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Impact of Keratoconus on Contrast Sensitivity

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Abstract:

Objective: Keratoconus (KC) disrupts corneal shape, leading to irregular astigmatism and increased higher-order aberrations (HOA), ultimately affecting visual quality. While visual acuity (VA) remains the standard, its limitations in early KC diagnosis are recognized. This study aimed to evaluate the impact of KC on contrast sensitivity function (CSF), a potentially more sensitive measure of visual performance.

Material and Methods: A case-control design compared CSF in KC patients (n=7) to healthy controls (n=16). All subjects achieved the best-corrected visual acuity (BCVA) of 6/9 or better (logMAR ≤0.10). Corneal topography was measured using Tomey TMS-5 to confirm KC diagnosis. CSF was assessed with the Functional Acuity Contrast Test (FACT).

Results: KC eyes exhibited significantly reduced CSF across all spatial frequencies compared to controls (p-value<0.05). Row A of the FACT chart (representing the lowest spatial frequency, 1.5 cpd) demonstrated the most prominent difference (t (21)=-3.073, p-value=0.003).

Conclusion: Our findings reveal that KC patients, despite achieving good BCVA, demonstrate measurable deficits in CSF. This suggests CSF measurement with FACT may be a valuable tool for the early diagnosis and monitoring of KC, potentially offering a more sensitive and comprehensive assessment of visual function compared to BCVA alone.

Keywords: contrast sensitivity function, functional acuity contrast test, early diagnosis, keratoconus, visual performance, spatial frequency

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Introduction

Keratoconus (KC) is an ectatic corneal disease that involves progressive thinning and steepening of the cornea[1]. Early detection of KC is challenging[2]. While corneal topography is the primary diagnostic tool, relying solely on a single parameter for early diagnosis and monitoring is insufficient. Hence the utilization of corneal pachymetry and higher-order aberration (HOA) data has now become a common practice to identify and monitor the progression of keratoconus[3]. However, the absence of these advanced diagnostic tools in most clinical practices could mis-diagnose or underdiagnose the condition, or a diagnosis could only be made when the condition is already higher in severity grade.

Although visual acuity (VA) is usually used in clinical practice, it offers limited information about the visual system[4]. Castro-Luna and Pérez-Rueda (2020) stated that the difference in best corrected visual acuity (BCVA) between normal eyes and eyes in the early stage of keratoconus (ESKC) was insignificant[5]. It is common that some patients with ocular diseases typically complain of poor vision but have a relatively normal VA[6]. This is because the VA assessed the minimal resolution of a target does not represent the entire vision quality and functioning status. Contrast Sensitivity Function (CSF) examines the ability to distinguish different levels of contrast across a range of spatial frequencies, providing a more comprehensive assessment of visual functioning in real-life scenarios compared with VA[7–9]. A stronger correlation was observed between low CS and diminished vision-related quality of life (VRQoL) compared to high contrast VA[10]. It is reported that the FACT chart has a sensitivity of 50.0%, and a specificity between 68.0 and 100.0%[11].

CS reduction was found to be highly correlated with the increase of HOA and an increase in HOA is strongly related to KC[12–14]. Therefore, understanding the relationship among these three may provide an alternative way to detect the condition and monitor the progression or vision deficits in the future, although without an aberrometer. Moreover, identifying the spatial frequency (SF) that showed reduction in mild and moderate KC was crucial to provide better insights into patient vision function deficits and valuable for ophthalmic practitioners in monitoring the progression of the condition. Hence, the aim of the study was to compare the CSF of eyes diagnosed with KC to that of non-KC.

Material and Methods

The study included subjects between the ages of 18 and 40 with best corrected monocular visual acuity (BCVA) with the spectacle of 6/9 or better. Subjects were divided into two groups: keratoconus, and control group. The keratoconus group included eyes that were diagnosed with keratoconus with Grade 1 to 3 severity based on the Amsler-Krumeich classification system and did not undergo corneal cross-linking treatment. The control group included eyes with similar average keratometry (AvgK) and corneal astigmatism as that of the keratoconus group. All soft contact lens wearers had to remove the lenses at least 30 minutes before the examination, while rigid corneal or scleral lens wearers ceased their CL wear the night before[14] Subjects who had undergone any ocular surgery including refractive surgery, with any systemic or other ocular diseases were excluded.

