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Cognitive Heuristics in the Operating Room: The Role of ‘Left-Digit Bias’ In Ophthalmic Surgical Selection

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Table 1 is available in the Supplementary Files section.

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Running Head: Left-Digit Bias in Ophthalmic Surgical Selection

Abstract:

Background/Objectives:

Left-digit bias (LDB) is a cognitive heuristic in which the leftmost digit of a number disproportionately influences judgement. This study evaluates the impact of perceived patient age on ophthalmic surgical decision-making.

Subjects/Methods:

Using the TriNetX U.S. Network, patients ages 39-86 were followed for 1 year after their initial healthcare visit (index event). Data was age stratified into 2-year intervals (e.g. 48/49, 50/51) and 1:1 propensity-score matched for race, sex, and ethnicity. The primary outcome was performance of a documented ophthalmic procedure after the index event. Patient age was used to calculate odds ratios (ORs) for each age interval using Chi-squared tests; OR<1 indicated lower likelihood of surgery in the younger cohort (e.g. 48/49 vs. 50/51).

Results:

Among 168,235,744 eligible patients, 503,832 underwent phacoemulsification and/or selected glaucoma and cornea procedures. Across several age-interval comparisons involving a left-digit shift (48/49 vs. 50/51, 58/59 vs. 60/61, and 68/69 vs. 70/71), younger cohorts were less likely to undergo phacoemulsification (OR 0.829 [95% CI, 0.796-0.863]; 0.721 [95% CI, 0.702-0.741]; 0.916 [95% CI, 0.897-0.935]; all p<0.001). No significant differences were observed at adjacent mid-decade age intervals. A modest reduction in minimally invasive glaucoma surgery was observed at 48/49 vs. 50/51 (OR 0.900 [95% CI, 0.869-0.932]; p<0.001). No LDB was observed for glaucoma drainage implant or keratoplasty procedures.

Conclusions:

Surgical frequency for phacoemulsification increased at the transition between decades across several age-interval comparisons, consistent with a left-digit bias. Clinicians should consider the potential influence of age perception in ophthalmic surgical decision making.

Introduction

Cognitive heuristics are simplified mental "shortcuts" used by individuals to quickly make judgements that aid in decision-making. By selectively focusing on pertinent information, heuristics may assist in time-sensitive or complex situations by promoting efficiency.[1] However, they may also introduce systematic errors or unconscious biases.[2] The use of cognitive heuristics can be applied to clinical decision-making and may be particularly influential in surgical settings,[3] where the introduction of cognitive bias has been found to have an overall negative impact on surgical performance and patient outcomes.[4]

Left-digit bias (LDB) is a cognitive heuristic in which decision-makers place disproportionate weight on the leftmost digit of a number, often leading to significant shifts in judgment at numerical thresholds The concept of left-digit bias has been well documented in psychology, marketing, and behavioral economics. One example is "99-cent pricing" in which consumers may disproportionately focus on the leftmost digit of a price, in turn judging items priced at $12.99 to be meaningfully cheaper than those at $13.00.[5]

Though clinicians frequently practice high-stakes decision-making influenced by cognitive heuristics, LDB has not been extensively investigated in many procedural subspecialties. In critical care and surgical settings in particular, clinicians may utilize heuristic approaches to quickly process complex information, develop differential diagnoses, and advise time-sensitive management plans.[6] For procedural specialties, LDB can skew the perception of a patient's age, introducing a cognitive bias that impacts both clinical judgement and the likelihood of surgical intervention. For instance, patients aged 59 vs. 60 years old may be viewed differently and receive varying clinical recommendations, though the true difference in age is clinically insignificant.

Studies in several surgical fields suggest that age-related LDB has the potential to meaningfully impact clinical decision-making. A study by Melucci et al. from the oncology literature demonstrated that patients with potentially curable rectal cancer who were perceived as "older" (60 vs. 58/59 and 80 vs. 78/79) were less likely to receive guideline-adherent chemotherapy.[7] Similar findings were reported in the neurosurgery literature among elderly patients with traumatic brain injuries, where 79-year-old patients had higher craniotomy rates than 80-year-olds.[8] Among patients with localized prostate cancer, 69-year-olds were more likely to undergo radical prostatectomy than 70-year-olds, as the "older" patient group was more likely to receive radiation therapy instead of surgery.[9] An orthopedic surgery study found that patients aged 78/79 were more likely than those 80/81 to undergo invasive decompression with instrumentation procedures rather than decompression alone for treatment of lumbar spinal stenosis.[10]

