Cost-Effectiveness of Pars Plana Vitrectomy versus Pneumatic Retinopexy for Rhegmatogenous Retinal Detachment: A Markov Chain Model Analysis

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INTRODUCTION

Rhegmatogenous retinal detachment (RRD) is an ocular emergency that occurs when a retinal break or hole permits fluid to enter into the subretinal space.[1,2] Prompt treatment is essential to prevent permanent vision loss. In the United States, RRD incidence was reported at 10–18 per 100,000 people.[1,3]

Two primary techniques for RRD repair are pars plana vitrectomy (PPV) and pneumatic retinopexy (PnR).[4] PPV, although more invasive, achieves higher primary anatomical success in treatment-naive patients (93.2% vs 80.8%) as per The Pneumatic Retinopexy versus Vitrectomy for the Management of Primary Rhegmatogenous Retinal Detachment Outcomes (PIVOT) Randomized Trial.[5] PPV is preferred in pseudophakic or aphakic eyes and complex cases, while PnR, a less costly outpatient procedure, is associated with better postoperative visual acuity (VA) and vertical metamorphopsia.[6–8]

A comprehensive understanding of the long-term cost-effectiveness of PnR and PPV is essential amid rising RRD costs and incidence of RRD.[9,10] Notably, most of the published literature pertaining to RRD compares the short-term cost of intervention to other procedures.[11,12] However, a significant gap in economic evaluations remains as few studies have reported on the cost-effectiveness between interventional strategies.

Computational models invoking probabilistic methods on empirical datasets present an opportunity to bridge this gap. This study aims to conduct a Markov Chain model analysis to compare costs, quality-adjusted life years (QALYs), and cost-effectiveness between PPV and PnR for adults with RRD.[11,13]

METHODS

Data Acquisition

The Markov Chain model used four inputs: timeframe, transitional probabilities, cost, and QALY. Transitional probabilities, cost, and QALY values for each health state were derived from the PIVOT trial and Ontario Health Insurance Plan (OHIP) physician billing data.[5,14,15] PIVOT was a landmark randomized controlled study that enrolled patients with primary RRD suitable for both PnR and PPV, provided comprehensive clinical outcome data, including anatomical success, VA, and complication rates, making it an ideal source for estimating health state transitions and utility values for the model.

Transitional probabilities were determined as the ratio of patients to study population for the PIVOT health states. The procedures from PIVOT (PPV, PnR, cataract surgery, laser retinopexy [LR] treatments, and repeat PPV or scleral buckle [SB] for re-detachments) were collected to calculate the cost associated with each patient's management and follow-up. Success and number of reoperations for each procedure were recorded. Each procedure was then correlated to its associated cost from OHIP physician billing data. Solving the linear combination of the sets of costs and count provided total cost for an individual patient. Finally, QALYs were computed through the Sharma visual acuity to utility function, relating logMAR-Snellen scores to utility values (Equation 1).[16]

Markov Chain Model Structure

A high-power discrete-state singular Markov Chain model was developed using R (version 4.3.3; R Foundation for Statistical Computing, Vienna, Austria) to compare

the long-run cost-effectiveness of PPV and PnR for primary RRD. Transition probabilities were parameterized from the 12-month PIVOT trial; the matrix power method then projected outcomes to long-run (lifetime) equilibrium, representing the probability of ultimately reaching each terminal clinical state. Clinical pathways are depicted in Figure 1 with main parameters of transition probability, cost, and QALY. The state probability vector was initialized at 1.00 for either S59 (PPV) or S58 (PnR) and 0.00 for all other states. Non-zero transition probabilities were populated from PIVOT data. Clinically implausible transitions were assigned 0.00; absorbing states were given self-transition probabilities of 1.00 characterizing their terminal nature.

Matrix Power Method

The transition probability matrix was raised to the power 1024 (2^{10}) to compute the limiting (stationary) distribution, the long-run probability of reaching each absorbing state from a given starting state. This represents the steady-state outcome distribution, not a fixed time-horizon projection. Convergence was verified by confirming that the difference between P^{1024} and P^{1025} was less than 10^{-6} in all entries.

Cost and QALY

Two 60×20 matrices were generated to store cost and QALY values for each absorbing state. Individual patient costs were computed as the sum of OHIP billing codes along each clinical pathway. Individual patient QALYs represent cumulative lifetime utility derived from final visual acuity, computed using the Sharma utility function[16] applied to PIVOT endpoint visual acuity data and weighted by remaining life

expectancy. The sets of costs and QALYs were averaged to assign a mean cost and QALY to each absorbing state.

Upon computing the steady state limiting probability vector, the expected total cost and QALY were reported for each treatment strategy, PPV: State S59 or PnR: State S58. The expected total cost for each starting state, *k*, was calculated as the sum of the products of the limiting probabilities, π*[*k*, *i*], and the average cost for each potential state, *i* (Equation 2). The expected total QALY for each starting state, *k*, was calculated using the limiting probabilities and average QALYs for each state (Equation 3). The cost-effectiveness ratio was evaluated as the weighted average of Q/C ratios using limiting probabilities as weights (Equation 4). Lastly, the incremental cost-effectiveness ratio (ICER) was calculated as the ratio of cost and QALY differences between PPV and PnR (Equation 5).

