TECHNIQUE

Use of P1-P4 Purkinje reflections as a surrogate sign for intraoperative patient fixation

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Circumferential, even anterior capsular overlap maximizes intraocular lens stability and posterior capsular opacification mitigation and provides best long-term outcomes for the cataract patient. P1 and P4 Purkinje reflections at patient fixation may provide a reliable marker for capsulotomy centration. However, patient fixation may be hindered during surgery because of anesthesia or light sensitivity. In this study, we demonstrate that the relationship between the P1 and P4 Purkinje reflections previewed prior to surgery when the patient is fixating may be recreated intraoperatively if fixation becomes difficult. The final position of P1 and P4 relative to one another at fixation is invariant in a given patient, but there are variations among patients. Knowledge of the P1 and P4 relationship can be used as a surrogate sign of patient fixation to assist in capsulotomy centration during cataract surgery.

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Long-term visual benefits from cataract surgery are dependent on the overall stability and position of the intraocular lens (IOL) implant. The IOL position within the capsular bag dictates not only the visual outcome through the effective lens position but suboptimal positioning with tilt, and decentration can also lead to poor visual outcomes and an undesirable visual phenomenon.[1–7] An important surgical factor governing IOL stability in the capsular bag is the presence of circumferential, even capsular overlap onto the IOL optic.[8,9] Symmetric mechanical forces on the optic help reduce the risk for posterior capsular opacification by preventing anterior and posterior capsule fusion that bring lens epithelial cells close to the posterior capsule and by supporting the barrier effects on cell migration achieved through IOL edge designs.[10–13,A]

We previously described an intraoperative method for centering the anterior lens capsulotomy on specific Purkinje reflections to help surgeons achieve consistent capsular IOL overlap and improved IOL centration.[14] The procedure was based on the concept of the subject-fixated coaxially sighted corneal light reflex (SFCSCLR) described by Chang and Waring, which has the advantage of not relying on nonanatomic theoretical nodal points for surgeon sighting along the patient's visual axis.[15] Through the use of surgeon-instructed patient fixation on a selected microscope light, the surgeon may identify an appropriate centration point for capsulotomy and proceed to create the capsulotomy using an automated capsulotomy technology such as the precision pulse capsulotomy (PPC) device.[16–21] Capsulotomy centration using Purkinje reflections has similarly been used in conjunction with capsulorhexis-assist devices for bag-in-the-lens implantation.[22]

In the present study, we describe the specific relationship between P1 and P4 during this Purkinje centration procedure and discuss how the P1/4 relationship can be used by surgeons as a reliable surrogate sign of patient fixation and potentially for capsulotomy centration. In patients with poor fixation or when anesthesia or other factors prevent accurate patient fixation, the surgeon can perform manual ocular rotation to replicate the relationship of the P1 and P4 reflections observed prior to surgery to approximate fixation in that patient and thus obtain guidance on potential locations for capsulotomy placement. For a given patient, the relative final positions of P1 and P4 to one another at fixation are constant. However, variability in the degree of P1/4 separation at final fixation is apparent between patients and may reflect their individual ocular anatomies.

SURGICAL TECHNIQUE

The intraoperative use of Purkinje reflections for capsulotomy centration described in this study is based on the concept of the SFCSCLR described by Chang and Waring.[15] Unlike historical definitions of the visual axis that have relied on the nonanatomic, theoretical concept of nodal points, the SFCSCLR depends only on patient fixation and a coaxial light source to

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allow the surgeon to sight along the same line extending from the patient's fixation point in space to a consistent and reproducible marker in the patient's visual system. The use of a method for consistent capsulotomy centration on the SFCSCLR may improve visual outcomes and requires further study.

Purkinje reflections arise because of changes in the refractive index at ocular tissue interfaces. The 2 Purkinje reflections of note for capsulotomy centration are P1, which arises at the interface of the convex anterior corneal (tear film) surface and air, and P4, which arises at the concave interface between the posterior lens capsule and the vitreous. The refractive index difference is large at the air/corneal interface; therefore, P1 is the brightest of the Purkinje reflections. As a smaller change in the refractive index occurs at the posterior lens/vitreous space interface, P4 is fainter and smaller than P1. As a result of light traveling through the lens, P4 can also be yellower than P1.