These findings suggestive of LDB in other surgical subspecialties support investigating its presence and potential impact on ophthalmic care. Prior studies in ophthalmology have examined cognitive heuristics and their potential to contribute to diagnostic bias among diseases with similar presentations.[11] However, no studies to date have examined LDB in ophthalmic surgery. Cataract surgery is among the most common procedures performed in the US, exceeding 3.5 million cases annually and projected to increase greater than 70% by 2036 due to an aging population and rising cataract prevalence.[12,13] Furthermore, cataract surgery is elective, minimally invasive, well-tolerated, and generally has a short recovery period. Unlike certain high-risk procedures that exhibit age-related avoidance, cataract extraction shows a unique susceptibility to left-digit bias. Patients crossing end-of-decade thresholds undergo surgery at

disproportionately higher rates, as the perceived transition to being 'older' appears to increase surgical eligibility rather than deterring intervention.[7,9]

There are currently no established guidelines recommending a specific age range for surgical intervention in adult ophthalmic care, allowing for individualized care based on the physicians' clinical judgement and shared decision-making models. The American Academy of Ophthalmology (AAO) guidelines for cataract surgery do not specify an optimal age for intervention and state that the main indication for cataract surgery is when visual function does not meet patient needs and surgery is expected to improve quality of life, regardless of age.[14]

Given that clinicians' recommendations lead to potentially life-altering surgical interventions, understanding the influence of LDB on clinical decision-making is imperative to ensure optimal patient outcomes. This study aims to assess the impact of LDB on surgical decision-making across common ophthalmic procedures, including cataract extraction via phacoemulsification, as well as corneal and glaucoma surgeries. Our findings characterize the prevalence of cognitive bias in these subspecialties, highlighting the need for its recognition and further evaluation in ophthalmic patient care.

Methods

This retrospective cohort study was conducted using de-identified electronic health record (EHR) data from the TriNetX U.S. Collaborative Network (TriNetX, Cambridge, MA, USA), a federated research platform representing approximately 130 million patients from multiple healthcare organizations across the United States at the time of query (November 23rd, 2025). All data were de-identified in accordance with the Health Insurance Portability and Accountability Act (HIPAA) Privacy Rule. This study was approved by the Albert Einstein

College of Medicine Institutional Review Board and conducted in accordance with the tenets of the Declaration of Helsinki.

Patients were identified within 2-year age cohorts (58/59, 60/61, etc.) and were included if they had documentation of a general health visit, which served as the index event. Patients were followed for 1 year after the index event to assess the occurrence of ophthalmic surgical procedures and evaluate potential age-related differences in surgical decision-making at left-digit age thresholds. This analysis included comparisons for end-of-decade 2-year cohorts (e.g., 48/49 vs. 50/51; 58/59 vs. 60/61) and mid-decade 2-year cohorts (e.g., 50/51 vs. 52/53; 52/53 vs. 54/55; 54/55 vs. 56/57; 56/57 vs. 58/59). Mid-decade analyses were conducted to distinguish potential LDB effects from gradual age-related increases in surgical incidence.

Outcomes included CPT-coded ophthalmic surgeries (Table 1). Selected ophthalmic surgeries include phacoemulsification, glaucoma drainage implant (GDI), minimally invasive glaucoma surgery (MIGS), and corneal transplantation procedures, including penetrating keratoplasty (PK) and endothelial keratoplasty (DSAEK/DMEK). As an exploratory analysis, mean hemoglobin A1C levels and type 1 and type 2 diabetes rates were compared between patients younger than 60 who underwent phacoemulsification and those who did not (Supplemental Table 1).

For each surgical outcome, odds ratios (ORs) with 95% confidence intervals (CIs) and p-values were calculated using Chi-squared tests to compare younger versus older 2-year cohorts, with OR < 1 indicating a lower likelihood of surgery in the younger cohort relative to the older cohort. All analyses were conducted within the TriNetX platform, with a stringent two-sided significance threshold of $p < 0.001$.

Inclusion criteria included age within the predefined 2-year cohort ranges, a documented routine health visit as the index event, and at least 1 year of follow-up. Patients with a prior history of the same ophthalmic procedure before the index event were excluded. To ensure comparability between age cohorts, patients were matched 1:1 using propensity scores based on sex, race, and ethnicity through TriNetX's built-in analytic tools. Cohort balance was assessed and confirmed prior to outcome analyses.

