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Price and evidence thresholds for wearable and continuous intraocular pressure monitoring in glaucoma: an early health-technology assessment in Türkiye

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Abstract

Wearable and continuous intraocular pressure (IOP) monitoring may reveal pressure patterns missed by office tonometry, but its effect on glaucoma progression and affordable reimbursement price remain uncertain. We developed a Markov cost-utility model comparing standard monitoring with wearable or continuous IOP monitoring added to standard care from the Turkish public payer perspective. The model evaluates a technology class rather than a specific device. Its main mechanism was a conditional reduction in progression; visit savings were secondary. Turkish costs were micro-costed from Sağlık Uygulama Tebliği (Health Implementation Communiqué) tariffs. The primary outcome was the headroom price: the maximum all-inclusive annual technology price compatible with cost-effectiveness at 1× and 3× GDP per capita. At $300/year and 15% progression reduction, the intervention gained 0.1866 QALYs at an ICER of $23,709/QALY. At 1× GDP per capita, headroom prices were $156, $231 and $305/year for 10%, 15% and 20% progression reductions. Cost-effectiveness probability was 20.3% at 1× and 89.7% at 3× GDP per capita. Progression-effect EVPPI was $97 per patient at 1× GDP. An illustrative high-risk scenario was cost-effective at $300/year with 15% progression reduction. The analysis provides device-agnostic price, trial-effect and research-priority targets rather than a universal reimbursement claim.

Keywords: glaucoma; wearable sensors; intraocular pressure; cost-effectiveness; early health technology assessment; Türkiye

Introduction

Glaucoma is a leading cause of irreversible visual impairment worldwide, and the number of affected individuals is expected to rise as populations age [1]. Intraocular pressure (IOP) remains the only consistently modifiable risk factor in routine glaucoma care [2]. Landmark randomized evidence shows that IOP lowering reduces disease progression: in the Early Manifest Glaucoma Trial (EMGT), treatment reduced progression risk, and each 1 mmHg lower IOP from baseline to first follow-up was associated with an approximately 10% lower progression risk [3,4]. The Ocular Hypertension Treatment Study similarly showed that ocular hypotensive treatment delays or prevents conversion to primary open-angle glaucoma in at-risk individuals [5].

A persistent limitation of standard monitoring is that office tonometry captures only intermittent IOP snapshots. Diurnal and nocturnal peaks, short-lived fluctuations and inadequate 24-hour

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medication coverage may be missed even when clinic readings appear acceptable. Contact-lens sensors, implantable telemetric sensors, home tonometry systems and sensor-linked analytic platforms have therefore been proposed as tools for more personalised monitoring and timelier treatment intensification [6-10]. In this study, “wearable and continuous IOP monitoring” denotes this broader technology class. The technologies differ in measurement principle, monitoring duration, invasiveness, calibration requirements, patient burden, data-review pathway and cost. Accordingly, the present analysis is a platform-level threshold assessment rather than an evaluation of a named commercial product. Its results should be interpreted by comparing a particular system’s all-inclusive annual pathway cost and plausible downstream clinical effect with the estimated headroom frontier, rather than as evidence that all monitoring technologies are clinically or economically equivalent. These technologies nevertheless share a common decision problem: whether the additional information obtained from more frequent IOP measurement changes management sufficiently to slow long-term glaucomatous damage.

The economic evidence base has not kept pace with device development. Existing glaucoma economic evaluations and costing studies have largely focused on screening, treatment strategies, disease-stage costs and monitoring-related resource use [11–15]. Dong et al. estimated that continuous IOP monitoring could reduce annual glaucoma outpatient-visit costs by 23.21%, but their analysis was a US claims-based visit-cost study rather than a lifetime cost-utility analysis with QALYs, progression and health-state transitions [11]. No prior model, to our knowledge, has evaluated wearable or continuous IOP monitoring as a conditional early health-technology assessment in a middle-income public payer setting.

This creates a decision problem that is different from a conventional cost-effectiveness question. Because long-term endpoint trials of wearable IOP monitoring have not yet established a definitive effect on glaucoma progression, assigning a precise base-case effectiveness would give false precision. The policy-relevant question is conditional: what annual technology price would be justified if monitoring reduces progression by a given amount, and what clinical effect must a future pragmatic trial demonstrate to support adoption at a specified price? We addressed this question using a threshold, or headroom, analysis from the Turkish public payer perspective, with explicit micro-costing from national tariffs, uncertainty analysis and exploratory value-of-information calculations. The analysis also examined whether its conclusions were robust to additional clinician-review costs, removal of the assumed visit-cost reduction, alternative uncertainty specifications for the progression effect and an illustrative high-risk progression scenario.

Results

Model behaviour and base-case outcomes

In the standard-care arm, the model generated 10.98 discounted QALYs and $320 discounted lifetime narrow-payer costs for an age-60 cohort beginning in early open-angle glaucoma. The low lifetime cost reflects the intentionally narrow Turkish public ophthalmic reimbursement perspective and the low dollar value of SUT tariffs after conversion at the stated exchange rate. It should therefore not be interpreted as a societal cost of glaucoma, a hospital accounting cost, or the full economic burden of visual impairment.

In the central illustrative intervention scenario, defined as a 15% reduction in annual progression probabilities (RR_prog = 0.85) and an annual technology price of $300, the intervention

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produced 0.1866 additional QALYs and $4,424 additional costs, yielding an ICER of $23,709 per QALY. This exceeds the conservative 1× GDP-per-capita reference value of $18,200/QALY but remains below the 3× reference value of $54,600/QALY. The result is driven mainly by the device price and assumed progression effect, not by disease-management cost offsets.

