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Evolution of refraction after Neodymium yttrium-aluminium-garnet capsulotomy

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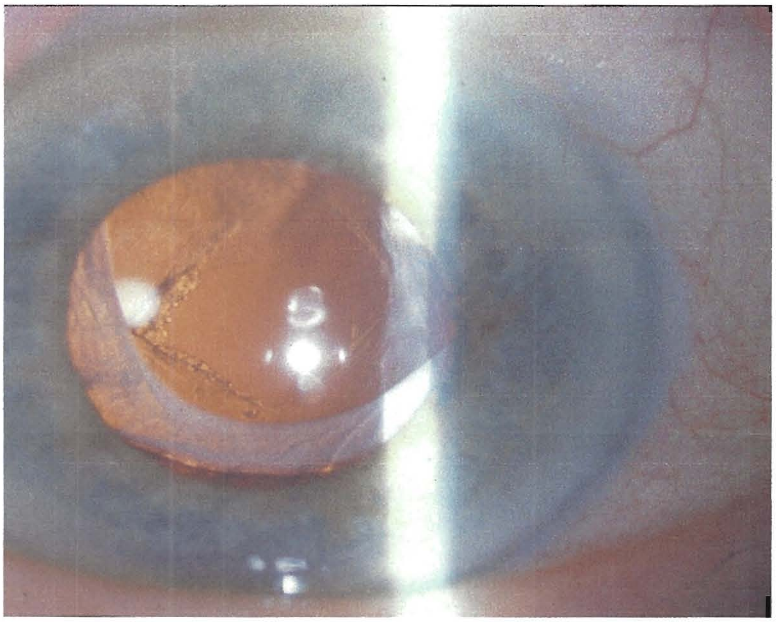

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Abbreviations

PCO- Posterior capsular opacification

YAG- Yttrium Aluminium Garnet

IOL- Intraocular lens

ACD- Anterior chamber depth

IOP- Intraocular pressure

RD- Retinal detachment

CMO- Cystoid macular oedema

BVCA- Best corrected visual acuity

SE- Spherical Equivalent

p_{se}- Power of spherical Equivalent

p_{cv}- Power of Jackson cross cylinder vertical

p_{c45}- Power of Jackson cross cylinder 45

MAR- Minimal Angle Resolve

Abstract

Background/Introduction: YAG-capsulotomy for treatment of posterior capsular opacification (PCO) often induces refractive error.

Purpose: To establish when after YAG-capsulotomy, spectacles can be prescribed without risk for short term change of refractive error.

Methods: 14 eyes of 14 patients were included. Refraction was measured subjectively with a digital visual acuity chart at 7, 11, 18 and 30 days after YAG-capsulotomy. Clinical notations were converted to power vectors for statistical analysis.

Results: 14 subjects of even gender ratio in the age interval 59-89 years completed the study. At 7 days after capsulotomy, the refractive error ranged from -2 to +2 D spherical and -1 to 0 D cylindrical error. The magnitude of each power vector was fitted against time after capsulotomy, assuming a first-degree polynomial. A 95 % confidence interval for the population mean temporal change of spherical equivalent, Jackson cross cylinder vertical and Jackson cross cylinder 45 was estimated to; -4.3 ± 19.0, 0.7 ± 4.1, $0.7 \pm 4.1 \times 10^{-2}$ ($D \times days^{-1}$), respectively. The 95 % confidence interval for the mean population difference between day 11 and 7 after YAG-capsulotomy was 0.07 ± 0.45 D spherical and 0.05 ± 0.06 D cylindrical error.

Conclusion/discussion: Spectacles can be prescribed 7 days after YAG-capsulotomy.

Populärvetenskaplig sammanfattning

Bakgrund

Den vanligaste komplikationen associerad till gråstarrbehandling är efterstarr. Efterstarr innebär att kvarvarande celler från den bortopererade linsen delar sig och orsakar störning av ögats ljusbrytning. Klar syn återskapas genom att med mycket korta laserpulser klippa ett millimeterstort hål i bakre delen av linskapseln, YAG-kapsulotomi.

Efter YAG-kapsulotomi kan den inopererade plastlinsen röra sig i relation till hornhinnan. Då ändras den totala ljusbrytningen i patientens öga så att behov av korrigerande optik ändras. Efter en viss tidsperiod stabiliseras linsen och därmed brytningsfelet. Då kan korrigerande glas förskrivas utan risk för att patienten kort därefter behöver annan korrektion.

Vår studie avser att fastställa när synen och brytningsfelet stabiliserar sig efter YAG-kapsulotomi så att glasögon kan förskrivas.

Metod

Ena ögat hos14 patienter som gjort YAG-kapsulotomi på Akademiska sjukhuset studerades. För deltagande krävdes att patienten skulle vara över 55 år och inte ha någon ögonsjukdom som skulle innebära ljusbrytningsförändring i ögats optik inom en månad.