To ensure our study had adequate statistical power, a prospective power analysis was performed. Based on a two-sample comparison of proportions ($\alpha = 0.05$, $\beta = 0.80$), 4,352 patients per cohort (8,704 total) were required to detect this difference. The available TriNetX sample exceeded this threshold by several orders of magnitude, confirming that the study was well-powered to detect even small age-related differences in phacoemulsification rates.

Results

Procedure Rates

In total, 168,235,744 patients aged 39-86 years were included, of which 503,832 patients underwent phacoemulsification, selected glaucoma procedures, and/or selected cornea procedures. Of these, 256,362 (50.9%) were cataract procedures. To account for expected age-related changes, the surgical rate was calculated for each procedure type at 2-year age cohorts from ages 40/41 to 84/85. Phacoemulsification rates rose from 0.01% at ages 40/41 to 0.11% at 58/59, increasing to the highest rate of 0.37% in mid-70s (Figure 1).

Rates of glaucoma and corneal procedures were lower overall compared to phacoemulsification. MIGS procedure rates rose from 0.03% at 40/41 to 0.17% at 72/73, after which surgery rates declined steadily. GDI procedure rates rose from 0.02% at 40/41 to 0.07% at

72/73, after which a similar decline in surgical rates was observed. PK and DSAEK/DMEK rates remained close to 0.01% across all ages (Figure 1).

Phacoemulsification Procedures

A) Expanded mid-decade analysis

Across expanded mid-decade age group comparisons, phacoemulsification rates increased steadily with age, reflecting the expected age-related rise in cataract surgery incidence (Figure 1). Adjacent mid-decade cohort comparisons from age 44/45 to 74/75 demonstrate ORs near 1.0 with overlapping CIs and p-values non-significant (Figure 2).

B) Two-year age end-of-decade cohort comparisons

By contrast, at several age thresholds when the left-most digit of a patient's age advanced numerically (48/49 vs. 50/51, 58/59 vs. 60/61, and 68/69 vs. 70/71), patients in the younger 2-year-age cohort were consistently less likely to undergo phacoemulsification compared to their older counterpart (OR 0.829, 0.721, 0.916; all $p<0.001$) (Figure 2).

Glaucoma Procedures

A) Expanded mid-decade analysis

No consistent overall trend was observed in adjacent mid-decade cohort comparisons from age 44/45 to 74/75 for glaucoma procedures (MIGS and GDI), where ORs did not hover as closely to 1.0 as observed in phacoemulsification. For MIGS procedures, patients in the younger cohort were more likely to undergo the procedure than their older counterparts at ages 60/61 vs 62/63, 62/63 vs 64/65, 66/67 vs 68/69, and 70/71 vs 72/73 (OR 0.926, 0.903, 0.905, 0.993; all

p<0.001). For GDI procedures, this was also observed at ages 60/61 vs 62/63 (OR 0.915; p<0.001) (Figure 3).

B) Two-year age end-of-decade cohort comparisons

Glaucoma surgery rates were comparable between younger and adjacent older cohorts, with a modest end-of-decade decrease in MIGS procedures at 48/49 vs. 50/51 (OR 0.900, p<0.001). Using a stringent p-value significance rate of 0.001, GDI procedures showed no significant differences between age cohorts (Figure 3).

Additional glaucoma procedures (trabeculectomy, iridotomy, trabeculoplasty) demonstrated no consistent end-of-decade pattern. However, significant results were noted at several points in mid-decade analysis. Patients aged 48/49 were less likely than those 50/51 to undergo trabeculectomy procedures (OR 0.820, p<0.001). In iridotomy and trabeculoplasty, patients aged 58/59 were less likely than those 60/61 (OR 0.853, OR 0.902, both p<0.001).

Corneal Transplantation Procedures

A) Expanded mid-decade analysis

PK procedures demonstrated no significant difference in odds of undergoing surgery. For DSAEK/DMEK procedures, patients in the younger cohort were more likely to undergo the procedure than their older counterparts at ages 56/57 vs 58/59, 60/61 vs 62/63, 62/63 vs 64/65, 64/65 vs 66/67, 70/71 vs 72/73, and 72/73 vs 74/75 (OR 0.765, 0.803, 0.812, 0.797, 0.842, 0.848; all p<0.001) (Figure 3).

