Original Article

Characteristics of Posterior Corneal Astigmatism in Different Stages of Keratoconus

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Abstract

Purpose: To evaluate the magnitudes and axis orientation of anterior corneal astigmatism (ACA) and posterior corneal astigmatism (PCA), the ratio of ACA to PCA, and the correlation between ACA and PCA in the different stages of keratoconus (KCN).
Methods: This retrospective case series comprised 161 eyes of 161 patients with KCN (104 men, 57 women; mean age, 22.35 ± 6.10 years). The participants were divided into four subgroups according to the Amsler-Krumeich classification. A Scheimpflug imaging system was used to measure the magnitude and axis orientation of ACA and PCA. The posterior-anterior corneal astigmatism ratio was also calculated. The results were compared among different subgroups.
Results: The average amounts of anterior, posterior, and total corneal astigmatism were 4.08 ± 2.21 diopters (D), 0.86 ± 0.46 D, and 3.50 ± 1.94 D, respectively. With-the-rule, against-the-rule, and oblique astigmatisms of the posterior surface of the cornea were found in 61 eyes (37.9%), 67 eyes (41.6%), and 33 eyes (20.5%), respectively; corresponding figures in the anterior corneal surface were 55 eyes (32.4%), 56 eyes (34.8%), and 50 eyes (31.1%), respectively. A strong correlation ($P \leq 0.001$, $r = 0.839$) was found between ACA and PCA in the different stages of KCN; the correlation was weaker in eyes with grade 3 ($P \leq 0.001$, $r = 0.711$) and grade 4 ($P \leq 0.001$, $r = 0.717$) KCN. The maximum posterior-anterior corneal astigmatism ratio (PCA/ACA, 0.246) was found in patients with stage 1 KCN.
Conclusion: Corneal astigmatism in anterior surface was more affected than posterior surface by increasing in the KCN severity, although PCA was more affected than ACA in an early stage of KCN.

Keywords: Astigmatism; Keratoconus; Refractive Error

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INTRODUCTION

Keratoconus (KCN) which is characterized by steepening of the cornea, visual disturbance, apical corneal thinning, and central corneal scarring, is the most common primary corneal ectasia.[1,2] Most estimates place the incidence of keratoconus between 50 and 230 per 100,000 of the general population.[3,4]

Biomicroscopic examination and Placido-based corneal topography are usually used to detect KCN in daily practice. Although Placido-based corneal

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topography is known to be a highly sensitive diagnostic instrument, it only examines the anterior corneal surface and does not evaluate the curvature or elevation of the posterior corneal surface, which is considered to be very important in the diagnosis of early stage KCN. Recent advances in technology, such as the innovation of Scheimpflug camera and optical coherence tomography, make possible to quantitatively measure the posterior corneal surface and provide accurate diagnostic information for the detection of KCN of any stage.

Some biomicroscopic findings in KCN, such as stromal thinning and Vogt's striae, suggest that the posterior surface of the cornea is altered independent of the anterior corneal shape. Although changes in the anterior curvature in KCN have been frequently described in the literature, only limited information is available regarding the posterior corneal surface. Tomidokoro et al[5] found that both the anterior and posterior curvatures were affected in eyes with different stages of KCN. Further, other researchers have observed high posterior elevations in eyes with different stages of KCN.[6,7]

Assessment of corneal astigmatism at both surfaces play an important role in vision correction procedures, e.g., rigid gas permeable contact lens fit and implantation of a toric intraocular lens (IOL). Ho et al[8] reported that ignoring posterior corneal astigmatism may significantly affect the estimation of corneal astigmatism. Since manifestations of KCN occur at the posterior corneal surface even in early stages of the disease, identifying these changes could help clinicians to detect early stage KCN.

The aim of this study was to investigate the magnitude, orientation, and correlation of anterior and posterior corneal astigmatism in the different stages of KCN using dual Scheimpflug imaging. We also compared the magnitude and axis of anterior and posterior corneal astigmatism in different stages of KCN.

METHODS

This retrospective study included consecutive patients with KCN who were visited at Farabi Eye Hospital, Tehran, Iran; and were assessed for corneal cross-linking surgery, intracorneal ring implantation, or penetrating keratoplasty between April 2012 and March 2015. All the participants underwent corneal power measurements with the dual Scheimpflug analyzer (Oculus Optikgeräte GmbH, Wetzlar, Germany).