Deltagare i studien var mellan 59–89 år med jämn genusfördelning. En digital syntavla presenterades på 4 meters avstånd. Undersökaren guidade patienten igenom tavlan, från största till minsta identifierbara bokstav. Glas med olika styrkor adderades enligt gällande praxis för glasprövning tills patienten nådde bästa korrigerade synförmåga.

För varje patient utfördes denna procedur dag 7, 11, 18 och 30 efter YAG-kapsulotomin.

Resultat

Alla kliniska mätresultat omvandlades för statistisk analys. Efter granskning av data, anpassades behovet av brytkraft för att uppnå bäst korrigerade synförmågan i förhållande till tiden efter YAG-kapsulotomi, till en rät linje. Tidsförändring av brytningsfel kunde ej påvisas för den definierade populationen.

Förändring av brytningsfel mellan dag 11 och 7 var inte signifikant.

Slutsats

Förskrivning av glasögon kan göras fr.o.m. dag 7 efter YAG-kapsulotomi.

Background

Refraction and visual acuity

Refraction occurs when electromagnetic waves travel from a medium with a given refractive index to a medium with another refraction index at an oblique angle. In clinical ophthalmology, the term refraction is used to describe the refractive correction needed to make an eye emmetropic. A refractive error can be spherical or cylindrical. A spherical glass can be either plus or minus. The plus glass corrects hyperopia, farsightedness which means that the image of a distant point is imaged behind the retina. A minus glass, on the other hand, corrects myopia, nearsightedness which in contrast to hyperopia signifies that an image at a distant point is imaged in front of the retina.

An optical surface that refracts in one meridian but not in the perpendicular meridian is called a cylindrical glass. The axis of the non-refracting meridian is defined as the cylinder axis. The cylinder axis thus varies in the interval 0-180 degrees. In astigmatism, there are two focal planes in the eye of the patient for perpendicular axes. The cylindrical glass corrects astigmatism if adjusted to the correct frontal plane angle. That is why astigmatism should be denoted with axis angle.

It is also common to examine ocular refractive error with a pinhole. The pinhole occludes peripheral errors in the optics of the eye and therefore cancels refractive errors.

Examination of refraction could be done either objectively or subjectively. For objective refraction, an autorefractor or a retinoscope is used. Light waves are sent through the pupil. The image back scattered from the retina reveals refractive errors. Autorefraction is often used as a first step by nurses at an eye clinic. Subjective examination on the other hand is tested using a visual acuity chart as the object. On the visual acuity chart, letters subtending visual angles from large to narrow are presented and patients are asked to identify the letter subtending the smallest letter perceived. When a letter is not perceived accurately, corrective glasses are added with a systematic strategy until no further improvement can be achieved with glasses added. In our study we have chosen to use subjective refraction.

Visual acuity is defined as the smallest angle resolved by the visual system. Letters printed black on white paper are high contrast objects that people see in their daily life. Therefore, letters are typically used as objects to determine the smallest angle resolved. The width of the letter strike is defined as the angle of resolution. Visual acuity is measured as Minimal Angle

Resolved (MAR). Since the visual system has a logarithmic response to stimulus, letter sizes are typically distributed linearly in an interval on a 10^{th} logarithm transformed MAR scale and the visual acuity is then noted in logMAR units. Historically, it has been common in Scandinavia to note visual acuity as a decimal fraction, the commonly agreed on reference minimum angle of resolution (1 arc minute) in relation to the measured minimum angle of resolution measured in arc minutes.

The transfer of information in the visual system is absolutely limited by the pupil size and a corresponding spatial density of photoreceptors in the retina. Refractive errors and light scattering decreases the contrast in the image on the retina and make it more difficult for the photoreceptors to discriminate between light and dark points in the object. Photoreceptor disturbance decreases angular resolution. Disturbance to neural transfer in the visual pathway may decrease resolution or limit the visual field.

Posterior capsular opacification

Cataract is the most common reason for visual loss in the elder population. During cataract surgery, the natural lens is replaced with an intraocular lens (IOL) that is inserted in the lens capsule. The capsule supports the IOL. When removing the lens, surgeons strive to remove the contents of the lens capsule. However, some lens epithelial cells always remain. These cells grow and divide and gradually invade the space between the IOL and the lens capsule. This leads to change in the matrix and cell organization (Wormstone, Wang, & Liu, 2009). These changes induce light scattering causing decreased contrast in the image on the retina and the patient perceives glare and halos and decreased contrast sensitivity can be measured. This pathological process is called posterior capsular opacification (PCO). When the contrast is below what adjacent photoreceptors need to differentiate light from dark, the visual acuity drops. The leading treatment for PCO is YAG-capsulotomy (Cetinkaya et al., 2015; MacEwen & Dutton, 1986; Murrill, Stanfield, & Van Brocklin, 1995).