Another unique feature of P4 is that it is inverted relative to P1 because of its origin on the concave posterior lens surface. As the patient executes eye movements to orient their gaze toward the center of the designated coaxial light (Figure 1, A, left to right), the positions of P1 and P4 as viewed through the eyepiece will generally begin to move toward each other (Figure 1, B, left to right). At completion of patient fixation, the surgeon looking through a coaxial eyepiece will generally see P4 positioned slightly temporal to P1.

For a given patient, the final positions of P1 and P4 relative to each other after achieving fixation as viewed through coaxial optics should always have the same spatial relationship with respect to one another. This is due to the fact that their relative positions are the result of the fixed anatomical relationships in that individual patient. Once fixated, a coaxially sighted P1 represents the patient's SFCSCLR, and this information can be potentially used for capsulotomy placement. In addition, an assessment of the relative P1/4 positions prior to intraocular surgery may provide the surgeon a preview of how P1 and P4 will be positioned relative to each other at fixation in a given patient. This P1/4 preview may be particularly useful in situations in which subsequent sedation affects the patient's ability to fully fixate during surgery and may allow the surgeon to manually position the eye to reproduce proper alignment.

It is important to note that the procedure described above does not give the precise location of the SFCSCLR with pinpoint accuracy because of 2 constraints imposed by current surgical microscopes. First, although SFCSCLR determination requires the use of true coaxial optics,[15] surgical microscopes may be coaxial or may have their light sources tilted 2 to 3 degrees or more off the true coaxial axis, and the effects of this tilt need to be taken into account. Any light source tilt from the true coaxial axis will theoretically offset the centers of the P1 and P4 Purkinje reflections from their true relationship with the SFCSCLR. If the tilt is small, the magnitude of any shift of P1 and P4 reflections is likely to be small, but it should be recognized and taken into account as needed. The alignment of the light sources to the optical elements in the microscope intended for performing this capsulotomy procedure should be verified. Second, although the SFCSCLR was originally described with respect to a point target, surgical light sources are designed to provide illumination and are not truly pinpoint. As a result, Purkinje reflections such as an individual P1 are themselves not pinpoint. Deviations from true coaxiality and non-pinpoint light sources combine to result only in a close approximation of the location of the SFCSCLR as formally defined.

RESULTS

An example of the intraoperative appearance of P1 and P4 Purkinje reflections in a patient visualized under a Leica

