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ORIGINAL RESEARCH

The Association of Vertically Integrated Delivery Networks on Lapses in Diabetic Retinopathy Care and Presenting Diabetic Retinopathy Severity

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Purpose: Vertical integration of ophthalmologists with primary care providers (PCP) may improve diabetic retinopathy (DR) by reducing lapses in care and promoting early detection. We examine how PCP integration impacts DR outcomes, and whether that relationship is affected by the distance patients live from the health system.

Methods: This retrospective cohort study included adults (≥18 years) with diabetes mellitus seen at the Wilmer Eye Institute from April 2013 to September 2023. The primary exposure was PCP type, classified as internal (within the Johns Hopkins Health System Corporation) or external. To assess whether PCP integration effects varied by distance, an interaction term with distance to clinic (≤7.6 vs. >7.6 miles) was included. The primary outcome was lapse in care, or not returning as recommended. Secondary outcomes, defined at the initial DR screening visit, were vision impairment, blindness, visual acuity (in logMAR), and DR severity. Multivariable regression models adjusted for age, race, insurance, comorbidities, and ocular disease.

Results: A total of 41,581 patients were included, and 81% had at least one lapse in care in two years. For lapses in care, having an external PCP, compared to internal, was associated with a 19% higher odds of a lapse but only for patients who lived >7.6 miles away. Having an external PCP was also associated with more severe disease at presentation regardless of the distance patients lived from the clinic, including: higher odds of vision impairment, blindness, worse visual acuity, higher DR severity.

Conclusion: Patients with external PCPs, particularly those living farther from the clinic, experienced higher odds of lapses in DR care and presented with more severe eye disease. These patients may benefit from targeted care coordination or outreach to support adherence and earlier referrals for DR.

Keywords: care coordination, diabetic retinopathy, vertical integration, lapse in care

Introduction

Diabetic retinopathy (DR) is one of the leading causes of preventable blindness in the adult population, affecting approximately 22% of patients with diabetes.[1] Early detection of DR through timely eye exams is critical to preventing irreversible vision impairment.[2] In fact, current guidelines from the American Diabetes Association (ADA) and International Council of Ophthalmology (ICO) recommend prompt, early screening after a diabetes diagnosis, followed by regular annual appointments with more frequent monitoring for those with higher risk or active disease.[3,4] Despite this, adherence to ophthalmic follow-up remains a major challenge with nearly 75% of patients having a lapse in DR care and not returning as recommended.[5–7] Missed or delayed ophthalmic care have been shown to be major drivers of poor vision outcomes.[8–11] Therefore, optimizing adherence to ophthalmic follow-up among patients with diabetes is critical.

Higher rates of non-adherence in diabetic patients exemplifies the challenge of managing chronic disease. In addition to maintaining glycemic control, diabetes management depends on regular surveillance of multi-system complications.[12] Fragmented care between primary care providers (PCPs) and specialists likely contributes to lapses in follow-up and

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worse clinical outcomes. This has led to a growing interest in care integration, which aims to coordinate services across specialties.

Existing literature suggests that integrated PCP and specialty models are associated with increased patient and provider satisfaction, reduced costs, and better diabetes-related outcomes.[13–17] Enhanced communication between PCPs and ophthalmologists may further improve adherence to DR care.[18] However, current research on diabetes care coordination has notable gaps. First, integration efforts have largely centered around primary care and endocrinology, with limited focus on the impact of integrated ophthalmology services. Second, prior studies have emphasized screening uptake rather than long-term adherence and follow-up. Third, most have examined the effects of co-location or integration in community-based settings, such as patient-centered medical homes, rather than within academic health systems. Furthermore, the role of geographic distance to clinic has not been thoroughly explored as a factor that may modify integration benefits.

Our study aims to address these gaps by examining whether having a PCP and ophthalmologist within the same vertically integrated academic health system is associated with reduced lapses in DR care and early detection of DR complications. By focusing on lapses in care, we capture adherence across a longitudinal time scale that extends beyond single-point screenings. Investigating care coordination in an academic vertically integrated context while accounting for distance allows us to understand the benefits of integrated care beyond a community-based setting. Our findings have the potential to identify patients at higher risk for lapses in care and may inform strategies to support adherence and improve outcomes in DR management.

Methods

Study Design and Population

We conducted a retrospective cohort study of adult patients (over 18 years) with diabetes mellitus seen at the Wilmer Eye Institute at Johns Hopkins Hospital between April 4th, 2013 to September 7th, 2023. Patients were included if they had completed ≥ 1 office visits for the screening or treatment of DR at Wilmer.[7] To ensure all patients had a full two-year follow up, we excluded patients whose initial encounters were after September 7th, 2021, and those whose providers recommended follow-up timeframe was missing or >52 weeks (Supplemental Figure 1). Patients were also excluded for missing sociodemographic, visual acuity, or primary care provider data. Only data from the initial office encounter for each patient was included.

Primary Exposure: PCP Location

We defined a patient's PCP as the individual serving as the primary point of contact for routine medical care, including physicians, nurse practitioners, and physician assistants. Patients were classified as having an internal PCP if that provider was also located within the Johns Hopkins Health System Corporation,[19] based on structured provider location data extracted from the Johns Hopkins Health data warehouse (Precision Medicine Analytics Platform (PMAP)).[20] External PCPs were defined as practicing outside the Johns Hopkins Hospital System Corporation. To validate the data extraction process, provider location was manually verified through chart review of randomly selected patient records (N=42, reviewed by first author S.Y).

Primary Outcome: Lapse in Care

Lapses in care were identified using a previously described methodology.[7] In brief, office visits relevant to the treatment or screening of DR were first identified. Then, providers' recommended follow-up timeline was extracted from structured electronic health record fields or unstructured clinical notes. The recommended interval was compared with the actual time to the next visit. A lapse was defined as returning later than the recommended interval, exceeding a pre-set threshold (around 25%) based on literature and expert recommendation. For example, an 8-week recommended follow-up would have a threshold of 2 weeks, and a 20-week follow-up would have a threshold of 4 weeks. Lapses in care were identified in a two-year observation period beginning after the initial visit.