Equations

$$Utility = 0.374 \times VA\_decimal + 0.514 \qquad \text{(Eq. 1)}$$

where VA_decimal is evaluated as $10\text{^}(\text{-}LogMAR\_VA)$.[16]

$$E[C_k] = \Sigma_i \, \pi^*[k, i] \times \bar{C}_i \qquad \text{(Eq. 2)}$$

$$E[Q_k] = \Sigma_i \, \pi^*[k, i] \times \bar{Q}_i \qquad \text{(Eq. 3)}$$

$$E[Q/C]_k = \Sigma_i \, \pi^*[k, i] \times (\bar{Q}_i / \bar{C}_i) \qquad \text{(Eq. 4)}$$

$$ICER = (E[C_{PPV}] - E[C_{PnR}]) / (E[Q_{PPV}] - E[Q_{PnR}]) \quad \text{(Eq. 5)}$$

The primary metric is the conventional cost-per-QALY ratio, E[C] / E[Q] (Equations 2 and 3). The weighted Q/C ratio (Equation 4) provides a complementary decomposition by absorbing state but differs mathematically (E[Q/C] ≠ E[Q] / E[C]). Both metrics are reported for completeness; the ICER (Equation 5) serves as the primary summary measure.

Discounted Analysis

QALYs extending beyond one year were discounted at an annual rate of 1.5% to reflect their diminishing value and align the analysis with CADTH guidelines.[26] Similarly, the sensitivity analysis is designed to test the minimal and maximal bounds outlined by CADTH for discounting rate. Life expectancy estimates were derived from Statistics Canada complete life tables (Table 13-10-0114-01, 2022–2024, both sexes).[27] The survivor function $l(x)$ was reconstructed from published life expectancy $e(x)$ values using the standard actuarial recursion:

$$l(x+1) = l(x) \times [2e(x) - 1] / [2e(x+1) + 1] \quad \text{(Eq. 6)}$$

For a patient of assumed age A, the discounted life-year annuity factor was computed as:

$$DA(A, r) = \Sigma_{t=0}^{110-A} (1/(1+r))^t \times l(A+t) / l(A) \quad \text{(Eq. 7)}$$

The QALY discount factor was then DF = $DA(A, r) / LE(A)$, where $LE(A)$ is life expectancy at age A. This factor was applied multiplicatively to each terminal-state QALY value. Procedure costs were assumed to occur at time zero (upfront at surgery), so the cost discount factor was 1.0. Sensitivity analyses explored alternative patient ages (55–70 years) and discount rates (0–5%).

Sensitivity Analysis

A one-way deterministic sensitivity analysis (DSA) was performed to evaluate the robustness of the base-case ICER to variation in key transition probabilities. Twelve parameters were selected based on clinical significance, including PnR initial branching probabilities, PnR reattachment success rates, PPV pathway probabilities, cataract development rates, and re-detachment rates. Each parameter was varied ±20% from its base-case value, clamped to [0, 1], with the remaining transitions in the same row renormalized to maintain unit row sums.

Monte Carlo Simulation

To validate the analytic limiting distribution derived from the matrix power method, a Monte Carlo simulation was conducted. One thousand independent patient trajectories were simulated from each starting state: S58 (PnR arm) and S59 (PPV arm). At each step, the next state was sampled according to the transition probability row for the current state. Each run terminated upon reaching an absorbing state. The empirical terminal-state frequencies were compared to the theoretical limiting probabilities to confirm model convergence.

US Medicare Cost Analysis

A parallel cost analysis was conducted using US Medicare reimbursement data. PnR costs (CPT 67110, $1,462 nonfacility total) were obtained from Elhusseiny et al. Table 2[17] and PPV costs (CPT 67108, $3,260 ASC total), recurrent PPV (CPT 67108-78, $2,346), scleral buckle (CPT 67107, $3,193), and cataract surgery (CPT 66984, $1,689) from Belin et al. Table 2.[28] Both sources used the lower-cost outpatient setting (Elhusseiny: nonfacility; Belin: ambulatory surgery center [ASC]). All costs were inflated to 2022 USD using the Bureau of Labor Statistics Consumer Price Index (CPI-U: 2019 to 2022 factor 1.1447; 2020 to 2022 factor 1.1308), yielding per-procedure costs of $1,673.58 for PnR, $3,686.30 for primary PPV, $2,652.78 for recurrent PPV, $3,610.54 for scleral buckle, and $1,909.87 for cataract surgery. Laser retinopexy (CPT 67145) was estimated at $400 (2022 USD) based on the CMS ASC fee schedule. Combined PPV/SB procedures were estimated at $4,186.30 (PPV cost plus an estimated $500 hardware add-on). Each absorbing state was assigned a US cost equal to the sum of its constituent procedures. The clinical pathway structure and QALY values remained identical to the Canadian model; only costs were substituted. For cross-jurisdictional comparison, US costs were also converted to 2026 CAD using the Bank of Canada mid-market exchange rate of 1.37199 USD/CAD. Sensitivity analyses varied the LR cost assumption ($300 to $600) and compared ASC versus hospital-based settings using total imputed cost ratios from each source study (PPV: hospital $8,125 / ASC $5,082 = 1.60 from Belin et al. Table 3; PnR: facility $4,451 / nonfacility $2,456 = 1.81 from Elhusseiny et al. Table 3).

RESULTS

Base-Case Analysis

Patients entered the Markov model at either S58 (PnR) or S59 (PPV) and transitioned through health states based on PIVOT trial probabilities. The encoded absorbing states and clinical outcomes are outlined in Table 1.