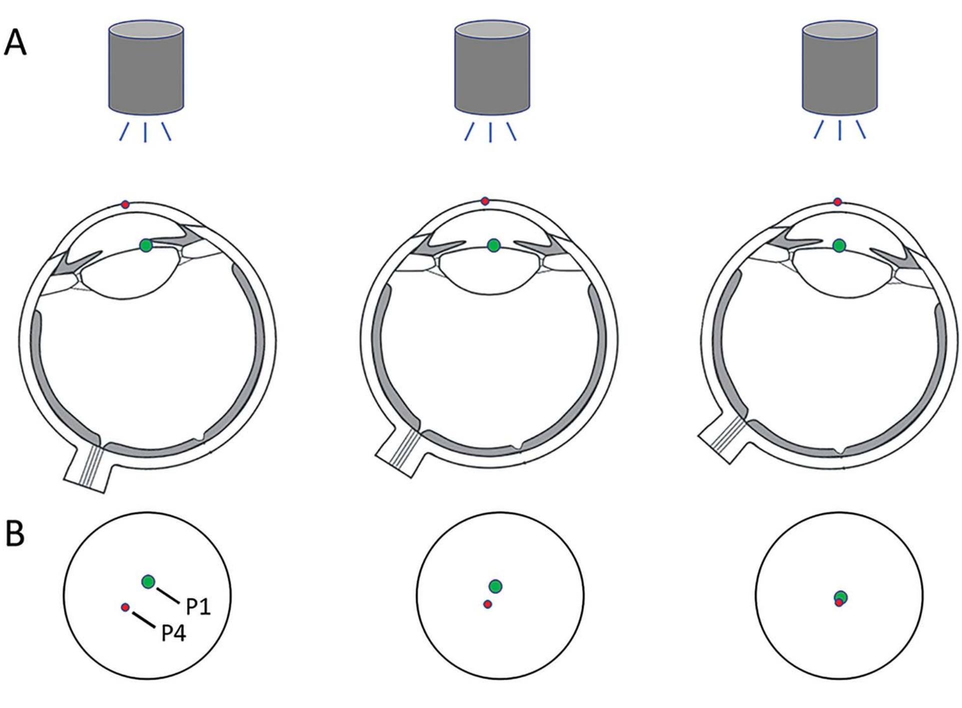

Figure 1. Schematic representation of intraoperative P1/4 relationship on attempted fixation. (*A*) Progressive intraoperative patient fixation on a surgeon-designated light source (from *left to right*). Note that P1 originates on the corneal surface but is actually visualized in the iris-IOL plan, whereas P4 originates at the posterior surface of the lens but is visualized at the corneal plane. Hypothetical locations of P1 on the iris–IOL plane and P4 on the corneal plane are depicted to illustrate the progressive movements of P1 and P4 during patient fixation. (*B*) Schematic diagrams showing the relative positions of P1 (*green dot*) and P4 (*red dot*) as viewed by the surgeon at corresponding positions of patient fixation shown in (*A*). The image on the right illustrates an example P1/4 relationship at fixation.

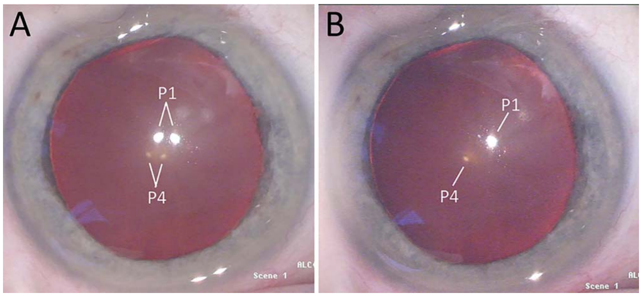

Figure 2. P1 and P4 Purkinje reflections observed with 1 or 2 microscope lights. (*A*) Two sets of P1 and P4 Purkinje images are observed when both microscope lights are used. (*B*) P1 and P4 Purkinje reflections after one microscope light are blocked by the surgeon's hand. The P1 and P4 reflections from the one remaining microscope light are arrayed diagonally from one another.

M844 F40 microscope is shown in Figure 2. The patient's right eye is shown with the surgeon seated for a superior surgical approach. Figure 2, A shows 2 sets of Purkinje images when both microscope lights are used. In Figure 2, B, one surgical light is blocked by the surgeon's hand to illustrate the Purkinje reflections (P1 and P4) resulting from the light that is not blocked. As shown, P1 and P4 reflections from the same microscope light are arrayed diagonally from one another. This diagonal relationship should be recalled during surgery when it is often not convenient to block a microscope light by one hand.

In Figure 3, the patient was instructed to fixate on one of the microscope lights, the P4 reflection corresponding to this light started to move closer to the P1 reflection corresponding to the same light (arrows in Figure 3, A–C) and was finally located near P1 at the completion of fixation (Figure 3, D). At fixation, the center of P1 approximated the patient's SFCSCLR. The movements of P1 and P4 reflections in the same patient starting from a different initial direction of gaze are shown in Figure 3, E–H. Although P1 and P4 have different starting positions relative to each other compared with Figure 3, A, they ended up with the same spatial relationship at fixation (Figure 3, H).

