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ChatGPT-Assisted Classification of Postoperative Bleeding Following Microinvasive Glaucoma Surgery Using Electronic Health Record Data

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Purpose: To evaluate the performance of a large language model (LLM) in classifying electronic health record (EHR) text, and to use this classification to evaluate the type and resolution of hemorrhagic events (HEs) after microinvasive glaucoma surgery (MIGS).

Design: Retrospective cohort study.

Participants: Eyes from the Bascom Palmer Glaucoma Repository.

Methods: Eyes that underwent MIGS between July 1, 2014 and February 1, 2022 were analyzed. Chat Generative Pre-trained Transformer (ChatGPT) was used to classify deidentified EHR anterior chamber examination text into HE categories (no hyphema, microhyphema, clot, and hyphema). Agreement between classifications by ChatGPT and a glaucoma specialist was evaluated using Cohen's Kappa and precision-recall (PR) curve. Time to resolution of HEs was assessed using Cox proportional-hazards models. Goniotomy HE resolution was evaluated by degree of angle treatment (90°−179°, 180°−269°, 270°−360°). Logistic regression was used to identify HE risk factors.

Main Outcome Measures: Accuracy of ChatGPT HE classification and incidence and resolution of HEs.

Results: The study included 434 goniotomy eyes (368 patients) and 528 Schlemm's canal stent (SCS) eyes (390 patients). Chat Generative Pre-trained Transformer facilitated excellent HE classification (Cohen's kappa 0.93, area under PR curve 0.968). Using ChatGPT classifications, at postoperative day 1, HEs occurred in 67.8% of goniotomy and 25.2% of SCS eyes ($P < 0.001$). The 270° to 360° goniotomy group had the highest HE rate (84.0%, $P < 0.001$). At postoperative week 1, HEs were observed in 43.4% and 11.3% of goniotomy and SCS eyes, respectively ($P < 0.001$). By postoperative month 1, HE rates were 13.3% and 1.3% among goniotomy and SCS eyes, respectively ($P < 0.001$). Time to HE resolution differed between the goniotomy angle groups (log-rank $P = 0.034$); median time to resolution was 10, 10, and 15 days for the 90° to 179°, 180° to 269°, and 270° to 360° groups, respectively. Risk factor analysis demonstrated greater goniotomy angle was the only significant predictor of HEs (odds ratio for 270°−360°: 4.08, $P < 0.001$).

Conclusions: Large language models can be effectively used to classify longitudinal EHR free-text examination data with high accuracy, highlighting a promising direction for future LLM-assisted research and clinical decision support. Hemorrhagic events are relatively common self-resolving complications that occur more often in goniotomy cases and with larger goniotomy treatments. Time to HE resolution differs significantly between goniotomy groups.

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Microinvasive glaucoma surgeries (MIGSs) represent a significant advancement in glaucoma treatment, offering an alternative to traditional surgical approaches with advantages such as subconjunctival tissue preservation and a lower rate of complications.[1,2] As the field of glaucoma surgery continues to evolve, the options provided by MIGS are increasingly favored over traditional glaucoma surgeries in mild to moderate disease.[3,4] Although infrequent, complications may arise after MIGS.[5,6] Blood reflux into the anterior chamber is a relatively common postoperative occurrence during these procedures, with rates estimated to range from 0.5% to 100% depending on the procedure and device used.[2,7−9] However, patterns of hemorrhage resolution have not been studied. Hemorrhage is often noted in initial postoperative examinations as the presence of a hyphema, blood clot, or red blood cells

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(RBCs) circulating in the anterior chamber (microhyphema), which typically resolve spontaneously within the first 2 weeks without the need for additional intervention.[2,7,10] In prospective studies, such as those regarding the Hydrus and iStent devices, postoperative hemorrhagic events (HEs) were reported collectively as "hyphema" without distinguishing between types or their clinical significance.[5,8,9] In addition, the time required for resolution of these HEs are rarely monitored or discussed. Hemorrhagic events are typically documented in the anterior chamber examination of the electronic health record (EHR) in a narrative text format.

Analyzing these postoperative complications within the EHR in a longitudinal fashion is a labor-intensive process. This traditional approach is particularly challenging when using large databases for research, necessitating more efficient methods for data analysis, particularly as the analysis of larger databases becomes more common. The advent of artificial intelligence (AI), specifically large language models (LLMs), offers useful solutions. Chat Generative Pre-trained Transformer (ChatGPT, OpenAI) is an LLM that has gained significant attention due to its ability to generate human-like responses after interpreting inputted text.[11] Since most health care data in EHR systems are in a free-text format, the potential use of LLMs is promising.[12] Fink et al showed the superiority of ChatGPT and GPT-4 models in data mining and labeling tasks compared with manual annotation methods of extracting oncologic phenotypes from free-text radiographic reports for lung cancer.[13] Stein et al recently developed a no light perception algorithm that reviewed lens examination data and accurately classified lens pathologies.[14] The purpose of this work was to evaluate the performance of ChatGPT in classifying anterior chamber examination data from EHR records of those patients undergoing MIGS, and to utilize such categorizations to evaluate the incidence as well as resolution of HEs.

Methods

The University of Miami Institutional Review Board approved this study and granted a waiver of informed consent given its retrospective nature. The study adhered to the Declaration of Helsinki and the Health Insurance Portability and Accountability Act. Of note, the Institutional Review Board reviewed and approved the entry of deidentified examination data into ChatGPT. The Bascom Palmer Glaucoma Repository contains demographic and ophthalmic data of eyes with or suspected of having glaucoma, examined at the clinical sites of the Bascom Palmer Eye Institute. These were identified using International Classification of Diseases codes (Table S1; available at https://www.ophthalmologyscience.org) from the Epic EHR (Epic Systems). The large Hispanic and Black populations in South Florida contribute to the diversity of this database. All patients were aged ≥18 years at their first visit. Prior work details the inclusion and exclusion criteria used for the Bascom Palmer Glaucoma Repository.[15,16]

Inclusion criteria in this study included eyes that underwent ≥1 MIGS procedure, with or without cataract extraction (CE) and intraocular lens implantation. All eyes were identified using Current Procedural Terminology (CPT) codes. Different subtypes of MIGS were categorized into 2 groups: goniotomy (i.e., CPT code of 65820 or 66174) and Schlemm canal stent (SCS) implantation (i.e., 0191T or 66991). Eyes missing visual acuity (VA) or anterior chamber examination notes at postoperative day 0 or postoperative day 1 (POD1) were excluded. We manually confirmed the goniotomy and stent CPT codes cases through review of operative notes. The degree of goniotomy treatment noted in the operative note was also manually reviewed. Any eyes with ambiguity regarding the degree of goniotomy were excluded from goniotomy angle analysis. We categorized goniotomy devices into 3 groups: blades, filaments, and illuminated microcatheters. The blade category included the devices of the Kahook Dual Blade (New World Medical), microvitreoretinal blade (MicroSurgical Technology), and Sion blade (Sight Sciences). The filament category included prolene suture and the Omni, TRAB360, and VISCO360 surgical systems (Sight Sciences), while the illuminated microcatheter category included iScience (iScience Interventional Corp) and iTrack microcatheters (Nova Eye Medical, Inc). We also reviewed all cases billed with CPT 66174 (viscocanalostomy), as this CPT code has been used frequently for both goniotomy and viscocanalostomy. We included only those eyes coded with CPT 66174 that received a goniotomy. We also reviewed any cases of CPT codes 65800 and 65815 among these eyes to ascertain whether any anterior chamber washouts were performed in the operating room.