Secondary Outcomes

Secondary outcomes included vision impairment (visual acuity (VA) worse than or equal to 20/40), blindness (VA worse than or equal to 20/200), and VA in logMAR,[21] all measured in the better-seeing eye at the initial office encounter. Severity of DR was also included and categorized as no DR, unspecified DR, non-proliferative DR (NPDR), and proliferative DR (PDR) as determined at the baseline visit by natural language processing (NLP).[22,23] A sensitivity analysis was performed using the worse-seeing eye.

Covariates

Additional covariates were extracted from the baseline visit and included sex, age, race (Hispanic, non-Hispanic Black, non-Hispanic White, and other), insurance (private, Medicare, Medicaid, other, none) and distance from patient's home to their ophthalmology clinic.[7] Distance to clinic was calculated using the GeoPy[24] package in Python; patient addresses and ophthalmology clinics were geocoded to a latitude and longitude based on PMAP data from 2018. We categorized patients as living within or beyond the median distance – 7.6 miles – of their clinic. Clinical covariates included the Charlson Comorbidity Index (CCI), Diabetes Complications Severity Index (DCSI), presence of glaucoma, and other retinal comorbidities as previously described.[25,26]

Statistical Analysis

All analyses were performed using Stata, version 18 (StataCorp) and Python version 3.8.5 (Python Software Foundation). Descriptive statistics summarized demographic and clinical characteristics of the study population, stratified by PCP location. Continuous variables (age, visual acuity, CCI, DCSI) were compared between internal and external PCP groups using 2-sample t-tests, and categorical or binary variables were compared using Pearson's chi-squared tests. Multivariate logistic or linear regression models were used to assess the association between PCP type with an interaction term of PCP type and distance from clinic and each primary or secondary outcome, adjusting for age, race, insurance, comorbidities, and ocular disease.

We assessed the interaction between primary care provider (PCP) type and distance to clinic using a likelihood ratio (LR) test that compared a full model including the interaction term with a reduced model without it. Statistical significance was set at α of 0.05. When the LR test suggested a potential interaction, we examined pairwise comparisons between PCP type (internal vs external) and distance category (≤7.6 vs >7.6 miles) using post-estimation contrasts with Bonferroni correction for multiple comparisons. To visualize the combined effects, predicted probabilities for each DR outcome category—no DR, unspecified DR, NPDR, and PDR—were derived from the fitted model using marginal estimates.

Before fitting the final model, we tested the proportional odds assumption with the omodel test, which indicated a violation (P <0.001). Therefore, we used a generalized ordered logistic regression (gologit2) model. Both autofit and partially constrained versions were evaluated; the constrained model, which held the gender effect constant across outcome thresholds, provided the best overall fit (LR P =0.804 for gender; all other variables P <0.05 for the unconstrained model).

Results

A total of 41,581 patients were included in this study (Table 1). The mean age was 61.8 years, with a roughly even distribution of male (48%, N=19,750) and female (53%, N=21,831) participants. Overall, 48% (N=20,030) of patients were non-Hispanic White, 37% (N=15,209) were non-Hispanic Black, 4% (N=1697) were Hispanic, and 11% (N=4645) identified as other. The majority of patients, 81% (N=33,494), had at least one lapse in care during the two year follow-up period.

Of all patients, 48% (N=19,998) had an internal primary care provider (PCP) and 52% (N=21,583) had an external PCP. Patients with an external PCP were, on average, older (mean age 63 vs. 60 years, P <0.001) (Table 1). Non-Hispanic White patients were more likely to have an external PCP (60% vs. 40%), whereas non-Hispanic Black and Hispanic patients were more likely to have an internal PCP (56% and 58%, respectively; all P <0.001).

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Table 1 Baseline Characteristics of Patients Included in the Study Stratified by Whether They Have an Internal Primary Care Provider (PCP), Within the Johns Hopkins Health System, or External PCP

	Total	Internal Care N (%)	External Care N (%)	*P*-value
Total	41,581 (100%)	19,998 (48.1)	21,583 (51.9)	
Sociodemographic Characteristics				
Age (years)*	61.82 (13.71)	60.19 (13.8)	63.3 (13.4)	<0.001
Gender				0.774
Female	21,831 (52.50%)	10,514 (48.2)	11,317 (51.8)	
Male	19,750 (47.50%)	9,484 (48.0)	10,266 (52.0)	
Race/Ethnicity				<0.001
Non-Hispanic White	20,030 (48.17%)	8,011 (40.0)	12,019 (60.0)	
Non-Hispanic Black	15,209 (36.58%)	8,541 (56.2)	6,668 (43.8)	
Hispanic	1,697 (4.08%)	975 (57.5)	722 (42.5)	
Other	4,645 (11.17%)	2,471 (53.2)	2,174 (46.8)	
Insurance				<0.001
Private	13,733 (33.03%)	6,092 (44.4)	7,641 (55.6)	
Medicare	18,139 (43.62%)	7,877 (43.4)	10,262 (56.6)	
Medicaid	3,563 (8.57%)	1,624 (45.6)	1,939 (54.4)	
Other	2,645 (6.36%)	2,222 (84.0)	423 (16.0)	
None	3,501 (8.42%)	2,183 (62.4)	1,318 (37.6)	
Ophthalmic Comorbidities				
Glaucoma				<0.001
Not Present	32,730 (78.7)	15,548 (47.5)	17,182 (52.5)	
Present	8,851 (21.3)	4,450 (50.3)	4,401 (49.7)	
Other Retina				<0.001
Not Present	38,696 (93.1)	18,918 (48.9)	19,778 (51.1)	
Present	2,885 (6.9)	1,080 (37.4)	1,805 (62.6)	
Overall medical complexity				
Charlson Comorbidity Index (CCI)*	1.50 (1.10)	1.50 (1.10)	1.33 (0.94)	<0.001
Diabetes Complications Severity Index (DCSI)*	0.88 (0.93)	0.88 (0.93)	0.73 (0.90)	<0.001
Distance (miles)				<0.001
≤7.6	20,740 (49.9)	10,694 (51.6)	10,046 (48.4)	
>7.6	20,841 (50.1)	9,304 (44.6)	11,537 (55.4)	

(*Continued*)

Table 1 (Continued).