Higher weighted QALYs were measured in the PnR arm compared to the PPV arm (22.860 vs 20.928; Figure 2). Most QALY gains in the PnR arm were attributable to high-utility absorbing states S14 (primary reattachment post-PnR and LR), S22 (primary reattachment post-PnR and LR, macula-off), and S23 (primary reattachment post-PnR, macula-off). In comparison, lower-contributing states were minimized. Several patients in the PPV arm transitioned to lower-utility absorbing states such as S40 (primary reattachment after PPV) and S41 (PPV after initial PnR and LR). In turn, reducing their cumulative QALYs relative to PnR.

Total weighted cost was lower in the PnR arm compared to the PPV arm ($1,427.75 vs $2,426.05; Figure 3). PPV costs were driven by high-probability absorbing states S37 (primary reattachment post-PPV with cataract, $405.85), S40 ($302.93), and S44 (primary reattachment post-PPV, macula-off, $820.73). While other states such as S56 (repeat PPV+SB with cataract, macula-off) and S57 (PPV+SB after initial PnR, macula-off) were more costly, their contributions were diminished due to low transition probability. Similarly, the largest proportion of costs in the PnR arm was associated with high-probability states S14, S15 (primary reattachment post-PnR), and S23. Amongst these, S15 contributed $472.14, representing 33.1% of total cost.

Cost-effectiveness analysis indicated that PnR provided greater value compared to PPV. The conventional cost-per-QALY ratio (E[C] / E[Q]) was $62.46 for PnR versus $115.92 for PPV. The complementary weighted Q/C ratio method (Equation 4, Table 2) yielded inverted cost-per-QALY (1 / E[Q/C]) of $55.37 (PnR) and $106.27 (PPV). Note that this metric differs from the conventional E[C] / E[Q] because the ratio of expectations is not equal to the expectation of ratios. States S14, S22, and S23 contributed most substantially to PnR's weighted Q/C ratio due to the combined effects of high transition probability and favorable per-state Q/C values (Table 2). In the PPV group, the only state with a comparably favorable Q/C ratio was S44, while several PPV states (S40, S41) yielded lower Q/C values reflecting poorer visual outcomes. The ICER was –$516.79 per QALY, indicating PnR dominance: patients undergoing PnR gained 1.932 additional QALYs while saving $998.29 compared to PPV. The negative ICER reflects this dual advantage rather than a marginal cost per incremental QALY gained.

Discounted Analysis

PnR remained dominant even after applying CADTH-recommended 1.5% discounting for a patient aged 61 years (QALY discount factor 0.8405, reflecting a 16.0% reduction). Discounted expected QALYs were 19.213 for PnR and 17.589 for PPV while costs were unchanged ($1,427.75 and $2,426.05 respectively). The discounted ICER was –$614.89 per QALY (Table 3). PnR dominance persisted across all ages (55–70) and discount rates (0–5%) as indicated by ICERs ranging from –$501.95 (age 70, r = 0%) to –$988.26 (age 55, r = 5%).

Sensitivity Analysis

The one-way deterministic sensitivity analysis demonstrated that PnR remained dominant (negative ICER) across all ±20% parameter variations (Figure 4). The three most influential parameters were the probability of the PPV-to-S25 pathway (ICER range: –$410.27 to –$707.04, spread $296.78), the PnR initial macula-on probability (range: –$415.43 to –$695.94, spread $280.52), and the PnR reattachment success probability to S15 (range: –$480.39 to –$558.56, spread $78.17). No parameter variation brought the ICER above zero.

Monte Carlo Validation

Monte Carlo simulations (1,000 runs each from S58 and S59) were performed to validate the analytic limiting distribution for both treatment arms. The empirical terminal-state frequencies were consistent with the theoretical limiting probabilities derived from the matrix power method, with no state deviating by more than approximately 2 percentage points in either arm. These results confirm that steady state behaviour is accurately projected from the Markov Chain model.

US Medicare Cost Analysis

Under US Medicare ASC pricing (2022 USD), expected costs were $2,308.79 (PnR) and $4,904.12 (PPV; Table 4). QALYs were unchanged from the Canadian analysis (22.860 and 20.928 respectively). The ICER was –$1,343.54 USD per QALY, confirming PnR dominance. The cost differential was larger under US pricing ($2,595.33) compared to Canadian OHIP pricing ($998.29), driven by the greater absolute cost of

PPV-related procedures in the US Medicare fee schedule. Sensitivity analysis on LR cost ($300–$600) showed ICERs of –$1,351.60 to –$1,327.41. Hospital-based setting analysis yielded –$1,957.42 USD per QALY. PnR was the dominant intervention in all US pricing scenarios.

DISCUSSION

This study projected clinical progression and economic outcomes over a long-run (lifetime) horizon for patients undergoing RRD repair with PnR or PPV using a Markov Chain model parameterized from the 12-month PIVOT trial. The results demonstrate that PnR is superior to PPV in cost-effectiveness, associated with more QALYs gained and lower expected total costs. These findings were summarized in the ICER of –$516.79 per QALY gained (undiscounted) and –$614.89 per QALY gained (discounted at CADTH 1.5%), reflecting PnR providing better health outcomes at lower cost than PPV.

