Retinal Fixation Point Location in the Foveal Avascular Zone

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The site of normal fixation is often assumed to be centered in the foveal avascular zone (FAZ). This assumed anatomic relationship is used during photocoagulation therapy as an objective guide to avoid damaging critical retinal structures on or near fixation. With laser therapy being directed closer and closer to the center of the FAZ, the accuracy with which the center of the FAZ locates the retinal point of fixation becomes an important therapeutic issue. Using an optimized technique for visualizing the retinal vasculature entoptically, the authors determined the location of the retinal point of fixation with respect to the foveal area vasculature in 26 eyes of 14 healthy subjects. In 23 eyes (12 subjects), a traditional FAZ was observed, and in either three eyes (two subjects) had capillaries near or crossing the center of fixation. Of the 23 eyes with a traditional FAZ, 20 had centers of fixation located eccentric to the center but in the FAZ, (average deviation from the center of the FAZ, 66.5 ± 49.5 μm) with the direction of deviation from the FAZ center appearing random. Consequently, when following protocols that advocate photocoagulation treatment with spot centers closer to the FAZ center than 300 μm, the center of the FAZ is a poor locator of a subject’s retinal point of fixation. When using the FAZ as a reference, the resulting uncertainty in the location of the subject’s retinal point of fixation increases the probability of significant damage to the actual point of fixation by up to 20%. Invest Ophthalmol Vis Sci 31:2099–2105, 1990

The posterior pole of the eye contains the anatomic fovea and foveola. These structures are highly specialized to maximize visual acuity. In the center of the anatomic fovea, the inner retinal layers down to the outer nuclear layer are displaced, forming a pit, the foveola, which contains the highest density of cones in the retina (147,000 cones per mm²).1 The retinal capillaries in the area of the fovea typically form concentrically arranged channels ending in a capillary loop approximately 0.5 mm across which outlines a capillary-free zone known as the “foveal avascular zone” (FAZ).1 The lateral displacement of inner retinal structures, including the retinal vasculature, presumably exists to leave an unobstructed light path to the site of phototransduction, thereby enhancing image quality.2

In a normal observer, visual performance is maximized at the subject’s point of fixation. That is, when asked to fixate a point in space, normal observers move their eyes such that the point of interest is imaged on the retinal region providing the highest resolution.3,4 The connection between fixation and optimal resolution, together with the histologic specialization of the retina, suggests that a normal individual will move the eye to place the image of the fixation point on the foveola. Thus the retinal point of fixation and the foveola are assumed to be coincident and reasonably centered in the FAZ.

Given current therapeutic trends to photocoagulate closer and closer to the point of fixation using the center of the FAZ as a guiding landmark,5–9 the accuracy with which the center of the FAZ locates the point of fixation becomes critical. That is, when using the FAZ as an anatomic landmark for locating the retinal point of fixation, significant deviation of the point of fixation from the center of the FAZ could lead to placement of laser burns closer to, or further from, the fovea than anticipated. As a result, burns may unintentionally lead to inappropriate laser-induced damage or incomplete coverage or nontreatment of a (sub)retinal neovascular lesion due to its assumed (as opposed to known) proximity to the retinal point of fixation.

We used optimization techniques for visualizing10 the smallest foveal capillaries entoptically to deter-
mine whether or not the retinal point used for fixation actually lies in the center of the FAZ, and if not, whether or not the deviations are significant enough to warrant clinical consideration.

**Materials and Methods**

A number of techniques have been used to examine the FAZ and its component capillaries in living humans, including fluorescein angiography, and two noninvasive subjective psychophysical techniques: the "blue-field entoptic effect" and the entoptic visualization of the retinal vasculature (commonly known as the Purkinje image). The blue-field entoptic effect provides the viewer an image of the white corpuscles as they flow through the retinal capillaries. The capillaries remain unseen, and the actual form of the vascular tree must be constructed in the mind of the viewer. An optimized Purkinje image allows simultaneous evaluation of a persistent, easily visible, high-contrast image of the foveal capillaries and the point of fixation.