	Total	Internal Care N (%)	External Care N (%)	*P*-value
Outcomes				
Patients ever lapse				0.792
No	8,087 (19.45%)	3,900 (48.2)	4,187 (51.8)	
Yes	33,494 (80.55%)	16,098 (48.1)	17,396 (51.9)	
Baseline Visual Acuity*				<0.001
Better Eye	0.13 (0.30)	0.108 (0.25)	0.156 (0.33)	
Vision impairment (Better Eye)				<0.001
>20/40	35,518 (85.42%)	17,647 (49.7)	17,871 (50.3)	
≤20/40	6,063 (14.58%)	2,351 (38.8)	3,712 (61.2)	
Blindness (Better Eye)				<0.001
>20/200	40,865 (98.28%)	19,775 (48.4)	21,090 (51.6)	
≤20/200	716 (1.72%)	223 (31.2)	493 (68.8)	
Severity of DR (Better Eye)				<0.001
Unspecified DR	1,497 (3.61%)	620 (41.4)	877 (58.6)	
Not DR	31,987 (77.16%)	16,349 (51.1)	15,638 (48.9)	
NPDR	5,286 (12.75%)	2,183 (41.3)	3,103 (58.7)	
PDR	2,685 (6.48%)	804 (29.9)	1,881 (70.1)	

Note: *Mean (Standard Deviation).

For the primary outcome of lapses in care, the interaction between PCP type and distance to clinic was statistically significant (likelihood ratio test, *P* =0.002), indicating that the relationship between PCP type and lapses differed by distance. Among patients living ≤7.6 miles from the clinic, predicted probabilities of lapse were nearly identical for those with external versus internal PCPs (0.79 vs.80; *P* = 1.00) (Figure 1). In contrast, among patients living >7.6 miles away, those with an external PCP had a higher predicted probability of lapse compared with those with an internal PCP (0.83 vs.80; *P* <0.001). In pairwise comparisons of patients living >7.6 miles from clinic, having an external PCP was associated with 19% higher odds of a lapse in care compared with those with an internal PCP (OR 1.19, 95% CI [1.08, 1.32], *P* <0.001).

For the secondary outcome of vision impairment, the interaction between PCP type and distance was not statistically significant (*P* =0.65). However, within each distance category, patients with external PCPs had higher predicted probabilities of vision impairment than those with internal PCPs—0.16 vs 0.11 (*P* <0.001) for ≤7.6 miles and 0.18 vs 0.13 (*P* <0.001) for >7.6 miles (Figure 2). On pairwise comparisons, having an external PCP was associated with 60% higher odds of vision impairment for patients living within ≤7.6 miles of clinic (OR 1.60, 95% CI [1.43,1.80], *P* <0.001) and 56% higher odds at >7.6 miles (OR 1.56, 95% CI [1.40, 1.74], *P* <0.001).

Findings were similar for the outcome of blindness. The interaction between PCP type and distance was not significant (*P* =0.64). However, there was a significantly higher predicted probability of blindness for patients comparing patients with external versus internal PCP at both distances: ≤7.6 miles: 0.02 vs 0.01, *P* <0.001; >7.6 miles: 0.03 vs 0.01, *P* <0.001 (Figure 3). Pairwise comparisons corresponded to an 113% (OR 2.13, 95% CI [1.47, 3.08], *P* <0.001) and

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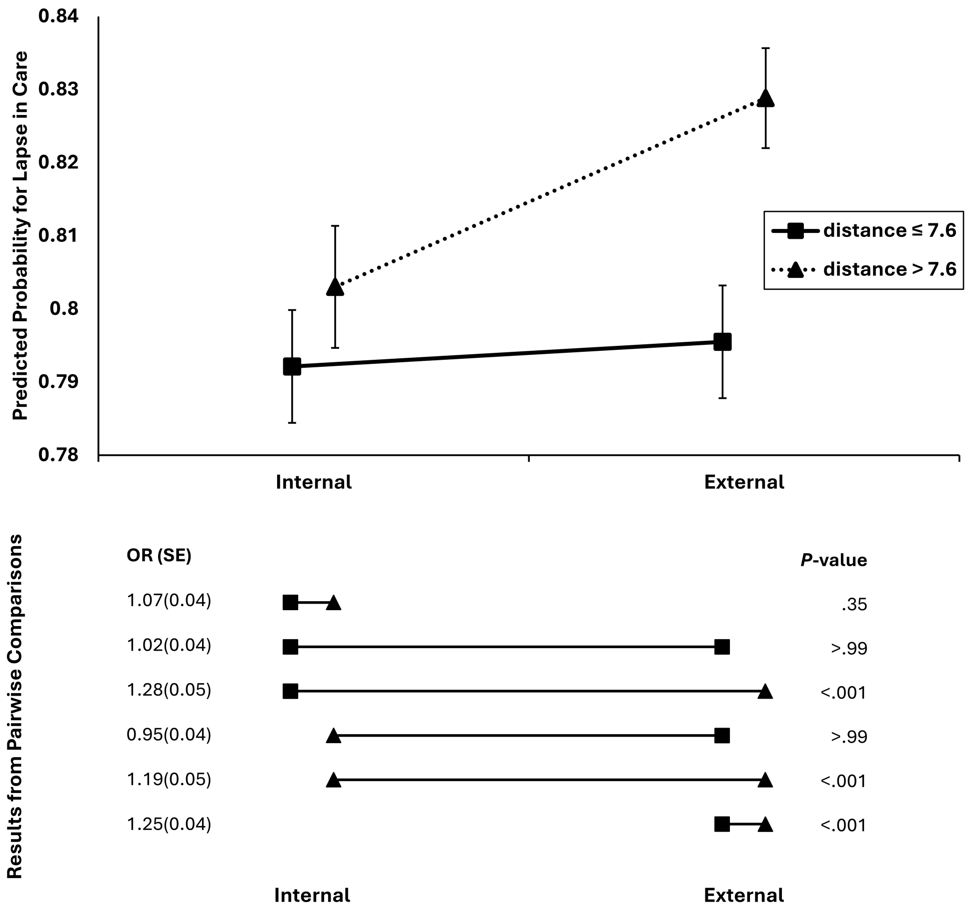

Figure 1 The predicted probability for having lapses in diabetic retinopathy care are shown for patients with internal compared to external primary care providers (PCPs), and stratified by the distance the patient lives from the Johns Hopkins health system. The odds ratios (OR), standard error (SE), and *P*-value for each comparison from the pairwise comparisons are shown below.