Scheimpflug images of the anterior eye segment were taken from the right eye in 161 patients with KCN. These 161 eligible eyes were divided into four KCN subgroups according to the Amsler-Krumeich classification (grade 1, 71 eyes; grade 2, 32 eyes; grade 3, 31 eyes; grade 4, 27 eyes)., The Amsler-Krumeich classification is based on astigmatism, myopia, keratometry, corneal transparency, and pachymetry.[9] Patients who wore rigid gas permeable or soft contact lenses were asked to stop using them for 3 weeks and 1 week, respectively, before assessment.

The study was approved by the Institutional Review Board at Shahid Beheshti University of Medical Sciences and followed the tenets of the Declaration of Helsinki. The requirement for informed consent was waived in view of the retrospective nature of the research.

Eyes with previous ocular trauma, other corneal diseases, or a history of surgery were excluded. Eyes with pellucid marginal degeneration, inferior corneal thinning and ectasia, and inflammatory signs detected on slit lamp biomicroscopy were also excluded.

All patients underwent a complete ocular examination, including corrected distance visual acuity, manifest refraction, and slit lamp and fundus evaluations that were performed by two highly experienced ophthalmologists. . The cornea was evaluated using a Scheimpflug imaging system that characterizes the anterior segment. A rotating Scheimpflug camera captures 100 images with 500 measurement points on both corneal surfaces over a 180-degree rotation. The measurement was performed as follows: the patient was asked to place his/her chin on the chin rest of the Pentacam device, press the forehead against the forehead strap, and stare at a central target or fixation light; when the patient's eye and visual axis were aligned, the patient was asked to blink and the image was captured. All measurements were based on data from a 3-mm diameter annular ring around the corneal apex. At our hospital, we regularly assess the Scheimpflug imaging parameters using a corneal diameter of 3 mm, which is comparable to that used in studies reported in the literature.[10] Pentacam images with not appropriate quality were excluded from the study and only patients with good quality Pentacam images entered the study.

The parameters obtained using the Scheimpflug system included corneal dioptric power in the steepest and flattest meridians in the 3.0 mm central zone as well as anterior corneal astigmatism (ACA) and posterior corneal astigmatism (PCA) in the 3.0 mm zone. The astigmatism axis orientation of each corneal surface was also recorded and analyzed. In addition, the posterior-anterior astigmatism ratio (PCA/ACA) was calculated.

Total corneal astigmatism and ACA were classified as with-the-rule (WTR) when the steep meridian was within 60–120 degrees and as against-the-rule (ATR) when the steep meridian was within 0–30 degrees or 150–180 degrees. Otherwise, the remaining astigmatism was classified as oblique astigmatism. The dioptric power of the posterior corneal surface was negative, so the PCA was classified as WTR when the steep meridian was within 0–30 degrees or 150–180 degrees and as ATR when the steep meridian was within 60–120 degrees. Otherwise, the remaining astigmatism was classified as oblique astigmatism, as described previously.

The statistical analysis was performed using SPSS software for Windows version 22 (IBM Corp., Armonk, NY, USA). All data samples were first checked for normality using the Shapiro-Wilk test. Correlation coefficients (Pearson or Spearman, depending on whether normality could be assumed) were used to assess the correlation between mean keratometry and astigmatism of the anterior and posterior corneal surfaces in each of the four groups of eyes. In addition, linear regression analysis was performed to determine the relationship between anterior and posterior parameters and to determine significant correlations between the parameters. When parametric analysis was not possible, the Kruskal-Wallis test was used for between-group comparisons, and a P value less than 0.05 was considered statistically significant.

RESULTS

The study evaluated 161 eyes of 161 patients [mean age 22.35 ± 6.10 (range 11–48) years] with a confirmed diagnosis of KCN. One hundred and four subjects (64.6%) were male and 57 (35.4%) were female. Seventy-one eyes (44.1%) had stage 1, 32 eyes (19.9%) had stage 2, 31 eyes (19.3%) had stage 3, and 27 eyes (16.8%) had stage 4 KCN according to the Amsler-Krumeich classification system.