**Instrumentation**

Stimulus optimization for the entoptic visualization of the macular area retinal vasculature and FAZ was achieved by modifying a standard Maxwellian-view system. We call the system, schematically illustrated in Figure 1, the Vascular Entoptoscope.

Source S, a 1-mm pinhole, back-illuminated by light from a fiber optic passing through a blue filter (3M, Visual Products Division, 3 M Center, St. Paul, MN, color filter part #47 with peak transmittance at 470 nm), was set to rotate at a speed of 3.5 hertz in a circular path 2 mm from, and concentric with, the optical axis of the instrument. Light from S was first collimated by lens L₁ and then imaged into the plane of the subject's pupil with unit magnification by lens, L₂. An iris diaphragm (aperture A), imaged at optical infinity by L₂, served as the field stop for the eye-apparatus system.

A second channel provided the subject a view of two dim point sources (PS₁ and PS₂) optically conjugate with aperture A through a beam splitter, B₁. Point source, PS₁, was attached to a motorized X-Y positioning plate and served as a guidelight for marking positions of interest in the field of view. Point source, PS₂, served as a stationary fixation point centered on the optical axis of the apparatus. The subject controlled the position of PS₁ with a joystick and could thereby locate, with respect to the point of fixation, any point on the capillary loop defining the FAZ. A variable voltage signal reflecting the location of moveable point source, PS₁, was sent from the X-Y position plate to an X-Y plotter for hard-copy documentation of the border of the FAZ.

Alignment of the subject's pupil to the optical axis of the apparatus and stabilization of the subject's

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**Fig. 1.** Schematic representation of Maxwellian view system. S = source, a rotating 1-mm pinhole, peak wavelength 470 nm; L₁ = collimating lens; A = variable iris diaphragm; B₁ = beam splitter; L₂ = Maxwellian view lens; B₂ = beam splitter; VC = video camera; FSM = front surface mirror; AR = alignment ring; PS₁, PS₂ = point sources.
head was obtained with a dental bite-bar mounted on a compound vice mobile in three planes. To insure the subject was properly aligned to the apparatus, a third channel provided a closed-circuit video view of the pupil entry location of the rotating beam and the corneal reflection of alignment ring AR (a circle of infrared light-emitting diodes concentric with the optical axis of the apparatus). The video view of the rotating beam was obtained by deflecting some of the beam from source S at beam splitter B2 onto a front surface mirror (FSM; optically conjugate with the subject’s entrance pupil) and back through beam splitter B2 into the video camera. The video view of alignment ring, AR, was obtained by reflection off the subject’s cornea back into the apparatus and reflection at beam splitter B2 into the video camera. By continually observing the information on the monitor, the experimenter could maintain subject/apparatus alignment by adjusting the position of the compound vice.

Subjects

We assessed 26 eyes in 14 healthy subjects ranging in age from 11–54 yr. There were 11 male and three female subjects, all with corrected vision of 20/25 or better.

Protocol

The purpose and methods of the experiment were explained to the subject, and informed consent was obtained. To familiarize the subjects with the experimental task, each was shown enlarged prints of fluorescein angiograms of several retinas having: (1) classic FAZs and (2) “variant FAZs” containing capillaries crossing the fovea in various patterns.11 After the subject was familiar with what they might see in their own eyes, a bite bar was made, and the subject was aligned to the optical axis of the apparatus.

Subjects, while carefully fixating point source PS2 used a joystick to move the guidelight (point source, PS1) to at least 12 locations along the borders of their FAZ. At each location the subject centered the guidelight on the capillary defining the FAZ border and pushed a button signaling the pen to drop on the X-Y plotter, thus making a dot outline of the FAZ. After exiting the optical system, subjects were shown their own eyes, a bite bar was made, and the subject was aligned to the optical axis of the apparatus.