Headroom analysis

The primary threshold findings are summarised in Fig. 1, which plots the maximum reimbursable annual technology price against the assumed percentage reduction in annual glaucoma progression. At 1× GDP per capita, the maximum cost-effective annual technology price was $80 at a 5% progression reduction, $156 at 10%, $231 at 15%, $305 at 20%, $379 at 25% and $450 at 30%. At the more permissive 3× reference value, the corresponding headroom prices were $233, $460, $686, $908, $1,127 and $1,341 per patient-year. Thus, a $300 annual technology price would require approximately 20% progression slowing in the general base-case cohort at the conservative 1× threshold, but only a modest effect under the 3× reference threshold.

Figure 1. Headroom frontier for wearable IOP monitoring

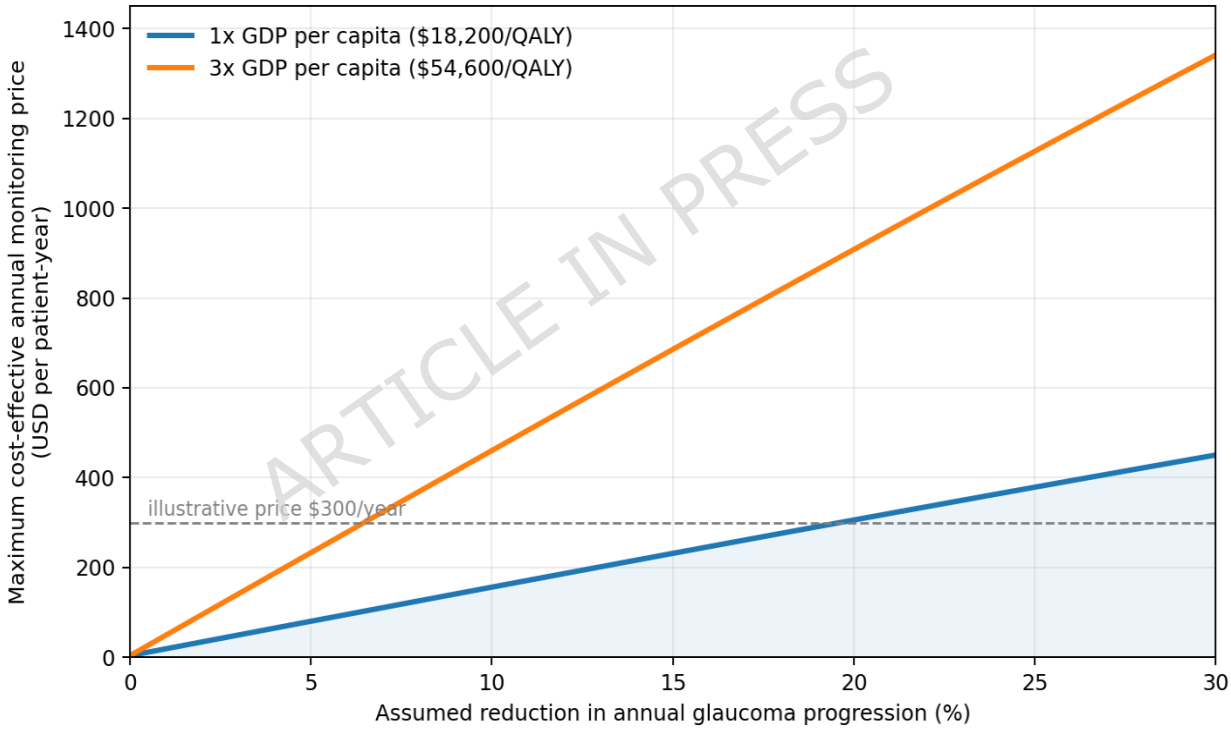

Figure 1 | Headroom analysis for wearable and continuous intraocular pressure monitoring. The curves show the maximum annual technology price that remains cost-effective at 1× and 3× Turkish GDP per capita across assumed reductions in annual glaucoma progression. Values on or below a curve are cost-effective at the corresponding willingness-to-pay reference value. The dashed horizontal line indicates an illustrative annual technology price of $300 per patient-year.

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Scenario analysis

Deterministic scenario analyses across alternative monitoring prices and effectiveness assumptions are reported in Table 1. At $100/year, the intervention was cost-effective at the 1× threshold when progression was reduced by at least 10%. At $200/year, the required effect was approximately 15%. At $300/year, the required effect was approximately 20%. At $500/year, the intervention was not cost-effective at the 1× threshold within the tested 5-30% effectiveness range, but became cost-effective at the 3× threshold once progression reduction was approximately 10% or greater.

Sensitivity, probabilistic and value-of-information analyses

The ranking of influential parameters in one-way sensitivity analysis is shown in Fig. 2. The ICER was driven primarily by annual technology price, the assumed progression risk reduction and baseline progression probabilities. The tariff-updating multiplier changed results in the expected direction: higher public tariff costs increased disease-cost offsets and modestly improved the ICER, but did not dominate the analysis. Health-state utilities and the blindness-entry cost had smaller effects over the tested ranges.