The difference in corrected distance visual acuity between the four groups was statistically significant ($P \leq 0.001$, Kruskal-Wallis test). Table 1 shows the magnitudes of anterior, posterior, and total corneal astigmatism in each stage of KCN. Anterior and posterior astigmatism, anterior and posterior elevation, and total corneal astigmatism showed a statistically significant increase as the stages of KCN progressed ($P \leq 0.05$).

Table 2 shows the correlation coefficients between the values for astigmatism and elevation of the anterior and posterior corneal surfaces in the different stages of KCN. There was a strong statistically significant correlation between anterior and posterior astigmatism in eyes with grade 1 KCN and between anterior and posterior elevation in eyes with grade 2 KCN [Figure 1]. Figure 2 shows the axis orientation values for anterior and posterior corneal astigmatism according to grade of KCN. The WTR and ATR astigmatism orientation values were approximately the same at the anterior corneal surface, and the dominant type of astigmatism orientation at the posterior corneal surface was ATR [Table 3].

DISCUSSION

Some researchers have reported that toric IOL implantation could be used to correct astigmatism in patients with KCN and cataract.[11,12] Until recently, PCA has not been taken into consideration for toric IOL power calculation which is a possible reason for refractive error after surgery. The change in the posterior corneal surface plays a more subtle role than the anterior corneal surface in optical performance because of the smaller difference in refractive indices between the cornea and aqueous, and it has been thought that the magnitude of PCA in the normal population is clinically negligible.[13] Some studies have reported mean PCA values in the normal population that could range from 0.26 to

Table 1. Magnitude of corneal astigmatism and elevation of both corneal surfaces in the different stages of keratoconus

Parameters	Grade 1	Grade 2	Grade 3	Grade 4	*P*	Total
CDVA						
Mean±SD	0.19±0.16	0.16±0.28	0.23±0.52	0.41±0.67	≤0.001	0.31±0.34
Range	0.00-1.00	0.00-0.69	0.15-1.00	0.09-1.55		0.00-1.55
ACA						
Mean±SD	3.24±1.98	4.01±1.98	4.92±1.62	5.35±2.70	≤0.001	4.07±2.21
Range	0.5-8.00	1.40-8.60	2.60-8.10	1.10-12.10		0.50-12.10
PCA						
Mean±SD	0.75±0.45	0.84±0.38	0.92±0.40	1.05±0.50	0.020	0.85±0.45
Range	0.00-1.90	0.10-1.90	0.010-2.10	0.40-2.30		0.00-2.30
Anterior elevation						
Mean±SD	17.67±8.51	21.75±10.43	31.61±10.58	44.03±17.39	≤0.001	25.59±14.77
Range	0.30-4.30	3.00-46.00	6.00-53.00	10.00-84.00		3.00-84.00
Posterior elevation						
Mean±SD	39.42±17.70	45.62±20.53	67.90±15.42	94.51±25.21	≤0.001	55.37±28.06
Range	6.00-87.00	4.00-92.00	40.00-99.00	51.00-149.00		4.00-149.00
TCA						
Mean±SD	2.85±1.82	3.36±1.55	4.09±1.63	4.69±2.28	≤0.001	3.50±1.94
Range	0.30-9.30	1.00-6.90	0.80-7.20	1.10-9.30		0.30-9.30

ACA, anterior corneal astigmatism; CDVA, corrected distance visual acuity; PCA, posterior corneal astigmatism; SD, standard deviation; TCA, total corneal astigmatism

Table 2. Correlation coefficients between astigmatism and elevation values at both corneal surfaces in the different stages of keratoconus

Parameters	Grade 1	Grade 2	Grade 3	Grade 4	Total
ACA and PCA					
r	0.924	0.824	0.711	0.717	0.839
P	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001
ACA and TCA					
r	0.867	0.897	0.757	0.792	0.854
P	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001
PCA and TCA					
r	0.765	0.712	0.571	0.614	0.72
P	≤0.001	≤0.001	0.001	0.001	≤0.001
Anterior and posterior elevation					
r	0.894	0.903	0.769	0.496	0.878
P	≤0.001	≤0.001	≤0.001	0.008	≤0.001
Anterior elevation and ACA					
r	0.603	0.346	0.004	0.109	0.503
P	≤0.001	0.052	0.982	0.588	≤0.001
Posterior elevation and PCA					
r	0.560	0.125	0.034	0.284	0.413
P	≤0.001	0.496	0.857	0.150	≤0.001
Anterior and posterior BFS					
r	0.819	0.603	0.85	0.874	0.923
P	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001

