

Relationship of retinal structural and clinical vision parameters to driving performance of diabetic retinopathy patients

Janet P. Szlyk, PhD; Carolyn L. Mahler, MS; William Seiple, PhD; Thasarat S. Vajaranant, MD; Norman P. Blair, MD; Mahnaz Shahidi, PhD

Research and Development Service, Department of Veterans Affairs Chicago Health Care System, West Side Division, Chicago, IL; Department of Ophthalmology and Visual Sciences, University of Illinois at Chicago, Chicago, IL; Department of Ophthalmology, New York University School of Medicine, New York, NY

Abstract—This study identifies clinical vision measures or retinal structural measures associated with the driving performance of diabetic retinopathy patients. Twenty-five licensed drivers with diabetic retinopathy (median age, 53 years; range, 34–72 years) completed clinical tests (visual acuity, letter contrast sensitivity, and Humphrey 30-2 visual fields) and structural examinations (retinal thickness analysis and fundus photograph grading of retinopathy and laser scarring). Driving performance was assessed with an interactive driving simulator and a driving history questionnaire. Increased retinal thickness was significantly correlated with a higher frequency of simulator accidents and near accidents. Laser scar grades significantly correlated with steeper brake-response slopes, increased brake-pressure standard deviation (SD), and longer response times. Subjects with focal laser scars had significantly higher average brake-pedal pressure and brake-pressure SD than subjects without focal laser scars. Retinal thickness and laser scarring correlated with driving simulator performance in subjects with diabetic retinopathy.

Key words: diabetic retinopathy, driving, laser scarring, retinal thickness.

INTRODUCTION

The estimate of the number of diabetic individuals in the United States is 10.3 million, with 5.3 million affected

with diabetic retinopathy [1]. Diabetic retinopathy is the second leading cause of blindness among the veteran population, affecting over 15 percent of veterans with vision problems [2,3]. Because the percentage of older veterans is increasing, the prevalence of diabetic retinopathy is expected to increase in the veteran population.

Abbreviations: df = degree of freedom, OD = ocular dexter (right eye), OS = ocular sinister (left eye), PRP = panretinal photocoagulation, RTA = retinal thickness analysis, SD = standard deviation.

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Address all correspondence to Janet Szlyk, PhD; VA Chicago Health Care System, 820 South Damen Avenue (M/C 151), Chicago, IL 60612; 312-996-1466; fax: 312-996-6685; email: janeszlyk@uic.edu.

Diabetic retinopathy can cause the loss of visual independence because it can affect both central and peripheral vision. Because of its potential to severely impact visual function, diabetic retinopathy may have consequences for driving. The safety of drivers with diabetic retinopathy is a concern for patients and their families, physicians, and the general public. Variability in pathology and disease severity makes blanket recommendations about driving impossible. The range of visual field loss caused by retinopathy itself or the treatment of retinopathy by photocoagulation further complicates decisions about driving [4,5].

Several studies addressed the negative effects of laser panretinal photocoagulation (PRP) on maintaining the United Kingdom visual field requirements for driving [6–8]. United Kingdom regulations require a binocular visual field that spans 120° horizontally by 40° vertically. (The United States field requirements are 140° binocularly and 105° monocularly.) Hulbert and Vernon found that 2 (11%) of 19 patients given bilateral laser PRP lacked the required visual field [6], while Mackie and coworkers reported that 19 (19%) of 100 patients no longer maintained the necessary visual field [7]. Additionally, Pearson et al. found that 4 (12%) of the 34 patients whom they examined did not meet the visual field criteria [8]. Concerned by these failure rates, Davies designed novel PRP treatment patterns that avoided the visual field areas required for United Kingdom driver's licensure [9]. He reduced burn spacing and changed treatment locations while keeping the total number of burns constant. Davies also proposed a randomized controlled clinical trial to test the effectiveness of alternative PRP patterns in controlling proliferative diabetic retinopathy.

These studies did not explore the effect of diabetic retinopathy on driving skills. For years, the question of whether diabetic drivers have an increased accident risk has been considered. Although studies from the 1960s and 1970s reported a statistically significantly increased crash risk for diabetic drivers [10,11], more recent studies found no difference or only a slight increase in the accident rate of diabetic drivers [12–14]. These studies, however, examined the general diabetic population, not just individuals with diabetic retinopathy [15].

The current study evaluated the relationship of diabetic retinopathy, with and without prior focal or scatter laser treatments, to driving performance. Our aim was to determine if any relationship exists between retinal structural parameters (which can be affected by diabetic

retinopathy and laser treatments) and driving performance. Laser treatment is the only option for slowing the progression of diabetic retinopathy. We were interested in learning as much as possible about the functional consequences of this technique so that physicians may be able to provide patients with as much information as possible about the potential functional consequences of these treatments.

MATERIALS AND METHODS

Subjects

Twenty-five subjects with diabetic retinopathy (16 men and 9 women), ranging in age from 34 to 72 years (median age, 53 years), participated in the study. The average duration of diabetes (\pm standard deviation [SD]) was 26 ± 10 years. **Table 1** lists subject age, sex, duration and type of diabetes, glycosylated hemoglobin level, and vision data. Individuals with type 1 (16 subjects, 64%) or type 2 (9 subjects, 36%) diabetes were included. They received a complete slit-lamp examination by one of the authors (NPB). Subjects had mild or no cataracts and no other eye disease besides diabetic retinopathy. A wide range of disease severity, with and without prior scatter or focal laser treatments, was represented in our sample. Participants were licensed drivers and drove regularly (at least 1,000 miles a year). Subjects who were physically or cognitively impaired were excluded from the study, as well as subjects with monocular vision. The local institutional review board approved the study protocol, and all subjects gave informed consent.

