimated a global prevalence of 3.5% among people aged 40–80 years, with some 112 million affected projected by 2040 [1]. The burden is shifting towards South Asia, where the number of affected individuals is projected to nearly double between 2013 and 2040, and where prevalence rises steeply with age with primary open-angle glaucoma (POAG) the dominant subtype [2]. In India the disease is doubly dangerous because it is usually silent: hospital- and population-based studies

alike show that a large proportion of patients are undiagnosed at presentation, by which time optic-nerve damage is established and irreversible [3].

No single measurement diagnoses glaucoma. Intraocular pressure (IOP) is the principal modifiable risk factor, but characteristic neuropathy occurs at statistically normal pressures and many with ocular hypertension never develop damage; conversely, gonioscopy is indispensable for separating open-angle from angle-closure mechanisms, which are managed differently. Contemporary guidance, including the Indian appraisal of the European and Asia-Pacific guidelines, therefore requires a multimodal assessment: visual acuity, slit-lamp examination, applanation tonometry, gonioscopy, careful evaluation of the optic nerve head and RNFL, and standardized visual-field testing [3].

Standard automated perimetry (SAP) remains the reference method for documenting functional loss. Mean deviation (MD), pattern standard deviation (PSD), the visual field index (VFI) and the glaucoma hemifield test quantify the presence and depth of damage, and serial fields measure its rate of change: Indian prospective data show that formal progression analysis adds clinically useful information beyond the baseline examination [4], and comparisons of MD-based with pointwise methods emphasise the value of longitudinal, location-specific analysis, particularly for central and paracentral loss [5]. Optical coherence tomography (OCT) complements perimetry by quantifying peripapillary RNFL, neuro-retinal rim and macular ganglion-cell parameters, and can reveal abnormality before reproducible field loss appears; recent Indian work comparing OCT with OCT angiography in suspects and early glaucoma illustrates the growing role of structural and vascular imaging at this stage [6]. Structural findings must nevertheless be interpreted alongside the disc appearance, IOP, gonioscopy and fields rather than in isolation.

Severity is conventionally staged from the visual field. The Hodapp–Parrish–Anderson (HPA) criteria grade damage as early, moderate or severe principally by MD [7], and staging matters because target pressure, review interval and the threshold for surgery all depend on it. Management ranges from observation in low-risk suspects through topical therapy with prostaglandin analogues the usual first-line agents to laser procedures and incisional surgery. Selective laser trabeculoplasty is now supported as primary therapy for open-angle disease by randomised evidence [8], laser iridotomy remains the initial step in angle closure, and trabeculectomy is still the commonest filtration operation in Indian practice, with drainage devices and minimally invasive procedures reserved for selected eyes [3,9]. The economic weight of lifelong therapy in India is considerable and itself shapes treatment choice [10].

The present prospective study was undertaken to evaluate a structured pathway combining comprehensive clinical examination, gonioscopy, tonometry, OCT and SAP for the detection and staging of glaucomatous damage; to examine the relationship between structural and functional loss; and to document the treatment given and the clinical, structural and functional outcomes in 196 consecutive patients at a tertiary care teaching hospital.

MATERIALS AND METHODS

Study design and setting

This prospective observational study was conducted in the Department of Ophthalmology, Ayaan Institute of Medical Sciences, Hyderabad, a tertiary care teaching hospital, between March 2023 and February 2025; participants were followed for a minimum of 12 months after initiation of management.

Ethical considerations

The study adhered to the Declaration of Helsinki and was approved by the Institutional Ethics Committee; a written informed consent was obtained from all participants, and data were handled in anonymized form.

Participants

Consecutive patients attending the ophthalmology outpatient department and glaucoma clinic with suspected or established glaucoma were enrolled. Patients were included if they were aged 18 years or older; had suspected or established glaucoma on the basis of optic-disc, IOP or visual-field abnormality; and could cooperate with examination and produce

reliable automated perimetry. Patients were excluded for media opacity precluding disc or retinal assessment; previous trauma or non-glaucoma ocular surgery likely to confound field interpretation; retinal or neurological disease capable of producing non-glaucomatous field defects; advanced systemic illness preventing completion of the protocol; persistently unreliable perimetry; or incomplete records or inadequate follow-up.