Figure 2. One-way sensitivity analysis of the central ICER

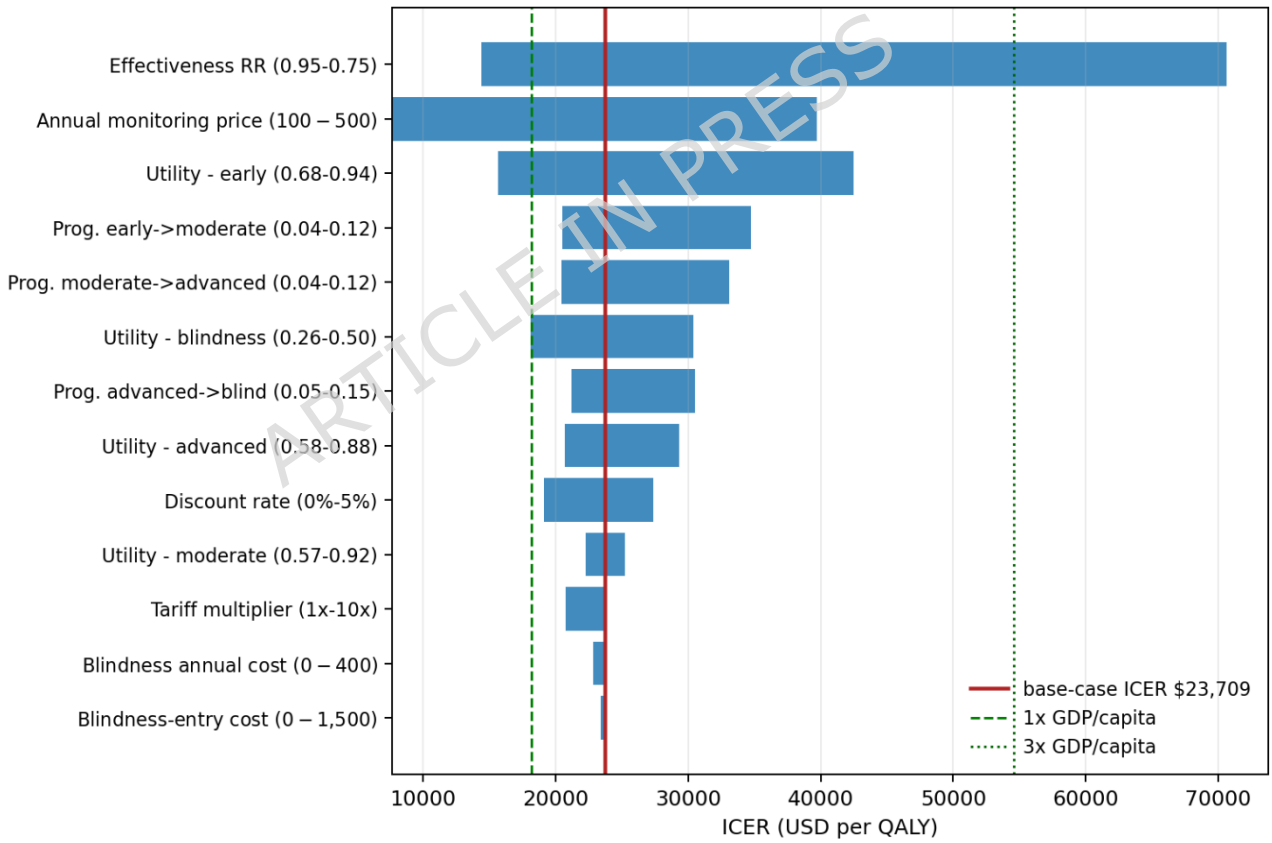

Figure 2 | One-way sensitivity analysis of the base-case ICER. The tornado plot shows the effect of varying key model parameters on the incremental cost-effectiveness ratio in the central illustrative scenario, defined as RR_prog = 0.85 and annual technology price = $300. Vertical reference lines indicate the base-case ICER and the 1× and 3× GDP-per-capita willingness-to-pay reference values.

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Probabilistic uncertainty around the central illustrative scenario is summarised in the cost-effectiveness acceptability curve in Fig. 3. The progression-effect parameter was sampled from a Beta distribution with α = 42.50 and β = 7.50, corresponding to a prespecified mean of 0.85 and standard deviation of 0.05. Across the 6,000 probabilistic iterations, the empirical mean RR_prog was 0.8499, and the 2.5th and 97.5th percentiles were 0.7404 and 0.9328, respectively. For the $300 annual technology-price scenario, mean incremental cost was $4,424 and mean incremental QALYs were 0.1785. The probability of cost-effectiveness was 20.3% at 1× GDP per capita and 89.7% at 3× GDP per capita. Complete distribution parameters for utilities, transition probabilities, RR_prog and the tariff multiplier are provided in Supplementary Table S6.