Clinical Vision Measures

Best-corrected visual acuity was determined with the use of Lighthouse Distance Visual Acuity Charts and protocol described by Bailey et al. [16]. Median visual acuity in the eye with better visual acuity was 20/20 (range, 20/12.5 to 20/32). Visual acuity in the eye with worse acuity ranged from 20/17 to 20/105. Letter contrast sensitivity was measured with the Pelli-Robson letter contrast sensitivity charts and protocol [17,18]. In the eye with better visual acuity, median letter contrast sensitivity was 1.60 (range, 1.15–1.90). Visual fields were assessed with the 30-2 program of the Humphrey visual field analyzer (Carl Zeiss, Inc., Dublin, California). Average visual field mean deviation in the eye with better visual acuity was -4.61 dB (range, $+1.62$ dB to -21.53 dB). Additionally, we used results from the Humphrey 30-2 testing to calculate the

Table 1.

Characteristics of subjects with diabetic retinopathy. Vision measures are for eye with better visual acuity.

Subject/Age (yr)/Sex	Diabetes Duration (yr)	Diabetes Type	Glycosylated Hemoglobin (%)	Visual Acuity (LogMAR)	Letter Contrast Sensitivity (Log)	Visual Field Mean Deviation (dB)*	Global Fundus Grade [†]
1/61/F	20	2	11.1	0.16	1.50	-7.86	7
2/39/F	35	1	7.1	0.00	1.50	-5.89	7
3/36/M	27	1	8.4	0.06	1.70	-0.47	3
4/72/M	12	2	6.7	0.10	1.55	-0.14	1
5/54/M	30	1	11.0	0.14	1.35	-4.16	5
6/43/M	41	1	10.0	0.02	1.65	-6.65	7
7/61/M	9	2	8.8	0.04	1.65	0.02	4
8/51/F	40	1	6.7	0.12	1.65	-0.47	3
9/34/M	27	1	9.2	-0.12	1.60	1.62	7
10/50/M	25	1	11.3	0.04	1.35	1.33	4
11/43/M	35	1	10.5	-0.12	1.60	0.27	3
12/56/M	36	1	7.8	0.22	1.15	-10.72	7
13/36/M	27	1	11.0	0.22	1.60	-21.53	7
14/72/M	30	2	10.3	0.00	1.45	-1.92	3
15/55/F	25	2	11.6	0.06	1.60	-6.44	5
16/54/M	40	1	6.4	0.02	1.90	-6.96	7
17/56/M	19	2	6.8	-0.18	1.85	0.04	2
18/53/M	29	1	N/A [‡]	0.12	1.50	-7.69	7
19/63/F	10	2	9.6	-0.10	1.45	-3.78	4
20/52/F	4	2	9.3	0.08	1.35	-0.95	4
21/41/F	35	1	8.5	-0.14	1.35	-9.27	7
22/37/M	13	1	6.8	-0.06	1.65	0.58	1
23/48/F	27	1	9.2	0.06	1.65	-6.19	7
24/53/M	20	2	8.4	0.00	1.65	-9.76	3
25/55/F	30	1	11.0	0.12	1.35	-8.18	4
Mean	25.8	—	9.1	0.03	1.54	-4.61	5
Median	27.0	—	9.2	0.04	1.60	-4.16	4
Standard Deviation	10.3	—	1.7	0.11	0.17	5.27	2

*Using Humphrey 30-2 program.

[†]Using a modified Airlie House classification. *Source:* Klein R, Klein BEK, Magli YL, Brothers RJ, Meuer SM, Moss SE, et al. An alternative method of grading diabetic retinopathy. *Ophthalmology.* 1986;93:1183-87.

[‡]Data not available.

M = Male

F = Female

visual field loss in the specific areas assessed during retinal structural evaluation that is described in the next section, entitled Retinal Structural Measures. **Figure 1** shows the nine $6.7^\circ \times 6.7^\circ$ areas that were assessed in the central 20° field. **Figure 1** labels the locations with regard to the retina, where Areas 1, 2, and 3 correspond to superior retina but inferior visual field (corresponding to the dashboard region of the visual display), and Areas 1, 4, and 7 would be located toward the nasal retina but temporal visual field (corresponding to peripheral information, such as the lane borders).

It has been our experience with driving tasks and everyday task performance that the patient with compromised vision most often relies on the eye with better acuity. Our analysis was based on the analysis of the better eye for three reasons: (1) Averaged binocular visual acuity was highly correlated with the acuity measures for the eye with better acuity ($r[24 \text{ df}] = 0.70$, $p < 0.001$), (2) time required to perform the retinal thickness analysis procedure (described in the next section) is extensive, and (3) simultaneous binocular testing is not possible with the retinal thickness device. We believe that the

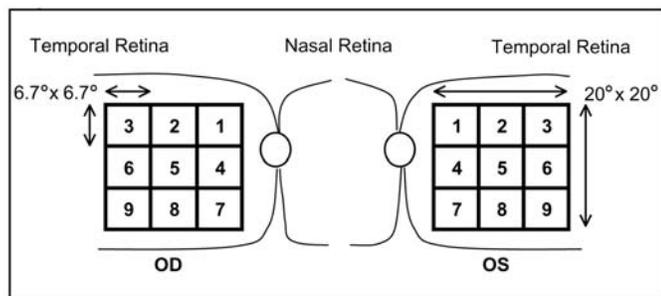


Figure 1.