PCO occurs only after cataract surgery and is more common in younger individuals due to higher cell proliferation rate in youth (Mackool & Chhatiawala, 1991).

YAG-capsulotomy

YAG-capsulotomy has been used for more than 30 years. Improved contrast sensitivity and visual acuity after YAG-capsulotomy has been documented for decades and the procedure remains the method of choice worldwide. Ozkurt et al. (Ozkurt, Sengör, Evciman, & Haboğlu,

2009) found a significant improvement of visual acuity from 0.38 ±0.13 decimal to 0.93 ±0.11 decimal already one day postoperatively. This improvement continued up to 3 months after YAG-capsulotomy. Cetinkaya (Cetinkaya et al., 2015) and Karahan (Karahan, Tuncer, & Zengin, 2014) stated a positive effect on best corrected visual acuity (BCVA).

The potential impact of various factors associated with the YAG-capsulotomy on the post-operative BCVA has been analyzed. Many studies have examined the impact of the amount of energy used, and the shape and size of the capsulotomy opening considering that different strategies require different number of laser impacts. Some showed that the size of the opening did not have an impact on BVCA or refraction (Yilmaz, Ozdil, Bozkir, & Maden, 2006). Other studies (Cetinkaya et al., 2015) showed that an opening of 3.5 mm or less with a cruciform shape provides the best improvement in visual acuity and minimizes complications.

Some complications after YAG-capsulotomy were documented. Some of them are reversible. Mild complications such as moving bodies are common days to weeks after the procedure and are often described by patients as flies in the visual field. Patients can see moving bodies due to fragments of capsular tissue or pieces of lens cortex that occur in the vitreous after the procedure. Moving bodies are more common, and noted to be more pronounced in patients treated with a larger YAG incision (Cetinkaya et al., 2015).

Another common complication is transiently increased intraocular pressure (IOP). IOP elevation, is more pronounced for patients receiving a large incision than if the incision is small and is due to capsular particle release and inflammatory response. It was reported that IOP elevation occurs in 15-30 % of patients undergoing YAG-capsulotomy despite prophylactic treatment (Karahan et al., 2014) (Minello, Prata Junior, & Mello, 2008) (Lin, Katz, Spaeth, & Klancnik, 2008).

Other previous studies noted severe complications, such as retinal tear with subsequent retinal detachment. The risk for this complication is 0.8-1.9% after capsulotomy (Van Westenbrugge, Gimbel, Souchek, & Chow, 1992, Powell & Olson, 1995, Burq & Taqui, 2008). This complication was reported more pronounced after large capsulotomy openings (Karahan et al., 2014).

Cystoid macular oedema (CMO) is another complication which can occur in the interval 3 weeks - 11 months after the capsulotomy. The incidence of CMO is different in different studies. Some showed an incidence of 1.23 % (Steinert, Puliafito, Kumar, Dudak, & Patel, 1991). Others showed an incidence as high as 9.6 % (Burq & Taqui, 2008), while in a study by Karahan (Karahan et al., 2014) none of the investigated patients showed to have CMO.

During cataract surgery, it is important to maintain the barrier function between the anterior and posterior chamber. This barrier function is of huge importance to avoid complications such as retinal detachment and cystoid macula oedema and anterior segment neovascularization (C.-Y. Hu, Woung, Wang, & Jian, 2000; Wormstone et al., 2009).

In general, more complications appear after big YAG openings. However, there is no doubt that the positive effect on visual acuity outweighs the negative effects (Karahan et al., 2014).

Intraocular lens movement

When PCO is formed, fibrous epithelial cell metaplasia occurs. This creates a contractile force as the posterior capsule wrinkles. When capsulotomy is performed, the integrity of the posterior capsule is disrupted, and the traction force vectors are redistributed, at the same time as a retraction and a smoothening of the contours occur (Capone, Rehkopf, Warnicki, & Stuart, 1990). This redistribution of powers leads to change in IOL orientation. Thus, YAG-capsulotomy makes the IOL suddenly more moveable.

Considering close to optical axis refraction, the total refractive power of the optics of the eye, F_T, is equal to the sum of the refractive power of the cornea simplified to one surface, F_C, the refractive power of the IOL simplified to one surface, F_{IOL}, and a term for the distance between the two refracting surfaces, d (Eq.1).

$$F_T = F_C + F_{IOL} - d \times F_C \times F_{IOL} \qquad \textit{Eq. 1}$$

It has been shown that the IOL may move both backward and forward after YAG-capsulotomy (Khambhiphant, Liumsirijarern, & Saehout, 2015). A backward movement induces hyperopia(Chua, Gibson, & Kazakos, 2001; Findl et al., 1999; C.-Y. Hu et al., 2000; Karahan et al., 2014) and a forward movement induces myopia (Eq.1). According to Karahan, the refractive change is progressive up to 4 weeks after large capsulotomy openings. The driving force is believed to be a positive pressure difference between the vitreous and the anterior chamber and the movement depends on the type of IOL and the size of the YAG-capsulotomy opening (Karahan et al., 2014; Oztas, Palamar, Afrashi, & Yagci, 2015).

