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Mini-review: Far peripheral vision

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ABSTRACT

The region of far peripheral vision, beyond 60 degrees of visual angle, is important to the evaluation of peripheral dark shadows (negative dysphotopsia) seen by some intraocular lens (IOL) patients. Theoretical calculations show that the limited diameter of an IOL affects ray paths at large angles, leading to a dimming of the main image for small pupils, and to peripheral illumination by light bypassing the IOL for larger pupils. These effects are rarely bothersome, and cataract surgery is highly successful, but there is a need to improve the characterization of far peripheral vision, for both pseudophakic and phakic eyes. Perimetry is the main quantitative test, but the purpose is to evaluate pathologies rather than characterize vision (and object and image regions are no longer uniquely related in the pseudophakic eye). The maximum visual angle is approximately 105^0, but there is limited information about variations with age, race, or refractive error (in case there is an unexpected link with the development of myopia), or about how clear cornea, iris location, and the limiting retina are related. Also, the detection of peripheral motion is widely recognized to be important, yet rarely evaluated. Overall, people rarely complain specifically about this visual region, but with "normal" vision including an IOL for >5% of people, and increasing interest in virtual reality and augmented reality, there are new reasons to characterize peripheral vision more completely.

1. Introduction

This mini-review of "far peripheral vision" was stimulated by an evaluation into the cause of "dark shadows" that are seen by some intraocular lens (IOL) patients in their temporal visual fields (Davison, 2000; Henderson & Geneva, 2015; Holladay & Simpson, 2017; Holladay, Zhao, & Reisin, 2012; Simpson, 2014, 2015a, 2015b). It gradually became clear that vision at very large visual angles was not really thought of as being a particular field of study, with little active research, apart from topics related to perimetry and the measurement of visual fields (Anderson, 1987). Perimetry is probably perceived to be capturing everything about peripheral vision that is important, but although it is very successful, the reason for the measurement is typically because of concern about the potential loss of central vision, or to evaluate visual pathways, and not to evaluate far peripheral vision for its own sake. Measurements are rarely made at large visual angles, and modern equipment cannot even measure the limiting temporal visual field because measurements only go up to 90 degrees.

The research into vision with IOLs has led to what may be new questions about far peripheral vision, relating not only to the use of IOLs by older cataract patients, but also to the phakic eye, including the youthful eye as it develops. It is also possible that the IOL patients who are bothered by "negative dysphotopsia", which is the more formal name given to the perception of peripheral dark shadows, might be experiencing a characteristic of vision that has not been previously reported. The theoretical evaluations reviewed here show that the far peripheral vision of the pseudophakic eye has different imaging properties to those of the phakic eye anyway, whether or not dark shadows are seen (Holladay & Simpson, 2017). Even if there were no complaints about dark shadows, these evaluations raise questions about vision characteristics in the far periphery. Some IOL patients have also been bothered by "positive dysphotopsia", where they see bright arcs or flashes of light at night. These are primarily caused by light reflected from within the lens hitting the foveal region, and they are not evaluated here.

This mini-review does not review the many papers that have discussed negative dysphotopsia with IOLs, which are already covered in review papers and the recent literature (Holladay et al., 2012) (Henderson & Geneva, 2015; Holladay & Simpson, 2017) (Makhotkina, Berendschot, & Nuijts, 2016) (Makhotkina, Nijkamp, Berendschot, van den Borne, & Nuijts, 2017). It starts instead with the observation that it is just not possible for an IOL to create an image at very large visual angles because it has a diameter that is much smaller than the natural lens. This perspective was not included in most of the earlier papers on the topic. IOLs had already been used for decades with no clinical observations of

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peripheral shadows, but there seem to have been no published theoretical calculations about imaging in this visual region for either phakic or pseudophakic eyes. The new theoretical calculations show that "vignetting" occurs because the IOL is much smaller than the natural crystalline lens (Simpson, 2015b), and this creates shadowlike regions that are very similar to the clinical reports of negative dysphotopsia. However, light can also bypass the IOL, and light can be scattered, and these can illuminate the retina and affect the perception of a shadow. There is no consensus in the literature yet about the primary cause of negative dysphotopsia, and the discussion is at the point where additional clinical data need to be recorded to confirm the cause, particularly because the visual angle at which the phenomenon is perceived is not given in most of the clinical reports. However, the fundamental nature of the difference in the basic imaging properties of the pseudophakic eye in the periphery, compared to the phakic eye, has led to the questions about vision that are addressed in this mini-review.