ACA, anterior corneal astigmatism; BFS, best fit sphere; PCA, posterior corneal astigmatism; TCA, total corneal astigmatism

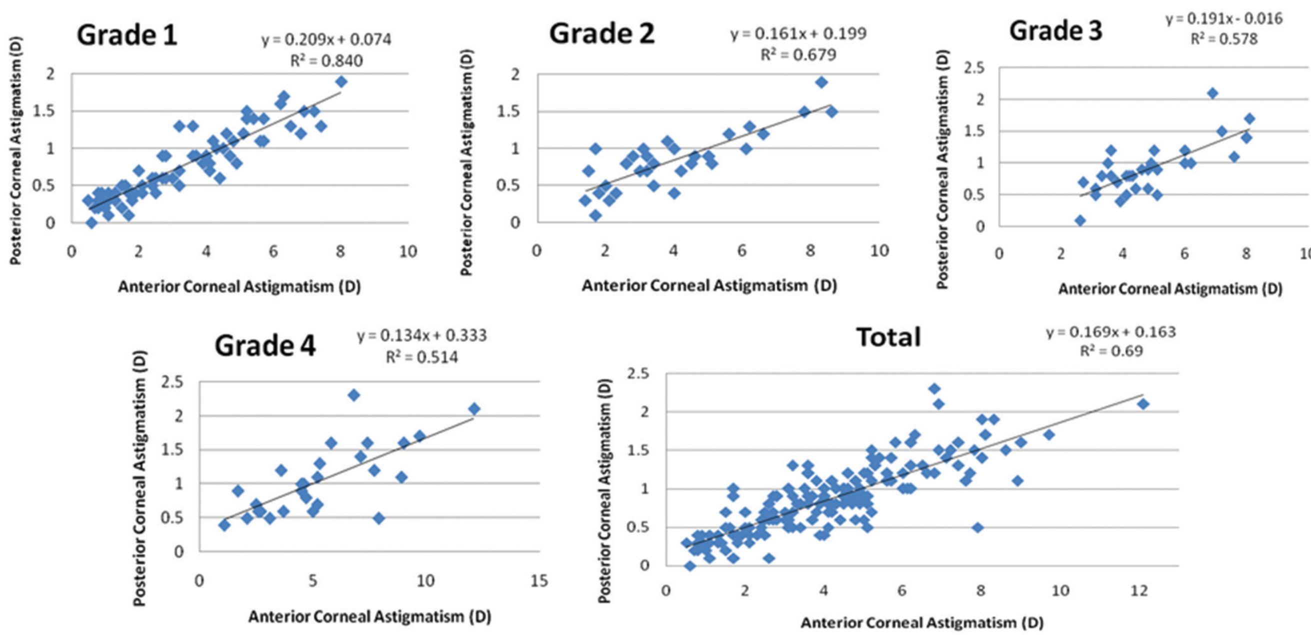

Figure 1. Correlations between the magnitudes of anterior and posterior corneal astigmatism in the different stages of keratoconus (Pearson correlation coefficient).

0.78 D,[14,15] but the few studies which have evaluated PCA in eyes with KCN have reported mean values that are significantly higher than those in the normal population [Table 4]. Thus, the presence of PCA cannot be ignored when considering toric IOL implantation, particularly in eyes with KCN, and the assumption of total corneal astigmatism instead of ACA may be helpful for selecting a more accurate toric IOL power, especially for KCN. However, most of the previous studies of the posterior corneal surface have not reported details of