B) Two-year age end-of-decade cohort comparisons

In end-of-decade analysis, both PK and DSAEK/DMEK procedures did not demonstrate a LDB effect, with no significant inflection points observed (Figure 3).

Discussion

Our results suggest that left-digit bias (LDB) may impact surgical decision-making in ophthalmic surgery. As demonstrated in the phacoemulsification model, the absence of significant differences across mid-decade comparisons, alongside the isolated presence of differences at end-of-decade transitions, supports the interpretation that these findings are consistent with LDB rather than random age-related variation alone. Across multiple decades, phacoemulsification was more likely to occur in patients at the beginning of a new decade of life than in similarly aged patients at the end of the prior decade (48/49 vs 50/51, 58/59 vs 60/61, and 68/69 vs 70/71). In contrast to the significant LDB effect seen in phacoemulsification, no such pattern emerged for glaucoma or corneal procedures. These findings suggest that LDB may be more relevant in procedures with greater flexibility in surgical timing, whereas glaucoma and corneal procedures may be more influenced by other clinical considerations.

Phacoemulsification Procedures

Phacoemulsification rates increased steadily with age, consistent with the age-related prevalence of cataracts. However, across several age cohorts when the leftmost digit of a patient's age advanced (i.e., 48/49 to 50/51), patients at the start of the new decade were significantly more likely to undergo surgery compared to those at the end of the previous decade, consistent with a LDB effect.

Several mechanisms may underlie this observation. In contrast to many other ophthalmic pathologies, cataracts are typically managed electively, with surgical indications primarily driven by patient-reported symptoms and the perceived impact of visual impairment on daily life. Thus,

AAO recommends that surgical indication be assessed through patient questionnaires and discussion.[15] Additionally, cataracts typically progress gradually, making the timing of surgical intervention flexible and largely dependent on shared decision-making. Further, cataract surgery is generally a well-tolerated ambulatory procedure often performed under local anesthesia with mild sedation, obviating the need for medical clearance for many patients.[12] Phacoemulsification maintains an excellent safety profile even in advanced age groups, with low complication rates of approximately 0.05% to 2.2% of cases[16] and rapid visual recovery.[17] These favorable characteristics, combined with the age-related nature of cataracts, may lead to surgical deferral until patients reach a clinically appropriate age threshold perceived as "older." For instance, when a patient transitions from 58/59 to 60/61, clinicians may subconsciously categorize patients as being "in their 60s", influencing perceptions of surgical appropriateness despite minimal clinical differences across this boundary. This cognitive anchoring may also influence patients' self-perceived age, increasing willingness to pursue surgery at the start of a new decade.

The presence of LDB in surgical decision-making for phacoemulsification procedures may have important clinical implications. Given that cataract extraction can improve quality of life and reduce injury risk,[15] patients should be offered surgical intervention when clinically appropriate, regardless of age. Identifying age-based biases can encourage more consistent, patient-centered decision-making and ensure that clinical recommendations are guided by objective clinical data.

Glaucoma Procedures

Glaucoma procedures showed no pronounced age-based bias, likely reflecting differences in the clinical indication and time-sensitive nature as compared to elective cataract surgery. Glaucoma interventions are indicated based on objective clinical markers of disease severity and

progression, such as intraocular pressure. Since these parameters may differ across glaucoma procedures, we considered the role of age-related bias in MIGS and GDI separately.

Glaucoma Drainage Implants (GDI)

GDIs are commonly indicated in advanced or rapidly progressive glaucoma, when IOP must be aggressively lowered to prevent irreversible optic nerve damage. Because the decision to perform GDI procedures is largely dependent on disease severity and target IOP, there is limited influence of age-related biases. This aligns with our findings, which showed no significant differences in surgical likelihood at mid-decade versus end-of-decade comparisons in GDI procedures.

Minimally Invasive Glaucoma Surgery (MIGS)

MIGS procedures are preferred in milder glaucoma cases to improve IOP control and are often performed with cataract extraction. Compared with GDI or trabeculectomy procedures, MIGS procedures have a more favorable safety profile, with faster visual recovery and lower complication rates,[18] and are favorable for patients earlier in the disease course.[19]

No major LDB effect was observed in the timing of MIGS procedures, suggesting that surgical decision-making is primarily driven by objective measures of glaucoma severity rather than age-related bias. Because MIGS is typically performed concurrently with cataract surgery,[20] it is difficult to determine whether surgical timing is influenced by glaucoma severity, cataract burden, or both. In this study, we were unable to distinguish concurrent MIGS and cataract procedures compared to standalone MIGS procedures, which may represent an important consideration for future investigation.