The alignment of P1/4 reflections can still be observed after capsulotomy because removal of the anterior lens capsule does not affect P1 or P4 (Figure 4). P4 should still be visible as long as the exposed anterior lens surface is intact and does not scatter light, and any invasion of the ophthalmic viscosurgical device into Berger space does not change its refractive index significantly compared with that of the lens. As long as the final unique spatial relationship of P1 and P4 in that patient is maintained, the P1 image can be used as a visual check that the capsulotomy has been approximately centered on the SFCSCLR (Figure 4, C). If the capsulotomy was centered on the SFCSCLR, the positioning of the IOL to achieve even capsular overlap with the PPC capsulotomy edge will also center the IOL on the patient's SFCSCLR. Continued patient fixation is not necessary during adjustment of IOL position. It is worthy to note that the SFCSCLR is commonly assumed to be associated with the location of the visual axis, although this assertion requires formal proof. The term visual axis has been variously defined and thus can lead to confusion, whereas the SFCSCLR is a well defined, although less frequently recognized, concept.

The examples shown in this study used the PPC device to perform an automated capsulotomy centered at P1. In principle, other forms of automated capsulotomy and manual capsulorhexis may be used. The incorporation of a capsulotomy centration point that is guided by the SFCSCLR may be generally useful.

Of note, overfilling of the anterior chamber with the ophthalmic viscosurgical device should be avoided when using the P1/4 Purkinje method because it could change lens position and thus the position of the Purkinje reflections.

This method of tracking of P1/4 movements and their relative positions at fixation can assist in capsulotomy centration in cases of poor patient fixation due to the progressive effects of sedation (Figure 5) or light sensitivity. To do so, the surgeon previews the relative positions of P1 and P4 reflections at fixation prior to anesthesia. This P1/4 preview may be obtained with the patient lying on the surgical table and instructed by the surgeon to fixate on one of the surgical lights. The surgeon observing through a given eyepiece observes the movement of P1 and P4 toward each other and notes their final relative positions at fixation. If needed subsequently after commencement of surgery, when the patient is unable to fixate because of the effects of

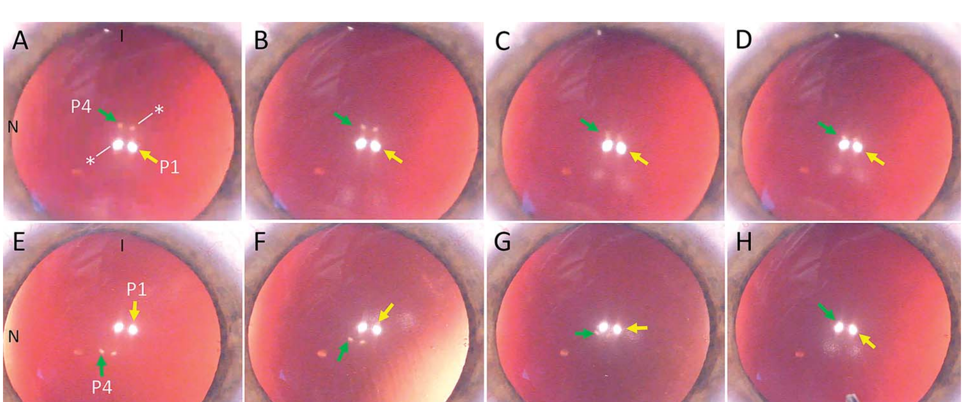

Figure 3. Varying distances of the P1 (yellow arrow) and P4 (green arrow) Purkinje reflections from one another during patient fixational efforts on a surgeon-selected light source. Patient's right eye viewed from a superior approach. (*A–D*) Sequence of individual video frames obtained during the fixation process ending with patient fixation on the chosen light source (*D*) (The *white asterisk* indicates the P1 and P4 Purkinje reflections provided by the other surgical light.) (*E–H*) Sequence of reflections showing P1/4 movement in the same patient starting at a different direction of gaze (*E*) and ending with fixation (*H*). I = inferior; N = nasal

