Contrast and glare testing in keratoconus and after penetrating keratoplasty

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Aim: To compare the performance of keratoconus, penetrating keratoplasty (PK), and control subjects on clinical tests of contrast and glare vision, to determine whether differences in vision were independent of visual acuity (VA), and thereby establish which vision tests are the most useful for outcome studies of PK for keratoconus.

Methods: All PK subjects had keratoconus before grafting and no subjects had any other eye disease. The keratoconus (n = 11, age 35.0 (SD 11.1) years), forme fruste keratoconus (n = 6, 33.0 (13.0)), PK (n = 21, 41.2 (7.9)), and control (n = 24, 33.7 (8.6)) groups were similar in age. Vision testing, conducted with optimal refractive correction in place, included low contrast visual acuity (LCVA) and Pelli-Robson contrast sensitivity (PRCS) both with and without glare, as well as VA.

Results: Normal subjects saw better than PK subjects who in turn saw better than keratoconus subjects on all raw measures. However, when adjusted for VA, the normal group only saw significantly better than the keratoconus group on LCVA (low contrast loss 0.05 (0.04) v 0.15 (0.12), F2,48 = 6.16; p < 0.01, post hoc Sheffe p < 0.05), and the decrements to glare were no worse than for normals. The forme fruste keratoconus group were indistinguishable from normals on all measures.

Conclusions: PK subjects have superior vision to keratoconus subjects, but not as good as normal subjects. Including mild keratoconus subjects within a keratoconus group could confound these differences in vision. While VA is an excellent test for comparing normal, keratoconus and PK groups, additional information can be provided by LCVA and PRCS, but not by glare testing. Outcomes research into keratoconus management should include a measure in the contrast domain.

Keratoconus was first described by Nottingham in 1854, and has been comprehensively reviewed by several authors since. Visual acuity (VA) has been the mainstay of assessing the progression of the severity of keratoconus and the effectiveness of treatment. Visual acuity is also an important factor in determining the change in treatment method from spectacles to rigid contact lenses and on to penetrating keratoplasty (PK). However, the inadequacy of high contrast VA as an indicator of visual quality is widely appreciated.

Several studies have investigated other measures of vision in keratoconus. Most of these have looked at contrast sensitivity (CS), and some have demonstrated that the loss of contrast sensitivity in keratoconus cannot be predicted from VA measurement. The value of low contrast visual acuity (LCVA) testing in keratoconus is less clear. While LCVA has shown to be reduced in keratoconus, the independence of this reduction from VA has not been established.

Penetrating keratoplasty has been demonstrated to be an effective treatment for keratoconus, as measured by an improvement in VA. However, contrast vision after PK for keratoconus has not been so well studied. Contrast sensitivity after PK is usually better than in keratoconus, but not in all studies. Further research on this seems warranted. Low contrast visual acuity in PK has had minimal investigation with one study reporting some abnormal values, and another showing no difference from keratoconus eyes. Glare testing in keratoconus and PK subjects has been the subject of several small studies that have shown glare losses in keratoconus greater than in normals or PK subjects. However, two studies have shown glare losses greater after PK than in keratoconus. This confusion is at odds with the clinical impression that patients benefit from PK. This inconsistency seems worthy of further investigation.

In this study, LCVA and CS, with and without glare, were measured and compared across age similar groups of keratoconus, PK, forme fruste keratoconus, and normal subjects. This was done to determine whether LCVA detected losses in keratoconus subjects that were independent of VA, to add to the published data on contrast vision in PK subjects, and to investigate the value of glare testing in keratoconus and PK subjects. Vision was assessed using standard clinical tests so that those which proved most useful could then be used for routine clinical testing, or incorporated into a protocol for PK for keratoconus outcomes research. The study groups were selected to be uncomplicated, stable, and typical of the condition and, in addition, a forme fruste keratoconus group was included to investigate the potential confounding effect of disease severity sampling on comparing keratoconus subjects with PK and normal subjects.