Corneal Transplantation Procedures

No LDB effect was observed in corneal transplantation procedures, including penetrating keratoplasty (PKP) or lamellar keratoplasty (e.g. DSAEK/DMEK). These findings suggest that the decision to undergo corneal transplantation was primarily determined by the type and extent of underlying pathology rather than perceived patient age.[21,22]

Although patient age generally does not preclude corneal transplantation, significant age-related differences may influence postoperative outcomes. DSAEK and PK have shown comparable graft survival rates between younger and older geriatric patient cohorts.[23] However, older DMEK recipients may have higher comorbidity-related risks that may be associated with graft failure.[24] Despite these considerations, the absence of LDB at decade transitions suggests that corneal transplantation decision-making is driven more by underlying corneal pathology than perceived age.

Strengths, Limitations, and Future Directions

Our findings suggest that phacoemulsification may be uniquely susceptible to age-based cognitive heuristics, likely due to its flexible timing, reliance on patient-reported symptoms, and structure of shared decision-making. In contrast, corneal and glaucoma surgeries may be more strongly guided by objective measures and urgency of intervention. These findings highlight clinically relevant differences in factors that may guide ophthalmic surgical decision-making.

This study also has several strengths. The use of TriNetX, a large multicenter database, allowed us to evaluate age-based decision-making patterns across several ophthalmic procedure types. Further, the significance of decade-boundary comparisons and the absence of said differences at mid-decade comparisons for phacoemulsification support the interpretation that phacoemulsification is susceptible to LDB. Nevertheless, several important limitations should also be considered. The TriNetX database enabled cohort matching by age, sex, race, and

ethnicity, but not by specific comorbidities that may influenced surgical timing. Additionally, although the study was adequately powered, cohort sample sizes were not equal for each procedure, which required adjustment in our analysis. Lastly, the retrospective study design is susceptible to misclassification errors arising from ICD diagnostic coding and CPT procedural coding.

Further research is needed to better characterize the role of LDB in ophthalmic surgical decision-making, particularly in elective procedures such as phacoemulsification. Structured qualitative surveys of ophthalmic surgeons could assess whether end-of-decade age thresholds influence recommendations for surgical interventions in clinically similar patients, as well as clinician awareness of LDB and the relative influence of age versus clinical factors in surgical decision-making. Expanding this approach across diverse healthcare settings (i.e., high-volume vs. lower-resource settings) would further clarify variation in practice patterns. Ultimately, understanding how age perception influences clinician decision-making may improve consistency in surgical timing and optimize patient outcomes.

The presence of LDB in phacoemulsification procedures may contribute to inconsistent surgical timing despite clinically insignificant differences in patient age. Given that cataract extraction is safe, well-tolerated, and associated with high patient satisfaction and improved quality of life, clinical decisions should be guided by patient goals and objective findings rather than age-related cognitive heuristics.

Greater recognition of LDB in ophthalmic surgery provides an opportunity for clinicians to strengthen patient-centered care. As the demand for cataract extraction continues to rise with our aging population, small adjustments in clinical judgement and surgical guidance can have a profound effect in optimizing visual outcomes and patient satisfaction.

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Data Availability Statement

The TriNetX Research Network is a fully de-identified, cloud-based database that adheres to the standards set forth by the Health Insurance Portability and Accountability Act (HIPAA) Privacy Rule, including Section §164.514(b)(1), as well as ISO 27001:2013 information security certification. Due to patient privacy protections and data use agreements, individual-level data from the TriNetX platform is not publicly available. However, de-identified, population-level aggregate data supporting the findings of this study may be accessed through the TriNetX Research Network by qualified researchers who establish a license agreement with TriNetX (https://trinetx.com).

Conflict of Interest

The authors have no conflicts of interest to disclose.

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Author Contribution Statement

KS, RZ, ZM, and AS contributed to the conception and design of the study. JS and JYM contributed to data collection, data analysis, and interpretation. KS, RZ, JS, and AS drafted the

manuscript and created figures and tables. LY and AS critically revised the manuscript for important intellectual content. All authors reviewed and approved the final manuscript and agree to be accountable for all aspects of the work.

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Figure Legends

Figure 1.