Data Selection and Collection

Data available from July 1, 2014, to February 1, 2022 were analyzed. We obtained demographic and clinical information from the Bascom Palmer Glaucoma Repository, including VA, intraocular pressure (IOP), the count of topical antiglaucoma medications, the use and type of antiplatelet or anticoagulant medications, postoperative HE, and the presence of a medical history related to diabetes and hypertension. Visual acuity and IOP data were recorded at the preoperative visit, and at POD1, postoperative week 1 (POW1; range: 5−14 days), and postoperative months 1 and 3 (POM1; range: 21−40 days and POM3; range: 83−97 days). If an eye had multiple visits during the POW1, POM1, or POM3 timeframes, all examination data were extracted. Cornea and anterior chamber examination text from these visits were also extracted from the EHR. Snellen visual acuities were converted to the logarithm of the minimum angle of resolution for subsequent statistical analysis using the standard formula of logarithm of the minimum angle of resolution = −1 * log(Snellen fraction). Low vision values of counting fingers, hand motion, light perception, and no light perception were assigned values of 2.0, 2.3, 2.6, and 3.0 respectively.

The use of antiplatelets and anticoagulants was collected from the clinical records of the included patients based on EHR medication records. We verified that the medication was prescribed prior to the date of surgery. We screened for the use of salicylates, P2Y12 inhibitors, warfarin, heparin, and direct oral anticoagulants (e.g., apixaban, rivaroxaban, dabigatran, and edoxaban). Past medical history of hypertension and diabetes was noted through manual chart review.

Outcome Definition and LLM Prompts

We used 2 bleeding-related outcomes, HEs and clinically significant HEs (CSHE), which were both classified using ChatGPT. Hemorrhagic events were defined as presence of hyphema, clot, or RBCs/microhyphema postoperatively. Clinically significant HEs were defined as HE with postoperative Snellen equivalent VA ≤20/200 in eyes that had preoperative VA >20/100. This cutoff aligns with the visual impairment definition by the United States

Social Security Administration.[17] The 20/100 preoperative cutoff was chosen to ensure that postoperative vision loss represented $\geq$2 lines decrease in VA, a metric used to gauge vision loss in the tube versus trabeculectomy and primary tube versus trabeculectomy studies.[18,19] Hemorrhagic events were identified by assessing the anterior chamber examination extracted from the EHR, with classification into 4 groups: no hemorrhage, microhyphema, blood clot, or hyphema. Labeling was completed by ChatGPT 3.5 (Open AI). The LLM was given specific rules to follow to categorize the HEs, which included a weightage towards larger HEs if multiple terms were mentioned (i.e, hyphema > clot > microhyphema). The term "RBCs" in the anterior chamber examination was categorized as microhyphema, while mention of "clot" and "hyphema" led to their respective categorizations. The specific prompt given to ChatGPT was as follows: "Please read the CSV file containing clinical exam notes written by ophthalmologists and determine whether the patient had a bleeding event. A bleeding event is defined as the mention of 'hyphema', 'heme', 'clot', 'RBCs,' or 'microhyphema.' Mention of only 'cell', 'mixed cell', or 'fibrin' does not qualify as a bleeding event. List the output for each row. The output should have 2 columns - the first has a category value of '1', '2', '3', or '4'. '1' corresponds to 'hyphema' or 'heme,' '2' corresponds to 'clot,' '3' corresponds to 'RBCs' or 'microhyphema,' and '4' corresponds to no bleeding event. If 2 terms are present, classify as the category with the lower value (for example, 1 is lower than 2, 2 is lower than 3). The second column should have the rationale (that is, the reason for that categorization), if any, based on the input. Please be mindful of potential typos by the clinicians (e.g., 'hyphema' may be misspelled as 'hpyhema' but should still be categorized as '1'.) Provide the original data and the output in tabular format as a comma-separated values (CSV) file. Addend the output as additional rows with the titles 'category' and 'rationale.' Please do not skip repeated lines."

To process the clinical notes, we developed the following pipeline. We extracted deidentified examination data into a CSV file, which was then uploaded to ChatGPT with the prompt. This process was initially completed with batches of 200 examinations for the first 1000 examinations (i.e., 5 batches) to ensure the output was as desired and for preliminary quality assessment. Future iterations clarified how the LLM should classify examinations when multiple terms were mentioned in the text; we also noted that the LLM would occasionally skip lines if the same text was repeated (e.g., "Deep and quiet"). Once the prompt had been optimized, we subsequently obtained classifications in batches of 1000 examinations. A total of 4330 anterior chamber examinations were classified; all examinations between postoperative day 0 and day 97 were categorized.

We also utilized ChatGPT 3.5 to evaluate corneal examination data from these same examinations to exclude those eyes with corneal abnormalities from affecting the CSHE definition. We asked ChatGPT to identify eyes with mention of corneal folds or edema postoperatively in the corneal examination field at the postoperative day 0 or POD1 examination. The prompt provided to ChatGPT 3.5 for this task was as follows: "Please read the CSV file containing clinical exam notes written by ophthalmologists and determine whether the cornea had any abnormalities, which is defined by any mention of the terms 'DMF', 'D-folds,' 'Descemet folds,' 'D folds,' 'corneal edema,' 'K edema,' 'microcystic edema,' or 'MCE.' Please label these rows with a 1. If the row does not have any of these terms, then label the row with a 0. Please be mindful of potential typos by the clinicians (e.g., 'corneal edema' may be misspelled as 'croneal edema' but should still be labeled as '1'.) Export the input and output as a CSV file. Addend the output as an additional row with the title of 'category'. Please do not skip repeated lines." These eyes were excluded from the CSHE calculation, as the visual decrease could not be definitively attributed to the HE.

LLM Output Validation

To ensure the reliability and accuracy of the data processed by ChatGPT, a validation step was included. A fellowship-trained, board-certified glaucoma specialist (S.S.S.) classified a subset of anterior chamber examination notes blinded to the LLM's categorization. This labeling was considered the gold standard. The specialist evaluated the first examination for each time point of all eyes in the cohort (i.e., if an eye had multiple examinations between postoperative days 5 and 14, the first examination was labeled by the specialist, although ChatGPT was used to label all these examinations as noted above). A total of 2677 examinations were labeled by the specialist. Concordance between the AI-derived labels and the gold standard was evaluated using Cohen's Kappa statistic, a measure of interrater agreement. The Kappa values were interpreted as follows: values ranging from 0 to 0.20 indicated slight agreement; 0.21 to 0.40 signified fair agreement; 0.41 to 0.60 denoted moderate agreement; 0.61 to 0.80 reflected substantial agreement; and 0.81 to 1 represented almost perfect agreement. We also constructed confusion matrices and calculated sensitivity, specificity, true positive rate, true negative rate, false positive rate, false negative rate, positive predictive value, and negative predictive value with their 95% confidence intervals (CIs). Receiver operating characteristic curves and precision-recall (PR) curves were plotted to assess the discriminative ability and PR trade-off of the model, respectively. The PR curve was utilized given the significant class imbalance that was noted. Area under the receiver operating characteristic curve (AUC) and area under the PR curve (AUPRC) were computed to quantify model performance.

Statistical Analysis

Categorical variables are presented as frequencies and percentages, and continuous variables as means $\pm$ standard deviation. Group differences in continuous variables were compared using the Wilcoxon rank-sum test and categorical variables with the chi-squared test. Between-group differences in postoperative VA and IOP were calculated only in those eyes undergoing combined CE/intraocular lens implantation with MIGS.