SUBJECTS AND METHODS

Informed consent was obtained from all subjects after the nature of the study had been fully explained. The tenets of the Declaration of Helsinki were followed and the study gained approval from the Flinders University ethics committee. Inclusion criteria were age 15 years or older, and normal healthy eyes with a VA better than 0.1 logMAR (6/7.5 Snellen equivalent) for the control group, or keratoconus (for the keratoconus group), or having undergone PK for keratoconus with an uncomplicated postoperative course (for example, no melting).
rejection, cataract development, etc) of at least 12 months
(for the PK group). Keratoconus was defined by the staging
system of Krumeich et al as being at least stage 1 (eccentric
corneal steepening, induced myopia/astigmatism <5D, corneal
radians <48D, Vogt’s striae, no scars). Subjects with
probable mild keratoconus as suggested by a history of
keratoconus or having had PK for keratoconus in the other
eye, as well as abnormal retinoscopy but not meeting the
criteria for stage 1, were included as a separate forme fruste
keratoconus group.

Exclusion criteria were any ocular pathology (other than
keratoconus for the keratoconus group) or abnormality such
as amblyopia and strabismus, any previous ocular surgery
(other than penetrating keratoplasty for the PK group), any
neurological problem, systemic disease, or taking of any
medication which may affect contrast sensitivity, inability to
speak English sufficiently to be instructed to perform the
tests, insufficient mental ability to perform the tests, and
physical disability which would make it arduous to perform
the tests (for example, wheelchair bound). Subjects with
keratoconus and PK for keratoconus were drawn from the
anterior segment clinic of the Department of Ophthalmology
at Flinders Medical Centre (FMC) on a consecutive attend-
dance basis. Control subjects were drawn from medical
students and staff of FMC.

Data were collected on the visual performance of 11 eyes of 11
keratoconus subjects, six eyes of six forme fruste keratoconus
subjects, 21 eyes of 21 PK subjects, and 24 eyes of 24 normal subjects. The subjects had a mean age of 36.4
(SD 9.8) years. Data were collected in a single session. All
subjects were refracted and optimally corrected before data
collection. For the subjects who normally wore contact lenses (keratoconus 8/11, PK 7/21, normal 2/24) refraction
and optimal correction took place over their contact lenses. The
measurements taken were logMAR high contrast visual
acuity, LCVA, Pelli-Robson contrast sensitivity (PRCS),
LCVA with glare, and PRCS with glare.

Both VA and LCVA were measured on a computerised
monitor based system.24 The program utilises the psychophy-
sical “staircase” method, using a forced choice protocol, to
determine the acuity end point, which is taken as the average
of 13 staircase reversals. This offers excellent reliability and
validity and is free from learning effects. The program uses
the same 5x4 letters used in Bailey-Lovie logMAR charts and the
results are given in logMAR.25 Low contrast visual acuity
is analogous to VA testing except that the target optotypes are
reduced in contrast. Twenty five per cent (Weber) contrast
optotypes were utilised since this has been reported to be the
most suitable contrast level for detecting visual loss in early
cataracts under glare conditions and thus may be suitable for
keratoconus subjects.33 Testing was conducted at 3.0 metres
and the monitor had a maximum luminance of 185 cd/m².
Low contrast visual acuity was also measured under glare
conditions (LCVAglare).

There is no accepted standardised method for glare testing.
In this study, LCVA and Pelli-Robson contrast sensitivity
were measured with and without the presence of a light
source directed at the subject. The glare source consisted of
two projection lamps placed either side of the test chart and
monitor. The baseline room illuminance was 80 lux. The
luminance of the projector sources was 1800 cd/m². Natural
pupils were used and care taken to ensure neither occlusion
of the glare source nor macular photostress occurred.34

The Pelli-Robson contrast sensitivity (PRCS) chart was
used according to previously published methodology.35 36 This
test was chosen from among other available clinical charts for
its superior validity and reliability36 37 especially compared to
sinusoidal grating charts such as the Vistech and FACT.38 The
use of a letter reading task for both CS and LCVA testing also
allowed easy comparison of the two techniques. The Pelli-
Robson chart was positioned 3 metres from the subject and
had a luminance of 100 cd/m². The test was scored by the
modified method of letter by letter scoring,39 and results were
given in units of log contrast sensitivity (logCS). Contrast
sensitivity was also measured under the same glare condi-
tions (PRCSglare) as LCVAglare.