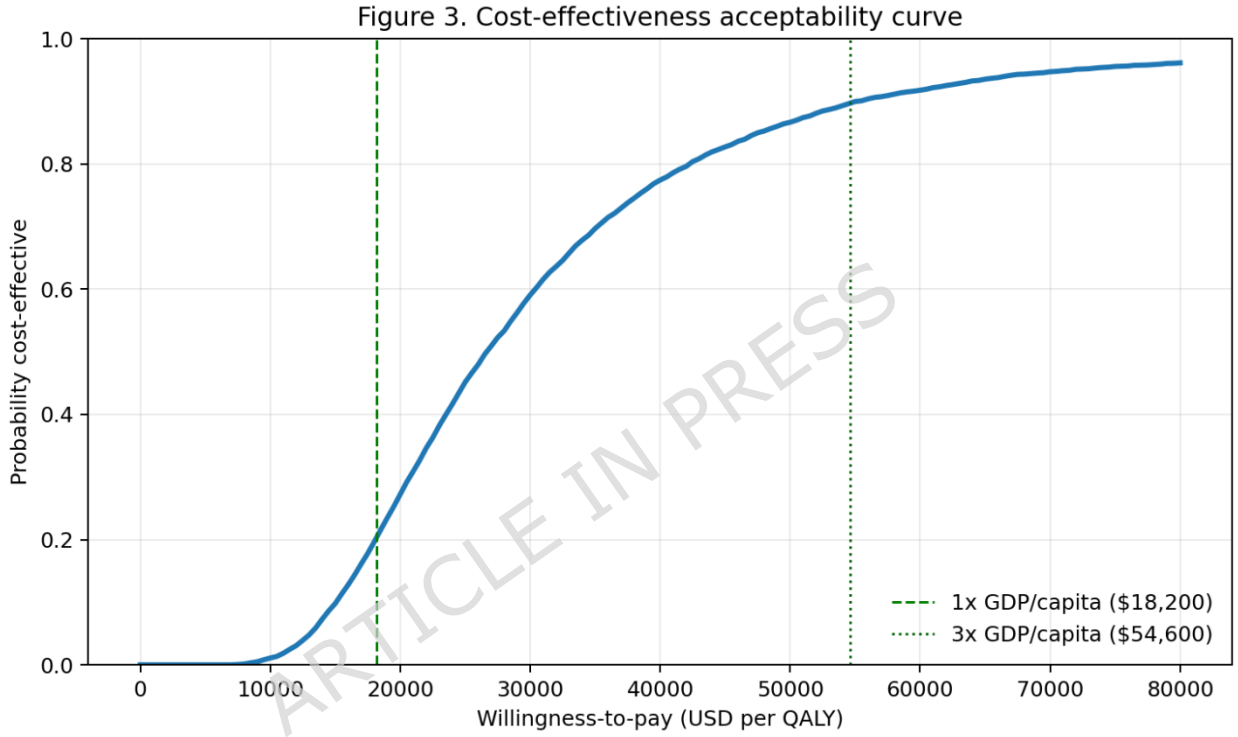

Figure 3 | Cost-effectiveness acceptability curve for the probabilistic sensitivity analysis. The curve shows the probability that wearable and continuous intraocular pressure monitoring is cost-effective across alternative willingness-to-pay values in the probabilistic sensitivity analysis for the $300 annual technology price scenario, with RR_prog distributed around a mean value of 0.85.

Exploratory value-of-information calculations supported the same interpretation. At the 1× GDP-per-capita reference value, the expected value of perfect information was $252 per patient, while the expected value of partial perfect information for the progression-effect parameter was $97 per patient. The tariff-cost and baseline-progression modules contributed negligible partial value of information under the central 20-bin specification. RR_prog EVPPI at the 1× threshold was $88.6, $97.2 and $97.8 per patient when 10, 20 and 40 equal-frequency bins were used, respectively, indicating that the principal research-priority conclusion was not materially dependent on the selected bin count. At the 3× threshold, absolute EVPPI values remained substantially smaller and were more sensitive to binning because the intervention was already cost-effective in most probabilistic draws. Full bin-count and variance-sensitivity results are

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reported in Supplementary Table S7. At the 3× threshold, the corresponding EVPI and 20-bin progression-effect EVPPI were $137 and $4.5 per patient. The main residual decision uncertainty is therefore the clinical progression effect rather than the exact SUT costing multiplier. The CEAC probability and EVPPI answer different decision questions. The CEAC reports how often the intervention has positive incremental net benefit at a specified threshold, whereas EVPPI measures the expected opportunity loss that could be avoided by resolving uncertainty in a parameter before making the adoption decision. Consequently, a modest probability of cost-effectiveness does not necessarily imply a low EVPPI: uncertainty may still have substantial value when the financial or health loss associated with selecting the wrong decision is large.

One-way sensitivity analysis and EVPPI should not be interpreted as interchangeable rankings. One-way sensitivity analysis measures how far a parameter can move the ICER when varied across its range, whereas EVPPI estimates whether resolving uncertainty in that parameter would alter the optimal adoption decision and avoid an expected opportunity loss. Although baseline progression probabilities rank highly in the one-way sensitivity analysis shown in Fig. 2, their EVPPI is low because, within the parameter ranges tested, knowing the exact baseline progression rate would rarely alter the binary adopt/do-not-adopt decision at the current annual technology price and progression-effect assumptions.

Risk-stratified adoption scenario

Because continuous IOP monitoring is unlikely to be offered to every patient with stable glaucoma, we examined an illustrative high-risk scenario in which all three baseline annual progression probabilities were increased uniformly by 50%. The 50% multiplier was a transparent structural sensitivity assumption and was not estimated from a named high-risk phenotype or interpreted as an observed transition rate for pseudoexfoliation glaucoma, nocturnal IOP elevation or any other specific subgroup. The scenario therefore illustrates how higher baseline progression risk can change the economic value of monitoring; it does not establish cost-effectiveness for any particular phenotype without device- and subgroup-specific clinical evidence. Population-based evidence from Western Türkiye also indicates that POAG risk is heterogeneous rather than uniform across adults [16]. In this illustrative high-risk cohort, the 1× GDP-per-capita headroom at a 15% progression reduction increased to $341 per patient-year, and a $300 annual technology price yielded an ICER of $15,972/QALY. These results are reported in Supplementary Table S4.

Additional monitoring-management costs

The principal headroom conclusions were robust to removing the assumed reduction in routine visit costs and to adding an illustrative clinician-review cost. Eliminating the 23.21% visit-cost reduction increased the central ICER from $23,709 to $23,988/QALY and reduced the 1× headroom price at RR_prog = 0.85 from $231 to $228/year. Adding an annual $25 per-patient clinical-management cost while retaining the visit-saving assumption increased the ICER to $25,711/QALY and reduced the corresponding technology-price headroom to $206/year. In the combined conservative scenario of no visit-cost reduction and an additional $25 annual management cost, the ICER was $25,991/QALY and the headroom technology price was $203/year. In the illustrative high-risk cohort, the same combined conservative assumptions produced an ICER of $17,509/QALY and a headroom price of $313/year, remaining below the 1× GDP-per-capita reference value. The $25 input was an illustrative stress-test value rather than an observed Turkish reimbursement fee and was chosen to represent a non-trivial

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recurring review burden relative to the $15.04 early-state annual follow-up cost. Full results are provided in Supplementary Table S8.