Incidence of HE and CSHE were calculated at each time point (POD1, POW1, POM1, POM3) using the first examination for each time point if multiple examinations were available. Time-to-resolution of HE and CSHE was assessed using a Cox proportional-hazards model. For this analysis, all examinations between postoperative day 0 and 97 were utilized. We performed a global log-rank test to assess overall differences among groups and conducted pairwise comparisons using the pairwise log-rank test with Benjamini−Hochberg procedure for multiple comparisons. Risk factor analysis was performed using generalized estimating equation logistic regression as some patients contributed 2 eyes to the analysis. Univariable and multivariable models evaluating the incidence of HEs or CSHEs at POD1 were computed, evaluating the impact of age, self-reported sex, self-reported race, self-reported ethnicity, medication subtypes, and degrees of goniotomy treatment. Concurrent viscodilation and goniotomy device were not included due to collinearity with degrees of treatment.

A P value <0.05 was considered statistically significant. Analyses were completed in R version 4.3.0 (R Foundation for Statistical Computing) and Python version 3.8.19 (Python Software Foundation).

Results

We analyzed the data of 758 patients, 368 that underwent goniotomy and 390 that received SCS (Table 2). The cohort average age was 68.9 ± 14.4 years, with goniotomy patients younger than SCS patients (64.1 ± 17.6 years vs. 73.5 ± 8.2 years, $P < 0.001$). More males received goniotomy (54.6% vs. 44.9% in SCS, $P = 0.007$). Most patients were White, with a higher proportion receiving SCS (77.4% vs. 69.6% in goniotomy, $P = 0.042$). Black or African American patients constituted 22.8% of the goniotomy group versus 17.7% in SCS. Anticoagulant or antiplatelet use was comparable (goniotomy: 22.0% vs. SCS: 17.2%; $P = 0.094$), but salicylate use was higher in the goniotomy group (17.1% vs. 11.0% in SCS; $P = 0.047$).

Goniotomy procedures were performed with a diverse combination of filament (248 eyes; 57.0%), blade (105 eyes; 24.0%), and illuminated microcatheter (82 eyes; 19.0%) instruments. A significant portion of goniotomies (305 eyes; 70.0%) was performed with viscodilation/canaloplasty. The extent of the angle treated during goniotomy were 90° to 179° in 143 cases (34%), 180° to 269° in 78 cases (18%), and 270° to 360° in 201 cases (48%). In the SCS group, the stents used were primarily iStent (404 eyes; 77%), with Hydrus used in 126 eyes (23%). Most cases involved implanting a single stent (255 eyes; 63.1%), while a smaller proportion had 2 iStents (147 eyes; 36.4%), and a minimal number had 3 iStents (2 eyes; 0.5%).

Performance of ChatGPT Classification

Chat Generative Pre-trained Transformer-assisted HE classification featured excellent agreement with expert review, yielding a Cohen's Kappa statistic of 0.93 (95% CI: 0.91−0.94). The receiver operating characteristic curve analysis yielded an AUC of 0.985 (95% CI: 0.979−0.991), indicating excellent model performance in distinguishing between hemorrhagic and non-HEs (Fig 1). Similarly, the PR curve demonstrated an AUPRC of 0.968 (95% CI: 0.959−0.976, Fig 2). In this binary classification, ChatGPT classification showed strong performance, with a sensitivity of 0.989 (95% CI: 0.979−0.995), specificity of 0.981 (95% CI: 0.974−0.986), positive predictive value of 0.943 (95% CI: 0.925−0.958), negative predictive value of 0.996 (95% CI: 0.993−0.998), and an accuracy of 0.983 (95% CI: 0.978−0.987) correctly identifying 2263 "No Hemorrhage" cases and 734 "Hemorrhage" cases, with a false positive rate of 1.94% and false negative rate of 1.09% (Fig 3).

In the 4-group classification, the model effectively differentiated "Hyphema" (383 correct classifications, true predictive value (TPV): 0.941, negative predictive value (TNV): 1.0), "Microhyphema" (204 correct classifications, TPV: 0.923, TNV: 1.0), and "Clot" (110 correct classifications, TPV: 0.965, TNV: 1.0). However, some patterns in misclassifications were noted: "Hyphema" was occasionally confused with "Clot" (11 cases) and "Microhyphema" (6 cases), while "Microhyphema" was sometimes mislabeled as "Hyphema" (12 cases) or "Clot" (4 cases; Fig 4). "Clot" was predominantly accurately classified, though it was sometimes mistaken for "Hyphema" (2 cases) and "Microhyphema" (2 cases). We noticed a pattern of some examinations noting "heme on endothelium," referring to some blood on the corneal endothelium, leading to misclassification by ChatGPT as "Hyphema." There were no clear hallucinations noted in this analysis.

VA and IOP Analysis of Goniotomy and SCS Combined With Cataract Extraction

Since all SCS cases were completed with CE, we compared these eyes (528 eyes) with those that received goniotomy

Table 2. Baseline Patient Characteristics

Characteristic	Overall, N = 758	Goniotomy, N = 368	SCS, N = 390	P Value*
Age (years)	68.9 ± 14.4	64.1 ± 17.6	73.5 ± 8.2	<0.001†
Gender				0.007†
Female	382	167 (45.4%)	215 (55.1%)	
Male	376	201 (54.6%)	175 (44.9%)	
Race				0.042†
White	558	256 (69.6%)	302 (77.4%)	
Black or African American	153	84 (22.8%)	69 (17.7%)	
Unknown/other	47	28 (7.6%)	19 (4.9%)	
Ethnicity				0.200
Hispanic or Latino	270	143 (38.9%)	127 (32.6%)	
Non-Hispanic or Latino	457	211 (57.3%)	246 (63.1%)	
Unknown/other	31	14 (3.8%)	17 (4.4%)	
Anticoagulant/antiplatelet usage	148	81 (22.0%)	67 (17.2%)	0.094
Medication subclass				0.047†
Salicylates	106	63 (17.1%)	43 (11.0%)	
DOAC/antiplatelet/Coumadin	42	18 (4.9%)	24 (6.2%)	
None	610	287 (78.0%)	323 (82.8%)	
Diabetes	139	59 (16.0%)	80 (20.5%)	0.110
Hypertension	365	164 (44.6%)	201 (51.5%)	0.055

DOAC = direct oral anticoagulant; SCS = Schlemm's canal stent.
*Wilcoxon rank sum test; Pearson's chi-squared test.
†Indicates statistical significance.

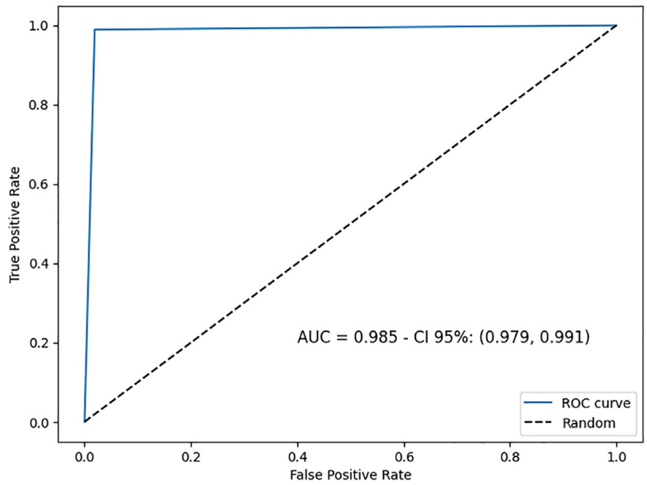

Figure 1. Receiver operating characteristic curve for hemorrhage detection using ChatGPT labeling of the anterior chamber examination notes distinguishing between hemorrhagic and nonhemorrhagic events. AUC = area under the receiver operating characteristic curve; ChatGPT = Chat Generative Pre-trained Transformer; CI = confidence interval; ROC = receiver operating characteristic.