The Markov Chain model found PnR to provide 1.09 times more utility than PPV at 22.860 versus 20.928 total weighted QALYs gained. The advantage in utility for PnR compared to PPV was driven by PnR health states being associated with higher VA in the PIVOT study. These states would then convert to substantial average QALYs gained correspondingly. Additionally, the model evaluated PPV to be approximately 1.70 times more expensive than PnR following surgical intervention at a total average cost of $2,426.05 to $1,427.75 respectively. The increased expense of PPV patients was associated with a higher transitional probability into absorbing states that progressed into cataracts and other complications requiring follow-up procedures more often

compared to PnR, with PIVOT trial cataract surgery rates of 65% vs 16% respectively for phakic patients. In comparison, PnR had few notable high-cost states, S41, S52 (PPV after initial PnR, macula-off), and S57. These absorbing states all bore low transitional probability and involved redetachment with PPV as a follow-up procedure.

Several absorbing states in the PPV arm (S40: primary reattachment post-PPV, mean QALY = 21.26; S41: PPV after initial PnR and laser retinopexy, mean QALY = 22.89) yielded lower average QALYs compared to the PnR arm in this model. These states carry a combined limiting probability of approximately 23.2% in the PPsV arm. Under the Sharma utility function (Equation 1), lower utility values correspond to poorer final visual acuity, with the magnitude of lifetime QALYs reflecting both post-operative VA and remaining life expectancy. The prevalence of patients in the PIVOT trial reaching these states following PPV contributed to the QALY disadvantage of PPV in this analysis. While the Sharma utility function has been validated for cataract surgery populations,[16] its applicability at the extremes of the visual acuity spectrum in RRD patients warrants further investigation. Future studies should evaluate alternative utility instruments for this population.

The conclusions drawn from the Markov model are consistent with the results of previous model-based cost-effectiveness of retinal detachment repair studies. In their model for non-facility settings, Chang and Smiddy calculated weighted costs (USD) for PnR (assuming 60%, 75%, and 90% success rates) as $2,615, $2,011, and $1,408, respectively, and for PPV (assuming 90% success rate) as $4,048. The corresponding costs per QALY were $1,007, $780, and $554 for PnR, and $1,637 for PPV.[11] These success rates were determined from literature with the range of variability in PnR

indicating the minima, midpoint, and maxima found through trials. Comparably, Elhusseiny et al.'s decision analysis model reported cost per QALY for PnR of $751 and $414 for the entire cohort compared to PPV at $1,312 and $833 in facility and nonfacility settings respectively. For macula-off procedures, their model computed PnR costs of $821 and $453 while PPV required $1,499 and $952 per QALY gained.[17] As such, both models' reported cost-effectiveness of PnR relative to PPV are in alignment with the results of this study. Similarly, there is a vast body of clinical literature evidencing PnR as associated with better functional outcomes, lower procedural cost, and fewer complications and follow-up procedures, especially in patients of phakic lens status.[8,18,19]

Notably, this model's results contradict Felfeli et al.'s microsimulation findings.[20] However, the microsimulation was limited as it drew from two Cochrane systematic reviews which omitted PIVOT to determine transitional probabilities. Moreover, the PnR/SB systematic review consolidated results from two RCTs published before 2000.[21] These studies also had small sample sizes and ineffectively compared functional outcomes by excluding standardized patient-reported outcome measures and objective distortion metrics captured in the PIVOT trial.[22] Additionally, Felfeli et al. justify their low anatomical success rate for PnR by citing the two most recent rates in literature. Yet, one of these papers is specific to fellows, who performed a median of 7 cases, and is an inappropriate benchmark as practitioner expertise and RRD complexity are non-generalizable.[23] Hence, if the microsimulation inputs had been derived from a comprehensive selection of RCTs inclusive of PIVOT, the results would provide a more robust estimate of PnR cost-effectiveness and outcomes as demonstrated by Elhusseiny et al.[17] The Markov Chain also diverged from the microsimulation as it

implemented OHIP Schedule of Benefits data to produce average costs while the microsimulation used US Medicare data.[20]

The addition of a US Medicare cost analysis in this study directly addresses this cross-jurisdictional question. Under US Medicare ASC pricing, PnR remained dominant, with an ICER of –$1,343.54 USD per QALY, a substantially larger magnitude than the Canadian result, reflecting the higher absolute cost differential of PPV-related procedures in the US fee schedule. This finding persisted across LR cost assumptions and hospital-based settings, confirming that the cost-effectiveness advantage of PnR is not an artifact of Canadian pricing.

The discounted analysis using CADTH-recommended 1.5% rate and Statistics Canada life tables strengthened the base-case findings. Discounting reduced QALYs by 16.0% for both arms (since the discount factor is applied uniformly to terminal-state QALYs), widening the ICER magnitude because the cost differential remained unchanged while the absolute QALY values decreased. Sensitivity analysis across ages 55–70 and rates 0–5% showed PnR dominance persisting throughout, with the ICER becoming increasingly negative at higher discount rates and younger ages, reflecting the longer time horizon over which the QALY advantage accrues.