Discussion

This early health-technology assessment does not claim that current wearable or continuous IOP monitoring systems are universally cost-effective in Türkiye. Its contribution is to translate unresolved clinical-effectiveness uncertainty into explicit price and trial-effect targets. Under a Turkish public payer perspective based on micro-costed SUT tariffs, a $300 annual technology price requires approximately 20% progression slowing in a general early-glaucoma cohort at a conservative 1× GDP-per-capita reference threshold. The same price becomes cost-effective with a 15% progression reduction in a high-risk cohort, and is clearly within the cost-effective region at the more permissive 3× reference threshold.

The clinical plausibility of the tested effect range was anchored in the established IOP-progression relationship rather than in an assumed device-specific treatment effect. In EMGT, an additional 1 mmHg lower IOP was associated with an approximately 10% lower progression risk [4]. Interpreted cautiously, the modelled 10–20% progression-reduction range corresponds approximately to the clinical value of achieving and sustaining an additional 1–2 mmHg effective IOP benefit, if monitoring leads to earlier recognition of uncontrolled pressure patterns and effective treatment intensification. Existing studies of contact-lens sensors, implantable telemetric sensors, home monitoring and related analytic systems demonstrate measurement feasibility and identify pressure patterns that may be missed by office tonometry, but they do not provide a validated causal estimate linking peak detection to treatment modification and subsequently to long-term structural or functional progression [6–10]. Deriving the model effect directly from observed peak-detection frequencies would therefore require two unsupported conversions: from detection to management change and from management change to progression reduction. EMGT was consequently used only to define an outcome-linked plausibility envelope for the threshold analysis, not as evidence that wearable monitoring itself produces an equivalent IOP reduction or clinical benefit.

The analysis also shows why the Turkish payer perspective differs from high-income-country cost-effectiveness studies. In the United States and parts of Europe, stage-specific glaucoma and blindness-related costs are high enough that avoided advanced disease can generate substantial monetary offsets [14,15]. By contrast, Turkish SUT tariffs for outpatient examination, visual-field testing, OCT/NFA and glaucoma procedures are low when converted to US dollars. Consequently, the payer-perspective model is conservative with respect to the device: most value comes through QALY gains from delayed progression, not through cost savings. This is precisely why an explicit price-effectiveness frontier is more informative than a single favourable or unfavourable ICER.

A distinctive implication of the narrow SUT-based payer perspective is that the model does not impose a monotonic cost gradient across all severity states. In the base case, the blindness/low-vision state has lower reimbursed ophthalmic follow-up costs than the advanced-glaucoma state because visual-field testing, OCT/NFA monitoring and glaucoma surgery are no longer assumed to continue routinely after bilateral blindness. This should not be interpreted as implying that blindness is inexpensive for patients, families or society. Rather, it reflects the narrow set of ophthalmic items reimbursed within the Turkish public tariff schedule. The

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assumption is conservative against wearable monitoring because it gives the model little monetary reward for delaying blindness; the value of avoiding blindness is therefore driven mainly by QALY gains, with broader blindness-related costs tested separately.

The cost construction was deliberately transparent. Annual state costs were built from a severity-specific resource-use schedule using public SUT tariffs rather than imported US or European costs. Because Turkish tariffs may lag inflation and exchange-rate movements, we treated the dollar conversion as a reporting convention and tested tariff-updating multipliers. Increasing all Turkish tariff-based costs up to tenfold improved the ICER only modestly, because the annual technology price remained the dominant incremental cost. A broader blindness-cost scenario also improved cost-effectiveness but did not change the central conclusion: the progression effect and device price are the binding uncertainties.

Continuous monitoring may also generate rather than displace some clinical activity, including data review, additional consultations, confirmatory testing or treatment escalation. The base-case visit-saving assumption was therefore not essential to the central conclusion. Removing visit savings changed the central ICER only modestly, while adding a $25 annual management cost reduced the 1× headroom at a 15% progression effect from $231 to approximately $203–206/year, depending on whether visit savings were retained. These scenarios reinforce the interpretation that the annual technology price and the clinical progression effect, rather than small changes in routine monitoring expenditure, remain the principal determinants of value.

The role of artificial intelligence should also be interpreted narrowly. Wearable IOP systems may require algorithmic interpretation to summarise noisy, high-frequency or circadian sensor data and to alert clinicians to actionable patterns. The present model did not assign a separate independent therapeutic effect to AI. Instead, it evaluated the combined clinical pathway of additional IOP information, interpretation and potential treatment intensification. This avoids treating AI as an ornamental label or an unmeasured source of benefit.

The estimates should also be interpreted at the platform level. Contact-lens sensors, implantable telemetric systems and home tonometry devices differ substantially in invasiveness, measurement duration, calibration, patient acceptability, clinical workflow and cost. The model does not imply that these technologies are substitutable or equally effective. Instead, the headroom frontier provides a common decision framework: for any particular technology, its all-inclusive annual cost and credible expected progression effect can be located relative to the threshold curve. A device-specific reimbursement decision would still require evidence on measurement validity, adherence, discontinuation, adverse effects, clinician-response protocols and downstream treatment consequences.

The findings favour risk-stratified implementation. Offering continuous monitoring to all stable patients with glaucoma is unlikely to be the most efficient use of payer resources at current plausible device prices. Targeting patients with higher baseline progression risk, unexplained progression despite apparently acceptable office IOP, suspected nocturnal peaks or major treatment-escalation decisions is more clinically credible and economically favourable. This is consistent with the broader logic of wearable sensors in healthcare: continuous measurement is most valuable when additional information can change management in patients with actionable risk.