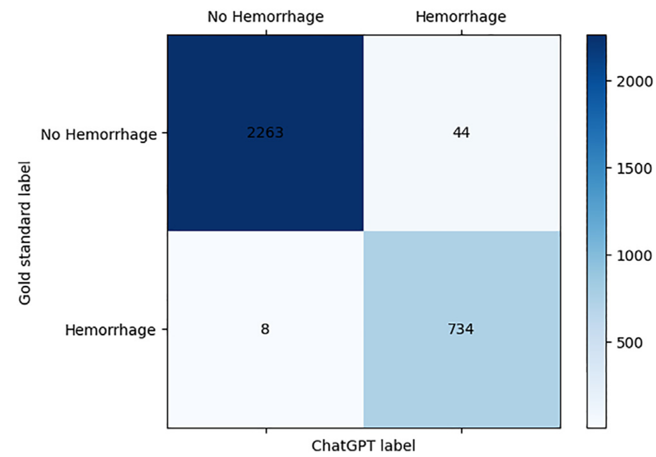

Figure 3. Confusion matrix comparing ChatGPT labeling accuracy to the gold standard in binary classification of hemorrhagic events. ChatGPT = Chat Generative Pre-trained Transformer.

with CE (219 eyes). Differences in both preoperative and postoperative VA were noted (Table 3). At POD1, VA was significantly worse in CE/goniotomy (0.8 ± 0.7) compared with SCS (0.4 ± 0.5; $P < 0.001$), with goniotomy having lower IOP (16.0 ± 7.3 mmHg vs. 17.7 ± 7.9 mmHg in SCS; $P = 0.004$). By POM3, VA and IOP differences were no longer significant.

Incidence and Resolution of Postoperative HEs

Significant differences in HE and CSHE were observed between the goniotomy and SCS groups at POD1, with HEs occurring more often in goniotomy cases (67.8%) versus SCS cases (25.2%; $P < 0.001$, Table 4). Clinically significant hemorrhagic events were more frequent in the goniotomy (15.2%) group versus the SCS group (3.8%, $P < 0.001$, Table 4). Differences in HEs persisted into the POM1 period, with the goniotomy group showing a reduced but substantial incidence (13.3%) compared with the SCS group (1.3%; $P < 0.001$). However, the incidence of CSHE was similar between the 2 groups at POM1 (goniotomy: 1.9% vs. SCS: 0%, $P = 0.055$). By POM3, HEs had essentially resolved in both groups.

The rates of HE resolution among the goniotomy and SCS groups differed, with faster resolution noted in the SCS group (Fig 5, log-rank $P < 0.001$). Median resolution time was longer in the goniotomy (14 days) versus SCS group (10 days). Only 2 eyes had CPT codes indicating anterior chamber washouts; however, these were determined to be

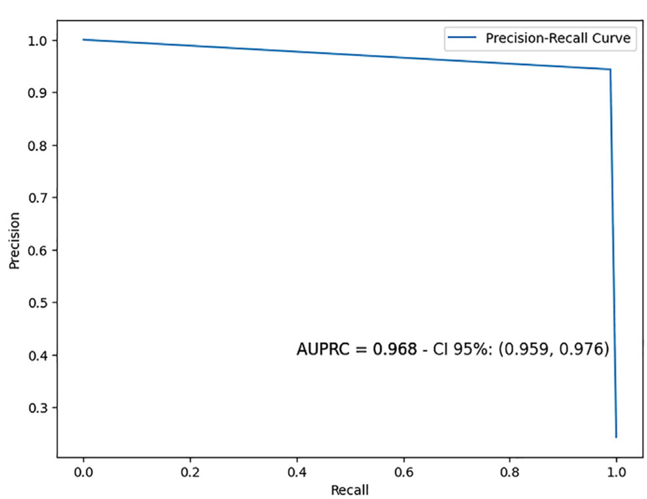

Figure 2. Precision-recall curve for hemorrhage detection based on ChatGPT analysis of anterior chamber examination notes distinguishing between hemorrhagic and nonhemorrhagic events. AUPRC = area under the precision-recall curve; ChatGPT = Chat Generative Pre-trained Transformer; CI = confidence interval.

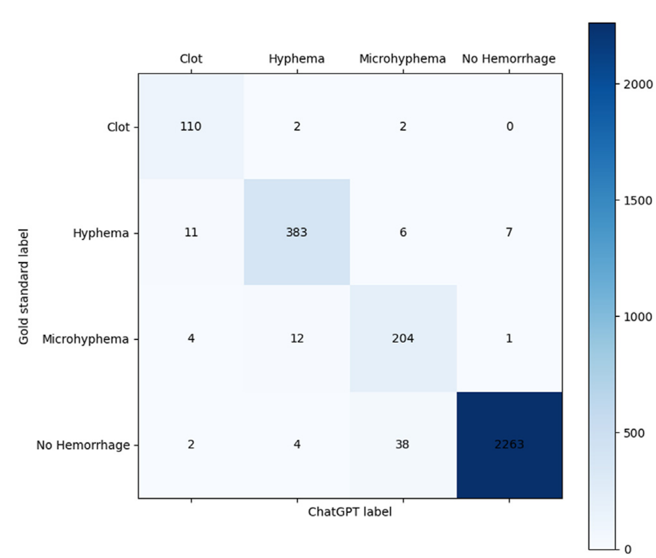

Figure 4. Multiclass classification confusion matric of hemorrhage classification by ChatGPT vs. the gold standard labeling of hemorrhagic events. ChatGPT = Chat Generative Pre-trained Transformer.

Table 3. VA, IOP, and Number of Topical Glaucoma Medication Among Goniotomy and SCS Insertion Cases

Characteristic	Overall	Goniotomy	Goniotomy With CE	SCS With CE	*P* Value*
Preoperative	962	434	219	528	
VA	0.3 ± 0.4	0.4 ± 0.5	0.4 ± 0.5	0.3 ± 0.3	0.006†
IOP	19.1 ± 7.1	21.6 ± 8.7	17.6 ± 5.8	17.1 ± 4.7	0.600
No. topical glaucoma medication	2.0 ± 1.3	2.1 ± 1.3	2.2 ± 1.3	1.9 ± 1.2	0.009†
POD1‡	962	434	219	528	
VA	0.6 ± 0.7	0.9 ± 0.8	0.8 ± 0.7	0.4 ± 0.5	<0.001†
IOP	17.1 ± 8.0	16.5 ± 8.1	16.0 ± 7.3	17.7 ± 7.9	0.004†
POW1	787	374	180	413	
VA	0.4 ± 0.6	0.6 ± 0.7	0.4 ± 0.5	0.2 ± 0.3	<0.001†
IOP	17.1 ± 7.4	17.2 ± 8.4	16.6 ± 7.0	17.0 ± 6.5	0.200
No. topical glaucoma medication	1.4 ± 1.4	1.3 ± 1.3	1.4 ± 1.4	1.5 ± 1.4	0.500
POM1	653	287	139	366	
VA	0.2 ± 0.4	0.3 ± 0.5	0.2 ± 0.3	0.1 ± 0.2	<0.001†
IOP	16.0 ± 5.5	16.5 ± 6.6	15.3 ± 4.7	15.5 ± 4.4	0.300
No. topical glaucoma medication	1.5 ± 1.4	1.4 ± 1.3	1.5 ± 1.4	1.5 ± 1.4	0.600
POM3	221	125	51	96	
VA	0.2 ± 0.4	0.3 ± 0.5	0.1 ± 0.2	0.1 ± 0.2	0.400
IOP	15.2 ± 5.6	15.8 ± 6.2	14.3 ± 3.7	14.5 ± 4.5	0.800
No. topical glaucoma medication	1.5 ± 1.4	1.5 ± 1.4	1.7 ± 1.4	1.4 ± 1.4	0.200

CE = cataract extraction; IOP = intraocular pressure; POD1 = postoperative day 1; POM1 = postoperative month 1; POM3 = postoperative month 3; POW1 = postoperative week 1; SCS = Schlemm's canal stent; VA = visual acuity.
*Comparison between goniotomy with CE and SCS with CE groups only.
†Indicates statistical significance.
‡No. topical glaucoma medications was not calculated at POD1 due to significant variability regarding medication usage immediately after surgery.

paracentesis completed in the clinic, not washouts in the operating room.

