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Intraocular pressure in keratoconus

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Abstract:

Aims: To investigate IOP measurements with the dynamic contour tonometer (DCT) and non contact tonometer (NCT) in subjects with keratoconus.

Methods: Twenty keratoconic subjects and 20 age-matched control subjects had IOP measurements taken using DCT and NCT instruments. Central and off-centre measures were taken with the DCT in order to highlight any systematic errors associated with corneal biomechanical factors. Measures of anterior and posterior corneal topography and thickness were also taken for each subject.

Results: No significant difference was found between the central and off-centre DCT IOP readings for the keratoconics and age-matched controls ($p>0.05$). The average DCT IOP for the keratoconics was 14.2 ± 1.4 mmHg and for the age-matched controls was 14.2 ± 1.6 mmHg. However, the average NCT readings differed significantly ($p<0.001$) between the keratoconics (9.2 ± 1.5 mmHg) and age-matched controls (12.9 ± 2.4 mmHg). DCT IOP showed no significant ($p>0.05$) correlation with the severity of keratoconus, as determined through measures of corneal topography and thickness. NCT IOP was correlated significantly with certain measures of corneal curvature and thickness in the keratoconic population. The difference between DCT and NCT IOP was strongly correlated with measures of corneal topography and thickness, with differences increasing for more advanced keratoconus.

Conclusions: The measurements from the DCT do not appear to be dependent upon corneal factors, unlike the NCT. The presence or severity of keratoconus was not correlated with DCT IOP values.

Keywords: Keratoconus, intraocular pressure, dynamic contour tonometry, corneal topography, corneal thickness.

Introduction:

Keratoconus is a non-inflammatory, usually bilateral (although often asymmetric) corneal condition known to result in substantial alterations in the shape, thickness and biomechanical properties of the cornea (Edmund 1989; Rabinowitz 1998; Luce 2005; Hayes et al. 2007; Shah et al. 2007; Touboul et al. 2008). The corneal changes associated with keratoconus, may potentially lead to difficulties in the accurate determination of intraocular pressure (IOP) in these patients, as tonometric devices based upon the applanation principle, are known to be affected by altered corneal parameters (Whiteacre & Stein 1993; Damji et al. 2003; Liu & Roberts 2005).

Previous studies investigating IOP in keratoconus using applanation tonometric techniques have highlighted the potential inaccuracies of these measures in keratoconus, and typically note patients with keratoconus to exhibit lower than normal IOP (Brooks et al. 1984; Swann & Waldron 1986; Edmonds 1993; Goodman et al. 1996; Böhm et al. 1997; Patel & McLaughlin 1999; Browning et al. 2004). The majority of these studies suggest the IOP levels found in keratoconic subjects are falsely low, due to errors associated with applanation tonometry in measuring corneas with altered biomechanical properties.

The Pascal Dynamic Contour Tonometer (DCT) (Ziemer Ophthalmic Systems, Port, Switzerland) is a newly introduced contact instrument for measuring IOP. The DCT is based upon the principle of contour matching, and theoretically measures IOP independently of corneal thickness and biomechanical properties

(Kanngiesser et al. 2005). Recent clinical studies of normal subjects indicate that IOP measures from the DCT are relatively unaffected by corneal properties (Kaufmann et al. 2004; Kanngiesser et al. 2005; Kotecha et al. 2005; Ku et al. 2006; Schneider & Grehn 2006). The DCT might therefore be expected to provide a more accurate reflection of IOP in keratoconic patients. A number of recent studies have investigated IOP with the DCT in keratoconus patients (Barreto et al. 2006; Ozbek et al. 2006; Meyenberg et al. 2008; Mollan et al. 2008; Papastergiou et al. 2008; Schädle et al. 2008). These studies have reported the DCT to give higher IOP readings than applanation tonometry. However, some investigators have suggested that the DCT may be influenced to some degree by corneal biomechanical properties in eyes with irregular corneas (Barreto et al. 2006; Meyenberg et al. 2008).

In this study, we investigated IOP measures using the DCT instrument in subjects with keratoconus and an age-matched control population, using a protocol utilizing both central and off-centre IOP readings (designed to highlight any dependence of the technique upon corneal factors). We compared these IOP readings with those from an applanation tonometer (a non-contact tonometer). In order to examine the potential relative dependence of IOP measures upon corneal factors, each subject also underwent a comprehensive series of corneal topographical and biometric measures.