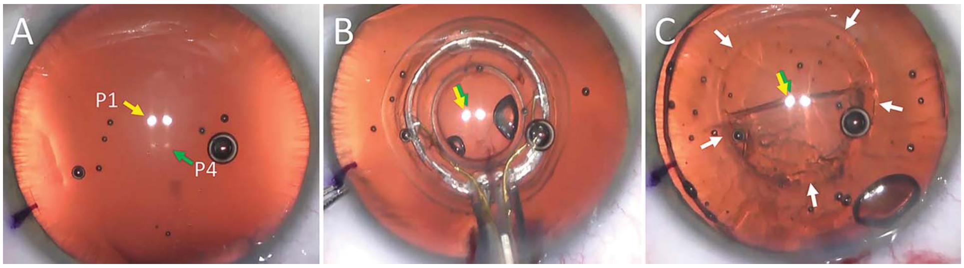

Figure 4. Example of P1/4 movements in a patient during cataract surgery with capsulotomy performed using PPC. (*A*) P1 and P4 at the start of surgery. The P1 Purkinje reflection (*yellow arrow*) and the P4 Purkinje reflection (*green arrow*) originating from the left microscope light on which the patient was instructed to fixate and were tracked by the surgeon during patient fixation. The other set of Purkinje reflections from the other microscope light was ignored. (*B*). Final positions of P1 and P4 at the completion of fixation as viewed through the transparent suction cup of the PPC device. (*C*) Image after the performance of a PPC capsulotomy that was centered on P1. The P1 and P4 Purkinje reflections remained visible. As long as the unique relationship of P1 and P4 is maintained, P1 indicates the approximate location of the SFCSCLR and can be used to check the centration of the capsulotomy. PPC = precision pulse capsulotomy; SFCSCLR = subject-fixated coaxially sighted corneal light reflex

anesthesia or light sensitivity, the spatial relationship of P1 and P4 reflections at fixation can be duplicated by manually rotating the eye. The creation of a centered capsulotomy may then be performed by placement of the center of the PPC device's capsulotomy ring on P1, which represents approximately the SFCSCLR.

As the eye is not a perfect optical system, there is another aspect of P1 and P4 that is noteworthy. In conventional optical systems and instruments, optical elements are rotationally symmetric with no tilt or decentration, and the centers of curvature of all the optical elements are lined up to form the system's optical axis. If the eye was constructed as a conventional optical system, a surgeon performing the SFCSCLR identification procedure with patient fixation and viewing through a coaxial eyepiece would observe that at patient fixation, all Purkinje reflections line up behind P1.

Such perfect Purkinje image alignment during fixation and viewed through coaxial optics does not exist for the human eye. In fact, at patient fixation, a small distance should in theory always separate P1 from P4 reflections, and the separation distance is related to how the capsular bag is anatomically tilted and offset with respect to the SFCSCLR. Intraoperatively, the surgeons will typically observe that the nasal aspect of the P4 reflection is either close to the temporal aspect of the P1 reflection or even touching the temporal aspect of P1 (Figure 6, A and B). Less commonly, the surgeon might see that P4 is completely subsumed within P1, corresponding to a patient with little capsular bag tilt/offset with respect to their SFCSCLR. Similarly, on occasion, a larger gap may separate P1 and P4 at final patient fixation (Figure 6, C and D). Note that although patients can demonstrate noticeable differences in P1 and P4 separation, the characteristic P1/4 relationship in a given patient at fixation was repeatable and constant.

DISCUSSION

This study describes the typical intraoperative movement of P1 and P4 toward each other during patient fixation, the use of P1 at final fixation to approximate the patient's SFCSCLR for capsulotomy centration and the potential optimization of capsular overlap, and the reproduction of the relationship of P1 and P4 reflections at fixation by manual ocular rotation to assist in cases of poor patient fixation. Patient variations in the final relationship between P1 and P4 at fixation exist. The range of the distance separating P1 and P4 at fixation is likely due to variation in individual ocular anatomy and needs to be better quantified in additional studies. Although it is potentially useful for assistance in defining a consistent marker in the patient's visual system during surgery, manual reproduction of the P1/4 relationship by the surgeon eliminates the fixation aspect and should be performed only with a cautious understanding that it is not a perfect replacement for patient fixation.