Incidence and Resolution of Postoperative HEs Based on Goniotomy Degree

We also assessed postoperative HE and CSHE with respect to the degree of goniotomy performed (Table 5). At POD1, significant differences in hemorrhage types were observed ($P < 0.001$). Hyphema was most frequent in the 270° to 360° group (55.5%), followed by the 180° to 269° (41.0%) and 90° to 179° (25.2%) groups. Microhyphema was more common in eyes receiving less goniotomy, observed in 16.8% of the 90° to 179° group. Eyes in the 90° to 179° group were most likely to not have an HE (50.3%). Clinically significant hemorrhagic events were more frequent in the 270° to 360° group (21.9%) compared with the 90° to 179° (7.9%) and 180° to 269° (7.7%) groups ($P = 0.003$). By POM3, there were no significant differences in HE types ($P = 0.700$). Analysis of HE resolution rates in the goniotomy group based on the degree of goniotomy treatment demonstrated a significant difference in time to resolution between groups (log-rank $P = 0.034$, Fig 6). Median time to resolution was 10 days, 10 days, and 15 days for the 90° to 179°, 180° to 269°, and 270° to 360° groups, respectively.

Postoperative Bleeding Event Risk Factor Analysis

Risk factor analysis for SCS demonstrated no significant risk factors (data not shown). When evaluating risk factors for postoperative HE and CSHE among goniotomy cases (Table 6), older age was protective; each additional decade was associated with lower odds of postoperative HE events (odds ratio [OR]: 0.76, 95% CI: 0.65−0.89, $P < 0.001$). However, the angle of goniotomy was a significant predictor, with patients undergoing procedures with an angle of 270° to 360° having greater odds of postoperative HE (OR: 4.08, 95% CI: 2.40−6.93, $P = 0.001$) and CSHE (OR: 2.35, 95% CI: 1.21−4.57, $P = 0.012$) compared with the 90° to 179° reference group. None of the other covariates, including gender, self-reported race, self-reported ethnicity, and notably medication subclass (e.g., anticoagulant use), showed significant associations with postoperative HE or CSHE in multivariable analysis. Tables S7 and S8 further explore these associations, including analysis with concurrent viscodilation and goniotomy device type respectively (available at https://www.ophthalmologyscience.org). These were modeled separately due to collinearity with degree of goniotomy angle treatment.

Discussion

This study demonstrates that the novel application of an LLM to EHR text can accurately classify HEs, which occurred more frequently with goniotomy procedures compared with SCS insertions. The LLM performance, demonstrated by a high Cohen's Kappa of 0.93, indicates near-perfect agreement with human graders. This is further supported by the AUC of 0.985 and an AUPRC of 0.968, showing the model's exceptional capability in distinguishing between hemorrhagic and non-HEs. Such metrics

Table 4. Rate of Hemorrhage and Clinically Significant Hemorrhagic Event among Goniotomy and SCS Insertion Cases

	Overall	Goniotomy	SCS	*P* Value*
POD1	962	434	528	
Hemorrhage type				<0.001†
Hyphema	230	181 (41.7%)	49 (9.3%)	
Clot	72	52 (12.0%)	20 (3.8%)	
Microhyphema	125	61 (14.1%)	64 (12.1%)	
No bleed	535	140 (32.3%)	395 (74.8%)	
Clinically significant hemorrhagic event	62	50 (15.2%)	12 (3.8%)	<0.001†
POW1	787	374	413	
Hemorrhagic type				<0.001†
Hyphema	100	85 (22.7%)	15 (3.6%)	
Clot	36	28 (7.5%)	8 (1.9%)	
Microhyphema	73	49 (13.1%)	24 (5.8%)	
No bleed	578	212 (56.7%)	366 (88.6%)	
Clinically significant hemorrhagic event	27	24 (8.5%)	3 (1.3%)	<0.001†
POM1	653	287	366	
Hemorrhagic type				<0.001†
Hyphema	18	16 (5.6%)	2 (0.5%)	
Clot	6	6 (2.1%)	0 (0.0%)	
Microhyphema	19	16 (5.6%)	3 (0.8%)	
No bleed	610	249 (86.8%)	361 (98.6%)	
Clinically significant hemorrhagic event	4	4 (1.9%)	0 (0.0%)	0.055
POM3	221	125	96	
Hemorrhagic type				0.500
Hyphema	0	0 (0.0%)	0 (0.0%)	
Clot	0	0 (0.0%)	0 (0.0%)	
Microhyphema	2	2 (1.6%)	0 (0.0%)	
No bleed	219	123 (98.4%)	96 (100.0%)	
Clinically significant hemorrhagic event	0	0 (0.0%)	0 (0.0%)	>0.900

POD1 = postoperative day 1; POM1 = postoperative month 1; POM3 = postoperative month 3; POW1 = postoperative week 1; SCS = Schlemm's canal stent.
*Pearson's chi-squared test.
†Indicates statistical significance.

highlight the LLM's strength in interpreting EHR text, matching traditional human review. This work also provides an example of how LLM-assisted classification can be used to complete a clinical study, namely the evaluation of the incidence and resolution of HEs after MIGS procedures. Only 25.2% of SCS insertions (13.1% hyphema or clot) resulted in HEs on POD1, in contrast to 67.8% with goniotomies (53.7% hyphema or clot). By POW1, over half of goniotomy eyes (56.7%) were free of any HEs. By POM1, only 13.2% of goniotomy eyes had persistent HEs. Hemorrhagic events required more time to resolve in goniotomy cases, particularly with larger treatments. This

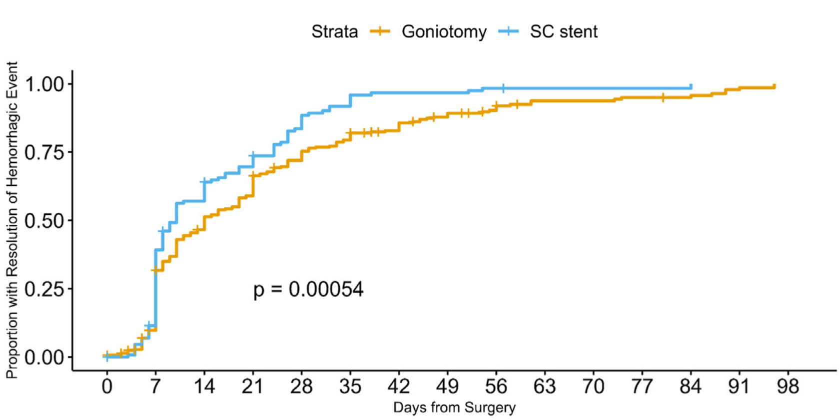

Figure 5. Kaplan−Meier cumulative probability curve for hemorrhagic event resolution after goniotomy vs. SC stent insertion. SC = Schlemm's canal.