The results are reported as raw measures and three derived
measures of contrast and glare loss. Taking the simple
arithmetic difference between glare and no glare, or high and
low contrast demonstrates the effect of contrast or glare
independent of baseline VA or CS. This facilitates comparison
of groups of disease versus no disease where matching for VA
is not possible. Low contrast loss (LCL) is defined as the
difference between the high contrast VA and LCVA: LCL = LCVA – VA.40 41 Low contrast visual acuity glare loss
(GLvLCVA) is defined as the difference between the LCVAglare
and LCVA: GLvLCVA = LCVAglare – LCVA.40 Pelli-Robson
contrast sensitivity glare loss (GLPRCS) is defined as the
difference between PRCS and PRCSglare: GLPRCS = PRCS –
PRCSglare.40

One way analyses of variance (ANOVA) with Sheffé post
hoc significance testing were used to compare groups. All
statistical analyses were performed on the SPSS software
package v10.0 (SPSS Inc, Chicago, IL, USA).

RESULTS

The results of visual performance of the normal control group
and the study groups are listed in Table 1. The three groups
were similar for age (F2,39 = 3.32; p > 0.05). The normal
controls performed better on all raw vision measures than
both the keratoconus and PK groups. Similarly, the PK group
performed better than the keratoconus group. However, as
the groups were not matched for VA (F2,49 = 30.60; p<0.001),
they were also compared using three difference measures.
Only two significantly different results were identified. The
keratoconus group had a greater low contrast loss than the
normal group (0.15 (0.12) v 0.05 (0.04), F2,49 = 6.16; p<0.01,
post hoc Sheffe p<0.05)—that is, the measurement of LCVA
identified loss of vision in the keratoconus group not
predicted by VA testing. Conversely, the keratoconus group
had a smaller glare loss with the Pelli-Robson contrast
sensitivity chart than the normal group (-0.16 (0.36) v 0.07
(0.16), F2,49 = 4.23; p<0.05, post hoc Sheffe p<0.05)—that is,
the vision in the normal group worsened under glare but
improved in the keratoconus group. On all three difference
measures the PK group was indistinguishable from the
normal and keratoconus groups. Low contrast visual acuity
and CS testing did identify visual loss in keratoconus and PK
not appreciated with VA testing, but glare testing did not
provide any such useful information.

To examine the influence of disease severity on vision loss
in the keratoconus group, a forme fruste keratoconus group
was also tested. This group was age similar (33.0 (13.0) years;
p>0.05) and was also indistinguishable from normals on all
measures of vision (VA -0.15 (0.04) p>0.05; LCVA -0.06
(0.08) p>0.05; LCVAglare -0.03 (0.09) p>0.05; PRCS 1.65
(0.12) p>0.05; PRCSglare 1.5 (0.15) p>0.05; LCL -0.05
(0.05) p>0.05; GLvLCVA 0.03 (0.09) p>0.05; GLPRCS 0.00 (0.13)
p>0.05).

DISCUSSION

The normal control group performed significantly better on
all raw measures of vision compared to the keratoconus and
PK groups. However, this chiefly reflects that the normal and
study groups were not matched for VA. When adjusting for
VA differences by using the difference measures low contrast
loss and glare loss, the normal group was only significantly
better on LCL (logMAR drop between VA and LCVA) and
Table 1  Mean (SD) for the five raw vision measures* and three difference measures† in normals, keratoconus, and penetrating keratoplasty subjects