Several limitations should be acknowledged. First, transition probabilities were literature-consistent and internally calibrated rather than estimated from Turkish longitudinal glaucoma

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cohorts. Second, the effect of wearable monitoring on progression is not established by randomized endpoint trials; this is why threshold analysis was used as the primary design. Third, the payer-perspective cost base excludes informal care, productivity losses, private out-of-pocket costs and many consequences of visual disability. Fourth, health-state utilities were drawn from international glaucoma utility literature rather than elicited from Turkish patients. Fifth, the model simplifies glaucoma into one-step irreversible severity transitions and does not separately model both eyes, adherence, device discontinuation, discomfort or false-positive treatment escalation. These limitations make the results best interpreted as adoption and trial-design guidance rather than definitive reimbursement evidence.

The analysis identifies practical evidence targets. A future pragmatic trial should not merely show that wearable monitoring detects more IOP variation; it should demonstrate whether this information changes treatment and slows structural or functional progression. At a $300 annual price, a general-cohort trial would need to support approximately 20% progression slowing to justify adoption at a conservative Turkish reference threshold, whereas a high-risk cohort could justify the same price with a smaller effect. The value-of-information analysis reinforces this conclusion: reducing uncertainty about progression effect is more valuable than refining tariff-based cost estimates. The relatively low 20.3% probability of cost-effectiveness at the 1× threshold does not conflict with the $97 progression-effect EVPPI. The latter reflects the expected loss from making an incorrect adoption decision under uncertainty, not simply the frequency with which the intervention is cost-effective. Taken together, the headroom and value-of-information results provide complementary evidence targets. The headroom analysis identifies the annual technology price and progression effect required for adoption, while the EVPPI analysis shows that the highest-value next research step is a pragmatic clinical study capable of estimating whether monitoring-induced management changes translate into slower structural or functional progression.

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Methods

Study design and reporting

We conducted a model-based cost-utility analysis and early health-technology assessment of wearable or continuous IOP monitoring added to standard glaucoma care. The analysis followed CHEERS 2022 reporting guidance for health economic evaluations [17]; a completed checklist is provided in the Supplementary Information. The study used only published aggregate parameters, public tariff schedules and simulated model outputs.

Population, perspective and time horizon

The base-case cohort comprised adults aged 60 years with early open-angle glaucoma. The primary perspective was the Turkish public payer perspective. Costs and QALYs were accumulated over a lifetime horizon of 40 annual cycles, with 3% annual discounting applied to both costs and QALYs. Willingness-to-pay values of 1× and 3× Turkish GDP per capita were used as reference values, not as official Turkish reimbursement thresholds. The 1-3× GDP rule is widely used but has been criticised because it may not reflect health-opportunity costs [18,19].

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Model structure

We used a cohort state-transition Markov model with five mutually exclusive states: early glaucoma, moderate glaucoma, advanced glaucoma, bilateral blindness and death. Disease progression was irreversible and one-step: early to moderate, moderate to advanced, and advanced to blindness. Death was possible from every living state and was modelled using an age-increasing all-cause mortality function. The model used annual cycles, half-cycle correction and a lifetime horizon. Health-state utilities and costs were assigned to the average state occupancy within each cycle.

Comparator and intervention

Standard care consisted of intermittent clinic tonometry, routine follow-up, visual-field testing, OCT/NFA testing and treatment escalation according to clinical judgement. The intervention represented a platform class of wearable and continuous IOP-monitoring pathways, including contact-lens sensors, implantable telemetric sensors, home tonometry systems and associated data-interpretation platforms [6-10]. The analysis did not evaluate or directly compare a named commercial product.

The intervention affected the model through two principal channels: a conditional relative reduction in annual forward progression probabilities, denoted RR_prog, and a partial reduction in routine monitoring costs. The annual technology price represented the total recurring payer-facing technology cost and was intended to include hardware or sensor acquisition, consumables, software or algorithmic-interpretation licensing, data transmission and storage, and technical support. It did not include incremental clinician review, additional consultations, confirmatory testing or downstream treatment-escalation costs. These clinical-management costs were examined separately in scenario analysis.

The clinical pathway may include algorithmic or AI-enabled interpretation of high-frequency IOP data, but the model did not assign an additional AI-specific therapeutic effect beyond the assumed effect of the complete monitoring and management pathway on progression.

Clinical effectiveness assumptions

The biological plausibility range was anchored to randomized evidence that IOP reduction reduces glaucoma progression. In EMGT, each 1 mmHg decrease in IOP from baseline to first follow-up was associated with an approximately 10% lower progression risk, and treatment approximately halved progression risk [3,4]. We therefore explored RR_prog from 1.00 to 0.70, corresponding to 0-30% reductions in annual progression probabilities. RR_prog = 0.85, a 15% progression reduction, was used only as a central illustrative scenario. Because no long-term randomized endpoint trial yet establishes the progression effect of wearable monitoring itself, the primary results were expressed as conditional headroom thresholds rather than as a definitive base-case reimbursement claim.

Studies of wearable, implantable and home-monitoring systems support the feasibility of obtaining IOP information outside conventional office measurements and demonstrate that additional temporal pressure patterns can be detected [6–10]. They do not, however, provide a validated causal estimate of the effect of such detection on long-term glaucoma progression. Using observed peak-detection rates as the progression-effect parameter would require assumptions about the probability that a detected pattern triggers treatment intensification, the effectiveness and adherence of that treatment, and the resulting change in structural or

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functional progression. We therefore used the EMGT IOP-progression association only to define a clinically interpretable plausibility range for RR_prog. It was not treated as evidence of device-specific efficacy.

