Analysis of intraocular lens dynamics induced by involuntary eye movements

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The study involved the analysis of high-speed video recordings of eyes implanted with intraocular lenses following cataract surgery. The investigation demonstrated how the positions of Purkinje images vary during small, involuntary eye movements. Quantitative measurements allowed for the assessment of temporal changes in relative displacements of the intraocular lens. These observations provide insight into the dynamic behavior of ocular structures and contribute to a better understanding of lens stability and eye biomechanics after cataract treatment.

Keywords: Purkinje imaging; pupil; IOL; eye movement

INTRODUCTION

Involuntary eye movements, even the smallest ones, leadto shifts in the position of anatomical structures located near the pupil. The phenomenon known as lens sway has therefore been widely investigated [1–3]. In this study, the authors aim to characterize the temporal changes in pupil size and position, as well as the displacement of an artificial intraocular lens (IOL) in eyes following cataract surgery.

Purkinje images were quantitatively analyzed by comparing the relative positions of the fourth Purkinje images (PIV, originating from the posterior lens surface) with the first Purkinje image (PI, reflected from the anterior corneal surface).The results demonstrate measurable changes in position during subtle, involuntary eye movements.

METHODS

A high-speed camera was employed to capture images of eyes with a clearly visible pupil and reflections of the illuminator from the corneal and lens surfaces. Recordings were obtained at 200 frames per second from twenty-two subjects with intraocular lenses implanted after cataract surgery. Each recording lasted up to 10 seconds, during which participants fixated on a stationary target positioned 1.5 m away. Short segments containing small, involuntary eye movements were selected to evaluate pupil and lens kinetics.

The video data were converted into three-dimensional matrices and analyzed using MATLAB (The MathWorks Inc.). Dedicated algorithms were applied separately to assess Purkinje images position. Based on the numerical data, the successive temporal positions of the geometric centers of the first Purkinje image (PI), and the fourth Purkinje image (PIV) were determined. Subsequently the oscillation trajectory of the IOL was determined. An example of temporal positional changes of PI and PIV was presented in Figure 1.

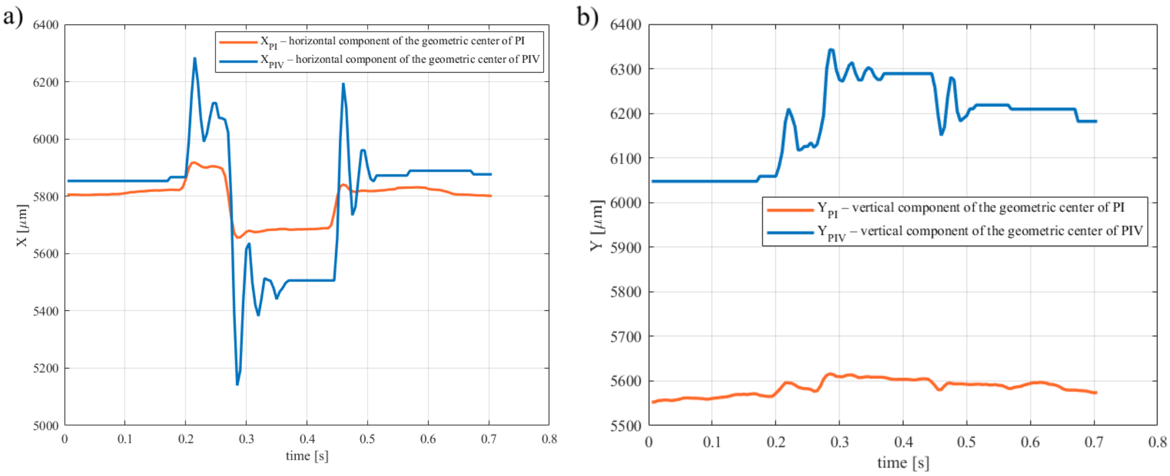

Figure 1.Change in a) the horizontal X and b) the vertical Y component of the center of image PI and PIV over time

RESULTS

Since the PI and PIV centers were determined, their relative behavior over time was subsequently examined. Differences between the positions of PI and PIV (denoted as PP) were calculated and interpreted as the displacement relative to the entire eye [1, 3, 4]. The parameters X_{PP} and Y_{PP} were defined as: $X_{PP} = X_{PIV} - X_{PI}$, $Y_{PP} = Y_{PIV} - Y_{PI}$. Figure 2 illustrates this situation separately for the horizontal (X) and vertical (Y) axes.