Table 5. Rate of Hemorrhage and Clinically Significant Hemorrhagic Event Among Goniotomy Cases Based on Degree of Treatment

Characteristic	Overall	90°−179°	180°−269°	270°−360°	*P* Value*
POD1	421	143	78	200	
Hemorrhage type					<0.001†
Hyphema	179	36 (25.2%)	32 (41.0%)	111 (55.5%)	
Clot	50	11 (7.7%)	6 (7.7%)	33 (16.5%)	
Microhyphema	59	24 (16.8%)	11 (14.1%)	24 (12.0%)	
No bleed	133	72 (50.3%)	29 (37.2%)	32 (16.0%)	
Clinically significant hemorrhagic event	50	7 (7.9%)	4 (7.7%)	39 (21.9%)	0.003†
POW1	374	118	69	177	
Hemorrhage type					<0.001†
Hyphema	84	18 (15.3%)	10 (14.5%)	56 (31.6%)	
Clot	27	4 (3.4%)	3 (4.3%)	20 (11.3%)	
Microhyphema	48	11 (9.3%)	9 (13.0%)	28 (15.8%)	
No bleed	205	85 (72.0%)	47 (68.1%)	73 (41.2%)	
Clinically significant hemorrhagic event	24	3 (4.2%)	2 (4.1%)	19 (12.1%)	0.076
POM1	280	86	63	135	
Hemorrhage type					<0.001†
Hyphema	16	1 (1.2%)	0 (0.0%)	15 (11.4%)	
Clot	5	0 (0.0%)	0 (0.0%)	5 (3.8%)	
Microhyphema	16	3 (3.5%)	5 (8.1%)	8 (6.1%)	
No bleed	243	82 (95.3%)	57 (91.9%)	104 (78.8%)	
Clinically significant hemorrhagic event	4	0 (0.0%)	1 (2.5%)	3 (2.6%)	0.600
POM3	122	38	22	62	
Hemorrhage type					0.700
Hyphema	0	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Clot	0	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Microhyphema	2	0 (0.0%)	0 (0.0%)	2 (3.2%)	
No bleed	120	38 (100.0%)	22 (100.0%)	60 (96.8%)	
Clinically significant hemorrhagic event	0	0 (0.0%)	0 (0.0%)	0 (0.0%)	>0.900

POD1 = postoperative day 1; POM1 = postoperative month 1; POM3 = postoperative month 3; POW1 = postoperative week 1; SCS = Schlemm's canal stent.
*Pearson's chi-squared test.
†Indicates statistical significance.

study did not focus on 1 type of surgery (goniotomy or SCS insertion), but rather evaluated a large cohort with a balanced representation of goniotomy and SCS techniques at a large academic institution. Our work provides useful information regarding average times to HE resolution in the 2 groups with further characterization of the HE type—all which may serve as useful information to share with patients when discussing postoperative expectations.

Our findings of HEs occurring more frequently with goniotomy procedures compared with SCS insertions requiring more time to resolve is consistent with a recent report.[20] Goniotomy often involves direct manipulation of the trabecular meshwork, leading to a direct connection between the anterior chamber and collector channel system, leading to blood reflux. Conversely, SCS insertions involve a less invasive approach with no direct

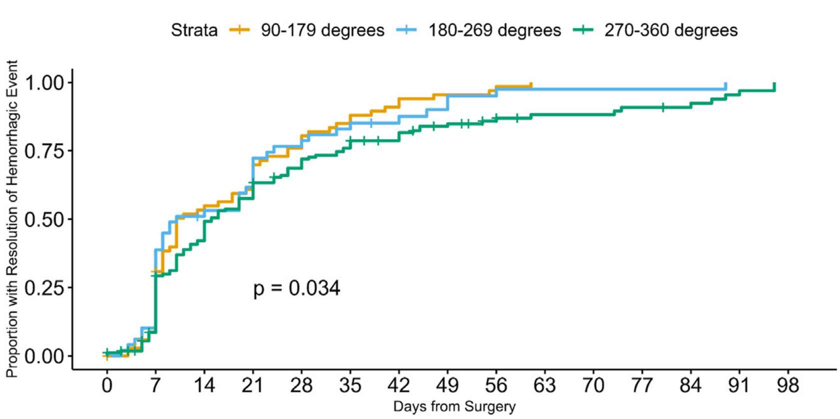

Figure 6. Kaplan−Meier cumulative probability curve for hemorrhagic event resolution by degree of goniotomy angle treated.

Table 6. Logistic Regression Evaluating the Risk of Hemorrhage in Goniotomy Eyes Based on Angle of Treatment

	Univariable HE			Multivariable HE			Univariable CSHE			Multivariable CSHE		
Characteristic	OR	95% CI	P Value	OR	95% CI	P Value	OR	95% CI	P Value	OR	95% CI	P Value
Age (per decade)	0.72	0.62, 0.83	<0.001*	0.76	0.65, 0.89	<0.001*	1.04	0.89, 1.22	0.603	1.07	0.90, 1.27	0.438
Gender												
Male	—	—		—	—		—	—		—	—	
Female	1.17	0.76, 1.83	0.474	1.35	0.84, 2.17	0.209	0.85	0.50, 1.45	0.553	0.94	0.54, 1.62	0.821
Self-reported race												
White	—	—		—	—		—	—		—	—	
Black or African American	1.05	0.62, 1.78	0.849	0.80	0.44, 1.45	0.455	0.61	0.29, 1.31	0.207	0.54	0.23, 1.30	0.169
Unknown/other	2.31	0.75, 7.06	0.144	1.72	0.55, 5.40	0.355	2.30	0.93, 5.73	0.073	2.11	0.76, 5.80	0.150
Self-reported ethnicity												
Non-Hispanic or Latino	—	—		—	—		—	—		—	—	
Hispanic or Latino	0.95	0.61, 1.49	0.837	0.79	0.48, 1.30	0.359	0.75	0.43, 1.29	0.292	0.71	0.38, 1.31	0.270
Medication subclass												
None	—	—		—	—		—	—		—	—	
DOAC/antiplatelet/Coumadin	0.62	0.24, 1.56	0.306	0.81	0.35, 1.89	0.631	0.30	0.04, 2.32	0.248	0.35	0.05, 2.44	0.288
Salicylates	0.87	0.49, 1.56	0.647	1.10	0.61, 1.99	0.749	1.80	0.96, 3.38	0.066	1.87	0.97, 3.61	0.061
Goniotomy angle												
90°–179°	—	—		—	—		—	—		—	—	
180°–269°	1.67	0.95, 2.94	0.075	1.63	0.92, 2.89	0.094	1.26	0.54, 2.98	0.591	1.24	0.54, 2.84	0.616
270°–360°	5.00	2.97, 8.40	<0.001*	4.08	2.40, 6.93	<0.001*	2.21	1.16, 4.20	0.015*	2.35	1.21, 4.57	0.012*

CI = confidence interval; CSHE = clinically significant hemorrhagic event; DOAC = direct oral anticoagulant; HE = hemorrhagic event; OR = odds ratio.
*Indicates statistical significance.

excision of trabecular meshwork, resulting in less trauma and fewer HEs. We identified a higher incidence of postoperative HE and CSHE in those eyes receiving 270° to 360° goniotomies. While in theory a more extensive goniotomy could potentially result in greater IOP reduction due to decreased resistance to aqueous fluid outflow, studies have shown that varying degrees of goniotomy do not necessarily yield significant differences in long-term IOP reduction but may contribute to an increase in complications, such as HEs and transient postoperative IOP spikes.[8,21–23] For example, Zhang et al found a higher incidence of hyphema in larger goniotomies (360-degree), regardless of concurrent CE.[23]

Novel concepts in our study include the idea of CSHE, a metric to characterize anterior chamber hemorrhage. Prior descriptions of hyphemas in the literature have been typically binary (i.e., present or absent), lacking interpretability regarding their impact on VA, and thus clinical significance. By defining CSHEs as HEs that have a significant impact on VA, our approach provides a clinically pertinent measure regarding postoperative HEs. We would encourage future glaucoma surgical studies to utilize this type of descriptor to classify the severity of HEs, which can range in their impact of patients' quality of life. In addition, while prior studies have evaluated the incidence of HEs,[23,24] our study advances the understanding of postoperative HEs by evaluating their resolution over time. We believe that surgeons performing MIGS will find these results regarding HE resolution to be useful when counseling patients about potential postoperative complications.