Surgery rates for cataract surgery (A) and glaucoma and corneal procedures (B) were calculated across age cohorts from 40/41 through 84/85.

Figure 2.

Procedure rates of phacoemulsification: (A) 44 to 55 years old, (B) 54 to 65 years old, and (C) 64 to 75 years old, demonstrating a significant change only when the left-digit advances (boxed in red). (D) Surgeons were less likely to perform phacoemulsification on younger patients immediately before the left-digit increases numerically, as evidenced by a lower OR at each turn of decade.

Figure 3.

(A): Surgeons were less likely to perform MIGS procedures in patients aged 48/49 compared to 50/51 years old when the left digit advances. (B-D): For GDI and keratoplasty procedures, advancement of the left digit did not meaningfully impact odds of undergoing surgery.

Figures

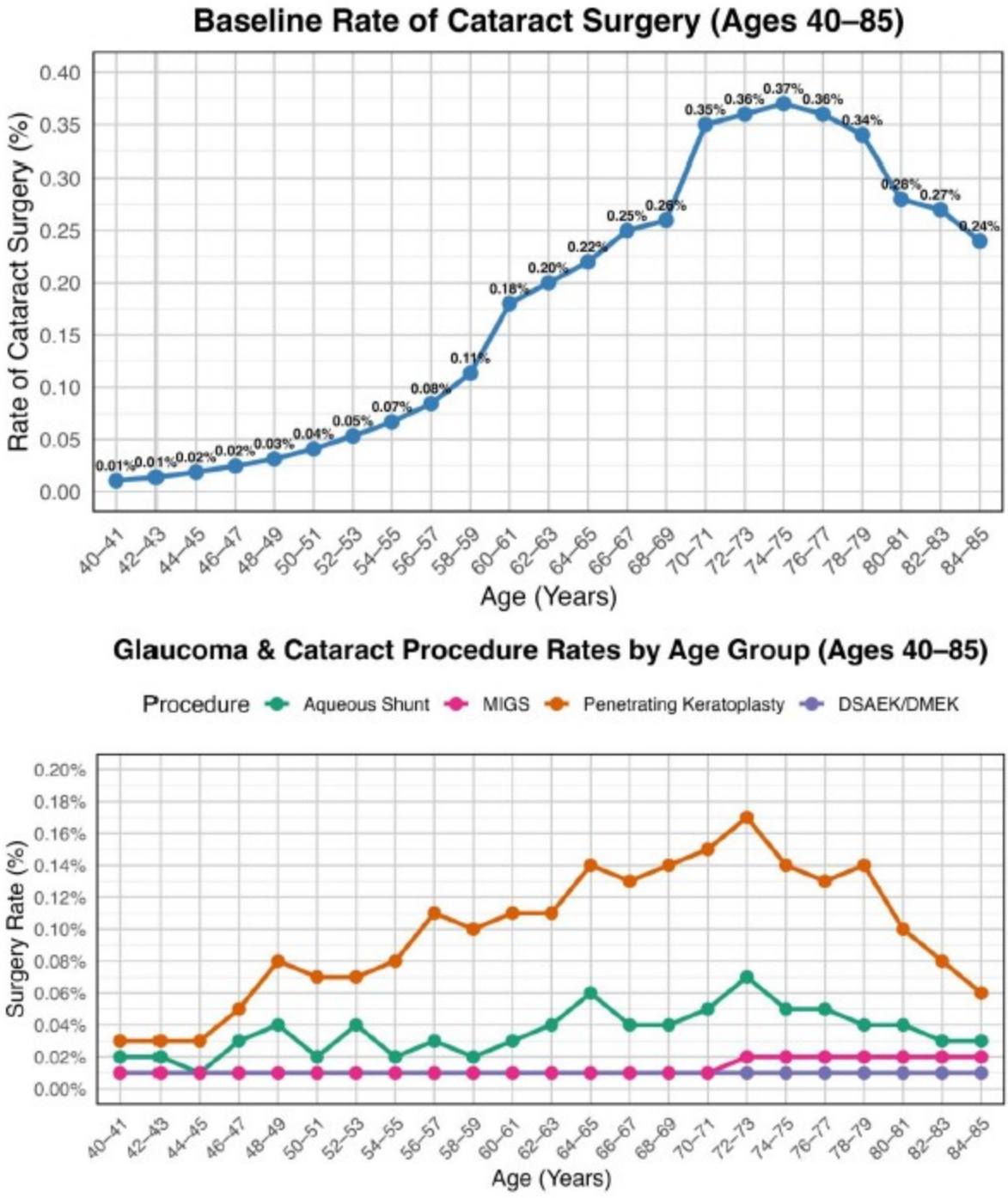

Figure 1

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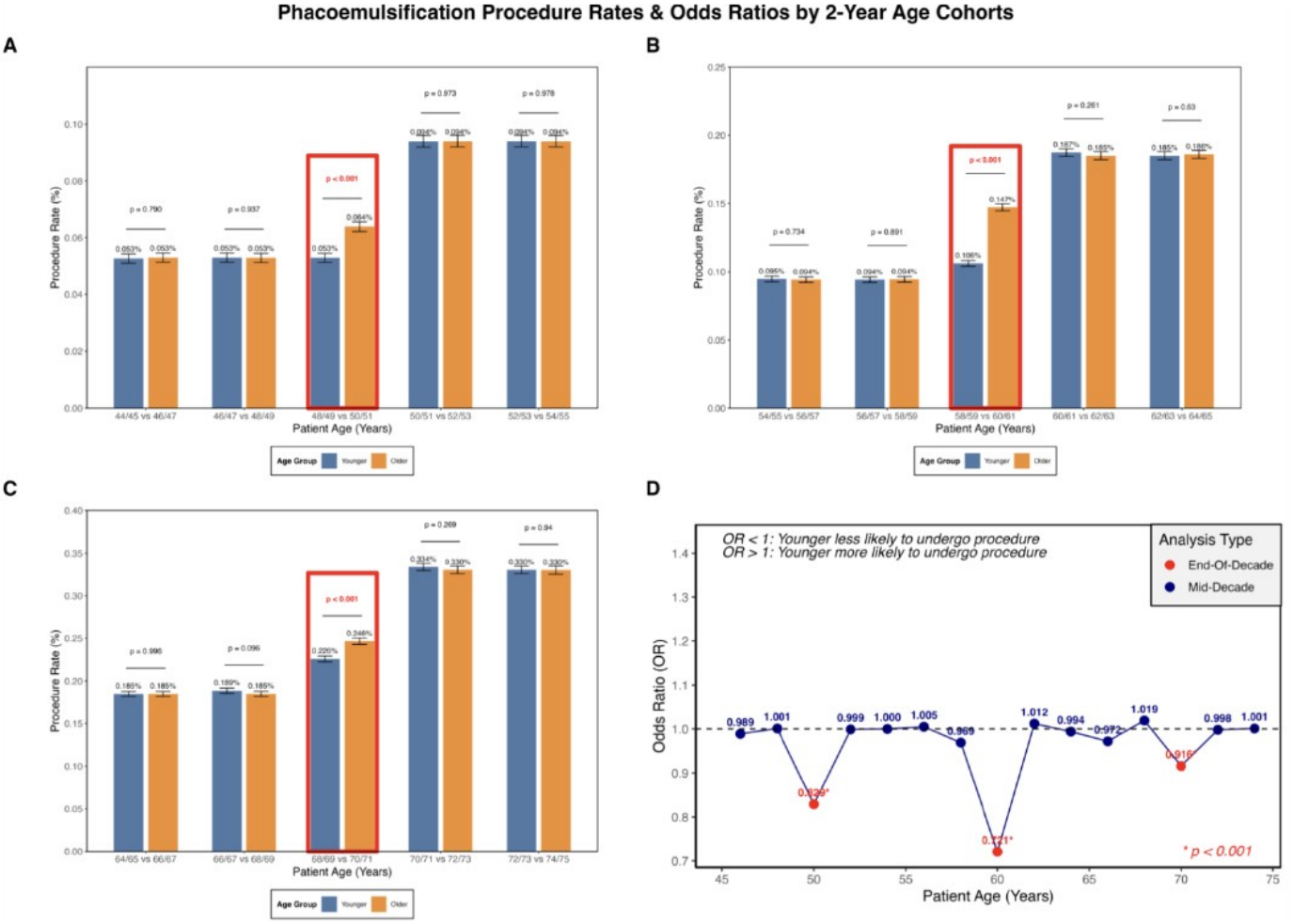

Figure 2

Procedure rates of phacoemulsification: (A) 44 to 55 years old, (B) 54 to 65 years old, and (C) 64 to 75 years old, demonstrating a significant change only when the left-digit advances (boxed in red). (D) Surgeons were less likely to perform phacoemulsification on younger patients immediately before the left-digit increases numerically, as evidenced by a lower OR at each turn of decade.