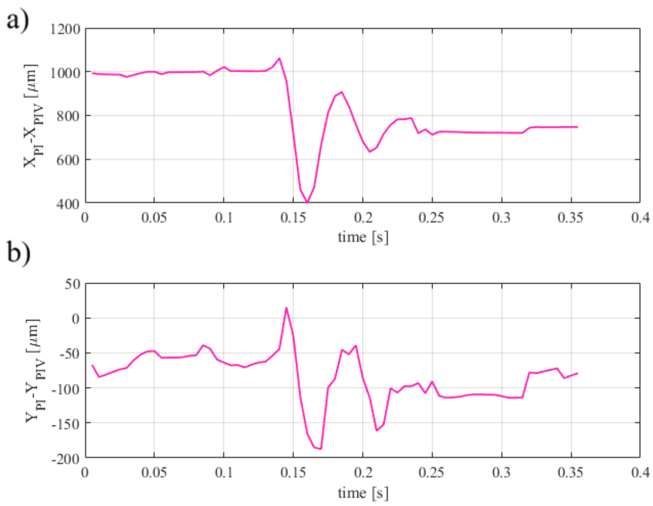

Figure 2. Differential movement of the IOL relative to the first Purkinje image in a) the horizontal and b) the vertical direction

The results indicate that after a microsaccade, the intraocular lens performs short-term inertial vibrations resembling a damped oscillator. The lens does not return to its initial position, resulting in variable decentration of its optical center.

Because involuntary eye movements occurred in different directions, the displacement length r was calculated from the increments of variables X and Y per unit time (ΔX and ΔY) using the relation: $r = \sqrt{(\Delta X^2 + \Delta Y^2)}$.To determine the direction of motion of the analyzed elements, the displacement angle α of PP and PIV oscillations was calculated using $\alpha = \mathrm{arctg}\left(\frac{\Delta Y}{\Delta X}\right)$ in each sequence. This histogram of that angle is shown in Figure 3.

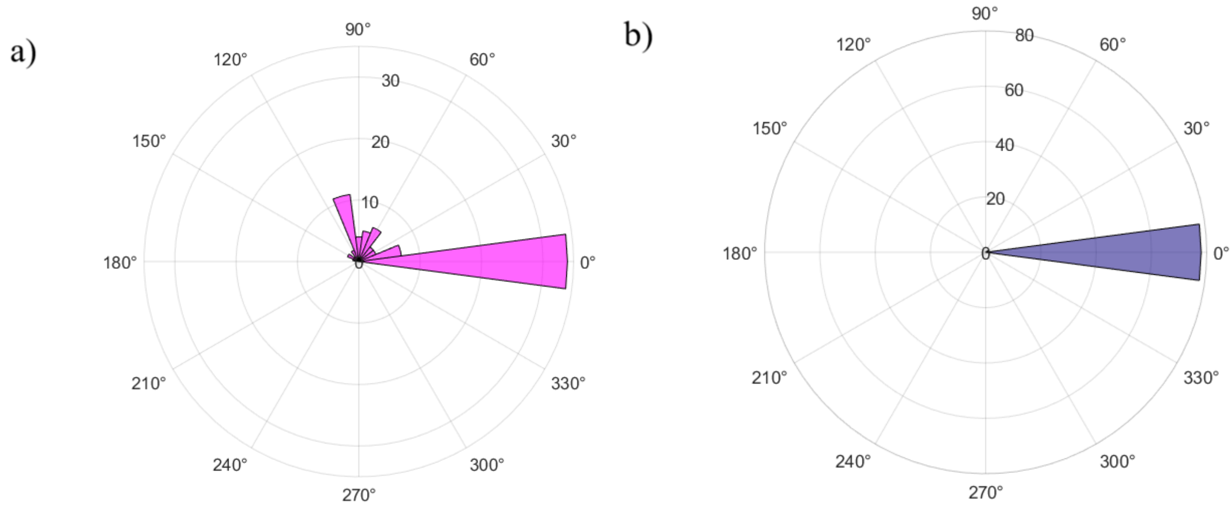

Figure 3. Histograms of the frequency of motion at a given angle over time: a) for difference between PI and PIV and b) for image PIV

CONCLUSIONS

The motion of the lens is brief and dynamic, resembling a damped harmonic oscillator with an amplitude that decreases over time. As in the case of natural lens oscillations, a gradual reduction in IOL displacement is observed until complete stabilization is achieved. Variable decentration of the optical center may lead to visual disturbances such as halos, starbursts, and reduced contrast sensitivity.

The diversity of intraocular lenses, particularly the design of their haptics [5], may result in different distributions of forces acting on the lens, thereby influencing its stability and movement within the eye. This may consequently contribute to the visual disturbances mentioned above. Analysis of the vibration directions (Fig. 3) suggests that the haptics are oriented perpendicular to pupil motion; however, their movement differs from that of the eye as a whole.

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