Areas tested during retinal thickness analysis. OD = ocular dexter (right eye), OS = ocular sinister (left eye).

conclusion would have been essentially the same for visual acuity, contrast sensitivity, and visual fields done binocularly. A strong precedence can be found in the functional performance literature for using the data for the better eye in relating vision to everyday performance of tasks (tasks that are typically performed binocularly). However, to understand group data and have some consistency across vision and retinal structural tests, we chose the better eye in this study.

Retinal Structural Measures

Scanning retinal thickness analysis (RTA), previously described in detail [19], was used as an objective and quantitative measure of retinal thickness. Shahidi et al. showed that RTA detects smaller amounts of retinal thickening than slit-lamp biomicroscopy or stereophotography [20]. Before RTA measurements were taken, the subject's eyes were dilated with 2.5 percent phenylephrine hydrochloride and 1 percent tropicamide. The subject sat in front of a modified slit-lamp biomicroscope and was provided a fixation target while a helium-neon laser light was projected at an angle onto the retina. The reflection and scattering of the laser light from the vitreoretinal and chorioretinal interfaces created optical section images. The laser was scanned across specific retinal locations, creating a series of optical section images that were captured by a charged-coupled device video camera. Nine $6.7^\circ \times 6.7^\circ$ areas were scanned to map the retinal thickness in the central 20° field (**Figure 1**). Images were digitized by an imaging board and analyzed by a software program. The retinal thickness measurements were averaged in each of the nine areas.

Color fundus photographs were taken of the seven Diabetic Retinopathy Study standard fields. Examiners (NPB and TSV) masked to the subject's identity performed

global grading, based on Klein's modified Airlie House system [21], producing one score per eye (scores ranged from 1 to 7). A normal eye would receive a score of 1. In this group of 25 diabetic patients, the median grade in the eye with better acuity was 4. These scores are reported in **Table 1**. The presence or absence of focal or scatter laser scars was also recorded.

A second retinopathy grading system, described in **Table 2**, was developed based on the modified Airlie House system and the methods of Greenstein et al. [21,22]. We centered the color slide of standard field 2 on the macula during fundus photography by providing a fixation target to the subject. The color slide of the fundus was scanned by a slide scanner and converted to digital format. A grid indicating the nine areas of retinal thickness imaging was overlaid on the digital color fundus image in Adobe Photoshop software. The grid size was adjusted to the different image magnifications according to the areas of retinal thickness imaging, displayed on the composite images, as described previously [19]. Each area received a grade for retinopathy level and a laser scar grade from 0 to 4, indicating the number of quadrants containing laser photocoagulation scars. The grades for retinopathy and the quantification of laser scarring were based solely on the examination of fundus images. Retinopathy grades and laser scarring measurements were completely separate from the retinal thickness measurements.

Table 2.

Grading system for $6.7^\circ \times 6.7^\circ$ areas of central 20° .

Grade	Definition
Retinopathy	
1	No retinopathy
1.5	Retinal hemorrhages only, no microaneurysms
2	Microaneurysms only
3	Microaneurysms and less than 10 hard exudates
4	Microaneurysms and 10 or more hard exudates
5	Microaneurysms and soft exudates or intraretinal microvascular abnormalities
Laser Scarring	
0	No quadrant with scars
1	Scars present in 1 quadrant
2	Scars present in 2 quadrants
3	Scars present in 3 quadrants
4	Scars present in 4 quadrants

Driving Performance Measures

An interactive driving simulator (Atari Corp., Milpitas, California), previously described in detail [23,24], was used to measure driving-related skills. The driving simulator consisted of a driving console connected to a microprocessor. The driving console included a seat, a steering wheel, brake and gas pedals, and three 62.5 cm color monitors. The monitors provided a total of 160° of horizontal viewing field and 35° of vertical viewing field to subjects seated 57.5 cm from the center screen. The mean luminance of the display was 103 cd/m², as measured with a Spectra Spotmeter (Kollmorgen, Newburgh, New York). Subjects were instructed to drive as they normally would in their own car and to obey traffic rules. They practiced for 15 minutes on a training course before completing the 8-minute evaluation course. The evaluation course contained stop signs, traffic lights, and road hazards. Data were collected 16 times per second on the simulator variables described in **Table 3**.

Subjects reported their 5-year history of vehicular accidents. Previous studies in our laboratory found statistically significant correlations between self-reported accidents and state-reported accidents (central vision loss group, $r = 0.67$, $p < 0.05$; control group, $r = 0.52$, $p < 0.05$) [24] and found that more accidents were reported by subjects than by state records (especially for subjects with vision deficits) [23,24].

Glycosylated Hemoglobin Measurement

Blood was drawn so we could determine glycosylated hemoglobin levels. The median glycosylated hemoglobin level was 9.2 percent (range, 6.4% to 11.6%). Unlike blood glucose levels, which vary between days, glycosylated hemoglobin is a measure of hyperglycemia over a period of 2 to 3 months. Additionally, glycosylated hemoglobin has been shown to predict the progression of diabetic retinopathy [25].