Illustrative high-risk scenario

To examine how baseline disease risk affected headroom, we conducted a scenario in which each of the three annual forward progression probabilities was multiplied by 1.50. This uniform 50% increase was selected as a transparent illustrative stress test and was not calibrated to observed transition rates in a particular clinical phenotype. The scenario should therefore be interpreted as demonstrating the effect of higher baseline progression risk on economic value, rather than as an estimate for pseudoexfoliation glaucoma, suspected nocturnal IOP elevation, rapid progressors or another defined subgroup.

Costs and utilities

Health-state utilities were based on values used in prior glaucoma cost-utility models and methodological reviews of glaucoma utilities, with base-case values of 0.80, 0.75, 0.71 and 0.40 for early, moderate, advanced and bilateral blindness states, respectively [12,20-22]. Turkish costs were micro-costed from the 2026 Sağlık Uygulama Tebliği (SUT) EK-2B tariff schedule and outpatient examination tariff [23]. Unit costs included ophthalmology examination, visual-field testing, OCT/NFA, gonioscopy, glaucoma laser, trabeculectomy, tube/seton surgery, cyclophotocoagulation and low-vision assessment. Fluorescein angiography was excluded because it is not part of routine glaucoma monitoring. Annual state costs were calculated from an explicit resource-use schedule by severity and are summarised in Table 2, with full arithmetic in Supplementary Tables S1-S2. Costs were converted to US dollars using the Central Bank of the Republic of Türkiye indicative USD selling rate for 02 June 2026 [24]. Because SUT tariffs may lag inflation and exchange-rate movements, deterministic sensitivity analyses applied tariff-updating multipliers of 3×, 5x and 10x to all Turkish tariff-derived costs.

The routine monitoring cost displaced by the intervention was set equal to the base-case early-state annual follow-up cost, $15.04/year. The visit-reduction parameter was 23.21%, following the published estimate of potential outpatient-visit savings from continuous IOP monitoring [11]. Annual technology prices were not assumed to be observed market prices. They represented the combined recurring cost of the monitoring technology, associated sensors or consumables, software and analytics licences, data infrastructure and technical support. Prices of $100, $200, $300 and $500 per patient-year were tested, and the maximum compatible price was solved continuously in the headroom analysis. Incremental clinician-review and management costs were excluded from this technology-price variable and examined separately.

Threshold and cost-effectiveness analysis

The primary outcome was the maximum annual technology price at which the intervention would remain cost-effective for each assumed value of RR_prog. For a willingness-to-pay value λ, the headroom price was calculated as:

$$C^* = V - M + [\lambda \Delta Q(RR_prog) - \Delta C_D(RR_prog)] / L(RR_prog). \quad (1)$$

Here, C* is the maximum cost-effective annual technology price; V is the annual routine-monitoring cost displaced by the intervention; M is any additional annual clinical-management

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cost generated by monitoring; ΔQ is the incremental QALY gain; ΔC_D is the incremental disease-management and blindness cost, excluding technology and additional management costs; and L is the discounted number of living-years over which recurring intervention costs are incurred. In the base case, M was zero. Values below C* are cost-effective at the specified willingness-to-pay value, whereas values above C* are not. Direct ICERs were also calculated for deterministic price-effectiveness scenarios. A worked numerical example is provided in Supplementary Note S1.

Uncertainty and value-of-information analysis

One-way sensitivity analysis varied utilities, transition probabilities, tariff-derived state costs, blindness-entry cost, discount rate, annual technology price and RR_prog across prespecified ranges. In probabilistic sensitivity analysis, utilities and annual transition probabilities were sampled independently from Beta distributions. The complete α and β parameters are reported in Supplementary Table S6. Tariff-derived costs were varied jointly through a log-normal tariff multiplier with log-scale mean −0.125 and log-scale standard deviation 0.50, giving an arithmetic mean of 1.00. Independent Gamma distributions were not additionally applied to the same tariff-derived cost aggregates.

RR_prog was sampled from Beta(42.50, 7.50), corresponding to a mean of 0.85 and standard deviation of 0.05. The analysis used 6,000 Monte Carlo iterations with a fixed random-number seed for reproducibility and generated a cost-effectiveness acceptability curve. The annual technology price was fixed at $300 in the central PSA.

EVPI was calculated from incremental net benefit as the difference between the expected net benefit under perfect information and the net benefit of the decision based on current information. Exploratory EVPPI was estimated separately for RR_prog, the tariff-cost multiplier and the baseline-progression module. The latter was represented by the mean of the three sampled annual progression probabilities in each probabilistic iteration.

For each target parameter or module, probabilistic draws were divided into 20 equal-frequency quantile bins, yielding approximately 300 iterations per bin. Within each bin, all non-target parameters retained their sampled values, thereby preserving within-group uncertainty in the remaining model inputs. Conditional mean incremental net benefit was calculated in each bin, the optimal conditional decision was selected, and the weighted mean conditional value was compared with the value of the decision under current information. Twenty bins were selected as a compromise between conditional resolution and Monte Carlo stability. Sensitivity analyses repeated the calculation with 10 and 40 bins and with the variance of RR_prog halved and doubled. Because this grouped estimator is an approximation, EVPPI was interpreted as an exploratory research-priority measure rather than a definitive population-level valuation.

Two additional pathway-cost scenarios were evaluated. The first removed the assumed 23.21% reduction in routine monitoring costs. The second added an illustrative $25 annual clinical-management cost for data review, additional consultation or related follow-up. The scenarios were evaluated separately and jointly. The $25 input was not an observed tariff; it was selected as a transparent stress test representing a recurring management burden greater than the $15.04 annual early-state follow-up cost. The combined scenario was also applied to the illustrative high-risk cohort.