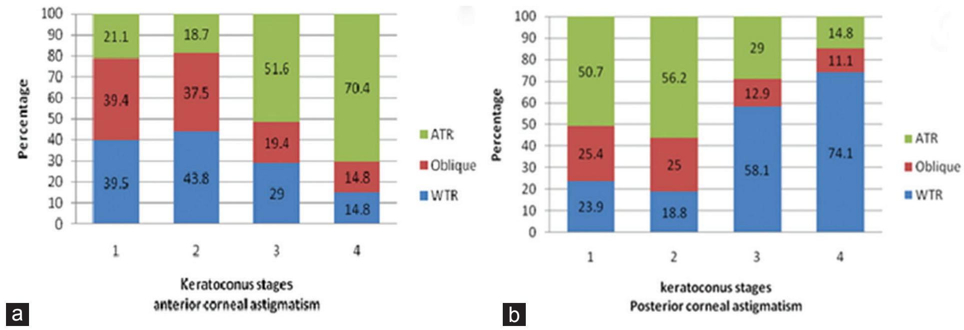

Figure 2. Distribution of the axis orientation in anterior (a) and posterior (b) corneal astigmatism in different stages in patients with keratoconus. ATR, against-the-rule, WTR, with-the-rule.

Table 3. Prevalence of WTR, oblique, and ATR astigmatism in the different stages of keratoconus

Axis orientation type of astigmatism	ATR astigmatism % (*n*)	Oblique astigmatism % (*n*)	WTR astigmatism % (*n*)
TCA			
Grade 1	19.7% (14)	47.9% (34)	31% (22)
Grade 2	28.1% (9)	50% (16)	21.9% (7)
Grade 3	19.4% (6)	35.5% (11)	45.2% (14)
Grade 4	7.4% (2)	33.3% (9)	44.4% (12)
ACA			
Grade 1	21.1% (15)	39.4% (28)	39.4% (28)
Grade 2	18.8% (6)	37.5% (12)	43.8% (14)
Grade 3	51.6% (16)	19.4% (6)	29% (9)
Grade 4	70.4% (19)	14.8% (4)	14.8% (4)
PCA			
Grade 1	23.9% (17)	25.4% (18)	50.7% (36)
Grade 2	18.8% (6)	25% (8)	56.2% (18)
Grade 3	58.1% (18)	12.9% (4)	29% (9)
Grade 4	74.1% (20)	11.1% (3)	14.8% (4)

ACA, anterior corneal astigmatism; ATR, against-the-rule; PCA, posterior corneal astigmatism; TCA, total corneal astigmatism; WTR, with-the-rule

the magnitude or axis orientation of posterior corneal astigmatism in eyes with different stages of KCN.

In the present study, we found that the mean magnitudes for ACA and PCA in our study population were 4.08 ± 2.21 D and 0.86 ± 0.45 D, respectively. Naderan et al[17] evaluated 1273 patients with KCN using Pentacam images and reported that the mean ACA and PCA magnitudes of 4.49 ± 2.16 D and 0.90 ± 0.43 D, respectively, which are very similar to our results. Our findings are also in line with those of Kamiya et al[16] who evaluated ACA and PCA in 137 patients with KCN using the Pentacam HR and reported mean respective magnitudes of 3.93 ± 2.73 D and 0.93 ± 0.64 D. Orucoglu et al[18] also evaluated ACA and PCA in patients with KCN using the Pentacam and reported mean magnitudes of 3.05 ± 1.97 D and 0.71 ± 0.44 D, respectively, which were lower than those in our study.

We found that the prevalence rates of ATR and WTR astigmatism were approximately the same at the anterior and posterior corneal surfaces in our patients with KCN. In contrast, Kamiya et al[16] found that WTR astigmatism was more prevalent at the anterior corneal surface (65.7%) and oblique astigmatism was more prevalent at the posterior corneal surface (78.8%). Our findings are also different from those of Naderan et al,[17] who reported that ATR astigmatism was more prevalent at the anterior corneal surface (57.4%) and that WTR astigmatism was more common at the posterior corneal surface (63.2%) in their patients with KCN.

The notable difference between the findings of our study and those of the two previous studies cannot be attributed to ethnic differences between the study populations. Naderan et al[17] reported that a possible reason for the difference between their Pentacam results for ACA and PCA axis orientation and those of Kamiya et al[16] was that their subjects were of Iranian descent (mostly Caucasian ethnicity), whereas those in the study by Kamiya et al were exclusively Japanese (Asian ethnicity). The difference in axis orientation values obtained in our study and those obtained by Naderan et al[17] cannot be explained by ethnicity because both study populations were Iranian.