RESULTS

Vision Correlations

Pearson correlations were performed among our vision variables. As illustrated in **Figure 2**, contrast sensitivities between both eyes were highly correlated ($r[24 \text{ df}] = 0.826$, $p < 0.001$), whereas acuities were not ($r[24 \text{ df}] = 0.056$, $p = 0.791$). No statistically significant association was found between the visual acuity and letter contrast sensitivity in the eye with better visual acuity ($r[24 \text{ df}] = -0.347$, $p = 0.090$). Because it was statistically

Table 3.

Driving simulator variables.

Variable	Definition
Speed	Mean speed in miles per hour
Gas-Pedal Pressure	Mean force applied to gas pedal
Gas-Pedal Pressure SD	SD of the force applied to gas pedal
Acceleration	Mean of 5 speed points after a complete stop at stop sign
Brake-Pedal Pressure	Mean force applied to brake pedal in arbitrary units
Brake-Pedal Pressure SD	SD of the force applied to brake pedal
Brake-Response Time	Mean time (seconds) elapsed between when a stop sign is displayed and when force is applied to the brake pedal
Response Time	Mean time (seconds) elapsed between when a stop sign is objectively displayed and when no force is applied to the gas pedal
Brake-Response Slope	Mean deceleration calculated as the ratio of change in speed to change in time before a complete stop at a stop sign
Brake Duration	Mean time (seconds) that force is applied to the brake pedal
Ran Stop Sign	Number of stop signs ran
Ran Red Light	Number of red lights ran
Off-Lane Time	Total time (seconds) spent over the left yellow line during the course
Off-Road Time	Total time (seconds) spent off road to the right onto the road's shoulder
Near Accidents	Number of situations in which an accident is narrowly averted, as determined by an experienced observer (JPS or CLM)
Accidents	Number of collisions with other cars or objects

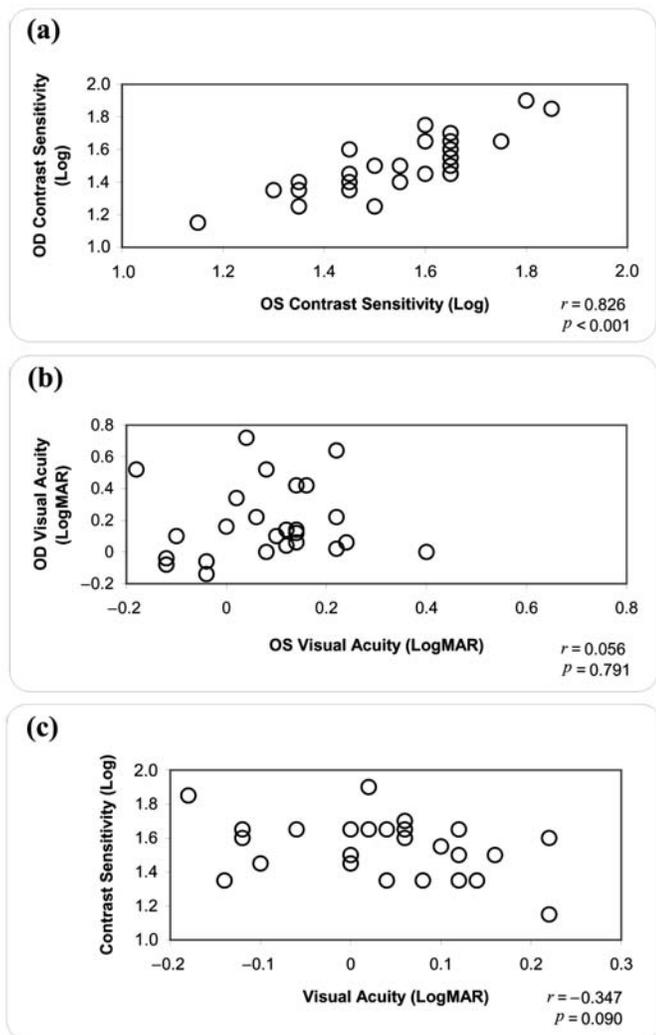


Figure 2. Vision correlations: (a) contrast sensitivity, right vs. left eye; (b) visual acuity, right vs. left eye; and (c) contrast sensitivity vs. visual acuity in better eye. OD = ocular dexter (right eye), OS = ocular sinister (left eye).

appropriate to analyze the data from only one eye, subsequent analysis used data from the eye with better visual acuity. If the visual acuities were the same in both eyes, we chose the eye with better letter contrast sensitivity.

Driving Simulator and Clinical Vision Measures

We performed a statistical analysis, consisting of Pearson and Spearman correlations, to compare clinical vision measures (visual acuity, letter contrast sensitivity, and Humphrey 30-2 visual field mean deviation) with the driving simulator variables listed in **Table 3**. If one or both of the variables were not normally distributed, we used

Spearman correlations. If both variables were normally distributed, we used Pearson correlations. Neither visual acuity nor letter contrast sensitivity correlated with any driving simulator variables. The results are presented for those simulator variables for which a statistically significant relationship was found. Although the overall Humphrey 30-2 visual field mean deviation did not correlate with simulator performance, visual field deficits within areas of the central 20° (Areas 4 and 7, within the nasal retina or temporal visual field) and off-road time were significantly correlated (**Figure 3**).