The incorporation of ChatGPT into the analysis of free-text anterior chamber examination findings represents a unique application in ophthalmic clinical research. This approach addresses the challenges associated with research using large databases, which often involves a labor-intensive manual review process. Leveraging ChatGPT to evaluate examination text free of patient identifiers in large batches facilitates the rapid categorization of clinical data with high accuracy. In this study, a subset of notes was used to evaluate agreement, while the entire set of ChatGPT-labeled classifications were used for subsequent analysis. The ability to classify data is crucial to "big data" ophthalmic research, as a substantial proportion of data is documented in free-text format. The reliability and accuracy of this tool, as evidenced by the Cohen's Kappa statistic as well as the AUC-receiver operating characteristic and AUPRC reflects almost perfect agreement between AI-assisted and expert labels. Chat Generative Pre-trained Transformer demonstrates high sensitivity and specificity in binary classification, identifying hemorrhagic conditions with minimal error—only 44 false positives (1.9% false positive rate) and 8 false negatives (1.1% false negative rate) were noted. A sensitivity analysis comparing the ChatGPT-annotated examinations with the gold standard showed consistent results, indicating no significant change in outcomes or their interpretation. Nonetheless, misclassifications highlight the challenges of using a generalized LLM and potential areas of improvement for its use in a health care setting.

Our research aligns with the growing trend of utilizing ChatGPT in clinical research.[25,26] Hu et al utilized ChatGPT to automate the extraction of details from radiologic reports, demonstrating that AI tools can achieve high performances for tasks such as tumor location identification.[27] However, our specific application of ChatGPT for processing unstructured patient chart in the EHR data are unique, particularly in the field of glaucoma. Wei et al study investigated the feasibility of ChatGPT in converting symptom narratives of patients with coronavirus disease 2019 into structured labels.[28] They demonstrated that ChatGPT significantly reduced the time and effort required in manual data compilation from unstructured text.[28] Stein et al developed an algorithm to identify lens pathologies in EHRs, achieving high accuracy.[14] In contrast, our methodology of using ChatGPT presents a more rapid and widely accessible approach—contingent upon the deidentification process and securing the requisite institutional approval.

Bleeding event risk factor analysis in the goniotomy group revealed distinct findings compared with previous work.[24] Eli et al showed male sex as a risk factor for hyphema after Kahook dual blade goniotomy combined with CE, attributing this difference to potential riskier behaviors in males that could impact postoperative outcomes. However, our study did not identify male gender as a significant risk factor for HEs. This difference could be due to our definition of HE (hyphema, clot, microhyphema, and presence of RBCs) or the diverse mix of goniotomy types in our study. Eli et al did not specify when the hyphema complication was recorded, whereas we restricted our risk factor analysis to HE rates at POD1, neutralizing the influence of any potentially riskier behaviors exhibited postoperatively and making the assessment of HE temporally related to the surgical procedure.

While Eli et al did not report age-related differences in hyphema incidence,[24] our study discovered a significant age-related trend. We found that the likelihood of postoperative HE decreases with increasing age in a multivariable model (OR: 0.76 per decade, 95% CI: 0.65−0.89, $P < 0.001$), indicating a distinct impact of age on hemorrhage risk. While older patients were more likely to receive a smaller goniotomy, goniotomy size was included as a covariate in the multivariable model, thereby adjusting for goniotomy size. This finding could be due to greater incidence of vasoconstriction with older age,[29] perhaps leading to less blood reflux due to changes in vascular tone in the episcleral system. In contrast, larger goniotomy was significantly associated with an increased risk of HEs ($270°−360°$ OR 4.08, $P < 0.001$) as well as CSHEs ($270°−360°$ OR 2.35, $P = 0.012$). Notably, we did not find the use of anticoagulants to be a significant risk factor for HEs, similar to the literature.[24,30] However, this result may be affected by selection bias in this retrospective study (i.e., surgeons only selecting those on mild anticoagulants for angle surgery) or altering the use of these medications in the perioperative period that was not clearly documented in the chart but could have affected the HE rate.

Limitations in this study include those related to the reliance on EHR data, which introduces potential biases, particularly in the accuracy of International Classification of Diseases or CPT coding, as well as the diagnosis and revision of examination text, which were inputted by the clinician. The greater use of iStent (77%) relative to Hydrus (23%) in our study cohort likely reflects the earlier introduction and subsequent adoption of the iStent in clinical practice compared with the Hydrus stent. We intentionally excluded complex cataract surgeries (CPT 66982 and 66989), as HEs could have occurred due to iris manipulation or other intraoperative challenges during CE. As previously noted, the lack of significance regarding anticoagulant use as a risk factor highlights the challenges and limitations of using retrospective data for risk factor analysis.

Future work may focus on enhancing the autonomy and accuracy of AI algorithms to process EHR free text, which could improve both research and clinical efficiency. In clinical practice, LLMs could guide providers in formulating more accurate or specific visit diagnoses with real-time natural language processing. For example, when a clinician inputs "2+ nuclear sclerosis" in the examination field for the lens, the LLM could automatically suggest a cataract diagnosis. Such innovation could greatly reduce the amount of charting burden on clinicians.

In summary, our study demonstrates that ChatGPT can be used to analyze unstructured, deidentified EHR data to help streamline data analysis and enhance research efficiency. Hemorrhagic event and CSHE are common yet self-resolving postoperative complications after MIGS, occurring more frequently in goniotomy cases with an overall median time to resolution of 14 days among these eyes. Resolution of HEs requires more time in cases with larger goniotomies. This work underscores the efficacy of LLMs in large database studies, suggesting a promising tool in EHR-based clinical research.

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Footnotes and Disclosures

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All authors have completed and submitted the ICMJE disclosures form.

The author(s) have made the following disclosure(s):

S.S.S.: Consultant − Sight Sciences, Abbvie/Allergan, Lumata Health; Honoraria − Heidelberg Engineering; Participation on a Data Safety Monitoring Board or Advisory Board − Topcon, Abbvie/ Allergan; Stock or stock options − Lumata Health; Meals − Alcon, Bausch & Lomb.

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Data sharing: The data that support the findings of this study are available from the authors upon reasonable request.

HUMAN SUBJECTS: No human subjects were used in this study. The University of Miami Institutional Review Board (IRB) approved this study and granted a waiver of informed consent given its retrospective nature. The study adhered to the Declaration of Helsinki and the Health Insurance Portability and Accountability Act. Of note, the IRB reviewed and approved the entry of deidentified examination data into ChatGPT.

No animal subjects were used in this study.