Anterior Chamber Depth

When the IOL moves backward after YAG-capsulotomy, the anterior chamber depth (ACD) increases (Findl et al., 1999). Oztas (Oztas et al., 2015) found a significant decrease in the

ACD up to one week after YAG-capsulotomy. A decrease in ACD is associated with postoperative complications such as myopia, IOP increase and acute glaucoma.

Other studies did not find any significant change in the ACD (Khambhiphant et al., 2015) (C.-Y. Hu et al., 2000).

Refraction change

In previous studies spherical equivalent have been not found to be significantly changed after YAG-capsulotomy (Cetinkaya et al., 2015; Ozkurt et al., 2009; Oztas et al., 2015; Chua et al., 2001; C.-Y. Hu et al., 2000; Karahan et al., 2014; Khambhiphant et al., 2015)

Oztas m.fl., 2015 showed a significant decrease in cylinder error comparing preoperative refraction to 1 month postoperatively. At one month after YAG-capsulotomy, a myopic shift in spherical error was observed but this change was not correlated to decreased ACD.

Hu et al. (C.-Y. Hu et al., 2000) noted a decrease in the magnitude of residual spherical and astigmatic refractive error during the first week after YAG-capsulotomy. Both errors then stabilized. However, Khambhiphant (Khambhiphant et al., 2015) who measured refraction with an autorefractor, found a change in the cylindrical refractive error at one week after YAG-capsulotomy which had decreased at 3 months follow up.

Most studies (C.-Y. Hu et al., 2000), showed that glasses can be prescribed 1 week after YAG-casuloptomy but according to Karahan (Karahan et al., 2014) glasses should be prescribed 1-4 weeks after the procedure depending on the size of the YAG-capsulotomy opening. After large capsulotomy openings, it may take up to 4 weeks before the refractive error stabilizes. Khambhiphant's (Khambhiphant et al., 2015) findings suggest that optimal prescription of corrective lenses should be done at 3 months after the procedure.

Power vectors

It was shown that the optical consequence of a spherical lens and a cylindrical lens can be transformed into three orthogonal power vectors, the spherical equivalent, p_{se} (D), Jackson cylinder vertical, p_{cv}(D) and Jackson cross cylinder 45°, p_{c45}(D) (Thibos, Wheeler & Horner 1997, Thibos & Horner, 2001). Since these power vectors are orthogonal, they may be represented in a Cartesian- or a 3 D polar coordinate system and a total measure of the refraction can be obtained by considering the vector sum of the power vectors (Thibos, Wheeler & Horner 1997) (Thibos & Horner, 2001).

The advantage of transformation of clinical notation into these power vectors is that each of them may be treated with normal algebra and then the result can be reconverted into clinical notation of refraction. The conversion from clinical notation of refraction in spherical power and cylindrical power and axis to power vectors, and back conversion from power vectors to clinical refraction, is straightforward (Miller, 2009).

Methods

Data Collection

All patients that were planned to undergo YAG-capsulotomy at Akademiska Sjukhuset Eye Clinic during September to October 2017 were examined for refractive error by the principal investigator or the supervisor. Thereafter, patients were asked to join the study if they complied with the inclusion criterion (Table 1).

Table 1 Inclusion criteria

Variable	Criterium
Age (years)	≥55
Diagnosis	No ocular disease strongly considered to cause visual acuity change within one month

Subjects were stratified in an equal number of men and women at inclusion. Before inclusion, all subjects were informed about the aim of the study, both verbally and in a written form, and asked to sign a consent form. Personal ID- number and contact information (phone number, address, and e-mail address) was obtained from all subjects included to make it easy to reach them and each subject included was affiliated with a unique code. This information, the subject key, was stored separately from all recorded data. Forms containing measurement data were only associated with subjects by the unique subject code.

YAG-capsulotomy

Totally, 3-4 different doctors performed YAG- capsulotomy. All of them were specialist doctors in training in ophthalmology. Different patients got different number of laser impacts, depending on the amount of PCO and thickness of the posterior capsule. The number of laser impacts also depended on the shape and size of the YAG-capsulotomy. All patients received topical treatment with the IOP-reducing drug Iodipin after the laser treatment.

Digital visual acuity chart

In the present work a digital chart, developed by professor Per Söderberg from Gullstrand laboratory, Ophthalmology, Dept. of Neuroscience, Uppsala University, was used. The digital diagram is custom made with a custom-made algorithm to visualize optotypes (Figure 1).