Sample size

All consecutive eligible patients presenting during the study period were enrolled, yielding 196 participants. For a descriptive study of this kind, a sample of 196 estimates a proportion of 50% with an absolute precision of ±7% at 95% confidence ($n = 1.96^2 \times 0.5 \times 0.5 / 0.07^2 = 196$).

Baseline assessment

Every participant was examined against a structured proforma recording demographic detail, systemic and ocular history, family history of glaucoma, and previous medical or surgical glaucoma treatment. The examination comprised best-corrected visual acuity; assessment of pupillary reactions, including evaluation for a relative afferent pupillary defect; slit-lamp biomicroscopy with assessment of anterior chamber depth; indentation gonioscopy for angle classification using the Lens and Grading System; Goldmann applanation tonometry, repeated where indicated; central corneal thickness measurement by pachymetry, where available; and dilated fundus examination with detailed evaluation of the optic disc, including the cup-to-disc ratio, neuroretinal rim configuration, disc asymmetry, focal rim thinning or notching, disc haemorrhage, and peripapillary atrophy. These assessments were supplemented, where available, by stereoscopic optic disc photography.

Structural imaging

OCT of the optic nerve head and peripapillary RNFL and of the macular ganglion-cell complex was performed in all patients. Global and sectoral RNFL thickness, disc and rim parameters and ganglion-cell measurements were recorded. Findings regarded as suspicious for glaucoma were focal or diffuse RNFL thinning, superior or inferior arcuate defects, corresponding rim loss, and an increased or asymmetric cup-to-disc ratio, particularly where these corresponded topographically with the field.

Visual-field assessment

SAP was performed with a computerized perimeter using a standard threshold strategy under standardized stimulus conditions with fixation monitoring. MD, PSD, VFI where available, the glaucoma hemifield test and the reliability indices (fixation losses, false positives, false negatives) were recorded, and fields failing the instrument's reliability criteria were repeated where possible; 181 patients (92.3%) produced a reliable baseline field. Defects assessed included nasal steps, paracentral and arcuate defects, temporal wedges and defects respecting the horizontal meridian, and each was compared with the corresponding disc and RNFL findings.

Classification and staging

Patients were classified from the combined findings of IOP, gonioscopy, disc appearance, OCT and perimetry as glaucoma suspect, ocular hypertension or established glaucoma, the last subdivided into primary open-angle, primary angle-closure, secondary and normal-tension glaucoma. Patients with suspicious structural change but normal or borderline fields were regarded as possible pre-perimetric glaucoma; reproducible field defects with corresponding structural abnormality defined established functional disease. Severity of established glaucoma was staged by the HPA visual-field criteria early, MD better than −6 dB; moderate, −6 to −12 dB; severe, worse than −12 dB [7] supported by VFI, the pattern of loss and the OCT findings. One eye per patient was analysed; all reported IOP, MD, VFI and RNFL values refer to the study eye.

Management and follow-up

Treatment was individualised by mechanism, baseline IOP, disc and field status, age and rate of progression: observation in selected low-risk suspects; topical therapy with prostaglandin analogues, beta-blockers, alpha-2 agonists, carbonic-

anhydrase inhibitors or fixed combinations; laser peripheral iridotomy for angle-closure mechanisms and other laser procedures as indicated; and filtration or drainage-device surgery for inadequate control or progression despite maximal tolerated therapy. Patients were reviewed at intervals set by severity, with IOP, acuity, disc status, adherence, adverse events and progression documented, and OCT and perimetry repeated when clinically indicated. Principal outcomes were the detection of structural and functional glaucomatous damage and their concordance, the severity distribution, IOP control, field stability, the need for treatment escalation, and final disease status.

Statistical analysis

Data were analysed with [software, version]. Continuous variables are given as mean ± SD and categorical variables as number (percentage). Baseline and final IOP were compared by the paired t-test, and correlations between RNFL thickness and the field indices (MD, VFI) by Pearson's coefficient. A two-sided $p < 0.05$ was taken as significant.

RESULTS

Demographic characteristics

Of the 196 patients, 124 (63.3%) were men and 72 (36.7%) women (ratio 1.72:1). Ages ranged from 28 to 82 years (mean 58.4 ± 11.7), with the 51–60-year (57; 29.1%) and 61–70-year (53; 27.0%) groups the largest; three-quarters of the cohort were older than 50. A family history of glaucoma was present in 42 (21.4%), diabetes mellitus in 54 (27.6%), hypertension in 71 (36.2%), and 38 (19.4%) had received previous glaucoma treatment (Table 1).