The typical movements of P1 and P4 as the patient fixates on a light source are readily apparent to the surgeon and can be followed to confirm the start and completion of patient-initiated fixation. However, there are clinical situations that prevent the use of Purkinje reflections for assistance in surgery. These include a patient unable to cooperate with surgeon instruction, or the presence of lens

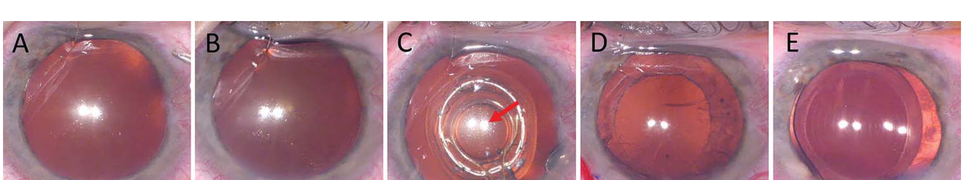

Figure 5. Manual ocular rotation and the use of the previously determined P1/4 relationship at fixation to assist in capsulotomy centration in a patient with poor fixation during surgery. (*A*) The relationship between P1 and P4 at patient fixation was noted prior to beginning surgery. (*B*) Poor voluntary fixation. (*C*) The P1/4 relationship noted prior to surgery was reproduced intraoperatively. The PPC ring was then centered on the P1 reflection (*red arrow*), and the PPC capsulotomy was performed. (*D*) After lens removal, the capsulotomy was observed to be well centered. (*E*) A PanOptix Trifocal IOL (Alcon Laboratories, Inc.) was placed with 360 degrees of anterior capsule overlap successfully achieved to promote long-term IOL stability. The patient was not fixating in this photograph. PPC = precision pulse capsulotomy

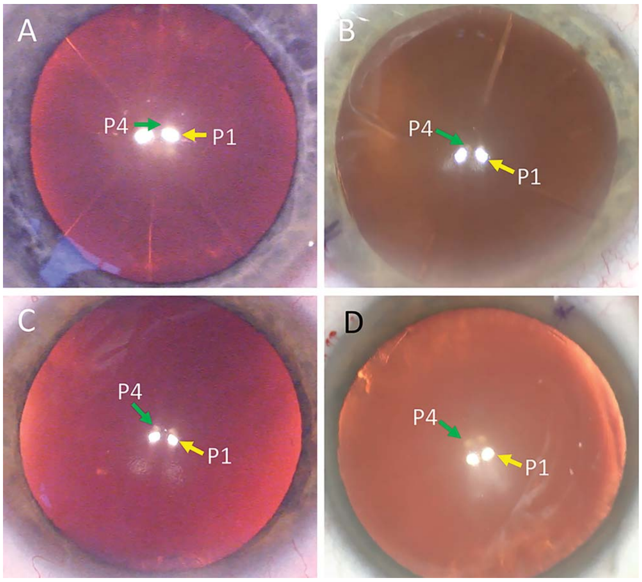

Figure 6. Examples of variability in the relative positions of P1 and P4 at patient fixation on a light source. The surgical photographs shown are from 4 different patients. (*A*) Example of closely spaced P1 (yellow arrow) and P4 (green arrow) at fixation. (*B*) P1 and P4 appear more distinctly separated in this example compared with *A*). (*C*) P1 and P4 are clearly separated with P4 located near the P1 from the other microscope light. (*D*) P1 and P4 are separated by a larger distance than the example in *C*). Note that the size of the Purkinje reflections is related to the size of the light source. A large microscope light source can in theory produce a relatively large P1 reflection that potentially subsumes P4, although the true pinpoint locations of P1 and P4 may not overlap.

opacification sufficient to prevent fixation or which results in the scatter or blockage of light rays from penetrating the lens; in which case no P4 will be present. The possibility that in the case of white cataracts, the limbus can be used to substitute for the lack of P4 has been proposed and deserves further study.[22] Similarly, external docking devices that introduce extraneous optical interfaces could eliminate or produce extra Purkinje reflections and render this method unusable.

The case of patients who lose the ability to fixate on a light source because of progressive effects of sedation is interesting as a surgeon viewing through coaxial optics may manually rotate the patient's eye to recapitulate the P1 and P4 relationship previously determined to locate the SFCSCLR. Once identified, P1 can be used as a reference landmark for the placement of the capsulotomy, either on the SFCSCLR or shifted a distance away, depending on surgeon preference.