This Markov Chain model study contributes novel insights as no prior study has incorporated OHIP Schedule of Benefits data to inform their model's cost analysis process, conducted a parallel US Medicare analysis for cross-jurisdictional validation, or applied formal discounting with national life tables. In turn, the findings of this study are particularly pertinent in guiding the clinical decision making of ophthalmologists from an economic and resource utilization perspective. Additionally, few studies in the past have

leveraged Markov Chain models to investigate the comparison of cost-effectiveness between PnR and PPV. Amongst these, none have used high-exponentiated long-run time modelling in addition to high quality RCT data such as PIVOT, prospectively collected, randomized to minimize confounding by indication and selection bias.[5,17] Moreover, the model developed for this study included 60 distinct health states and tracked accumulated costs in primary RRD treatment with higher resolution compared to previous studies. Due to the incorporation of techniques for the granular modeling of complex patient pathways, this model is notably more robust than many of its previous counterparts. Finally, this study involved the calculation of ICER and thereby provided incremental analysis standardized in a suitable format for developing conclusions regarding cost-effectiveness in literature and policy considerations.[20,24] Collectively, these aspects of the study offer healthcare providers with substantiated evidence for clinical decision making for patients with RRD to choose appropriate first-line intervention.

Nonetheless, there are several limitations inherent to the development and parameterization of the model that should be acknowledged. While transition probabilities were sourced from the 12-month PIVOT trial follow-up, the matrix power method projects outcomes to long-run equilibrium ($P^{1024} \approx P^{\infty}$), representing a lifetime horizon. The model therefore assumes that the 12-month transition structure observed in PIVOT is stable over time, which may not capture changes in clinical risk with aging. Relatedly, the model assumes time invariance and simplifies computation of transitional probabilities to a memoryless process due to the Markov property, thereby neglecting longitudinal clinical risks such as increased cataract formation with aging.[24,25]

Additionally, the data used for transition probability and utility from the PIVOT trial were not stratified based on patient characteristics and were used to generate averaged parameters when input into the model. In doing so, the results assume homogeneity amongst patients within health states and do not distinguish between clinical subgroups. Importantly, the generalizability of our findings is limited by the PIVOT trial's eligibility criteria, which focused on primary RRDs with limited superior breaks, while excluding more complex cases (e.g., inferior breaks, PVR ≥ Grade B). The OHIP schedule of benefits cost data restricts generalizability to the OHIP-covered population, though the parallel US Medicare analysis mitigates this concern. The US cost analysis used ASC/nonfacility costs as the base case, which represent the lower bound of US procedure costs; hospital-based costs, as shown in the sensitivity analysis, further strengthen PnR dominance.

Future studies can improve upon this model by integrating patient-level data to provide insight on the relationship between measurable patient characteristics (e.g., age and pre-existing conditions) and cost-effectiveness of surgical interventions for RRD. Additionally, cost-effectiveness modelling can be improved through inclusion of indirect costs due to lifestyle changes immediately following interventions (e.g., lost productivity). Furthermore, conducting comprehensive probabilistic sensitivity analyses (PSA) will enhance the robustness of the model by quantifying the influence of parameter uncertainty on the study outcomes. Additional and alternative modelling techniques that excel at evaluating variance and time-dependency may generate improved projections that better align with real-world patient experiences.

CONCLUSION

In conclusion, the Markov model analysis indicates that PnR is a more cost-effective initial treatment than PPV for suitable primary RRD patients over a long-run horizon, offering higher QALYs per dollar spent. This finding is robust to discounting at CADTH-recommended rates, deterministic sensitivity analysis of key transition probabilities, Monte Carlo validation, and cross-jurisdictional validation under US Medicare pricing. While PPV remains essential for complex or recurrent detachments, the insights from this study can be used in combination with clinical trial data to inform healthcare providers during the clinical decision-making process to promote optimal resource usage and patient outcomes in RRD management.

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FIGURE CAPTIONS

Figure 1. Markov chain state diagram for PnR (S58) and PPV (S59) treatment arms. Sixty health states are shown with transition probabilities derived from the PIVOT randomized controlled trial. Absorbing states (terminal outcomes) are depicted as shaded nodes.

Figure 2. Weighted QALY contributions by absorbing state for PnR (S58) and PPV (S59) arms.

Figure 3. Weighted cost contributions by absorbing state for PnR (S58) and PPV (S59) arms.

Figure 4. Tornado diagram showing one-way deterministic sensitivity analysis results. Each horizontal bar represents the ICER range when the corresponding transition probability is varied ±20% from the base case (–$516.79/QALY, dashed line). Blue bars indicate parameter decreases; orange bars indicate parameter increases. PnR remains dominant (negative ICER) across all variations.

Table 1. Absorbing State Definitions

State	Encoding	Clinical Description
S14	PnR; Mac ON; NO Cat; YES Laser	Primary reattachment post-PnR and LR
S15	PnR; Mac ON; NO Cat; NO Laser	Primary reattachment post-PnR
S16	PnR; Mac OFF; YES Cat; YES Laser	Primary reattachment post-PnR and LR with cataract surgery and macular involvement
S17	PnR; Mac OFF; YES Cat; NO Laser	Primary reattachment post-PnR with cataract surgery and macular involvement
S22	PnR; Mac OFF; NO Cat; YES Laser	Primary reattachment post-PnR and LR with macular involvement
S23	PnR; Mac OFF; NO Cat; NO Laser	Primary reattachment post-PnR with macular involvement
S37	PPV; Mac ON; YES Cat; NO Laser	Primary reattachment post-PPV with cataract surgery
S39	PPV; Mac ON; NO Cat; YES Laser	Primary reattachment post-PPV and LR
S40	PPV; Mac ON; NO Cat; NO Laser	Primary reattachment post-PPV
S41	PnR/PPV; Mac ON; NO Cat; YES Laser	PPV after initial PnR and LR
S44	PPV; Mac OFF; YES Cat; NO Laser	Primary reattachment post-PPV with cataract surgery and macular involvement
S47	Repeat PPV; Mac ON; YES Cat; YES Laser	Repeated PPV and LR with cataract surgery
S51	PPV; Mac OFF; NO Cat; NO Laser	Primary reattachment post-PPV with macular involvement
S52	PnR/PPV; Mac OFF; NO Cat; NO Laser	PPV after initial PnR with macular involvement
S54	PPV/SB; Mac ON; YES Cat; YES Laser	Repeat PPV+SB and LR with cataract surgery
S55	PPV/SB; Mac OFF; YES Cat; YES Laser	Repeat PPV+SB and LR with cataract surgery and macular involvement
S56	PPV/SB; Mac OFF; YES Cat; NO Laser	Repeat PPV+SB with cataract surgery and macular involvement
S57	PnR/PPV/SB; Mac OFF; NO Cat; NO Laser	PPV+SB after initial PnR with macular involvement