The visual acuity with spectacle correction was evaluated using a Snellen chart, and the results were later converted into logMAR equivalent. Ocular health was evaluated to ensure the absence of other ocular diseases. TMS-5 Scheimpflug and Topographer (Tomey Co., Ltd, Nagoya, Japan) were performed on all subjects to obtain the AvgK and cornea astigmatism. CSF was assessed monocularly with the BCVA using the trial frame with the Functional Acuity Contrast Test (FACT) chart (Stereo Optical Co., Inc, Chicago, USA) for all five spatial frequencies. Each row contains gratings of a single spatial frequency but with different orientations. Subjects were instructed to report the perceived orientation (e.g., left, right or straight) of the

gratings in each row. The termination criterion for each spatial frequency was established by either an incorrect response or the subject's inability to perceive the orientation. The CSF was then converted to log values for statistical analysis. Statistical Package for the Social Sciences (SPSS) version 29 was utilized for the data analysis. The normality of the data was assessed using the Shapiro–Wilk test. The homogeneity of variances for each data was assessed by Levene's Test for Equality of Variances. For data that showed homogeneity variances, an independent t–test was performed to establish any significant differences between both groups. For data that showed violated homogeneity of variances, the statistical difference between both groups was determined after Welch–Satterthwaite correction.

Results

Seven eyes diagnosed with grades 1 and 2 keratoconus based on the Amsler–Krumeich classification comprised the keratoconus group. The control group consisted of 16 eyes. Demographic data and mean values of relevant parameters for both groups are presented in Table 1. Notably, no statistically significant differences were observed in corneal astigmatism or mean keratometry between the groups. However, BCVA was greater (p–value=0.02), and age was younger (p–value=0.01) in the control group.

Data normality was assessed using the Shapiro–Wilk test. All data satisfied the assumption of normality (p–value=0.05). Consequently, independent–sample t–tests were performed to compare mean log contrast sensitivity between the keratoconus and control groups for each spatial frequency. Mean log contrast values for both groups are presented in Table 2.

Levene's test revealed homogeneity of variance only for data at 1.5 cpd (p–value=0.052). An independent–samples t–test with a 95% confidence interval (CI) for the mean difference demonstrated significantly lower contrast sensitivity in the keratoconus group at 1.5 cpd (t (21)=–3.073, p–value=0.003) compared to controls. The mean difference was –0.176 log units (95.0% CI, –0.296 to –0.057). Levene's test indicated violated homogeneity of variances for data at 3, 6, 12, and 18 cpd (all p–values<0.05). Therefore, Welch's t–test with a Satterthwaite correction was employed for these comparisons. The results demonstrated statistically significant reductions in contrast sensitivity for the keratoconus group compared to controls (mean±S.D. for KC and control, respectively: 1.89±0.09 vs. 1.86±0.11 at 3 cpd, 1.58±0.14 vs. 1.86±0.11 at 6 cpd, 1.21±0.12 vs. 1.77±0.11 at 12 cpd, and 0.72±0.12 vs. 1.21±0.12 at 18 cpd). The corresponding mean differences with 95.0% CI were –0.24 (–0.43 to –0.045), –0.33 (–0.66 to 0.00), –0.56 (–1.22 to 0.11), and –0.49 (–0.97 to –0.00), respectively.