<table>
<thead>
<tr>
<th></th>
<th>Normal (n = 24)</th>
<th>Keratoconus (n = 11)</th>
<th>PK (n = 21)</th>
<th>Statistics</th>
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</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>33.7 (8.6)</td>
<td>35.0 (11.1)</td>
<td>41.2 (7.9)</td>
<td>(F₂,42 = 30.60; p&lt;0.001 post hoc normal-keratoconus, p&lt;0.001, normal-PK, PK-keratoconus, p&lt;0.001)</td>
</tr>
<tr>
<td><strong>Visual acuity</strong></td>
<td>−0.18 (0.05)</td>
<td>0.17 (0.22)</td>
<td>−0.03 (0.11)</td>
<td>(F₃,42 = 41.70; p&lt;0.001 post hoc normal-keratoconus, normal-PK, p&lt;0.001, PK-keratoconus, p&lt;0.001)</td>
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<tr>
<td><strong>Low contrast visual acuity</strong></td>
<td>−0.12 (0.06)</td>
<td>0.29 (0.23)</td>
<td>0.10 (0.12)</td>
<td>(F₃,42 = 31.87; p&lt;0.001 post hoc normal-keratoconus, normal-PK, p&lt;0.001, PK-keratoconus, p&lt;0.001)</td>
</tr>
<tr>
<td><strong>Low contrast visual acuity under glare</strong></td>
<td>−0.11 (0.08)</td>
<td>0.35 (0.28)</td>
<td>0.08 (0.14)</td>
<td>(F₂,42 = 30.60; p&lt;0.001 post hoc normal-PK, PK-keratoconus, p&lt;0.001)</td>
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<tr>
<td><strong>Pelli-Robson contrast sensitivity</strong></td>
<td>1.80 (0.13)</td>
<td>1.10 (0.28)</td>
<td>1.39 (0.22)</td>
<td>(F₂,42 = 50.59; p&lt;0.001 post hoc normal-PK, normal-keratoconus, normal-PK, p&lt;0.001, PK-keratoconus, p&lt;0.001)</td>
</tr>
<tr>
<td><strong>Pelli-Robson contrast sensitivity under glare</strong></td>
<td>1.73 (0.11)</td>
<td>1.25 (0.46)</td>
<td>1.41 (0.21)</td>
<td>(F₂,42 = 17.09; p&lt;0.001 post hoc normal-keratoconus, p&lt;0.001, normal-PK, p&lt;0.01)</td>
</tr>
<tr>
<td><strong>Low contrast loss</strong></td>
<td>0.05 (0.04)</td>
<td>0.15 (0.12)</td>
<td>0.12 (0.09)</td>
<td>(F₂,42 = 4.16; p&lt;0.05 post hoc normal-keratoconus, p=0.05)</td>
</tr>
<tr>
<td><strong>Glaré loss (low contrast visual acuity)</strong></td>
<td>0.02 (0.08)</td>
<td>0.06 (0.11)</td>
<td>−0.02 (0.08)</td>
<td>(F₂,42 = 4.23; p&lt;0.05 post hoc normal-keratoconus, p=0.05)</td>
</tr>
<tr>
<td><strong>Glaré loss (Pelli-Robson contrast sensitivity)</strong></td>
<td>0.07 (0.11)</td>
<td>−0.16 (0.36)</td>
<td>−0.01 (0.21)</td>
<td>(F₂,42 = 4.23; p&lt;0.05 post hoc normal-keratoconus, p=0.05)</td>
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*Visual acuity (VA), low contrast visual acuity (LCVA), low contrast visual acuity under glare (LCVAglare) (all in logMAR), Pelli-Robson contrast sensitivity (PRCS), Pelli-Robson contrast sensitivity measured under glare (PRCSglare) (both in logCS).
†Low contrast loss = LCVA – VA, low contrast glare loss = LCVAglare – LCVA, PRCS glare loss = PRCS – PRCSglare.

only compared to the keratoconus group (normal 0.05 (0.04), keratoconus 0.15 (0.12); p<0.05). The PK group was indistinguishable from both normal and keratoconus groups on these three difference measures. This suggests that VA is a very effective measure for distinguishing between normal, keratoconus, and PK subjects, but that CS and LCVA do provide some additional information.

Previous studies on keratoconus subjects have found reduced LCVA compared to normal subjects, but none of these studies controlled for VA by looking at LCL. However, deriving LCL from published VA and LCVA data suggests there is slightly greater LCL in keratoconus subjects compared to normals (at 10% but not 30% contrast), slightly more LCL in keratoconus subjects with apical corneal scarring compared to keratoconus subjects without scarring, and greater LCL in more severe keratoconus. While these reports support our findings, these differences were not tested statistically. Similarly, previous studies where CS was measured in keratoconus found reduced CS compared to normals, in some cases these losses were shown to be independent of VA. Two of these studies measured PRCS in keratoconus. Rose et al found smaller losses of PRCS than we did, which may have been because they reported binocular measurements, or because their keratoconus group were less impaired than ours, which is possible since they gave no definition of keratoconus, and all subjects were able to habitually wear their optimal correction. Conversely, Brahma et al’s group had much worse PRCS and VA than ours, but this was because their group were all presenting for surgery and were therefore unable to achieve satisfactory visual correction. This conclusion is supported by their VA and PRCS data for the other eye, which were better than our keratoconus data, although these data were a mix of 12 keratoconus and six PK eyes. Another possible reason for differences between studies is a difference in the relative proportions of those wearing RGP contact lenses, as these have been shown to improve contrast sensitivity in keratoconus compared to spectacle wearers.