131% (OR 2.31, 95% CI [1.75, 3.05], *P* <0.001) increased odds for those with external versus internal PCP for those living closer and further, respectively.

For baseline visual acuity (logMAR), the interaction between PCP type and distance was significant (*P* =0.02). At both distances (≤7.6 miles or >7.6 miles), patients with external PCPs had higher predicted baseline visual acuity in logMAR (worse vision) than those with internal PCPs (≤7.6 miles: 0.14 vs 0.10, *P* <0.001; >7.6: 0.17 vs 0.12, *P* <0.001) (Figure 4). In pairwise comparisons, all contrasts were statistically significant after Bonferroni adjustment (*P* <0.001), though absolute differences were small.

Lastly, for baseline DR severity, the overall interaction term was not statistically significant (*P* =0.62). Nevertheless, within each distance category, PCP type was associated with higher severity (*P* <0.001) (Figure 5). Among patients living ≤7.6 miles, those with external PCPs had a lower predicted probability of having no DR (0.74 vs 0.85) and a higher probability of having PDR (0.08 vs 0.03) compared to those with internal PCPs (Figure 5A–D). A similar but more pronounced pattern was observed among patients living >7.6 miles away, where the predicted probability of no DR was 0.68 for external PCP versus 0.81 for internal PCP, and the probability of PDR was 0.11 versus 0.05, respectively (Figure 5A–D). In pairwise comparisons, for patients living ≤7.6 miles, the external PCP group had 144% increased odds of presenting with any DR, versus no DR, compared to the internal PCP group (OR 2.44, 95% CI [2.19, 2.73], *P* <0.001) (Figure 5A). For patients living >7.6 miles, the external PCP group had 138% increased odds of presenting with any DR, versus no DR, compared to the internal PCP group (OR 2.38, 95% CI [2.15, 2.63], *P* <0.001) (Figure 5A). This trend persisted across all levels of DR severity, with those with external PCPs showing significantly higher odds of more severe

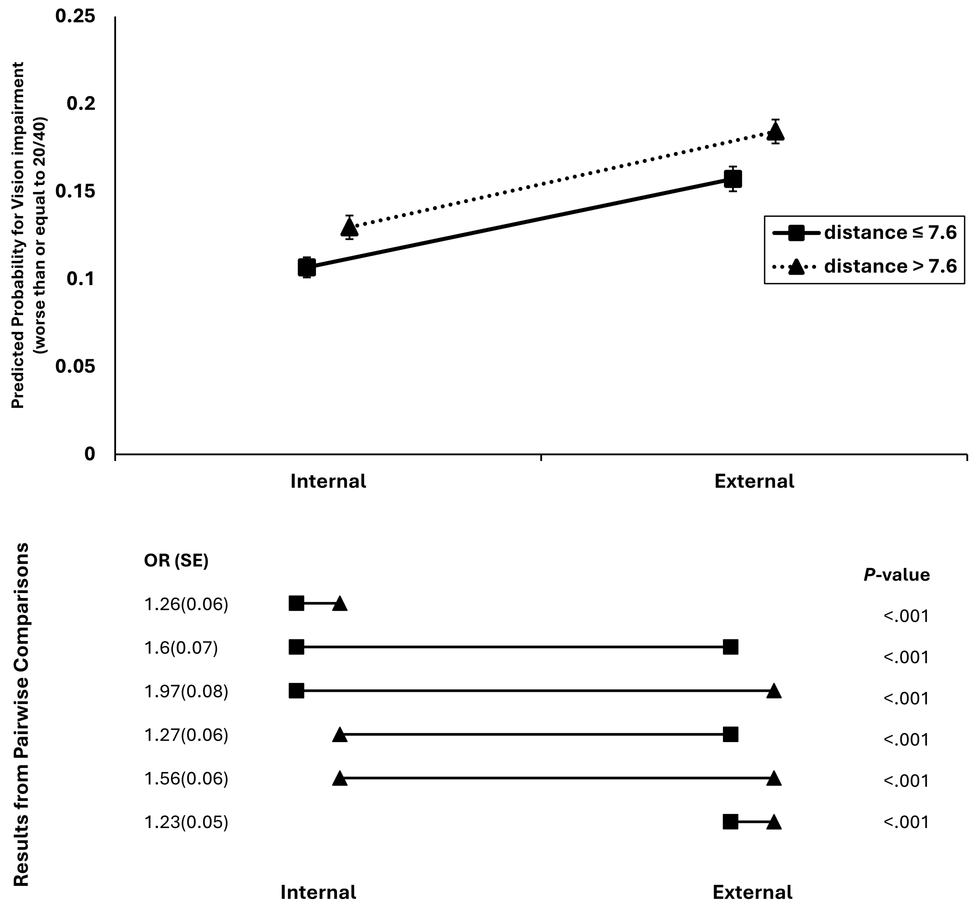

Figure 2 The predicted probability for having vision impairment (visual acuity worse than or equal to 20/40) at initial presentation for patients with internal compared to external primary care providers (PCPs), and stratified by the distance the patient lives from the Johns Hopkins health system. The odds ratios (OR), standard error (SE), and *P*-value for each comparison from the pairwise comparisons are shown below.

disease compared to those with internal PCPs at both distance categories (P <0.001 for all comparisons) (Figure 5B and C).

Results were similar when using the visual acuity of the worse seeing eye at baseline on sensitivity analysis (Supplemental Table 1).