Table 1. Demographic and baseline characteristics (n = 196)

Characteristic	n	%
Sex		
Male	124	63.3
Female	72	36.7
Age group (years)		
≤ 30	4	2.0
31–40	15	7.7
41–50	31	15.8
51–60	57	29.1
61–70	53	27.0
> 70	36	18.4
Mean ± SD	58.4 ± 11.7	
History		
Family history of glaucoma	42	21.4
Diabetes mellitus	54	27.6
Hypertension	71	36.2
Previous glaucoma treatment	38	19.4

Clinical and investigational findings

All 196 patients completed the full protocol. Mean baseline IOP was 23.8 ± 6.4 mmHg, and 119 (60.7%) had an IOP of 21 mmHg or more. The commonest disc abnormality was an increased or asymmetric cup-to-disc ratio (142; 72.4%), followed by focal rim thinning or notching (128; 65.3%); a disc haemorrhage was present in 24 (12.2%). Gonioscopy was abnormal in 43 (21.9%). OCT showed RNFL abnormality in 151 (77.0%) and ganglion-cell abnormality in 139 (70.9%), while reproducible glaucomatous field defects were present in 144 (73.5%); structure and function corresponded

topographically in 132 (67.3%) (Table 2). Structural abnormality on OCT was thus slightly more frequent than demonstrable field loss, the difference lying chiefly among patients with early or suspected disease.

Table 2. Principal clinical and investigational findings (n = 196)

Finding	n	%
IOP ≥ 21 mmHg	119	60.7
Increased/asymmetric cup-to-disc ratio	142	72.4
Neuroretinal-rim thinning/notching	128	65.3
Optic-disc haemorrhage	24	12.2
Abnormal gonioscopy	43	21.9
RNFL abnormality on OCT	151	77.0
Macular ganglion-cell abnormality	139	70.9
Reproducible glaucomatous field defect	144	73.5
Structure–function correspondence	132	67.3
Reliable SAP at baseline	181	92.3

IOP, intraocular pressure; OCT, optical coherence tomography; RNFL, retinal nerve fibre layer; SAP, standard automated perimetry.

Diagnostic classification

POAG was the commonest diagnosis (91; 46.4%), followed by primary angle-closure glaucoma (31; 15.8%), glaucoma suspect (36; 18.4%), ocular hypertension (16; 8.2%), secondary glaucoma (14; 7.1%) and normal-tension glaucoma (8; 4.1%) (Table 3). Established glaucoma was therefore present in 144 patients (73.5%), among whom POAG constituted 63.2%, angle-closure 21.5%, secondary 9.7% and normal-tension disease 5.6%.

Table 3. Diagnostic classification (n = 196)

Diagnostic category	n	%
Primary open-angle glaucoma	91	46.4
Primary angle-closure glaucoma	31	15.8
Secondary glaucoma	14	7.1
Normal-tension glaucoma	8	4.1
Glaucoma suspect	36	18.4
Ocular hypertension	16	8.2
Total	196	100.0

Severity

By HPA staging, 54 of the 144 established cases (37.5%) were early, 48 (33.3%) moderate and 42 (29.2%) severe. Mean MD deteriorated stepwise from −3.4 ± 1.5 dB in early to −8.7 ± 1.6 dB in moderate and −18.6 ± 5.2 dB in severe disease, with parallel declines in VFI (91.8 → 77.4 → 48.6%) and mean RNFL thickness (76.5 → 64.3 → 51.2 µm) (Table 4, Figure 1). RNFL thickness correlated with MD ($r = 0.68$, $p < 0.001$) and with VFI ($r = 0.64$, $p < 0.001$).

Table 4. Visual-field and structural parameters by severity (established glaucoma, n = 144)

Severity	n	Mean MD (dB)	Mean VFI (%)	Mean RNFL (µm)	Predominant field pattern
Early	54	−3.4 ± 1.5	91.8 ± 4.6	76.5 ± 8.7	Nasal step / early arcuate
Moderate	48	−8.7 ± 1.6	77.4 ± 7.2	64.3 ± 7.9	Arcuate / paracentral
Severe	42	−18.6 ± 5.2	48.6 ± 14.3	51.2 ± 8.5	Advanced arcuate / constricted

MD, mean deviation; VFI, visual field index; RNFL, retinal nerve fibre layer.