Cat = cataract surgery; LR = laser retinopexy; Mac = macular status; PnR = pneumatic retinopexy; PPV = pars plana vitrectomy; SB = scleral buckle.

Table 2. Average QALY-to-Cost Ratio (Q/C) by Absorbing State for PnR and PPV

State	Mean Cost	Mean QALY	Avg Q/C	Prob (PnR)	Wtd Q/C (PnR)	Prob (PPV)	Wtd Q/C (PPV)
S14	$1,299.83	26.188	0.020147	16.18%	0.003259	0.00%	0
S15	$1,215.47	24.479	0.020140	38.84%	0.007823	0.00%	0
S16	$2,025.38	6.107	0.003015	3.50%	0.000105	0.00%	0
S17	$1,557.23	18.109	0.011629	3.50%	0.000407	0.00%	0
S22	$1,230.90	26.019	0.021139	9.49%	0.002006	0.00%	0
S23	$1,291.69	19.935	0.015433	16.58%	0.002559	0.00%	0
S37	$2,354.80	26.864	0.011408	2.05%	0.000234	17.24%	0.001966
S39	$1,738.08	30.835	0.017741	0.46%	0.000082	3.87%	0.000686
S40	$1,742.65	21.258	0.012199	2.07%	0.000253	17.38%	0.002120
S41	$2,909.36	22.886	0.007866	0.69%	0.000054	5.79%	0.000455
S44	$2,372.76	18.949	0.007986	4.12%	0.000329	34.59%	0.002762
S47	$4,869.19	23.834	0.004895	0.23%	0.000011	1.92%	0.000094
S51	$1,705.74	17.565	0.010298	1.14%	0.000117	9.57%	0.000985
S52	$3,601.46	12.510	0.003474	0.23%	0.000008	1.92%	0.000067
S54	$3,726.23	12.977	0.003483	0.23%	0.000008	1.92%	0.000067
S55	$3,996.00	10.857	0.002717	0.23%	0.000006	1.94%	0.000053
S56	$5,028.06	17.093	0.003400	0.23%	0.000008	1.94%	0.000066
S57	$4,584.81	18.748	0.004089	0.23%	0.000009	1.93%	0.000079
Sum				**100.00%**	**0.017279**	**100.00%**	**0.009401**
					1/Sum = $57.87		**1/Sum = $106.38**

Wtd = weighted. Q/C ratio = mean QALY / mean cost for each state. 1/Sum gives cost per QALY under the E[Q/C] method (Equation 4). The conventional E[C]/E[Q] ratios are $62.46 (PnR) and $115.92 (PPV). All costs in CAD (OHIP). QALYs represent post-operative lifetime QALYs (Postop_Utilities × Remaining_Life).

Table 3. Discounted Cost-Effectiveness Analysis

Panel A. Undiscounted vs Discounted (CADTH 1.5%)

	PnR Cost	PnR QALY	PPV Cost	PPV QALY	ICER ($/QALY)
Undiscounted	$1,427.75	22.860	$2,426.05	20.928	-$516.79
Discounted (r = 1.5%, age 61)	$1,427.75	19.213	$2,426.05	17.589	-$614.89
Change (%)	0.0%	-16.0%	0.0%	-16.0%	

Panel B. ICER Sensitivity by Patient Age and Discount Rate ($/QALY)

Age \ Rate	r = 0%	r = 1.5%	r = 3%	r = 5%
55	-$508.16	-$639.25	-$782.66	-$988.26
58	-$507.32	-$626.99	-$756.72	-$941.53
61	-$506.32	-$614.89	-$731.49	-$896.48
65	-$504.69	-$598.97	-$698.99	-$839.17
70	-$501.95	-$579.31	-$660.14	-$771.99

All ICER values in $/QALY. Negative = PnR dominant. CADTH = Canadian Agency for Drugs and Technologies in Health. Costs assumed upfront (t = 0). QALYs discounted using Statistics Canada life tables (2022–2024). Primary analysis: age 61, r = 1.5%.