Materials and methods:

Twenty subjects previously diagnosed with keratoconus, and 20 age-matched control subjects participated in this study. The mean age of the two populations of subjects was 32 ± 6 years and 30 ± 5 years for the keratoconics and controls respectively. Both populations consisted of 10 male and 10 female subjects. No subject reported a history of any ocular pathology (apart from keratoconus), including glaucoma or ocular hypertension. Six of the keratoconic subjects wore rigid gas permeable (RGP) contact lenses on a full-time basis, and 7 of the normal subjects were soft contact lens wearers. Each subject underwent an initial ophthalmic examination to ensure good ocular health and to determine their refractive status. We excluded any eyes that exhibited significant corneal scarring, of greater than grade 1 according to the grading scale of McMahon et al. (2006).

Measurements were performed on the right eye only for the normal population, but for the keratoconic subjects, measurements were performed on both eyes and data from the most advanced keratoconic eye was used in all analyses. One keratoconic subject had a history of penetrating keratoplasty to one eye, and another exhibited substantial (grade 2) corneal scarring in one eye only, and so their fellow eye was used. To ensure that diurnal variations in IOP and corneal thickness had minimal confounding effects on our results, all measurements were collected between 10am and 4pm and at least 2 hours after subjects woke (Read et al 2008). Approval from the university human research ethics

committee was obtained prior to commencement of the study and all subjects were treated in accordance with the declaration of Helsinki.

A series of four anterior corneal topography readings using the Medmont E300 videokeratoscope (Medmont Pty. Ltd., Victoria, Australia) and five measurements of corneal thickness and posterior corneal topography using the Pentacam HR rotating Scheimpflug camera (Oculus Inc, Wetzlar Germany) were taken for each subject. For one keratoconic subject, reliable, well focussed measurements with the Medmont E300 were unable to be captured due to anatomical factors, and therefore videokeratoscopic measurements were obtained with the Keratron videokeratoscope (EyeQuip Division, Alliance Medical Marketing, Jacksonville, FL).

Following the collection of corneal data, measurements of IOP were carried out using the Canon Tx-F Full Auto Non-Contact Tonometer (Canon USA Inc, Lake Success, NY, USA), and the Pascal DCT (Ziemer Ophthalmic Systems, Port, Switzerland). The Canon TX-F Full Auto Tonometer is a non-contact “air-puff” tonometer based on the applanation principle. Non-contact tonometers estimate IOP by determining the force required for a pulse of air to applanate a known area of the cornea (Grolman 1972). The DCT is an electronic contact tonometer that works on the principle of contour matching and has been described in detail elsewhere (Kanngiesser et al 2005). The instrument has a concave tip (with a diameter of 7 mm and radius of curvature of 10.5 mm), that makes contact with

the corneal surface. Once the cornea conforms to the shape of the tip, (i.e. when contour matching between the cornea and instrument occurs), a small piezo-resistive sensor (of diameter 1.2 mm) built into the centre of the instrument's tip provides a direct measurement of IOP.

For each subject, three NCT IOP measurements and four valid DCT measures (i.e. with a quality score of 3 or better) were taken, with the DCT measures always performed last. Two DCT measures were captured with the instrument contacting the central cornea, and two were captured with the instrument (angled at ~15°) contacting the temporal non-central cornea, with central and off-centre measures alternated in sequence. We limited the number of DCT measures at each corneal location to 2 in order to reduce any changes in IOP due to repeated corneal contact (Johannesson et al 2008). For one subject, reliable off-centre DCT measures were unable to be collected due to a narrow palpebral aperture, therefore only their central measurements were used in analysis. Based upon analysis of each subject's corneal data along the horizontal meridian, we estimated that the DCT sensor tip came in contact with the cornea at a point approximately 2 mm temporal to centre for the off-centre IOP measures.

Statistical analysis:

Following data collection, the raw corneal topography and thickness data from the instruments were analysed using customised software to calculate average maps for each subject. The mean and steepest axial curvature (anterior and

posterior) was calculated over the central 4mm for each subject. The average anterior corneal height maps were analysed to determine the wave aberrations of the anterior corneal surface for a 4 mm pupil. The higher order RMS (HO RMS) was then derived from the corneal wavefront for each subject. Each subject's corneal thickness maps were also analysed to determine the central corneal thickness (CCT), and the minimum corneal thickness (MinCT), as well as the average corneal thickness over the central 4 mm and the thickness at a point 2mm temporal from map centre (i.e. the approximate point of corneal contact for the off-centre DCT measures). The percentage increase in corneal thickness from the thinnest corneal point to the averaged peripheral corneal thickness (i.e. for a ring of data of 8mm diameter concentric to this point) was also recorded from the Pentacam instrument.