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Model validation

We performed internal model validation before interpretation. Transition-matrix row sums were verified to equal one, with maximum absolute row-sum error of 0.0e+00 in the base-case annual matrix. The closed-form headroom solution was checked by re-inserting the solved annual technology price into the direct ICER calculation. For RR_prog = 0.85, the 1× GDP-per-capita headroom price was $231.24/year and the direct ICER at that price reproduced $18,200/QALY. Scenario-grid results were monotonic in the expected directions: ICERs increased with annual technology price and decreased with stronger effectiveness. Cohort trace mass was conserved across all annual cycles.

Ethics statement

This study used only published aggregate parameters, public tariff schedules and simulated model outputs. It did not involve human participants, animal subjects, patient-level health records or identifiable personal data. Formal ethics committee approval and informed consent were therefore not required.

Data availability

All parameters used in the model are reported in the main manuscript, Supplementary Information and Supplementary Data 1. The analysis uses only published aggregate evidence and public Turkish tariff data. No patient-level data were generated or analysed. The executable model code is provided as Supplementary Software 1. All data and codes can also be downloaded from here: https://doi.org/10.5281/zenodo.21800651

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Author contributions

C.Y.E. conceptualised the clinical pathway, defined glaucoma severity states, assessed clinical plausibility of monitoring scenarios and contributed to interpretation. C.E. designed the economic model, implemented the threshold, uncertainty and value-of-information analyses, and drafted the health-economic methods and results. Both authors reviewed the literature, interpreted the findings, revised the manuscript critically and approved the final version.

Additional information

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Table legends and tables

Table 1 | Scenario analysis of ICERs by annual technology price and assumed progression reduction. Incremental cost-effectiveness ratios are reported in US dollars per QALY for wearable and continuous intraocular pressure monitoring compared with standard intermittent clinic-based monitoring. Values below $18,200 per QALY are below the 1× GDP-per-capita reference value; values below $54,600 per QALY are below the 3× GDP-per-capita reference value. Bold values are at or below the 1× GDP-per-capita reference value. Italicised values exceed the 1× reference value but remain at or below the 3× reference value.

RR_prog (progression reduction)	$100/year	$200/year	$300/year	$500/year
0.95 (5%)	*$22,960*	*$46,793*	$70,626	$118,292
0.90 (10%)	**$11,500**	*$23,462*	*$35,423*	$59,345
0.85 (15%)	**$7,686**	**$15,697**	*$23,709*	*$39,731*
0.80 (20%)	**$5,784**	**$11,826**	**$17,868**	*$29,952*
0.75 (25%)	**$4,646**	**$9,512**	**$14,378**	*$24,109*
0.70 (30%)	**$3,891**	**$7,977**	**$12,063**	*$20,235*

Table 2 | Base-case model inputs, uncertainty ranges and parameter sources. The table reports health-state utilities, transition probabilities, monitoring costs, Turkish tariff-derived costs, effectiveness assumptions, discount rate and willingness-to-pay reference values used in the Markov model and sensitivity analyses. The full micro-costing schedule is reported in Supplementary Tables S1-S2.

Parameter	Base case	Range/distribution	Source/justification
Cohort age / horizon	60 years / 40 annual cycles	Scenario-tested	Model assumption
Utilities: early, moderate, advanced, blindness	0.80, 0.75, 0.71, 0.40	Beta; literature ranges	Glaucoma CUA literature [12,20-22]
Annual progression probabilities	0.08, 0.08, 0.10	Beta distributions specified in Supplementary Table	Literature-consistent treated progression; +50% high-risk

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Parameter	Base case	Range/distribution	Source/justification
		S6; 50% lower/higher deterministic ranges	scenario explicitly illustrative
Intervention effectiveness	RR_prog 0.85 in central illustration	0.70–1.00; Beta(42.50, 7.50) in PSA, mean 0.85 and SD 0.05	Conditional threshold assumption anchored to EMGT [3,4]
Annual state costs	Early $15.04; moderate $24.16; advanced $39.54; blindness/low vision $13.82	Tariff multiplier 1×-10x; broader blindness-cost scenario	SUT micro-costing schedule; narrow ophthalmic payer base case [23,24]
Blindness-entry cost	$74.38 one-time	Scenario $0-$1,500	Expected entry bundle based on probabilistic glaucoma surgery/CPC and low-vision assessment
Routine monitoring cost and visit saving	$15.04/year; 23.21% reduction	Monitoring cost varied with tariff multiplier	SUT pathway and Dong et al. [11]
Annual technology price	$300 central illustration	$100-$500; solved continuously	All-inclusive technology cost covering hardware/sensors, consumables, software/analytics licensing, data transfer/storage and technical support; excludes incremental clinician-management costs tested separately
Additional clinical-management cost	$0/year	$25/year scenario; also combined with no visit-cost reduction	Illustrative stress test for clinician data review, additional consultation or related follow-up
Discount rate	3% annually	0-5%	Health-economic convention
WTP reference values	$18,200 and $54,600/QALY	Threshold spectrum	GDP-per-capita reference values [18,19]

CUA, cost-utility analysis; CEAC, cost-effectiveness acceptability curve; EMGT, Early Manifest Glaucoma Trial; EVPI, expected value of perfect information; EVPPI, expected value of partial perfect information; IOP, intraocular pressure; PSA, probabilistic sensitivity analysis; QALY, quality-adjusted life-year; SUT, Sağlık Uygulama Tebliği; WTP, willingness-to-pay.

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