Discussion

In this retrospective cohort study of adults with diabetes at a vertically integrated delivery network, we found that patients whose PCP was outside of the hospital system generally had worse DR care than those with in-system PCPs. Patients with external PCPs had more lapses in DR care, but only when patients lived further away. And, patients with external PCPs were more likely to have vision impairment or blindness and greater DR severity at the initial visit. The effect of external PCP on presenting disease severity was more pronounced among patients living farther away. Our findings suggest that patients with external PCPs, especially those living farther away, may benefit from additional support to reduce disease progression.

Our findings suggest that staying within a vertically integrated system is associated with better follow-up adherence, particularly for patients who live further away. This aligns with prior studies in other subspecialties showing that having a PCP located within the same hospital as specialty care is associated with higher appointment attendance.[27,28] Several mechanisms may underlie this association. First, shared electronic health records and referral systems may streamline communication between PCPs and ophthalmologists, which is linked to better follow up adherence,[18] and enhance

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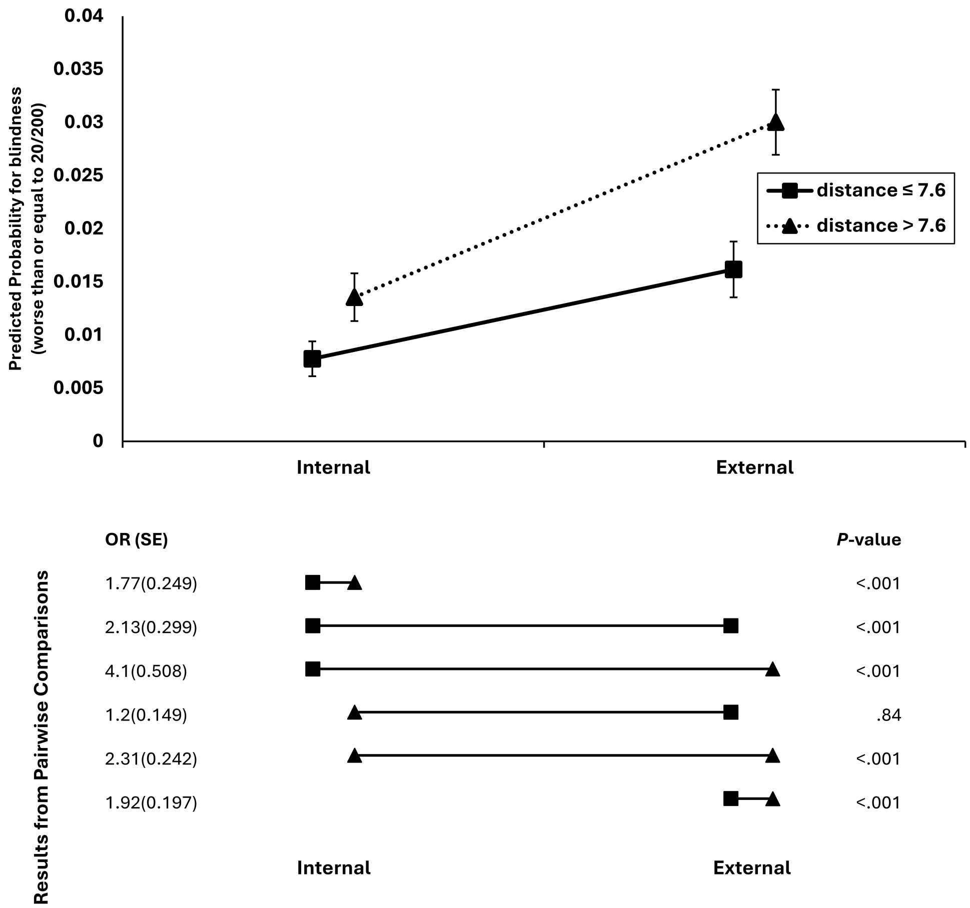

Figure 3 The predicted probability for having blindness (visual acuity worse than or equal to 20/200) at initial presentation for patients with internal compared to external primary care providers (PCPs), and stratified by the distance the patient lives from the Johns Hopkins health system. The odds ratios (OR), standard error (SE), and *P*-value for each comparison from the pairwise comparisons are shown below.

interdisciplinary collaboration.[29,30] Second, vertical integration may ease the logistical burden on patients; familiarity with the office site, provider,[31] and the ability to schedule ophthalmology appointments consecutively with PCP visits may increase the likelihood of adherence. Third, vertically integrated systems may enhance patient and provider education regarding the importance of ophthalmic care. Within an integrated network, PCPs and ophthalmologists can coordinate on clinical guidelines and updates, ensuring the ophthalmology is presented as an essential part of routine diabetes care.

Distance to the hospital also appeared to modify the relationship between PCP type and lapses in care, and to a lesser degree, disease severity. Distance mitigated the association between external PCP and lapses in care–such that patients living closer to the hospital had similar amounts of lapses in care regardless of PCP type. However, distance did not attenuate differences in presenting ophthalmic disease severity. Among both distance categories, patients with an external PCP presented with worse vision and more severe DR. This pattern suggests that lapses in care may be more sensitive to logistical and access-related factors, whereas disease severity could be more driven by longer-term systemic differences in care coordination and referral pathways that geographic proximity alone cannot overcome.