To better understand the significant relationships, we calculated the percentage of patients above and below certain natural cutoff points in the data. As may be seen in **Figure 3** for Area 4, of all the patients who had visual field sensitivities of -3 dB or better, 2 out of 21 (9.5%) had off-road times of greater than 0. In comparison, three out of four patients (75%) with visual field sensitivities worse than -3 dB had off-road times that were greater than 0. For Area 7, of all the patients who had sensitivities of -3dB or better, 3 out of 21 (14%) had off-road times greater than 0. Again, three out of four (75%) of those with visual field sensitivities worse than -3 dB had off-road times that were greater than 0. Clearly, Areas 4 and 7, areas within the temporal visual field, are correlated with a measure that relates to steering and control in the peripheral visual field. Off-road time is defined in **Table 3** as “Total time (seconds) spent off road to the right onto the road’s shoulder during the course.” The road’s shoulder is differentiated by a subtle change in the shade of gray from the road color. The gray differentiation appears to be related more to

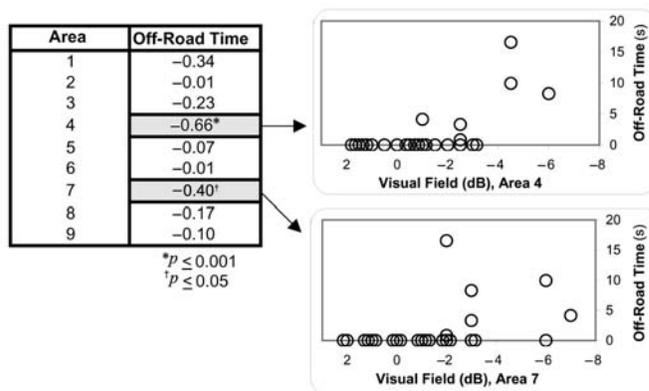


Figure 3. Correlation between retinal thickness (in eye with better acuity) and driving simulator performance. “Area” refers to retinal location corresponding to visual field.

visual field sensitivity than to the detection of the yellow lane meridian, since off-lane time was not similarly related to visual field sensitivity. Duration of diabetes did not correlate with driving simulator performance.

Driving Simulator and Retinal Structural Measures

Retinal Thickness

The relationship between retinal thickness measurements and driving simulator variables was evaluated. Increased retinal thickness was associated with increased simulator accidents and near accidents. The thickness of four areas and three areas within the central 20° correlated with simulator accidents and near accidents, respectively (Figure 4). Again, we calculated the percentage of patients with simulator and near accidents above and below natural breaks in the data. For Area 5, 1 out of 20 patients (5%) with a retinal thickness measurement of 300 μm or less had one or more simulator accidents, whereas 3 out of 5 patients (60%) with a retinal thickness measurement of greater than 300 μm had one or more simulator accidents. For Area 6, 1 out of 17 patients (6%) with a retinal thickness measurement of 300 μm or less had one or more simulator accidents, whereas 3 out of 8 patients (37.5%) with a retinal thickness measurement of

greater than 300 μm had one or more simulator accidents. For Area 8, 1 out of 18 patients (5.5%) with a retinal thickness measurement of 300 μm or less had one or more simulator accidents, whereas 3 out of 7 patients (42.9%) with a retinal thickness measurement of greater than 300 μm had one or more simulator accidents. For Area 9, 1 out of 20 patients (5%) with a retinal thickness measurement of 300 μm or less had one or more simulator accidents, whereas 3 out of 5 patients (60%) with a retinal thickness measurement of greater than 300 μm had one or more simulator accidents.

In the case of near accidents also shown in Figure 4, for both Areas 3 and 5, 2 out of 20 patients (10%) with a retinal thickness measurement of 300 μm or less had one or more near accidents. In comparison, three out of five patients (60%) with a retinal thickness measurement of greater than 300 μm had one or more near accidents. For Area 9, 1 out of 20 patients (5%) with a retinal thickness measurement of 300 μm or less had one or more near accidents, whereas 4 out of 5 patients (80%) with a retinal thickness measurement of greater than 300 μm had one or more near accidents, with one patient having had five near accidents.