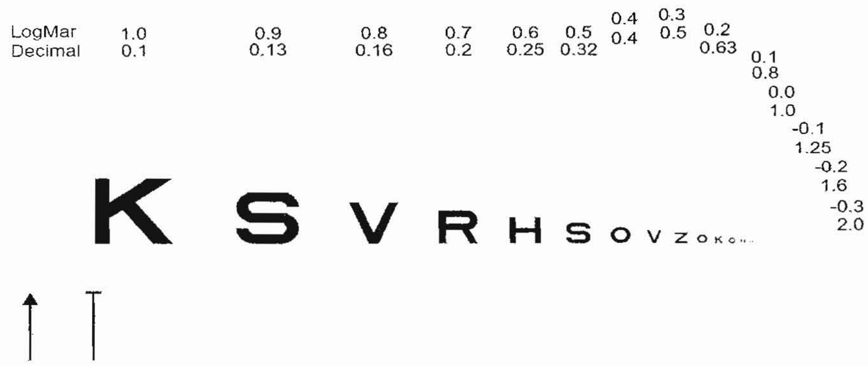

Figure 1 Digital chart used for refraction and visual acuity estimation.

This diagram is placed at 4 m distance from the patient assuming close to approximately distant vision. Via an Android Notepad, the examiner can choose what the patient can see on digital screen, connected to the Notepad. The examiner guides the patient through the visual chart from the Notepad during refraction. Different optotypes are visualized on the screen from large to smallest perceivable.

Procedure

For all refractions, the room illumination was controlled to be the same. All subjects were monocularly examined in one or two eyes intended for treatment of PCO. To ascertain independent data, only one eye in each subject was included in the study. The patient was asked to identify letters from left to right on the visual acuity chart until the smallest perceivable letter was identified (Figure 1). The smallest perceivable letter was then isolated on the chart and lenses were fitted in a trial frame in accordance with the Donders strategy. First, spherical lenses were added in steps until no further improvement could be achieved. Then, a cylindrical lens (0.5 D if $\leq$ 0.4 logMar, 1 D if $>$ 0.4 logMAR) was tried at 0, 45, 90 and 135 degrees. If one direction improved the vision, the subject was asked to fine tune the angle. Thereafter, the power of the cylindrical lens was changed in steps until no further improvement could be achieved. Finally, a small positive spherical correction was tried until no further improvement could be achieved. As a last step, a pinhole was added to verify that no further improvement occurred in order to check that the fitted correction was optimal.

For each subject and each measurement occasion, data on refraction and BCVA was recorded on a new form. This made it impossible to see results from the previous measurement. The examination before YAG-capsulotomy was not included since patients had already got cycloplegic tropicamide drops before the visit.

Subjects got a little patch with some outstanding color like yellow or red, where the date and time of the next appointment was written to avoid drop outs during the study. Further, subjects received a reminder message or a phone call from the principal investigator one day before each appointment to make sure they would be present for the scheduled examination.

Converting to power vectors

The clinically estimated refraction including information of spherical and cylindrical power with axis were converted to power vectors (Thibos & Horner, 2001). The reactive data expressed in power vectors were analyzed statistically.

Experimental design

Totally. 45 patients were asked to enter the study aiming for an equal gender distribution. Each subject was planned for examination at 7, 11, 18 and 30 days after YAG-capsulotomy. These dates were chosen assuming that the impact of YAG-capsulotomy on refraction would decay exponentially with postoperative time (Figure 2).

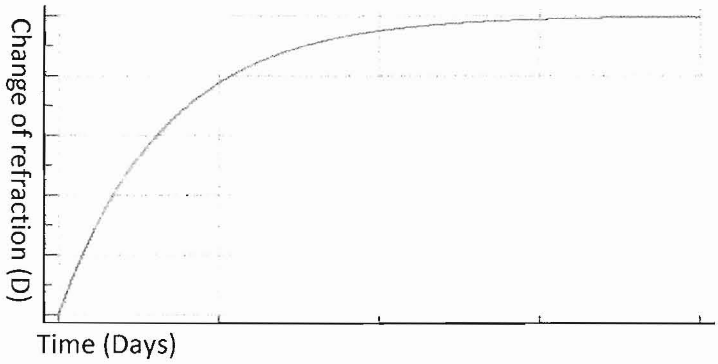

Figure 2. The graph illustrates the assumed temporal change of refraction.

Statistical parameters

The significance level was set to 0.05 and the confidence coefficient to 0.95, considering the limited sample size.

Ethical considerations

Ethical approval from ethical committee was not needed since the current project is a student project and the procedures applied are routinely used in the eye clinic and cannot affect the eye or vision in any way.

Results

Altogether, 18 patients approved to join the study. Of these, 14 subjects continued to the last visit. Among the lost patients, one was found not to have PCO, one patient had remaining PCO, 2 patients decided not to continue.

Some of the originally planned appointments were changed by the patients for different reasons. For example, appointments on weekends were moved to weekdays to facilitate travel to the appointment with the hospital transport services. All observations were within plus minus 2 days. For the last date, no change exceeding 30 days was accepted.

Sample characteristics

The characteristics of the sample is shown in Table 2.