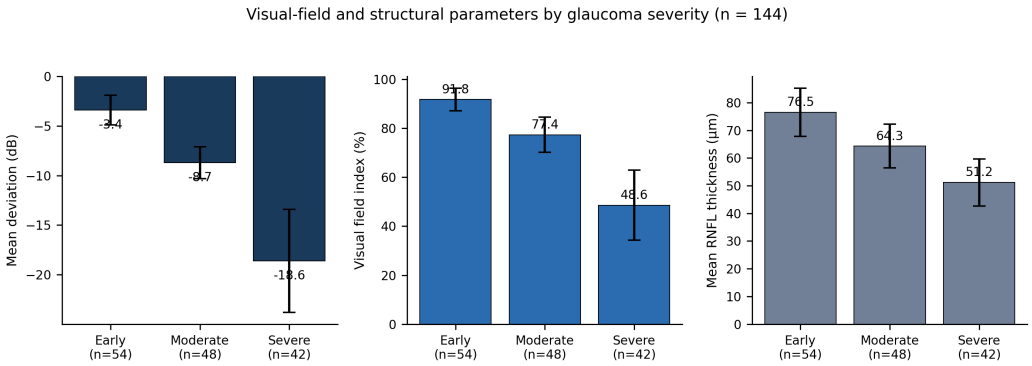

Figure 1. *Mean deviation, visual field index and RNFL thickness by severity stage (n = 144). Error bars show ± SD.*

Management and outcome

Of the 144 patients with established glaucoma, 103 (71.5%) were managed initially with topical therapy, 21 (14.6%) with laser and 20 (13.9%) with primary surgery for advanced disease, inadequate control or progression. Prostaglandin analogues were the commonest first-line agents (82; 56.9%), followed by beta-blockers (54; 37.5%), topical carbonic-anhydrase inhibitors (47; 32.6%) and alpha-agonists (29; 20.1%); 57 patients (39.6%) required combination therapy. Laser iridotomy was performed in appropriate angle-closure cases; trabeculectomy was the usual filtration procedure, with drainage devices in selected refractory eyes.

Mean IOP fell from 23.8 ± 6.4 mmHg at baseline to 15.9 ± 3.1 mmHg at final assessment, a reduction of 33.2% ($p < 0.001$). An IOP of 18 mmHg or less was achieved by 132 patients (91.7%); 126 (87.5%) had stable or improved fields and 128 (88.9%) structural stability on OCT. Treatment escalation was needed in 31 (21.5%), chiefly those with moderate-to-severe baseline disease, and 18 (12.5%) showed documented functional or structural progression, more often after presentation with severe disease. A serious treatment-related complication occurred in 4 patients (2.8%) (Table 5).

Table 5. Treatment and final clinical outcome (established glaucoma, n = 144)

Treatment / outcome	n	%
Initial management		
Medical therapy	103	71.5
Laser treatment	21	14.6
Primary glaucoma surgery	20	13.9
Medication use		
Prostaglandin analogue	82	56.9
Beta-blocker	54	37.5
Topical carbonic-anhydrase inhibitor	47	32.6
Alpha-agonist	29	20.1
Combination therapy required	57	39.6
Final outcome		
Final IOP ≤ 18 mmHg	132	91.7
Stable/improved visual field	126	87.5
Structural stability on OCT	128	88.9
Treatment escalation required	31	21.5
Documented progression	18	12.5
Serious treatment-related complication	4	2.8

Percentages use the 144 patients with established glaucoma as denominator

DISCUSSION

In this prospective series of 196 consecutive patients, a structured pathway combining clinical examination, gonioscopy, applanation tonometry, OCT and SAP allowed each patient to be classified by mechanism, staged by severity and treated accordingly. Three findings deserve emphasis: structural abnormality on OCT was detected somewhat more often than reproducible field loss; nearly a third of established cases were already severe at presentation; and individualised treatment achieved the target pressure in more than nine of ten patients, with documented progression in only one in eight over the follow-up period.