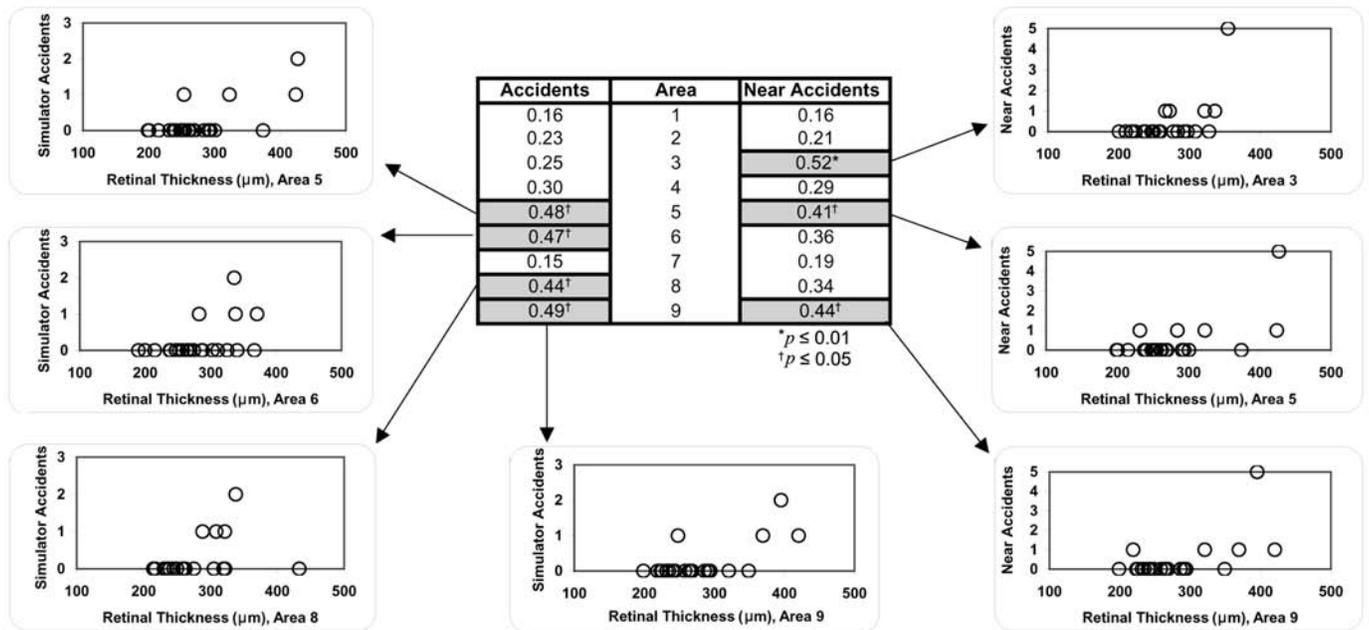


Figure 4.

Correlation between retinal thickness (in eye with better acuity) and driving simulator performance. “Area” refers to retinal location corresponding to visual field.

Retinopathy Grade

The global retinopathy scores and the scores for the nine $6.7^\circ \times 6.7^\circ$ areas were examined for possible correlation with driving simulator performance. No statistically significant relationships were found.

Laser Scarring

A statistical analysis between laser scarring grades determined from fundus images and driving simulator variables revealed several significant relationships. Increased laser scarring in the central 20° was significantly correlated with steeper brake-response slopes (**Figure 5**), increased brake-pressure SD (**Figure 5**), and longer response times (**Figure 6**). As shown in **Figure 5**, for Area 1, 5 out of 21 patients (23.8%) with laser grades of zero had brake-response slopes of -5 or worse. However, three out of four patients (75%) with laser grades of 1 or greater had brake-response slopes of -5 or worse. Similarly for Area 2, 1 out of 17 patients (23.5%) with laser grades of 0 had brake-response slopes of -5 or worse. Six out of eight patients (75%) with laser grades of 1 or greater had brake-response slopes of -5 or worse. For Area 4, 4 of 18 patients (22.2%) with laser grades of zero had brake-response slopes of -5 or worse. Four out of seven patients (57%) with laser grades of 1 or greater had brake-response slopes of -5 or worse. For Areas 7 and 8, 3 out of 18 patients (16.7%) and 2 out of 18 patients (11.1%), respectively, with laser grades of zero had brake-response slopes of -5 or worse. For both Areas 7 and 8, six out of seven patients (85.7%) with laser grades of 1 or greater had brake-response slopes of -5 or worse. These results for brake-response slope correspond with the results for brake pressure, also plotted in **Figure 5**. For Areas 4 and 7, 3 out of 18 patients (16.7%) and for Area 8, 4 out of 18 patients (22.2%) with laser grades of zero had brake-pressure variability greater than 70. In contrast, also for Areas 4 and 7, five out of seven patients (71.4%) and for Area 8, four out of seven patients (57.1%) with laser grades of 1 or greater had brake-pressure variability greater than 70. Laser grades in Areas 6, 7, and 8 were correlated with response times to stop signs as shown in **Figure 6**. For Area 6, 2 out of 12 patients (16.7%) with laser grades of zero had response times that were greater than 2 seconds. For both Areas 7 and 8, 4 out of 18 (22.2%) patients with laser grades of zero had response times that were greater than 2 seconds. For Area 6, 7 out of 13 patients (53.8%) with laser grades of 1 or greater had responses times greater than 2 seconds. For both Areas 7 and 8, five out of seven

patients (71.4%) with laser grades of 1 or greater had response times greater than 2 seconds.

The driving simulator performance of subjects with and without focal laser scars was compared using *t*-test analysis. Ten subjects had focal laser scars in the eye with better acuity, while fifteen subjects did not have focal laser scars in the eye with better acuity. Two braking variables showed statistically significant differences. Subjects with focal laser scars had higher average brake-pedal pressure (mean \pm SD, 112.8 ± 19.4) ($t[23 \text{ df}] = -2.293$, $p = 0.031$) and brake-pressure SD (73.7 ± 9.6) ($t[23 \text{ df}] = -2.580$, $p = 0.017$) than those without focal laser scars (brake-pedal pressure = 95.4 ± 18.1 ; brake-pressure SD = 63.1 ± 10.5).

Real-World Accidents and Simulator Variables

Simulator data from subjects with and without real-world accidents were compared. Twelve subjects had no real-world accidents within the past 5 years, while thirteen subjects had one or more accidents within the past 5 years. Subjects reporting real-world accidents within the past 5 years had significantly higher brake-pressure SD (mean \pm SD, 72.4 ± 9.2) ($t[23 \text{ df}] = -2.634$, $p = 0.015$) and brake-response slopes (-6.2 ± 3.4) ($t[23 \text{ df}] = -2.567$, $p = 0.017$) than those not reporting accidents (brake-pressure SD = 61.8 ± 11.0 , brake-response slope = -3.3 ± 1.9).