Our findings have several implications for the management of DR care. We show that patients who have external PCPs and live farther from the hospital appear to be at higher risk for lapses in care, and that patients with external PCPs present with worse disease, regardless of distance. Therefore, it may be beneficial for ophthalmologists to encourage patients to remain within the same medical system for their primary care services. Alternatively, for patients living far away with well-established external PCPs, targeted adherence support–such as appointment reminders, transportation

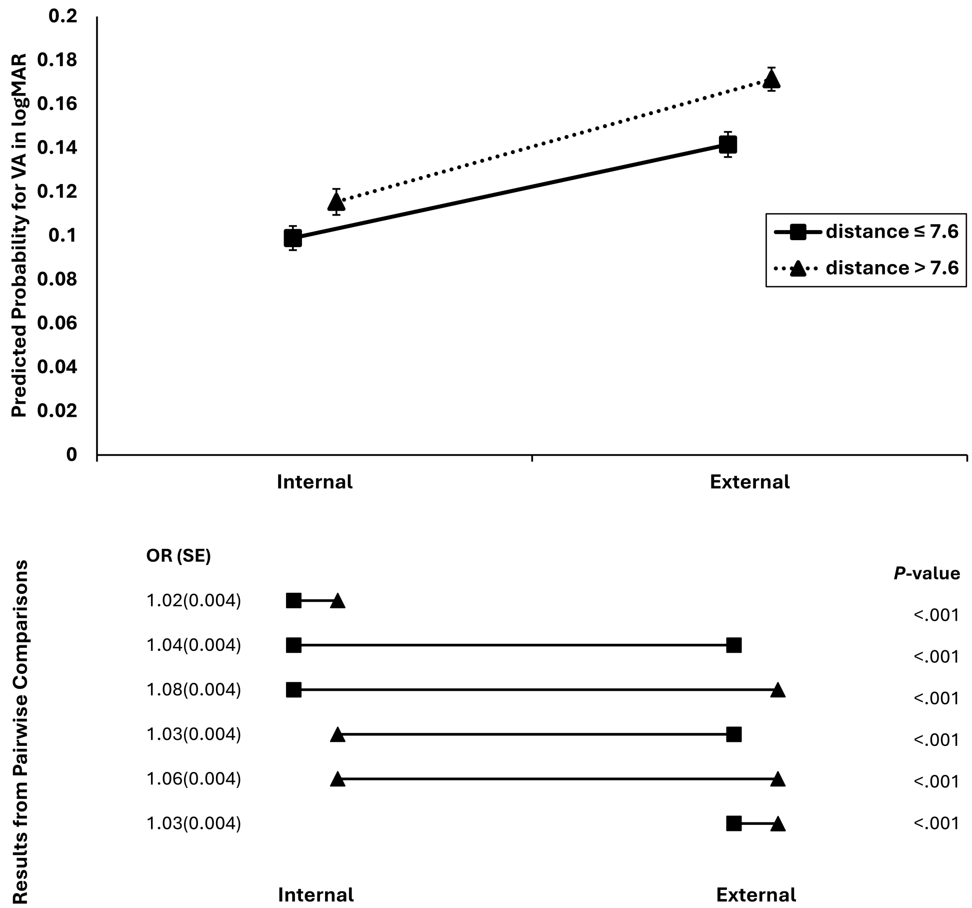

Figure 4 The predicted probability for visual acuity (in logMAR) at initial presentation for patients with internal compared to external primary care providers (PCPs), and stratified by the distance the patient lives from the Johns Hopkins health system. The odds ratios (OR), standard error (SE), and *P*-value for each comparison from the pairwise comparisons are shown below.

assistance, or coordinated scheduling–could help mitigate lapses in care.[32–35] From the PCP perspective, attention to the location of ophthalmology referrals may be important. For instance, patients with external PCPs may have achieved better disease control if their ophthalmology care was more local or better coordinated with their local provider. While emerging artificial intelligence-based screening tools may improve access to DR screenings, patients who screen positive will still need in-person ophthalmic evaluation, underscoring the continued importance of our findings.

Finally, our study had several strengths and limitations. Strengths included a large sample size, the ability to assess lapse in care–providing a more accurate assessment of follow-up adherence–and adjustment for multiple relevant covariates. Limitations include potential misclassification of PCP location, residual referral bias, single-institution design, and retrospective nature, all of which limit causal inference and the generalizability of the findings to other health systems. We also simplified patient distance to clinic as a binary variable; future studies could consider more nuanced measures. Additional work should also examine the association of vertical integration with follow-up adherence and disease severity in other diseases and specialties, as well as evaluate interventions to improve care for patients receiving care across multiple healthcare systems. Studies monitoring other variables, such as lab parameters, glycemic control, and treatment adherence, across DR follow-ups would also help characterize high-risk groups and inform subsequent interventions.

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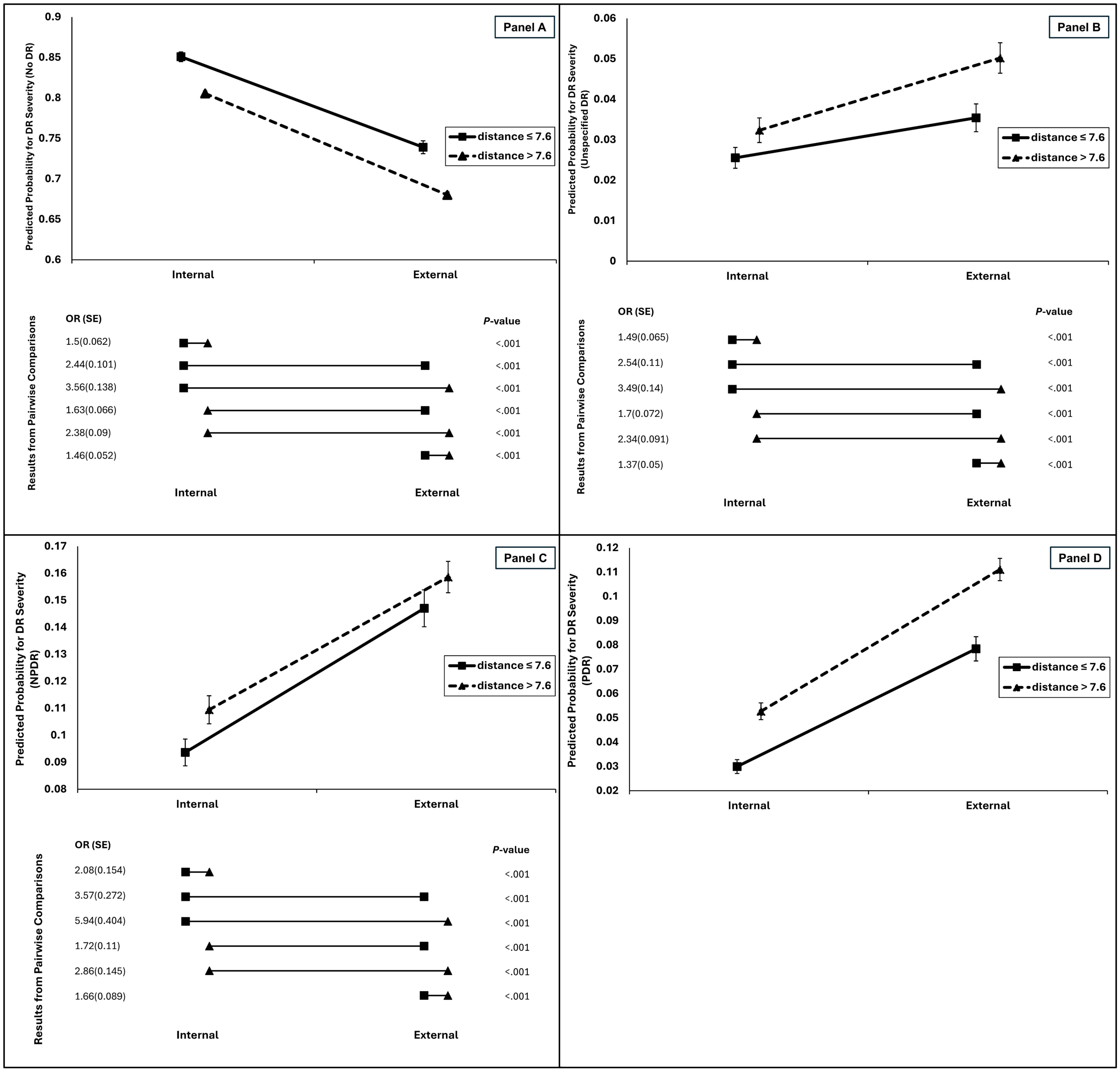