Five different parameters describing anterior corneal curvature, aberrations and thickness were used to determine which of the two eyes of the keratoconic subjects was the most advanced. These parameters were: mean and steepest anterior axial curvature, anterior corneal HO RMS, minimum corneal thickness and percentage increase in corneal thickness. The eye showing the steepest, most highly aberrated, thinnest cornea of the two eyes of each subject was deemed to be the most advanced.

For each subject, the mean IOP readings from the NCT (IOP_{NCT}), and from the central ($IOP_{DCT\text{-}C}$) and off-centre DCT ($IOP_{DCT\text{-}OC}$) measures were calculated. An

average DCT IOP ($IOP_{DCT-AVE}$) was calculated for each subject based on the mean of the (four) central and off-centre DCT IOP measures. The mean difference between $IOP_{DCT-AVE}$ and IOP_{NCT} was also calculated ($IOP_{DCT-NCT}$).

The Kolmogorov-Smirnov test revealed that the data for each of the corneal and IOP measures from the two populations of subjects did not differ significantly from a normal distribution and therefore parametric statistical methods were used throughout. Two-tailed independent sample t-tests were used to investigate for significant differences between the two populations of subjects in terms of both IOP and corneal parameters. Two-tailed paired t-tests were used to investigate for significant differences between the tonometric techniques used. To investigate for any significant dependence of the IOP measures on corneal parameters in our keratoconic subjects, correlation analysis was carried out for each of the measured corneal parameters and the IOP measures from each instrument.

Results:

The mean IOP measures for the central (IOP_{DCT-C}) and off-centre (IOP_{DCT-OC}) DCT and from the NCT (IOP_{NCT}) for the keratoconic and age-matched control populations are shown in Figure 1. The mean IOP_{DCT-C} was 14.3 ± 1.4 mmHg for the keratoconic subjects and 14.2 ± 1.7 mmHg for the age-matched control subjects. The mean IOP_{DCT-OC} was 14.1 ± 4.4 mmHg and 14.3 ± 1.6 mmHg for

the keratoconic and age matched control populations respectively and was not significantly different to IOP_{DCT-C} for either population ($p = 0.09$ for the keratoconics and $p= 0.29$ for the age matched controls). No significant difference was found in the mean IOP as measured with the DCT ($IOP_{DCT-AVE}$) between the keratoconic and age-matched control populations ($p=0.885$).

The mean IOP_{NCT} was 9.2 ± 1.5 mmHg for the keratoconic subjects and 12.9 ± 2.4 mmHg for the age-matched controls, which represents a highly statistically significant difference between the two populations ($p<0.0001$). The IOP_{NCT} was significantly different to the $IOP_{DCT-AVE}$ for both the age-matched controls ($p =0.001$) and the keratoconics ($p<0.0001$). The mean difference between the $IOP_{DCT-AVE}$ and IOP_{NCT} measures was 1.4 ± 1.6 mmHg for the age matched controls and 5.0 ± 1.5 mmHg for the keratoconic subjects.

An overview of the parameters describing the anterior and posterior corneal curvature and corneal thickness from the keratoconic and control populations is displayed in Table 1. As expected, the keratoconic subjects exhibited significantly ($p<0.001$ for all parameters) steeper anterior corneas, steeper posterior corneas, thinner central corneas, a greater percentage increase in corneal thickness between the thinnest point and peripheral corneal regions and larger magnitude of anterior corneal aberrations than the control subjects.

We investigated the association between each of the IOP measures (IOP_{NCT}, $IOP_{DCT-AVE}$, IOP_{DCT-C}, IOP_{DCT-OC}, and $IOP_{DCT-NCT}$) and the corneal topography and thickness data for the population of keratoconic subjects. Table 2 exhibits an overview of this correlation analysis. None of the DCT measures (i.e. neither IOP_{DCT-C}, IOP_{DCT-OC} or $IOP_{DCT-AVE}$) showed any significant correlation with any of the corneal topography or thickness measures for the keratoconic subjects. However, the IOP_{NCT} measures did exhibit a significant correlation with certain corneal parameters, such as the average ($r^2 = 0.20$) and steepest ($r^2 = 0.39$) anterior corneal curvature, average posterior corneal curvature ($r^2 = 0.25$) and percentage increase in thickness ($r^2 = 0.22$). These correlations indicate that steeper central anterior and posterior corneas, and larger differences between the central and peripheral corneal thickness values (i.e. corneal changes associated with more advanced keratoconus), are associated with lower IOP_{NCT} readings. The difference between the $IOP_{DCT-AVE}$ and IOP_{NCT} measures ($IOP_{DCT-NCT}$) showed a significant correlation with the majority of parameters describing the topography and thickness of the cornea, with r^2 values ranging from 0.19 to 0.55. This indicates that steeper, thinner, more highly aberrated corneas were associated with a greater difference between $IOP_{DCT-AVE}$ and IOP_{NCT} (i.e. the more advanced the keratoconus, the greater the difference between DCT and NCT IOP measures). Figure 2 illustrates the relationship between $IOP_{DCT-NCT}$ and parameters describing the anterior and posterior corneal curvature and thickness.