The cohort was predominantly male (63.3%) with a mean age of 58 years, a profile typical of hospital-based Indian glaucoma series, in which men and patients past the fifth decade predominate and primary glaucomas form the majority of the caseload [11,12]. POAG was the commonest diagnosis (46.4% of the cohort; 63.2% of established disease), with angle closure contributing about a fifth of established cases. Population-based work from southern India has shown that both open-angle and angle-closure disease contribute substantially to the Indian glaucoma burden, and that most affected individuals are undiagnosed in the community [13,14]; the reliance of classification on gonioscopy in every patient in the present study reflects the practical consequence of that epidemiology, since the two mechanisms diverge in management from the first visit.

OCT abnormality (77.0%) modestly exceeded reproducible field loss (73.5%), and the excess lay mainly among suspects and early disease the group in which structural measurement is expected to lead function. Macular ganglion-cell analysis was abnormal in 70.9%, and the diagnostic value of ganglion-cell parameters in early disease is well documented: ganglion cell-inner plexiform layer measurements discriminate early glaucoma with accuracy comparable to the best RNFL and disc parameters [15]. The correlations observed here between RNFL thickness and MD ($r = 0.68$) and VFI ($r = 0.64$) are of the size generally reported for the curvilinear structure–function relationship, and they support treating glaucoma as a structure–function diagnosis in which neither OCT nor perimetry alone suffices: structural imaging finds the disease early, and the field measures what matters to the patient.

The severity distribution 37.5% early, 33.3% moderate, 29.2% severe is sobering. Tertiary-care series from India consistently document a large fraction of advanced disease at presentation [11,12], and the pattern here, with severe disease concentrated among angle-closure and secondary cases, matches that experience. Opportunistic detection evidently fails a substantial minority of patients; systematic examination of high-risk groups those over 50, first-degree relatives, high myopes and diabetics is the practical remedy, and the structured pathway described here is directly transferable to that setting.

Treatment outcomes were satisfactory. Mean IOP fell by a third, 91.7% reached 18 mmHg or less, and 87.5% had stable or improved fields at final assessment. Most patients were controlled medically, with prostaglandin analogues predominating, in keeping with current first-line practice; randomised evidence now also supports selective laser trabeculoplasty as initial therapy in open-angle disease, achieving drop-free control in most eyes at three years [8], an option of obvious relevance where lifelong drop costs weigh heavily [10]. Where surgery was needed, trabeculectomy remained the default, consistent with Indian practice [3]; its effectiveness in difficult disease is well documented in refractory acute primary angle closure, trabeculectomy lowered median IOP from 42 to 13 mmHg at one year with 88% complete success [16] and multicentre audit data confirm high success rates of contemporary trabeculectomy more generally [17]. Minimally invasive procedures may suit selected eyes with milder disease and coexisting cataract, but the comparative evidence remains limited and heterogeneous [18]. The 12.5% progression rate must be read against the follow-up duration, which the authors are asked to state; stable pressure does not guarantee stable function, and continued perimetric and OCT surveillance is integral to the pathway rather than an optional extra.

Limitations

The study was conducted at a single tertiary centre, and its hospital-based population enriched with referred and advanced disease limits generalisation to the community. The follow-up period was limited to 12 months, restricting assessment of long-term progression and sustained surgical success. Treatment was individualised rather than randomised, so

comparisons between medical, laser and surgical groups are descriptive only. Perimetry is subject to learning and fatigue effects despite the reliability criteria applied, and OCT measurements can be degraded by media opacity and segmentation error. Diagnostic-performance analyses (sensitivity, specificity, receiver-operating-characteristic curves) were not undertaken and would be a valuable extension of this work.

CONCLUSION

A structured multimodal pathway clinical examination to establish the phenotype, gonioscopy to establish the mechanism, OCT to detect and quantify structural damage, and standard automated perimetry to establish functional loss and stage proved workable in routine tertiary practice and yielded a coherent classification for all 196 patients. Structural testing detected abnormality slightly more often than perimetry, structure and function correlated as expected, and individualised treatment achieved target pressure in 91.7% with progression in 12.5%. That nearly one-third of established cases were severe at first presentation is the study's most important public-health finding: earlier case-finding, not better technology, is the outstanding need in Indian glaucoma care.

Source of funding

None.

Conflicts of Interest

None declared.

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