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Results

All of the subjects easily saw the Purkinje image of their retinal capillaries. Ten of the 14 subjects graphed details of the shadow of their FAZ in both eyes and two (due to personal time constraints), in only one eye. Another subject observed a traditional FAZ in one eye but saw capillaries running through what should have been the FAZ in the other, and one subject saw capillaries running through the fixation point in both eyes. Figure 2 depicts a sample of the various FAZ tracings obtained. Panel A displays the tracing of one of only three eyes with a retinal point of fixation located in the geographic center of the FAZ as classically described anatomically. Panel B displays a tracing from an eye with the retinal point of fixation located a typical distance from the geographic center of the FAZ, and Panel C displays the tracing of the subject with the largest distance (189 μm) between the retinal point of fixation and the geographic center of the FAZ. Panel D displays the tracing of one of three eyes with vessels in the retinal area more commonly occupied by the FAZ. Even by casual observation, it becomes clear that the FAZ boundaries are not always concentric with the fixation point (Panel B and C).

Although classically described as circular, the FAZ is irregular in size and shape (Fig. 2). This irregularity in size and shape complicates the objective determination of the center of the FAZ. To solve this problem, a geographic “center” was defined in the following manner (Fig. 3). First, the largest possible rectangle having all four corners located inside the borders of the FAZ tracing was aligned such that the horizontal dimension of the rectangle was parallel to the horizontal axis of the tracing. Second, as illustrated in Figure 3A, distances from each side of the rectangle (labeled h, h', v, and v') to the traced FAZ border were measured at each of five equally spaced locations along each side of the rectangle (lines labeled v1–v5, v1–v5, h1–h5, and h'1–h'5). Third, as illustrated in Figure 3B, each of the four subsets of distances were averaged [eg, (h1 + h2 + h3 + h4 + h5)/5 = h, and (h'1 + h'2 + h'3 + h'4 + h'5)/5 = h', and these averages were added to the appropriate end of the horizontal or vertical dimension of the initial rectangle (dashed rectangle) to yield a new rectangle (solid rectangle) with a total horizontal dimension of H and total vertical dimension of V (ie, H = h + h' + h' and V = v + v + v'). The geographic center of the FAZ was, in turn, defined as the point GC formed by the crossing...
of a vertical line bisecting H and a horizontal line bisecting V (Fig. 3b).

All 23 eyes with FAZs had retinal fixation points located in the FAZ. However, only three eyes from three different subjects had their retinal points of fixation located at the geographic center of the FAZ. Vectors defining the distance from the geographic center of the FAZ to the subject's fixation point and the direction of deviation (with 0° being horizontal to the right) were determined for each FAZ tracing. These distances were then converted to retinal distances using the Gullstrand reduced model eye with a nodal-point to retina distance of 16.67 mm, after compensating for the optical magnification factor of the Maxwellian view optical system and the gain of the X-Y plotter. Figure 4 uses a polar-coordinate system to illustrate the location of the retinal point of fixation relative to geographic center of the FAZ for each eye tested. Although the data as a whole tends to cluster near the origin (ie, the retinal point used for fixation tended to be nearer the center of the FAZ compared with the edge of the FAZ), the distribution of directions of deviation appear random. The largest deviation of the retinal point of fixation from the geographic center of the FAZ was 189 μm. The average deviation from the geographic center across all
subjects was 66.50 μm. There was no tendency for the eccentricity of the retinal point of fixation to increase with increasing FAZ diameter.

Discussion

Our data indicate that the retinal point of fixation deviates from the geographic center of the FAZ by about 65 μm (standard deviation, ± 50 μm) with a
range of 0–190 μm. These findings suggest that laser burns centered on retinal points less than 300 μm from the geographic center of the FAZ run a significantly higher risk of falling directly on or nearer to the retinal point of fixation than intended. Furthermore, the risk of burning the point of fixation can markedly increase as burns are placed closer to the geographic center of the FAZ. The implications of this finding are profound and find support in current literature.