Table 1 Demographic data of the two groups in the study

Parameters	Keratoconus group	Control group	p–value
Number of eyes	7	16	
Age (Mean±S.D.)	30.4±8.1	21.5±0.7	0.01*
Mean BCVA (logMAR)	0.09±0.04	0.02±0.04	0.02*
Mean SER (D)	–1.45±1.96	–6.40±3.21	
Mean corneal astigmatism (D)	–3.86±–1.96	–3.23±0.78	0.14
Mean average keratometry (D)	44.88±1.86	45.08±1.24	0.38

*=Significant
BCVA=Best corrected visual acuity, SER=Spherical equivalent refraction, D=diopter

Table 2 Mean Log Contrast values for both groups for each row with the statical results

Row Log contrast value	Mean log contrast value		Parametric independent t-test Parametric independent t-test keratoconus versus control (t(df): t-statistic, p=significance value)
	Keratoconus group	Control group	
A	1.47±0.19	1.64±0.09	*t* (21)=-3.073, p=0.003**
B	1.65±0.21	1.89±0.09	*t* (7)=-2.911, p=0.011*
C	1.53±0.36	1.86±0.12	*t* (7)=-2.336, p=0.027*
D	1.02±0.72	1.58±0.14	*t* (6)=-2.041, p=0.043*
E	0.72±0.52	1.21±0.12	*t* (6)=-2.441, p=0.024*

*=Significant (p-value<0.05),
**= Significant (p-value<0.01)

Discussion

The present study found that the contrast sensitivity (CS) was reduced in all spatial frequencies (SF) for the keratoconus group compared to the control group although the BCVA in both the groups was the same. The prevalence of KC is 1.2% in Malaysia reported in a cornea specialist centre[15]. Studies found CS deficits during the early stage of various ocular diseases that may not be apparent in high contrast visual acuity (VA) including cataracts, diabetic retinopathy, and glaucoma[6,16–18]. The early stage of keratoconus (ESKC) is usually asymptomatic and only detectable with the aid of video keratography as the VA is usually affected only when the disease progressed to a later stage. Hence the assessment of CS was more vulnerable and could be considered a more sensitive indicator to detect any vision function anomaly for the keratoconus (KC) patient compared to just VA measurements[19].

The reduction in CS could be due to the increment of ocular higher-order aberration (HOA) in KC. Studies reported that spherical and higher-order aberrations (HOA) significantly increase in KC eyes, especially coma aberration that showed greater increment[12,20,21]. The coma aberration was shown to be about 3.74 times greater in KC than in normal[21]. This is because an ectatic cornea in KC usually presents with higher topographic indices, including inferior-superior value (I-SV), surface asymmetry index (SAI) and irregular astigmatism index (IAI), which represent the asymmetric power distribution in the cornea[22,23]. Increases in these topographic values meant an increase in cornea irregularity, which raised the HOA and led to a reduction in CS[23,24].

The present study only evaluated the impact of the average cornea curvature (AvgK) and cornea astigmatism but not the relationship between these topographic indices and CS. This is because most of the KC classification systems incorporate AvgK as one of the parameters for grading the severity[25,26]. Whilst, progression increase in cornea astigmatism was also the characteristic for KC[3]. Both groups in The present study demonstrated comparable AvgK and cornea astigmatism. This elucidates that the reduction of CS observed in the KC group was attributed to cornea asymmetry and irregularity rather than the increase in average keratometry and corneal astigmatism, which are commonly observed in keratoconus patients.

On the other hand, the 'cone' or the apex location in the cornea has different influences in the CS. Liduma and Krumina (2017) found that although the CS for both the apex at the center cornea (1.5 mm radius around the pupil) and at the periphery showed statistically significant decrement from normal CS curve (p-value<0.05), however, with the apex at the periphery exhibited a better CS at all SF compared to apex at the center, a more noticeable

deviation was starts with 7 cycles/degree (cpd)[27]. The also indicated that having the apex at the center demonstrated a greater difference in low to medium SF (3, 5 and 7 cpd) while with the apex at the periphery was more significant at medium to high SF (5, 7 and 11 cpd). All the KC subjects in this present study exhibit a cone apex at the center which leads to the expectation that low to medium SF will be more notably affected. Zhao et al. (2017) found that CS in low and medium SF (1.5, 3, and 6 cpd) was reduced significantly associated with the increased horizontal coma aberration while at the high SF (12 and 18 cpd), CS reduced with the rise of vertical trefoil aberration. As discussed earlier, coma aberration demonstrated the most significant increase in KC, leading to the belief that the low to medium SF would be most affected[2].