Figure 5 The predicted probability of no diabetic retinopathy (DR) (Panel A), unspecified DR (Panel B), non-proliferative diabetic retinopathy (NPDR) (Panel C), and proliferative diabetic retinopathy (PDR) (Panel D). The bottom panel depicts the odds ratios (OR), standard error (SE), and *P*-value from the pairwise comparison for DR severity comparing chances of having unspecified DR, NPDR, or PDR vs no DR (Panel A); NPDR or PDR vs Unspecified DR or No DR (Panel B); PDR vs No DR, Unspecified DR, or NPDR (Panel C).

Conclusion

In conclusion, our study demonstrates that having an internal PCP is associated with improved DR care compared to external PCPs within a vertically integrated hospital. Among patients living farther away from the hospital, having an external PCP is associated with higher odds of a lapse in DR care. Having an external PCP is associated with more severe baseline ophthalmic disease compared to patients with internal PCPs. Ophthalmologists and PCPs should consider the potential beneficial role of vertically integrated care delivery services when referring patients with DR, as they may reduce lapses in care and mitigate disease severity.

Ethics Approval

This study was approved by the Johns Hopkins Institutional Review Board (IRB:00264321). The requirement for informed consent was waived as this was secondary use of data and presented minimal risk to participants. All procedures were conducted in accordance with the Declaration of Helsinki and relevant institutional guidelines, and all patient data were de-identified to ensure confidentiality.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

CXC: Regeneron Pharmaceuticals Inc, Optomed USA Inc, Boehringer Ingelheim, 4D Molecular Therapeutics, Inc. (outside of the submitted work). The authors report no other conflicts of interest in this work.

References

1. Teo ZL, Tham YC, Yu M, et al. Global prevalence of diabetic retinopathy and projection of burden through 2045: systematic review and meta-analysis. *Ophthalmology*. 2021;128(11):1580–1591. doi:10.1016/j.ophtha.2021.04.027
2. Flaxel CJ, Adelman RA, Bailey ST, et al. Diabetic retinopathy preferred practice pattern®. *Ophthalmology*. 2020;127(1):P66–P145. doi:10.1016/j.ophtha.2019.09.025
3. Solomon SD, Chew E, Duh EJ, et al. Diabetic retinopathy: a position statement by the american diabetes association. *Diabetes Care*. 2017;40(3):412–418. doi:10.2337/dc16-2641
4. Wong T, Sun J, Kawasaki R, et al. Guidelines on diabetic eye care: the international council of ophthalmology recommendations for screening, follow-up, referral, and treatment based on resource settings. *Ophthalmology*. 2018;125(10):1608–1622. [PMID: 29776671]. doi:10.1016/j.ophtha.2018.04.007
5. Gao X, Obeid A, Aderman CM, et al. Loss to follow-up after intravitreal anti–vascular endothelial growth factor injections in patients with diabetic macular edema. *Ophthalmol Retina*. 2019;3(3):230–236. doi:10.1016/j.oret.2018.11.002
6. Ehlken C, Helms M, Böhringer D, Agostini HT, Stahl A. Association of treatment adherence with real-life VA outcomes in AMD, DME, and BRVO patients. *Clin Ophthalmol Auckl NZ*. 2017;12:13–20. doi:10.2147/OPTH.S151611
7. Cai CX, Tran D, Tang T, et al. Health disparities in lapses in diabetic retinopathy care. *Ophthalmol Sci*. 2023;3(3):100295. doi:10.1016/j.xops.2023.100295
8. Ramakrishnan MS, Yu Y, VanderBeek BL. Visit adherence and visual acuity outcomes in patients with diabetic macular edema: a secondary analysis of DRCRnet Protocol T. *Graefes Arch Clin Exp Ophthalmol*. 2021;259(6):1419–1425. doi:10.1007/s00417-020-04944-w
9. Matsunaga DR, Salabati M, Obeid A, et al. Outcomes of eyes with diabetic macular edema that are lost to follow-up after anti–vascular endothelial growth factor therapy. *Am J Ophthalmol*. 2022;233:1–7. doi:10.1016/j.ajo.2021.06.028
10. Obeid A, Su D, Patel SN, et al. Outcomes of eyes lost to follow-up with proliferative diabetic retinopathy that received panretinal photocoagulation versus intravitreal anti–vascular endothelial growth factor. *Ophthalmology*. 2019;126(3):407–413. doi:10.1016/j.ophtha.2018.07.027
11. Zhu G, Westlund E, Tran D, Cai CX. The association of lapses in diabetic retinopathy care with vision impairment. *Ophthalmol Sci*. 2026;6(1):100958
12. American Diabetes Association. 2025 ADA diabetes standards of medical care clinical guideline summary. Guideline Central. Available from: https://www.guidelinecentral.com/guideline/14119. Accessed November 30, 2025.
13. Russell AW, Baxter KA, Askew DA, Tsai J, Ware RS, Jackson CL. Model of care for the management of complex Type 2 diabetes managed in the community by primary care physicians with specialist support: an open controlled trial. *Diabet Med*. 2013;30(9):1112–1121. doi:10.1111/dme.12251
14. Elrashidi MY, Mohammed K, Bora PR, et al. Co-located specialty care within primary care practice settings: a systematic review and meta-analysis. *Healthc Amst Neth*. 2018;6(1):52–66. doi:10.1016/j.hjdsi.2017.09.001
15. Larsen DL, Cannon W, Towner S. Longitudinal assessment of a diabetes care management system in an integrated health network. *J Manag Care Pharm*. 2003;9(6):552–558. doi:10.18553/jmcp.2003.9.6.552
16. Stellefson M. The chronic care model and diabetes management in US primary care settings: a systematic review. *Prev Chronic Dis*. 2013;10.
17. Gretchen PA, Trevor OJ, Sharlene E, et al. Translating the chronic care model into the community: results from a randomized controlled trial of a multifaceted diabetes care intervention. *Diabetes Care*. 2006;29(4):811–817. doi:10.2337/diacare.29.04.06.dc05-1785