Table 2 Subject characteristics

Variables	Magnitude
Gender(female/male)	7/7
Age (Years)	[59;89]
Initial refraction	
Spherical error (D)	[-2: +2]
Astigmatic error (D)	[-1: 0]
Initial Best Corrected Visual Acuity (logMAR)	[0.8: 0]

Time dependence of power vectors

For each subject, refraction in clinical notation was converted to power vectors. Initially, a possible variation of each of the power vectors among time points was analyzed with analysis of variance for block design. These, analyses did not reveal any variation of the power vectors with time after YAG capsulotomy. Therefore, the magnitude of the power vector was fitted against time of capsulotomy, assuming a first-degree polynomial. The magnitude of the power vector, p (D), is equal to the magnitude of the power vector immediately after YAG-capsulotomy, k_0 (D), and a regression coefficient, k_1 (D $\cdot$days^{-1}) multiplied with the time after YAG-capsulotomy, t (days), plus a random measurement error, ε (D) (Eq. 2).

$$p = k_0 + k_1 t + \varepsilon \qquad \text{Eq. 2}$$

No substantial time dependence of power was found for any of the estimated power vectors (Figure 3)

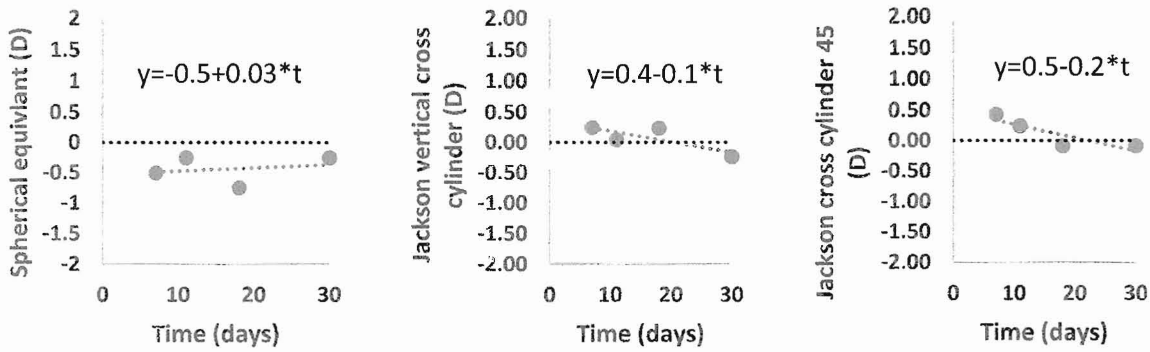

Figure 3 Power of spherical equivalent, Jackson vertical cross cylinder and Jackson cross cylinder 45 deg. as a function of time after YAG-capsulotomy. In each subfigure, the equation is the best fit first-degree polynomial and the dotted blue line is the plot of the best fit.

Estimates of 95 % confidence intervals for the inclination coefficient for the time dependence of each power vector indicated that there is no change of the power vector with time (Table 3, Figure 4).

Table 3 power vector time dependence

Power vector	95 % confidence interval for mean power vector time dependence (D·× days $^{-1}$) ×10^{-2}
Spherical equivalent	-4.3 ±19.0
Jackson vertical cross cylinder$_{cv}$	0.7 ±4.1
Jackson cross cylinder 45 deg.	0.7 ±4.3
Degrees of freedom= 13	

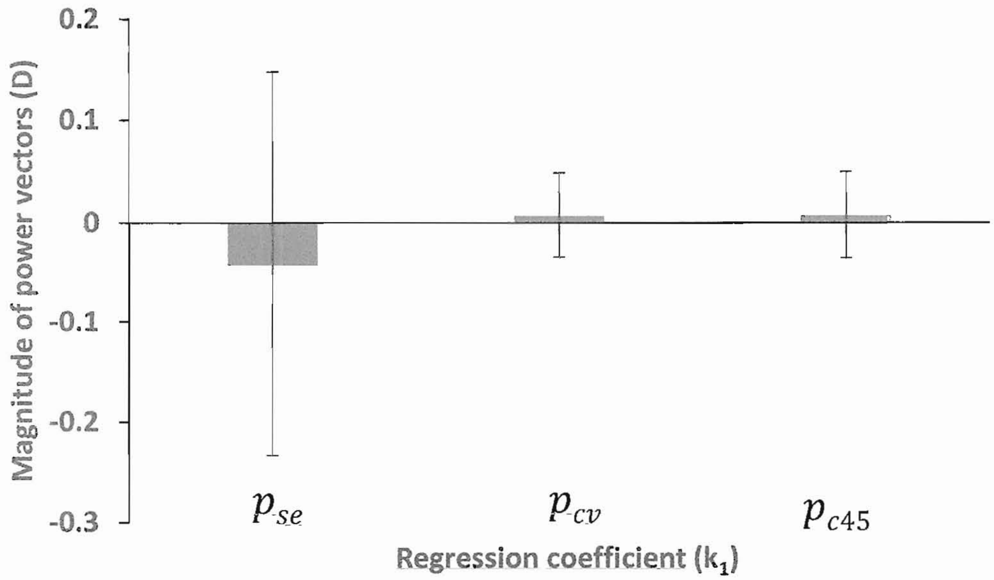

Figure 4. 95 % confidence interval for the population mean temporal change of power of the power vectors spherical equivalent, p_{se}, Jackson vertical cross cylinder, p_{cv}, and Jackson cross cylinder 45 deg., p_{c45}.