Our results showed a high prevalence of WTR ACA in eyes with early stage KCN, which changed to ATR astigmatism in eyes with stage 3 or 4 KCN. In contrast, there was a high prevalence of ATR PCA in stages 1 and 2, which changed to WTR astigmatism in eyes with stage 3 or 4 KCN. Kamiya et al[16] reported a high prevalence of WTR ACA and ATR PCA in the different stages of KCN, which gradually decreased with progression through the stages of KCN, without any change in the most prevalent axis orientation.

We found a significant correlation between the magnitude of ACA and that of PCA, which is in accordance with the reports by Naderan et al[17] and Kamiya et al.[16] We did not find any significant increase in ACA and PCA with the progressive stages of KCN, which again is consistent with the findings of Kamiya et al. However, Naderan et al reported a gradually significant increase in the magnitude of ACA and PCA in eyes with stage 1, 2, and 3 KCN. Although the

Table 4: Published values for mean posterior astigmatism in patients with keratoconus

Study	Country	Year	Imaging modality used	Cases examined, eyes/patients (*n*)	Mean age (Y) ±SD	Mean±SD, Range	Dominant astigmatism orientation	Correlation with ACA
Pinero et al[3]	Spain	2010	Scheimpflug imaging system (Pentacam,)	71/51	16-64	-	-	$r \geq 0.81$
Orucoglu et al[18]	Turkey	2015	Rotating Scheimpflug camera (Pentacam)	656/338	30.95±9.25	0.71±0.44	-	-
Kamiya et al[16]	Japan	2015	Rotating Scheimpflug imaging instrument (Pentacam HR)	137/137	36.9±12.2	0.93±0.64	ATR	$P<0.001$, $r=0.769$
Tomidokoro et al[5]	Japan	2000	Scanning-slit topography (Orbscan)	46/31	24.0±6.9	-	-	$P<0.001$, $r=0.872$
Naderan et al[17]	Iran	2016	Pentacam	-/1273	25±7	0.90±0.43	WTA	$P<0.001$, $r=0.785$
Present study	Iran	2016	Rotating Scheimpflug imaging (Oculus Pentacam)	161/161	22.35±6.10	0.85±0.45	ATR	$P<0.001$, $r=0.839$

findings of our study are similar to those in the above two studies, we detected larger ACA and PCA values in eyes with stage 4 KCN than in those with less severe KCN (stages 1–3). Moreover, there was a trend for a decrease in the prevalence of anterior and posterior oblique astigmatism as the severity of KCN increased. Similar to our findings, Naderan et al[17] reported a decrease in oblique astigmatism at both corneal surfaces as the severity of the disease increased. However, unlike Kamiya et al and Naderan et al, we did not find any relationship between change in axis orientation and severity of KCN.

Our results showed a maximum posterior-anterior corneal astigmatism ratio of 0.246, which was in eyes with stage 1 KCN. To our knowledge, our study is the first to find that the ACA is more affected than the PCA as the severity of KCN increases and that the PCA is more affected than the ACA in early stage KCN. Tomidokoro et al[5] reported that both the anterior and the posterior corneal curvatures were affected in KCN and that these changes could be observed even in early stage KCN, but they did not report in detail on whether the PCA changed with increasing disease severity. In another study, Pinero et al[3] reported that the mean posterior-anterior astigmatism ratio in eyes with subclinical KCN was higher than that in other KCN groups; however, they used a classification system devised by Alio and Shabayek, which is different from the one used in our study.

In conclusion, we found that the mean magnitudes of ACA and PCA were approximately 4 D and 1 D, respectively, and that the prevalence rates of WTR and ATR orientation of the ACA and PCA were higher than those for oblique orientation. The ACA and PCA values were significantly associated with the severity of KCN, and the corneal astigmatism values at the two surfaces were correlated. There was a trend of decreasing oblique astigmatism at both corneal surfaces with increasing severity of KCN. This is the first study to find that the ACA was more affected than the PCA by an increase in the severity of KCN, although the posterior corneal surface was more affected than the anterior corneal surface in the early stages of KCN. Our findings may be helpful for more accurate determination of axis orientation, toric IOL power calculation, and better prescription of rigid gas permeable lenses in the different stages of KCN.

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Conflicts of Interest

There are no conflicts of interest.

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