Table 4. Canada (OHIP) vs US (Medicare) Cost-Effectiveness Comparison

	Canada (OHIP, CAD)	US ASC (2022 USD)	US Hospital (2022 USD)
PnR expected cost	$1,427.75	$2,308.79	$4,059.44
PPV expected cost	$2,426.05	$4,904.12	$7,840.61
PnR expected QALY	22.860	22.860	22.860
PPV expected QALY	20.928	20.928	20.928
Cost per QALY, PnR (E[C]/E[Q])	$62.46	$101.00	$177.60
Cost per QALY, PPV (E[C]/E[Q])	$115.92	$234.33	$374.65
ICER (PPV vs PnR)	**-$516.79**	**-$1,343.54**	**-$1,957.42**
PnR dominant?	YES	YES	YES

QALYs identical across jurisdictions (clinical outcomes unchanged; only costs substituted). US ASC = ambulatory surgery center setting. US Hospital = hospital-based setting with adjustment factors (PPV ×1.60, PnR ×1.81). All values undiscounted. ICER negative = PnR dominant (lower cost, higher QALY).

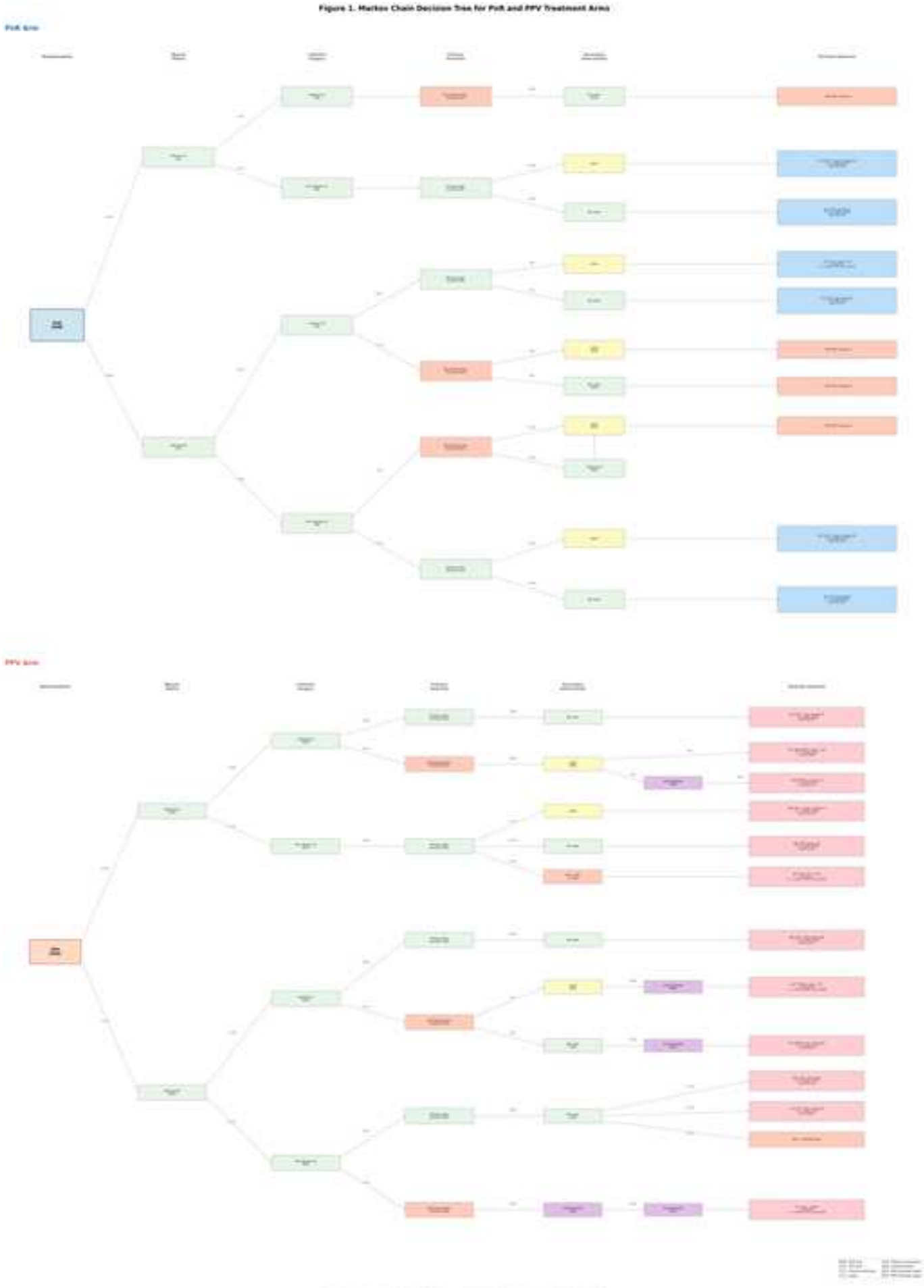

Figure 2. Weighted QALY Contributions by Absorbing State

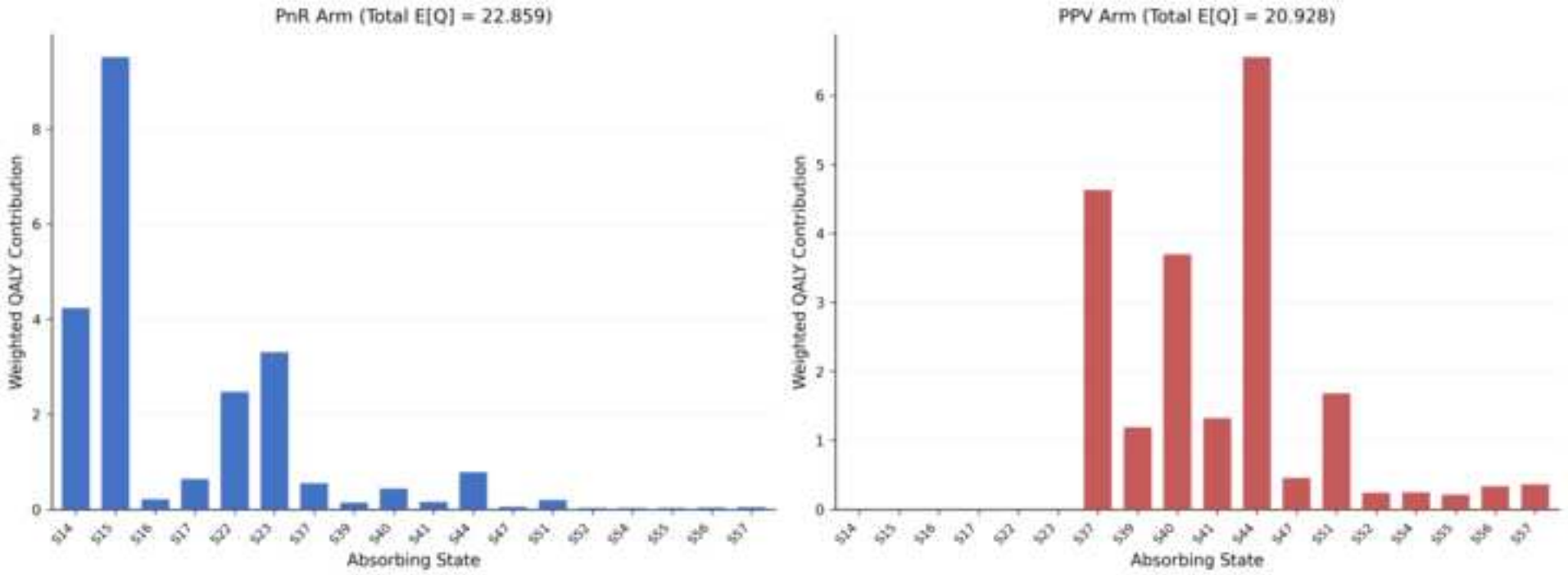

Figure 3. Weighted Cost Contributions by Absorbing State

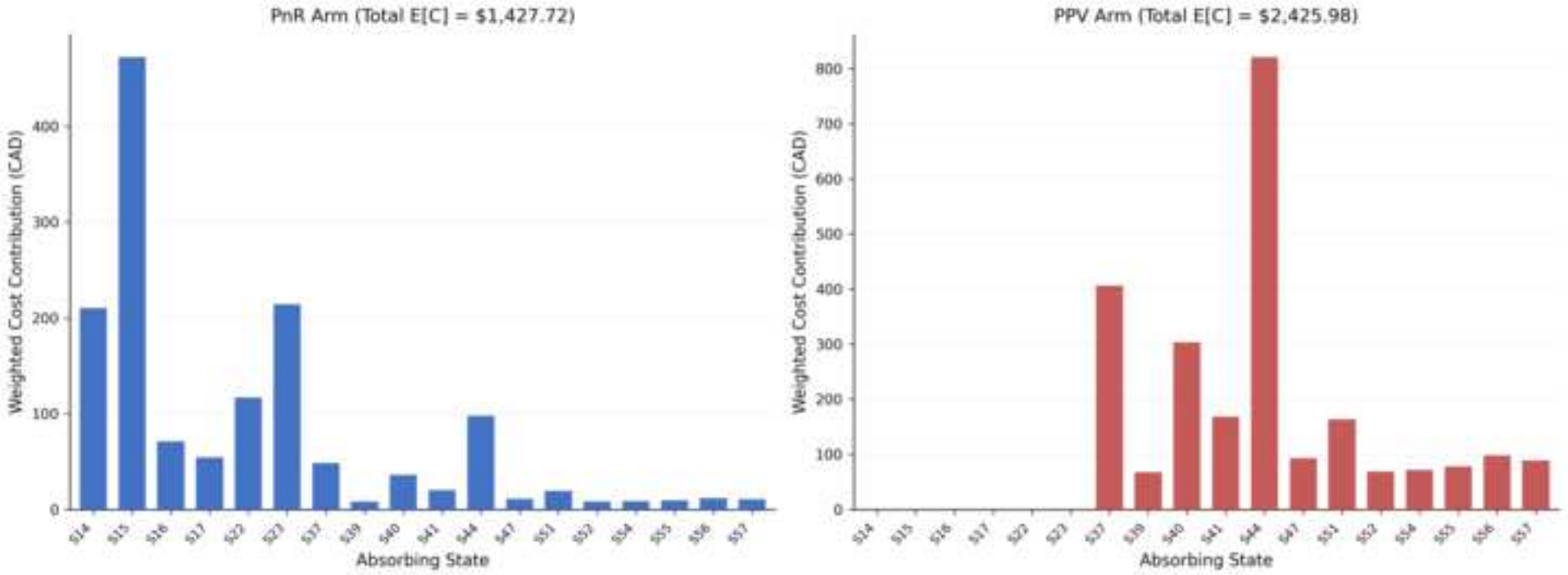

Figure 4. Tornado Diagram: One-Way Deterministic Sensitivity Analysis
PnR vs PPV for Primary RRD (Base case ICER: -$517/QALY)