It is worth noting that an exception to the movement of P1 and P4 toward each other during fixation can occur in certain patients if they start at a position of gaze a short distance away from fixation that brings their P1 and P4 reflections together. In this case, as the patient executes fixation, P1 and P4 may in fact seem to separate from each other a short distance. A possible way to guard against this scenario is to conduct several trials of fixation, each with the patient starting from different positions of gaze a significant distance away from the targeted fixation point. All fixation trials should in principle end up at the same fixation point and thus show the same P1 and P4 relationship.

If patient-fixated Purkinje reflections are used for capsulotomy centration, the capsulotomy can in principle be performed via standard manual capsulorhexis, capsulorhexis aided by devices placed onto the anterior capsule, or automated capsulotomy methods such as PPC as shown in the current study.[22] Compared with manual capsulorhexis, automated capsulotomy may provide more precision in producing a round capsulotomy of the desired diameter around an intended fixed center point.

A situation may be encountered where a microscope with coaxial optics is not available; that is, a microscope with its left ocular aligned on the same axis as the left light source and the right ocular aligned on the same axis as the right light source. In this case, a potential solution is that the patient fixates between the 2 light sources and the surgeon uses a reference point between the 2 P1 reflections. Although a measure of consistency for placement of a capsulotomy is provided, the precision that may be possible with the use of a microscope with coaxial optics and determining the SFCSCLR is lacking.

The precision of patient-fixated P1 and P4 viewed through certain microscope optics may benefit from improvements of the fixation light source. This includes the use of a smaller, designated pinpoint light source for intraoperative patient fixation that is integrated into microscopes to produce Purkinje reflections that are significantly smaller than those produced currently. In addition, this fixation light source should be truly coaxial with the optical system to further optimize surgeon sighting along the patient's SFCSCLR. As an example, the Zeiss Lumera microscope provides Stereo Coaxial Illumination. Another area for future development is the inclusion of corneal aberrations to further refine the optimal placement of IOL implants with complex optics. Given current equipment, the surgeon using this P1/4 alignment technique should familiarize themselves with their specific microscope and the equipment's true coaxiality or deviations from true coaxiality. Adjustments of the locations of the recognized P1/4 reflections can be made with experience to better approximate the SFCSCLR. This may assist in the creation of optimally located capsulotomy to achieve 360 degrees of capsule overlap for long-term implant stability.

Given the presence of symmetrically designed haptics located 180 degrees apart, the final position of IOLs in the eye will in principle always be defined by the capsular bag, although some manual nudging to a final desired placement may be possible. With new methods of automated capsulotomy now available and the possibility of intraoperative capsulotomy centration on the SFCSCLR, improved control of IOL position by locking IOLs onto the SFCSCLR may be desirable, especially for IOLs with more complex optics. A potential solution is offered by IOLs that are designed to be captured by the capsulotomy opening.[23–28]

WHAT WAS KNOWN

- Identification of the subject-fixated coaxially sighted corneal light reflex (SFCSCLR) theoretically allows the surgeon to sight along a line extending from the patient's fixation point in space to a consistent and reproducible marker in the patient's visual system.
- The SFCSCLR is commonly assumed to be associated with the location of the visual axis; although this assertion requires formal proof, and the term visual axis itself has been variously defined.
- The intraoperative use of Purkinje reflections may be helpful for identification of the SFCSCLR.

WHAT THIS PAPER ADDS

- P1 and P4 Purkinje reflections typically move progressively toward one another during intraoperative patient fixation on a surgeon-designated microscope light and with the surgeon viewing through a given eyepiece.
- At fixation, each patient has a closely spaced and invariant relationship between P1 and P4 that potentially reflects the relationship between their SFCSCLR and capsular bag anatomy.
- The preoperative relationship of P1 and P4 may be reproduced by the surgeon intraoperatively to approximate patient fixation.
- The approximate location of the SFCSCLR may be used as a centration point for automated capsulotomy and potentially help achieve capsular overlap.

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