The initial discussion about IOLs is followed by broader questions about far peripheral vision. People rarely seem to complain specifically about the quality of their vision in the far periphery, and this may have contributed to there being limited research into the "value" to the user of this visual region. Deficits may be measured by a clinician, but they are typically concerned about losses later at lower visual angles, rather than about the quality of far peripheral vision itself. This might be the case for glaucoma, for example, where initial losses in the periphery might be noted, and the concern would be that this would spread to more central visual angles. There seem to be no simple routine objective tests for either the total limit of the visual field, or for detecting motion in the far periphery. The observation of fingers may be the main data, using a confrontational test, with no detailed objective measurement of the visual angle or of motion characteristics. Other questions here relate to the structure of the eye, such as the extent of the retina, and the clear diameter of the cornea, while others relate to the way that signals from the periphery are processed. The limiting visual field is specifically addressed because it represents an upper limit for the visual field.

The main functional use of far peripheral vision is perhaps assumed to be self-evident because it is a continuous feature of everyday life. If something moves in the far periphery then it attracts attention, and the eye can be moved to look in that direction with a higher resolution portion of the retina. Peripheral vision is also thought to be important for lane tracking when driving (Huisingh, Wood, & Owsley, 2015; Owsley & McGwin, 2010), and for orienting an airplane relative to the ground when flying, but published evaluations do not typically extend to very large visual angles. A recent paper also evaluates optic flow at very large angles in a simulator (Mcmanus, Amour, & Harris, 2017), indicating that the far peripheral region is beneficial when walking. Questions about peripheral vision are also included in questionnaires (Sloane, Ball, Owsley, Bruni, & Roenker, 1992), but although these address both walking and driving situations, very large angles are not specifically evaluated.

The intent of this mini-review is to emphasize areas where little is known, but where there is increasing interest. This is particularly relevant to topics relating to ocular surgery and intraocular implants, but it may also be relevant to progress with virtual reality, augmented reality, and visual displays, where there is increasing interaction with the surrounding visual regions.

2. Defining the visual angles for "far peripheral vision

There does not appear to be a clear definition in the formal scientific literature about the visual angles that would be included in the "far" peripheral vision region. Visual angles above 60^0 degrees are assumed here to be the region of "far peripheral vision", which is the value used in a Wikipedia article on peripheral vision (Peripheral Vision., 2017). The article includes a clear figure for different visual regions that is not published elsewhere, which uses round numbers of 8^0–30^0 for near peripheral vision, 30^0–60^0 for mid-peripheral vision, and then taking everything above 60^0 as far peripheral vision, up to the limiting visual angle. This 60^0 angle seems appropriate, since this is an approximate value for occlusion by the nose and eyebrow, and also where light entering the eye will be incident on the retina near the equator (so the corresponding retinal region is in the anterior portion of the eye). Clinical measurements rarely include visual angles as high as this, however, and with this definition the far peripheral vision region exists mostly temporally, with the greatest extent infero-temporally.

3. Negative dysphotopsia with IOLs

Reports that a small number of intraocular lens (IOL) patients were bothered by peripheral dark shadows (negative dysphotopsia) first began in about 2000, many years after IOL surgery became a common surgical solution for cataracts (Davison, 2000; Henderson & Geneva, 2015). It is highly likely that this is actually an imaging phenomenon, rather than a shadow phenomenon, with the primary cause being that the IOL is much smaller than the natural crystalline lens that it replaces. This is illustrated in Fig. 1 where preoperative and postoperative OCT images for the same eye are superimposed (Simpson & Muzyka-Wozniak, 2017). The preoperative lens thickness is not measured by OCT, but it is illustrated here to have a thickness of 5 mm, which is a typical value for an eye over 70 years old (Atchison, Markwell, Pope, & Swann, 2008). Preoperatively the iris is in contact with the crystalline lens, and all the light that passes through the pupil creates a single image on the retina. After cataract surgery, the iris moves posteriorly, but the IOL is much thinner than the natural crystalline lens, and there is a gap between the posterior iris surface and the IOL surface. The IOL thickness is only about 0.8 mm in Fig. 1, with a lens diameter of 6 mm, compared to the 5 mm thickness and 9.5 mm diameter of a natural crystalline lens.

The ray paths for a single light beam entering the eye at 85^0 of visual angle, are illustrated in Fig. 2(a) using the Zemax raytrace

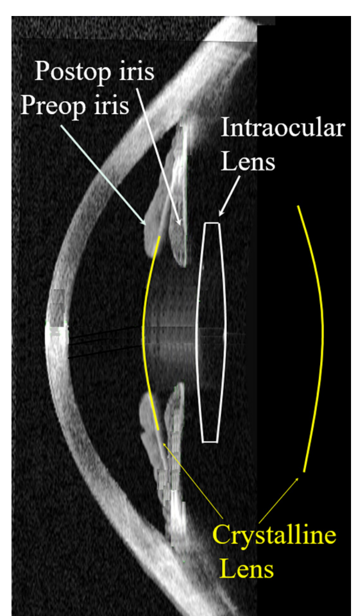

Fig. 1. Superposition of preoperative and postoperative OCT images for a single eye.