18. Storey PP, Murchison AP, Pizzi LT, et al. Impact of physician communication on diabetic eye examination adherence: results from a retrospective cohort analysis. *RETINA*. 2016;36(1):20. doi:10.1097/IAE.0000000000000652
19. The Johns Hopkins Health System Corporation. Johns Hopkins Medicine. Available from: https://www.hopkinsmedicine.org/about/johnshopkins-health-system-corp. Accessed December 23, 2025.
20. Platform (PMAP) | inHealth Precision Medicine. Available from: https://pm.jh.edu/platform-pmap/. Accessed December 23, 2025
21. Roberts MF, Fishman GA, Roberts DK, et al. Retrospective, longitudinal, and cross sectional study of visual acuity impairment in choroideraemia. *Br J Ophthalmol*. 2002;86(6):658–662. doi:10.1136/bjo.86.6.658
22. Harrigian K, Tang T, Gonzales A, Cai CX, Dredze M. An eye on clinical bert: investigating language model generalization for diabetic eye disease phenotyping. *arXiv.*
23. Harrigian K, Tran D, Tang T, et al. Improving the identification of diabetic retinopathy and related conditions in the electronic health record using natural language processing methods. *Ophthalmol Sci*. 2024;4(6):100578. doi:10.1016/j.xops.2024.100578
24. GeoPy contributors. GeoPy 2.4.1 documentation. Available from: https://geopy.readthedocs.io/en/stable/. Accessed December 16, 2025.
25. Glasheen WP, Renda A, Dong Y. Diabetes Complications Severity Index (DCSI)—Update and ICD-10 translation. *J Diabetes Complications*. 2017;31(6):1007–1013. doi:10.1016/j.jdiacomp.2017.02.018
26. Quan H, Sundararajan V, Halfon P, et al. Coding algorithms for defining comorbidities in ICD-9-cm and ICD-10 administrative data. *Med Care*. 2005;43(11):1130. doi:10.1097/01.mlr.0000182534.19832.83
27. Velu P, Wilson C, Kariveda RR, Weber PC, Levi JR. Factors associated with follow-up appointment attendance in adults with sensorineural hearing loss. *Otol Neurotol*. 2025;46(7):759. doi:10.1097/MAO.0000000000004530
28. Agarwal P, Nathan AS, Jaleel Z, Levi JR. Factors contributing to missed appointments in a pediatric otolaryngology clinic. *Laryngoscope*. 2022;132(4):895–900. doi:10.1002/lary.29841
29. Vos JFJ, Boonstra A, Kooistra A, Seelen M, van Offenbeek M. The influence of electronic health record use on collaboration among medical specialties. *BMC Health Serv Res*. 2020;20(1):676. doi:10.1186/s12913-020-05542-6
30. Chase D. *The Electronic Health Record: Effects on Clinician Collaboration in Primary Care*. Oregon Health and Science University; 2015. Available from: https://digitalcollections.ohsu.edu/record/2833. Accessed November 24, 2025.
31. Hermoni D, Mankuta D, Reis S. Failure to keep appointments at a community health centre: analysis of causes. *Scand J Prim Health Care*. 1990;8(2):107–111. doi:10.3109/02813439008994940
32. Hendrickson SB, Simske NM, DaSilva KA, Vallier HA. Improvement in outpatient follow-up with a postdischarge phone call intervention. *J Am Acad Orthop Surg*. 2020;28(18):e815. doi:10.5435/JAAOS-D-19-00132
33. Ulloa-Pérez E, Blasi PR, Westbrook EO, Lozano P, Coleman KF, Coley RY. Pragmatic randomized study of targeted text message reminders to reduce missed clinic visits. *Perm J*. 2022;26(1):64–72. doi:10.7812/TPP/21.078
34. Robotham D, Satkunanathan S, Reynolds J, Stahl D, Wykes T. Using digital notifications to improve attendance in clinic: systematic review and meta-analysis. *BMJ Open*. 2016;6(10):e012116. doi:10.1136/bmjopen-2016-012116
35. Shekelle PG, Begashaw MM, Miake-Lye IM, Booth M, Myers B, Renda A. Effect of interventions for non-emergent medical transportation: a systematic review and meta-analysis. *BMC Public Health*. 2022;22(1):799. doi:10.1186/s12889-022-13149-1