To illustrate, assume that, as in recent clinical trials,6–9 retinal lesions up to 200 μm from the FAZ center are treated with burns which overlap the lesion by up to 100+ μm. Furthermore, grant that our data form a representative sample of the population for the location of the retinal point of fixation with respect to the geographic center of the FAZ (data points, Fig. 5). With these assumptions, six of 24 eyes (25%) have retinal points of fixation which are potentially vulnerable to being burned (Fig. 5, lightly shaded area). However, since photocoagulation treatment is generally limited to or slightly overlaps the area of frank pathology (eg, neovascular membrane or histospot), it is likely that a series of burns will be placed only in the sector of the macular area containing the site of the lesion (Fig. 5, darkly shaded area). With these criteria and if the treatment sector of the macular area is limited to 90°, it is likely that for any one particular series of burns one or two eyes of our sample of 24 (4%–8%) would have their retinal point of fixation adversely affected by photocoagulation therapy.

The obvious question arises as to what percentage of treatment failures (loss of six lines of visual acuity or more at first follow-up) can be accounted for by variations in the location of the point of fixation with respect to the geographic center of the FAZ. Although we cannot answer this question definitively with the data collected to date, it is interesting to note that with argon treatment it has been reported that 9% of eyes treated for neovascular maculopathy,6 9% of the eyes treated for macular area ocular histoplasmosis,7 and 10% of those eyes treated for macular area idiopathic neovascularization8 lost six or more lines of visual acuity at first follow-up despite “successful” treatment of the pathology. This order of magnitude of initial follow-up failure is not unique to argon treatment. Studies using krypton therapy for histoplasmosis have reported a similar percentage of patients (8%) with a six-line loss in visual acuity at first follow-up.9 The argument is further fueled by the fact that the best predictor of visual acuity loss, despite adequate therapy, is treatment proximity to the center of the FAZ.10 When analysis is limited to eyes with lesions within 375 μm of the FAZ center between 8%–33% of the eyes successfully treated lost six lines or more at first follow-up depending on the particular study.6–9 Although this could be accounted for by assuming that pathology within 375 μm is more likely to affect the retinal point of fixation, our data suggest another possibility. Given the uncertainties of thermal spread, dose specification, actual spot size in the plane of the retina, variation in pigment absorption, and accuracy of burn placement with respect to desired location, the speculative estimate of 4%–8% may indeed be an underestimate of the number of retinal fixation points at risk. Simply allowing for 50 μm of uncertainty would raise the number of retinal fixation points at risk from 4%–8% up to 16%–20%.

To the extent this analysis is correct, it suggests that therapeutic failures at first visit for eyes with retinal lesions between 200–375 μm could be reduced by as much as 20% by using the actual retinal point of fixation as a reference as opposed to the geographic center of the FAZ. This, in turn, raises the issue of developing a clinically accurate technique for locating the retinal point of fixation.

In the unparalyzed eye having good visual acuity the retinal point used for fixation is relatively easy to identify.21 If techniques are adopted to paralyze the eye which do not compromise vision, then it would be a relatively easy to have the patient move a small fixation point (eg, with a joy stick), which is also visible to the clinician superimposed on the patient’s fundus, until the fixation point is exactly centered over the patient’s retinal point of fixation.

Unfortunately, with a visual acuity loss the patient may or may not be using their “normal” (prepathology) retinal point of fixation, and the procedures outlined above may or may not be appropriate. Yet, since visual acuity has been reported to recover, it remains important to identify the retinal point of fixation used before loss of visual acuity and avoid this retinal location during therapy. The uncertainty can be reduced, if not eliminated, by identifying the location of the retinal point of fixation in at-risk eyes (eg, confluent drusen,22–26 loss of absolute sensitivity,25–29 acquired tritan errors,30–32 or loss of vision in fellow eye33,34 in age-related maculopathies) before vision loss and using this point as the reference should therapy be needed at a later date.

Our data indicate the retinal point of fixation is not always centered in the FAZ. Furthermore, the deviations of the retinal point of fixation from the center of the FAZ can be large enough to jeopardize the retinal point of fixation during foveal area laser photocoagulation therapy which avoids the center of the FAZ compared with locating and avoiding the retinal point of fixation. This risk can be reduced by using...
the retinal point of fixation as the reference for foveal area photocoagulation rather than the center of the FAZ.

**Key words:** retinal fixation point, foveal avascular zone (FAZ), fovea, photocoagulation, Purkinje image

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**References**