Refractive change after YAG-capsulotomy

The 95 % confidence interval for the mean difference of spherical power and cylinder power respectively, between day 7 and 11, was 0.07 ±0.45 D and 0.05 ±0.06 D.

Discussion

YAG-capsulotomy is the golden standard treatment method for PCO. The improvement in visual acuity is well established. Ozkurt (Ozkurt et al., 2009), demonstrated a change in both spherical and cylindrical error one month postoperatively compared to pre-operatively. However, no data are available for the time period in between. Thus, that study demonstrated that the patient should be advised to examine the refraction for a potential new glass prescription after YAG-capsulotomy but did not reveal data on the temporal change of refraction. It is important to know how refraction changes after the procedure to be able to prescribe spectacles at the right time. In the current study we have therefore investigated refraction at different dates after capsulotomy, to identify when refraction is stabilized.

Methods

In the inclusion criteria, the lower age limit was set to 55 years (Table 1). This relatively low age limit was set to facilitate inclusion of subjects since onset of PCO starts earlier at young age due to high lens epithelial proliferation rate (Mackool & Chhatiawala, 1991). In addition, the low age limit decreased the risk for low visual acuity due to confounding eye pathology. For the same reason, the risk for confounding outcomes was minimized by the inclusion criteria (Table 1).

In our study, the gender distribution was stratified to even at inclusion (Table 2). Although we did not anticipate to find any difference, the even gender distribution was aimed for to avoid any bias from uneven gender distribution and to generalize the outcome to be independent of gender.

The process of recruiting subjects was rather uneasy since many of the patients lived far away and many patients found it difficult to attend 4 visits. We asked 45 patients, of which 18 accepted to participate. Totally, 4 of these dropped off. One turned out not to have PCO, another presented remaining PCO even after YAG treatment and the two others were not willing to continue due to other reasons. We do not believe that the loss of subjects impacted on the outcome.

Refraction was measured subjectively with a digital chart, which made the room illumination less important since the contrast of the optotypes against background is defined by the digital monitor. The digital chart used allows the subject to reach the smallest perceivable optotype promptly. This increases the precision of the examination since there is less risk that the subject becomes tired and loses focus on the examination. We used subjective rather than objective refraction with an autorefractor, to avoid measurement errors associated with autorefraction. The outcome of an autorefractor depends on the pupil size and therefore the room illumination. The outcome of an autorefractor depends on the optical design and it is known that autorefractors tend to overestimate refractive errors. On the other hand, subjective refraction might be dependent on the examiner and patients cooperative level, which might give individual differences.

Patients were examined with the digital chart at 4 different dates using the identical strategy at each date. In the current version of the visual acuity chart used, one of two optional letter sequences are shown at each visual acuity estimation. Therefore, there is a low risk that the measurement was impacted by the subject learning the letters.

All patients attended to the eye clinic at four dates distributed on a scale with geometrical progression. The geometrical progression was used because it was predicted that the initial healing process after YAG-capsulotomy progresses fast in the beginning and then gradually diminishes.

The estimated sphere, cylinder and axis in one single clinical measurement are all dependent response variables. Therefore, most previous studies were limited to statistically analyse one of the response variables expressed in clinical notation, usually the spherical equivalent, or wrongly treated both the spherical equivalent and the cylindrical power mathematically. In the current study, all data collected were transformed from clinical notation to orthogonal power vectors. Since the power vectors are mathematically orthogonal, each power vector can be independently mathematically treated before retransformation of the power vectors to clinical notation.

We have not considered the impact of type of IOL design, since earlier studies failed to demonstrate an impact of type of IOL on refractive outcome after YAG-capsulotomy. (Khambhiphant et al., 2015).

Results

The present study is based on observations of subjects between 59 and 89 years of age which makes the results of the current study limited to a population in that age interval. The initial refraction and best corrected visual acuity varied a lot among subjects, indicating that the randomization within the age interval was valid with regard to refraction and visual acuity.

The finding that the 95 %confidence interval for the rate of refractive change in the time interval 7-30 days included zero (Table 3, Figure 4) indicates that there is no change of refractive power within that interval after YAG-capsulotomy. The fact that the 95 % confidence interval for the change of refractive power between day 7 and 11, implicates that the refraction has stabilized already at day 7. These findings agree with most previous studies (Cetinkaya et al., 2015; Chua et al., 2001; C.-Y. Hu et al., 2000; Karahan et al., 2014; Khambhiphant et al., 2015; Ozkurt et al., 2009; Oztas et al., 2015), that showed no significant change in spherical equivalent.