Real-World Accidents and Glycosylated Hemoglobin

The glycosylated hemoglobin levels of subjects with and without real-world accidents were assessed. Subjects having one or more real-world accidents within the past 5 years had significantly higher glycosylated hemoglobin levels ($t[22 \text{ df}] = 2.06$, $p = 0.05$) than those not reporting accidents.

The normal range of glycosylated hemoglobin in non-diabetic individuals is 4.0 to 6.0 percent. The American Diabetes Association recommends a target goal of <7.0 percent for diabetic patients [26]. Five study participants had glycosylated hemoglobin levels <7.0 percent, and 19 study participants had glycosylated hemoglobin levels >7.0 percent (the glycosylated hemoglobin measure was not available for one study participant). Although some reports have suggested that a threshold for retinopathy exists at 8 percent glycosylated hemoglobin, the Diabetes Control and Complications Trial was unable to identify a threshold value (short of normal glycemia) below which there was no risk of the development or progression of long-term complications, including retinopathy [27].

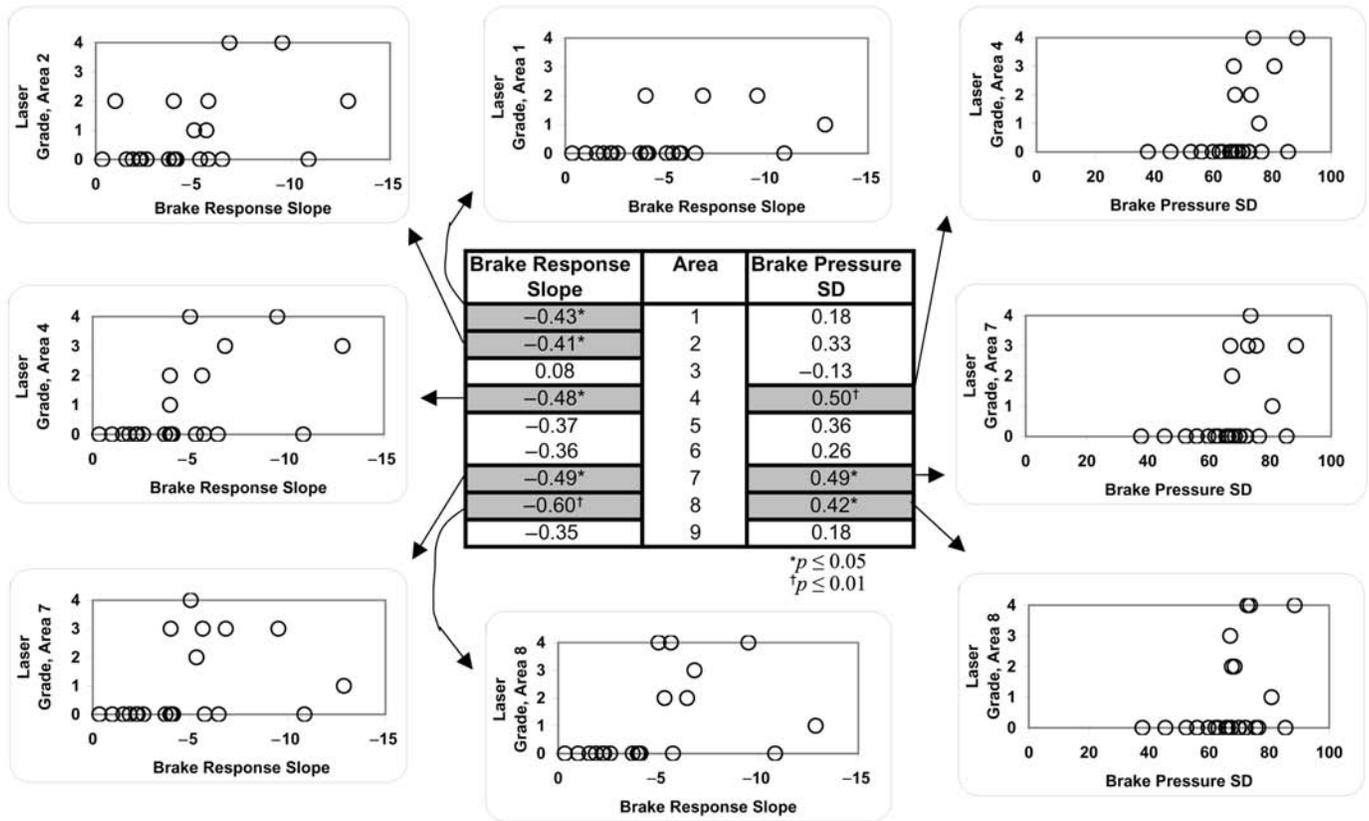


Figure 5.

Correlation between laser scarring (in eye with better acuity) and driving simulator braking parameters. “Area” refers to retinal location corresponding to visual field. SD = standard deviation.