In the present study, the CS showed the most significant reduction in Row A (1.5 cpd) in the keratoconus group (p-value<0.01). This finding aligns to the two statements mentioned earlier: having the 'cone' apex at the center and an increase of coma aberrations in KC, both will affect the CS in low SF. Yet, there was no previous study that evaluated the CS in KC with the FACT chart that was comparable with the present study.

Shneor, Pinero and Doron (2021) used Gabor patches with an interval 2 alternative forced choice staircase procedure to evaluate the CS threshold in medium to high spatial frequencies (6, 9, and 12 cpd). The results showed that the CS was notably diminished in KC (all p-value<0.001) and KC with 0.00 LogMAR VA (p-value<0.001 for 6 cpd; p-value=0.001 for 9 and 12 cpd) in contrast to normal control groups[14]. They reported that the focus on measuring the medium and high frequencies in this study was because these frequencies were found to be diminished in individuals with KC before the VA was affected. In other words, the KC subjects exhibit a higher CS threshold for the three SF evaluated.

A study evaluated the quick CSF (qCSF) for 215 KC eyes with three severity group that were categorized based on their maximum keratometry of the anterior corneal surface (Kmax≤48D; 48D<Kmax≤55D; Kmax>55D for Group 1, Group 2 and Group 3 respectively)[6]. They reported that qCSF at 1 and 1.5 cpd was statistically lower in Group 3 than in Group 1 and 2 but it was not significant between Group 1 and 2. In addition, they also found that the CS from 3 cpd to 18 cpd decreased notably among all three groups as the severity increased. As they do not compare with normal subjects, it was unclear that the mild KC subject exhibiting CS reduction began in which SF. Moreover, Bilen, Hepsen, and Arce (2016) reported a mean log CS value of 1.25±0.46 with the Hamilton-Veale letter-contrast sensitivity chart in a total of 71 eyes with early to moderate KC[24]. Okamoto et al. (2007) that also utilized a letter-contrast sensitivity chart (CSV-1000 LV chart, Vector Vision) with 2.4 cpd showed a significant lower in KC eyes (17.4±3.8 letters) compared to normal eyes (21.8±1.4 letters)[13]. However, a globally accepted and standardized CS tests method has not been found yet[28]. A study to compare three different types of CS test revealed that different instruments or charts exhibited different characteristics and the results may not be interchangeable[29]. Therefore, although these studies identified a decrement of CS in KC eyes, supporting the results of the present study, the contrast arises due to the variation in testing instruments and utilization of different values.

There are some suggestions from the results of the present study which can be applied to future studies. Primarily, the measurement of pupil size plays a critical role when evaluating the CS. Larger pupil size may induce spherical aberration and smaller pupil size has higher diffraction that may affect the CS results[30]. Next, the age range between the two groups needs to be comparable as studies found generally lower CS in elderly populations[31,32]. However, CS was found to start to reduce around 40

years[14,33]. Li et al. (2020) also found that 20 to 40 years age group demonstrated the highest mean CS compared to the other two age groups (41–60 years and >60 years)[34]. According to Beazley et al. (1980), the CS increases with age at all SF until the maximum levels in 18 years old. In the present study, all the subjects included were above the age of 18 and were not more than 40 years old[35]. Hence, it can be assumed that the influence of age variance was minimal. Further investigation of FACT tests in patients with early or forme fruste keratoconus is encouraged.

Conclusion

Contrast sensitivity does have an impact on keratoconus. Contrast sensitivity was reduced in eyes with KC compared to the control for all spatial frequencies even when the visual acuity was normal or not significantly affected. Incorporating contrast sensitivity testing with visual acuity tests provides more valuable insight into patients' vision functioning status and can act as a fast and easy diagnostic and monitoring tool in clinical practice. The FACT chart is easy and effective in measuring the contrast sensitivity of keratoconus patients.

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