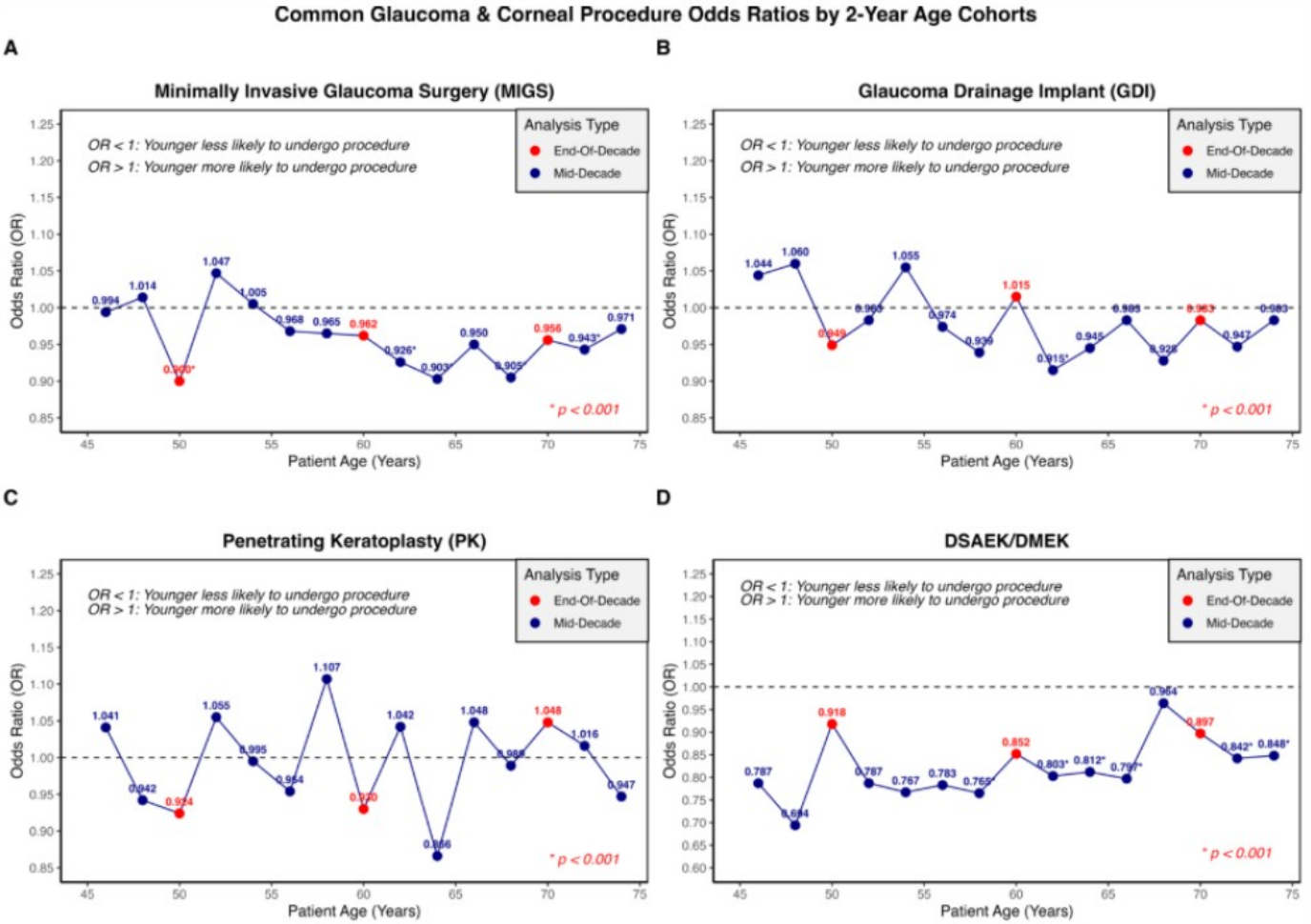

Figure 3

(A): Surgeons were less likely to perform MIGS procedures in patients aged 48/49 compared to 50/51 years old when the left digit advances. (B-D): For GDI and keratoplasty procedures, advancement of the left digit did not meaningfully impact odds of undergoing surgery.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1LDB.docx
- SupplementalTable1LDB.docx