Low contrast visual acuity data in PK subjects has previously been shown to include subnormal values in one series, and to be indistinguishable from keratoconus eyes in another. Subnormal CS after PK for keratoconus has also been shown previously. Two longitudinal studies of keratoconus subjects before and after PK both found improved CS after PK. Several cross sectional studies comparing PK to keratoconus eyes support this finding. Our data consolidate these findings, in that subjects with fully healed PK have CS better than keratoconus subjects, but not as good as normals, and LCVA losses which do not exceed normals. Those studies where PK subjects have been shown to have greater deficits in CS than keratoconus subjects were either in the early postoperative period, or during a rejection episode.

The two glare loss measures did not yield any further vision losses in the keratoconus and PK groups, not identified with LCVA or PRCS testing alone. For GL/C, all groups were similar, but for Gl/P, the normal group (0.07 (0.11)) was significantly worse than the keratoconus group (0.16 (0.36); F₂,42 = 4.16; p<0.05, post hoc Sheffe’ p<0.05). While the keratoconus group did better than the normal group in terms of the change in CS under glare conditions the raw PRCS under glare scores were still worse in the keratoconus group compared to the normals (1.41 (0.21) v L73 (0.11); F₂,42 = 17.09; p<0.001, post hoc Sheffe’ p<0.001). That glare testing is of no value in either keratoconus or PK reflects that the main mechanism of visual loss in keratoconus and PK is optical aberration rather than light scatter. Our same experimental set-up finds large glare losses in cataract since the main mechanism of optical disturbance from cataract is forward light scatter. If the main problem is aberrations, visual performance must be pupil dependent. The use of natural pupils, which will constrict in the presence of a bright glare source, reduces the chance of finding decreased visual performance under glare and, in this study, probably explains the significant increase in PRCS in the presence of glare for the keratoconus group. This raises the possibility that glare testing with a less bright glare source may be more useful in keratoconus. Alternatively, instead of testing vision under glare, perhaps low illumination testing, such as with the Smith Kettlewell Institute Low Luminance (SKILL) Card, which could allow use of maximum natural pupil size and hence sample more aberrated optics, may be more appropriate in keratoconus.

The only longitudinal study of keratoconus subjects before and after PK (n = 18), in which glare testing was done (using the Brightness Acuity Tester (BAT) with VA and PRCS...
Defining the point along a spectrum from normal to disease state at which the transition from one entity to the other occurs is not a difficulty confined to keratoconus. However, for keratoconus this difficulty has led to debate over the existence of unilateral keratoconus, issues for study design, and difficulty determining patient suitability for laser-refractive surgery. For this study we defined keratoconus according to an accepted, but conservative, system. To illustrate that the inclusion of more mild cases of keratoconus could confound the results, we also tested a group of six forme fruste keratoconus subjects. This group were indistinguishable from the normal group on all vision measures. If we had included these subjects in the keratoconus group then the results of this study would have been different. This highlights the problem of sampling disease severity for cross-sectional design studies. This problem could be avoided by using a longitudinal outcome study design. Indeed, the clinical impression that PK patients see better than keratoconus patients arises from comparing pre-PK keratoconus patients who want visual improvement to their post-PK state. Such pre-PK keratoconus subjects often proceed to surgery because they are unable to tolerate optimum refractive correction, so it is possible that this clinical impression is exaggerated by undercorrection of refractive error. Thus it is important in longitudinal study execution to ensure vision testing is conducted with optimal refraction in place.

While PK provides vision superior to keratoconus, it does not achieve levels of vision as good as normals. The pursuit of improvement in the surgical management of keratoconus requires vision testing to establish these improvements. Based on our findings, studies of treatments for keratoconus should include a measure of contrast vision, either PRCS or LCVA.

ACKNOWLEDGEMENTS
KP is supported by NHMRC Sir Neil Hamilton Fairley Fellowship 0061.

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