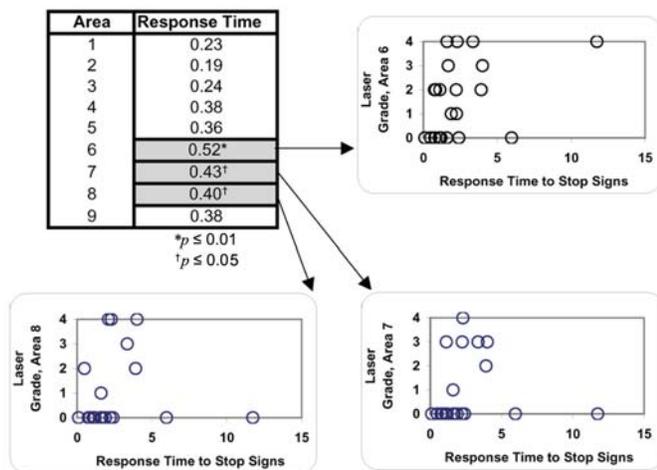


Figure 6.

Correlation between laser scarring (in eye with better acuity) and response time to stop signs (seconds). “Area” refers to retinal location corresponding to visual field.

Therefore, we can conclude that in our study group, the majority of patients have not achieved the target level for glycosylated hemoglobin that is recommended by the American Diabetes Association. Epidemiological studies (Wisconsin Epidemiologic Study of Diabetic Retinopathy and the National Health and Nutrition Examination Survey III) have indicated that the majority of persons with diabetes do not achieve the target goal for glycosylated hemoglobin. Although there is no glycemic threshold for diabetic retinopathy, it is well established that as the glycosylated hemoglobin level increases, so does the risk of progression of diabetic retinopathy [25].

DISCUSSION

Our results illustrate some relationships between retinal structural abnormalities and behavioral function in patients with diabetic retinopathy. We evaluated retinal changes caused by diabetic retinopathy and laser treatments

and related them to the behavioral measure of simulated driving performance. Objective retinal thickness measurements and the presence of laser scars were more often related to driving simulator performance than were traditional clinical vision measures and subjective retinopathy grades. Increased retinal thickness within some areas of the central 20° including the fovea correlated with a higher frequency of driving simulator accidents and near accidents. The presence of laser scars within the central 20° was significantly correlated with steeper brake-response slopes, increased brake-pressure SD, and longer response times, all reflecting an abrupt braking profile. This relationship seems to suggest that the changes in retinal structure may produce some overall changes in latency or the speed of visual processing. These alterations in latency would not be reflected in static measures of visual function such as visual acuity or contrast sensitivity and may explain the lack of relationships found with these traditional clinical vision measures. Additionally, we found that subjects with focal laser scars had higher average brake-pressure and brake-pedal pressure SD than did subjects without focal laser scars. Although we are not aware of a documented link between peripheral neuropathy and driving skills, it is possible that increased braking pressure might be caused by peripheral neuropathy in this group of diabetic patients. However, there was no mention of peripheral neuropathy in the patients' medical histories.

Because focal laser treatments for macular edema were applied to the leaking areas of the retina, the combination of both the damage caused by retinal edema and the laser may impact driving skills. Visual field deficits within the central 20° correlated with only one simulator variable (off-road time). One explanation for this finding is that the calculation of local visual field loss, by averaging 1 to 4 points from the Humphrey 30-2 testing, may have lacked the resolution needed for a precise measure of visual field deficits. Our data also showed dissociation between structural changes and field sensitivity; no significant correlations were found between the retinal structural measures and Humphrey visual field sensitivities. It is also possible that laser treatments impact driving performance by mechanisms other than visual field loss. Laser treatment has numerous detrimental effects, including increased glare [28], decreased hue discrimination [29], and optic neuropathy [30], which may influence driving performance. Greenstein et al. reported that following focal laser treatment, they found little or no change in visual fields [31]. However, the results of their localized multifocal

electroretinogram testing showed increases in implicit time and decreases in response amplitudes after treatment. As stated earlier in this section, retinal function may have changes that are not detected with visual field testing or the traditional measures of visual function (visual acuity and contrast sensitivity) that may impact behavior. Projects designed to investigate these relationships in the future should perhaps employ visual function tests that use more transient testing conditions (e.g., reaction time, attentional visual field tests, dynamic acuity, the multifocal electroretinogram). Laser treatments are critically important for managing diabetic retinopathy. Although the present study found correlations between laser scarring and driving performance, we do not intend to convey that laser treatment has no ameliorative effects or that it should not be done. Future research is needed to clarify the relationship between laser treatments, visual field loss, and driving performance.

In addition to our findings regarding retinal structural measures, we also found that subjects having one or more real-world accidents within the past 5 years had greater brake-pressure SD and steeper brake-response slopes than did subjects not reporting accidents. Logistic regression analyses in previous studies have found both brake-pressure SD and brake-response slope to predict real-world accident involvement [24,32]. However, preliminary data comparisons between diabetic subjects and age-matched controls indicated that the diabetic subjects drove more cautiously and at slower speeds, suggesting that they used compensation techniques. Szlyk et al. have reported that while drivers with certain eye diseases [32], such as age-related macular degeneration, perform poorly on the driving simulator, they can reduce their accident risk by avoiding unfamiliar areas, by not driving at night, and by reducing their speed. Future research must examine the extent of compensation that drivers with varying retinopathy and laser scarring levels can achieve.

CONCLUSION

We have found some relationships between retinal structural measures and the driving performance of subjects with diabetic retinopathy. Clearly, this study raises some important questions related to the comparison of structure and function in diabetic retinopathy. Hopefully, this study may provide insight into techniques that may or may not be effective in future investigations.

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