According to Hu et al. 2000, the magnitude of astigmatism is lower at one week after YAG-capsulotomy compared to before. However, that study was designed with another purpose than our study. Hu et al. 2000 ignored vector change, which could have underestimated the real change and lead to false negative results. Nevertheless, they concluded that glasses can be prescribed at one week after capsulotomy, which agrees with our findings. Further, Ozkurt (Ozkurt et al., 2009) did not find any variation of spherical equivalent between observations at pre-YAG-capsulotomy and one day, one month and three months after. These findings correspond with our results. However, the Ozkurt study (Ozkurt et al., 2009) neglected a concurrent change in cylinder power and axis.

Khambhiphant, Liumsirijarern & Saehout 2015 demonstrated a change in cylindrical error one week after YAG-capsulotomy and an observation at 3 months after YAG-capsulotomy indicated a decrease of the cylindrical error. Therefore, theses authors suggested prescription of corrective lenses at 3 months after YAG-capsulotomy. However, the same authors argued that the change of cylinder was too small to be clinically relevant. It should be noted that in that study refraction was measured with an autorefractor and autorefraction is known to overestimate refractive errors. Also, the size of the YAG-capsulotomy was the same for all patients (5 mm in diameter). Further, the authors claimed that in patients with thick capsule more energy was required to make the incision. Both the large opening in the posterior capsule and the higher energy required may have affected the ACD and therefore the refractive error.

Strength of the study

We used a correct and elegant way of estimating change of refraction by converting clinical notation to power vectors, (Miller, 2009; Thibos & Horner, 2001) which none of the mentioned previous studies used. Since the power vectors currently applied are orthogonal, they are independent of each other. The power vectors therefore make it possible to compare different cylinder errors with each other without dependency of the spherical errors. Once the power vectors have been mathematically transformed, the information can easily be back converted to meaningful clinical notation.

Another strength with the current study is that different doctors executed the YAG treatment. Different doctors may have caused increased variation in the outcome. However, by including different doctors, the sample can be considered representative for the eye clinic at Akademiska sjukhuset. This is in contrast to other studies where only one surgeon treated all the patients (C.-Y. Hu et al., 2000) and the outcome therefore is applicable for that surgeon only. In addition, the included subjects were refracted by two different examiners, the principal investigator and the supervisor. This may have increased the variability but also makes the outcome more generally applicable for the eye clinic.

The current study focuses on refraction change after capsulotomy only. We do not consider or analyze other variables since the outcome of each of them would depend on the others.

The consecutive measurements of refraction over time after YAG-capsulotomy in the current study allowed time resolution of refractive change after YAG-capsulotomy. This allowed detailed information on the earliest possible time point to prescribe glasses after YAG-capsulotomy where no further change is expected. Such data was not available in earlier studies (Khambhiphant et al., 2015; Ozkurt et al., 2009; Oztas et al., 2015).

Weakness of the study

The sample was limited to 14 subjects (Table 2).Therefore, the precision of the estimates is limited as reflected by the 95% confidence intervals for the temporal change of magnitude of the power vectors (Table 3). However, the confidence interval for the change of refraction between day 7 and day 11 indicates a clinically sufficient precision in the estimates since a refractive change less than 0.5 D can be neglected clinically. In the clinic, the lowest corrective glass used for refraction is 0.5 D and changes lower than that is not considered to be significant, to recommend patients buy new glasses.

The age limits of the sample (Table 2) make the outcome applicable to only that age interval. In a future study it would be of interest to analyze the outcome for younger age intervals. Further, the current sample included subjects with a limited range of pre-operative refractive errors (Table 2). Further information is needed for patients that express larger refractive errors. This could be achieved by intentionally stratifying subjects in specified refractive error intervals at inclusion.

It is potentially possible that the examiners could became better at investigating refraction during the study. If so, the measured data would have been more variable in the beginning than at the end of the study. However, the magnitude of the random error appears to be constant throughout the whole period of measurement (Figure 3). Therefore, we believe that examination skill was sufficient at the beginning of the study and did not improve during the study.

Conclusion

Our measurements showed no time dependent change in power vectors in the time interval 7-30 days after YAG-capsulotomy. An estimation of refractive change between day 7 and day 11 after YAG-capsulotomy using power vectors did not show a clinically significant change when the change was re-transformed to spherical and cylindrical power.

In conclusion, for patients elder than 55 undergoing YAG-capsulotomy, no further immediate change of the refraction is expected subsequently to 7 days after the procedure. Therefore, patients undergoing YAG-capsulotomy can be advised to renew their glasses within a week after the YAG-capsulotomy. Additional studies with larger sample size would further verify the conclusion.

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