Author Contributions:

Conception and design: Shaheen, Swaminathan

Data collection: Shaheen, Afflitto, Swaminathan

Analysis and interpretation: Shaheen, Swaminathan

Obtained funding: N/A

Overall responsibility: Shaheen, Afflitto, Swaminathan

Abbreviations and Acronyms:
AI = artificial intelligence; **AUC** = area under the receiver operating characteristic curve; **AUPRC** = area under the precision-recall curve; **CE** = cataract extraction; **ChatGPT** = Chat Generative Pre-trained Transformer; **CI** = confidence interval; **CPT** = Current Procedural Terminology; **CSHE** = clinically significant hemorrhagic event; **CSV** = comma-separated values; **EHR** = electronic health record; **HE** = hemorrhagic event; **IOP** = intraocular pressure; **LLM** = large language model; **MIGS** = microinvasive glaucoma surgery; **OR** = odds ratio; **POD1** = postoperative day 1; **POM1** = postoperative month 1; **POM3** = postoperative month 3; **POW1** = postoperative week 1; **PR** = precision-recall; **RBC** = red blood cell; **SCS** = Schlemm's canal stent; **VA** = visual acuity.

Keywords:
Goniotomy, Hyphema, Large language models, Minimally invasive glaucoma surgery, Schlemm canal stent.

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References

1. Fellman RL, Mattox C, Singh K, et al. American Glaucoma Society position paper: microinvasive glaucoma surgery. *Ophthalmol Glaucoma*. 2020;3:1–6.
2. Gallo Afflitto G, Swaminathan SS. Minimally invasive glaucoma surgery. *Int Ophthalmol Clin*. 2023;63:33–60.
3. Yang SA, Ciociola EC, Mitchell W, et al. Effectiveness of microinvasive glaucoma surgery in the United States: intelligent research in sight registry analysis 2013-2019. *Ophthalmology*. 2023;130:242–255.
4. Yang SA, Mitchell WG, Hall N, et al. Usage patterns of minimally invasive glaucoma surgery (MIGS) differ by glaucoma type: IRIS Registry analysis 2013-2018. *Ophthalmic Epidemiol*. 2022;29:443–451.
5. Ahmed IIK, De Francesco T, Rhee D, et al. Long-term outcomes from the HORIZON randomized trial for a Schlemm's canal microstent in combination cataract and glaucoma surgery. *Ophthalmology*. 2022;129:742–751.
6. Denis P, Hirneiss C, Durr GM, et al. Two-year outcomes of the MINIject drainage system for uncontrolled glaucoma from the STAR-I first-in-human trial. *Br J Ophthalmol*. 2022;106:65–70.
7. Saheb H, Ahmed II. Micro-invasive glaucoma surgery: current perspectives and future directions. *Curr Opin Ophthalmol*. 2012;23:96–104.
8. Sato T, Kawaji T. 12-month randomised trial of 360° and 180° Schlemm's canal incisions in suture trabeculotomy ab interno for open-angle glaucoma. *Br J Ophthalmol*. 2021;105:1094–1098.
9. Vinod K, Gedde SJ. Safety profile of minimally invasive glaucoma surgery. *Curr Opin Ophthalmol*. 2021;32:160–168.
10. Bicket AK, Le JT, Azuara-Blanco A, et al. Minimally invasive glaucoma surgical techniques for open-angle glaucoma: an overview of cochrane systematic reviews and network meta-analysis. *JAMA Ophthalmol*. 2021;139:983–989.
11. OpenAI. *ChatGPT*. OpenAI; 2022. https://openai.com/chatgpt. Accessed January 18, 2024.
12. Hossain E, Rana R, Higgins N, et al. Natural language processing in electronic health records in relation to healthcare decision-making: a systematic review. *Comput Biol Med*. 2023;155:106649.
13. Fink MA, Bischoff A, Fink CA, et al. Potential of ChatGPT and GPT-4 for data mining of free-text ct reports on lung cancer. *Radiology*. 2023;308:e231362.
14. Stein JD, Zhou Y, Andrews CA, et al. Using natural language processing to identify different lens pathology in electronic health records. *Am J Ophthalmol*. 2024;262:153–160.
15. Swaminathan SS, Berchuck SI, Rao JS, Medeiros FA. Performance of linear mixed models in estimating structural rates of glaucoma progression using varied random effect distributions. *Ophthalmol Sci*. 2024;4:100454.
16. Gallo Afflitto G, Swaminathan SS. Racial-ethnic disparities in concurrent rates of peripapillary & macular OCT parameters among a large glaucomatous clinical population. *Eye (Lond)*. 2024. https://doi.org/10.1038/s41433-024-03103-3.
17. Social Security Administration. Understanding supplemental security income SSI eligibility requirements. https://www.ssa.gov/ssi/text-eligibility-ussi.htm#blind; 2024. Accessed March 1, 2024.
18. Gedde SJ, Schiffman JC, Feuer WJ, et al. Treatment outcomes in the tube versus trabeculectomy (TVT) study after five years of follow-up. *Am J Ophthalmol*. 2012;153:789–803.e2.
19. Gedde SJ, Chen PP, Heuer DK, et al. The primary tube versus trabeculectomy study: methodology of a multicenter randomized clinical trial comparing tube shunt surgery and trabeculectomy with mitomycin C. *Ophthalmology*. 2018;125:774–781.
20. Rowson AC, Hogarty DT, Maher D, Liu L. Minimally invasive glaucoma surgery: safety of individual devices. *J Clin Med*. 2022;11:6833.
21. Okada N, Hirooka K, Onoe H, et al. Comparison of efficacy between 120° and 180° Schlemm's canal incision microhook ab interno trabeculotomy. *J Clin Med*. 2021;10:3181.
22. Hirabayashi MT, Lee D, King JT, et al. Comparison of surgical outcomes of 360° circumferential trabeculotomy versus sectoral excisional goniotomy with the Kahook dual blade at 6 months. *Clin Ophthalmol*. 2019;13:2017–2024.
23. Zhang Y, Yu P, Zhang Y, et al. Influence of goniotomy size on treatment safety and efficacy for primary open-angle glaucoma: a multicenter study. *Am J Ophthalmol*. 2023;256:118–125.

24. Pratte EL, Ramachandran M, Landreneau JR, An JA. Risk factors for hyphema following Kahook dual blade goniotomy combined with phacoemulsification. *J Glaucoma*. 2023;32:165–170.
25. Ruksakulpiwat S, Kumar A, Ajibade A. Using ChatGPT in medical research: current status and future directions. *J Multidiscip Healthc*. 2023;16:1513–1520.
26. Sallam M. ChatGPT utility in healthcare education, research, and practice: systematic review on the promising perspectives and valid concerns. *Healthcare (Basel)*. 2023;11:887.
27. Hu D, Liu B, Zhu X, et al. Zero-shot information extraction from radiological reports using ChatGPT. *Int J Med Inform*. 2023;183:105321.
28. Wei WI, Leung CLK, Tang A, et al. Extracting symptoms from free-text responses using ChatGPT among COVID-19 cases in Hong Kong. *Clin Microbiol Infect*. 2024;30:142.e1–142.e3.
29. Gerhard M, Roddy MA, Creager SJ, Creager MA. Aging progressively impairs endothelium-dependent vasodilation in forearm resistance vessels of humans. *Hypertension*. 1996;27:849–853.
30. Widder RA, Lappas A, Rennings C, et al. Influence of oral anticoagulation on success rates and risk of bleeding events after iStent inject implantation combined with phacoemulsification. *Graefes Arch Clin Exp Ophthalmol*. 2020;258:2483–2487.