Discussion:

In our current study, no significant difference was found between the DCT IOP measures of our age-matched control and keratoconic subjects, and these measures were also not significantly correlated with any measures of corneal shape or thickness. Furthermore, no systematic differences were found between the DCT IOP measures taken from the central and off-centre corneal regions in either the keratoconic or age-matched control populations. As the off-centre measures represent IOP estimates where the instrument is contacting a thicker, flatter region of the cornea, systematic errors in the DCT measures should manifest as differences between these central and off-centre IOP measures. This suggests that the DCT instrument is not being substantially influenced by the altered corneal biomechanics of keratoconus, and is performing reliably for IOP measures in these patients. The fact that valid central and off-centre DCT measures were able to be collected for both our keratoconic and control populations confirms that contour matching at the DCT sensor can occur for a wide range of corneal curvatures.

Our findings are in general agreement with previous studies of IOP with the DCT in keratoconus (Barreto et al. 2006; Ozbek et al. 2006; Meyenberg et al. 2008; Mollan et al. 2008; Papastergiou et al. 2008; Schädle et al. 2008). The majority of these recent studies have also reported differences between DCT and applanation tonometry readings of similar magnitude, and no significant association between DCT IOP and corneal thickness or curvature measures in

keratoconic eyes. These studies have primarily reported upon associations between IOP and central corneal thickness and anterior keratometric curvature readings. In our current study, we derived a comprehensive range of parameters describing the thickness (central, peripheral thickness measures and estimates of thickness progression), and shape of the cornea (curvature of both the anterior and posterior cornea and corneal aberrations), and found no significant association between DCT IOP and any of these parameters. This further supports the contention that the DCT is providing IOP measures that are largely independent of corneal factors in keratoconus.

In contrast to the DCT IOP measures, the NCT measures do appear to be significantly influenced by certain corneal factors in keratoconus. The NCT may have substantially underestimated the IOP in our keratoconic subjects, in comparison to both age-matched controls as well as to measures with the DCT instrument. This potential underestimation of IOP with the NCT increased with more advanced keratoconic corneal topographical changes. We found an average difference between NCT and DCT, of 5 mmHg in our population of keratoconic subjects, (with a maximum difference of 8 mmHg) which is substantial and could significantly influence a patients' clinical management. Previous studies have also reported lower than normal IOP readings with the NCT instrument in keratoconic patients (Swann & Waldron 1986; Edmonds 1993; Papastergiou et al. 2008).

The NCT measures in our keratoconic subjects were also significantly correlated with a number of corneal parameters. The majority of these significant associations were with corneal parameters describing the shape of the cornea, with lower IOP readings being associated with steeper corneal shapes. In normal subjects, steeper corneal curvatures can lead to an overestimation of IOP with applanation tonometers (Whiteacre and Stein 1993; Fukuoka et al 2008). The reason for our finding of a lower IOP being associated with a steeper corneal curvature is therefore unlikely to be a direct influence of corneal curvature on the tonometry measures, and is more likely due to an association between steeper corneas and more advanced keratoconic corneal changes (i.e. altered corneal structural characteristics and biomechanics). Other recent studies (Papastergiou et al 2008; Meyenberg et al 2008) have not found a significant association between applanation IOP measures and keratometric corneal curvature readings in keratoconic subjects. In our current study, the most significant association was found between NCT IOP and the steepest corneal curvature (across the central 4 mm), a corneal characteristic that may not have been detected through analysis of keratometric curvature readings due to the substantial asymmetric corneal topographical characteristics typically found in the keratoconic cornea.

In our keratoconic subjects, no significant association was found between CCT and NCT IOP. NCT measures in normal subjects (Eysteinsson et al 2002, Tonnu et al. 2005; Pelit et al. 2009) and subjects with glaucoma and ocular hypertension (Erdurmus et al. 2008) have previously been found to be influenced by corneal

parameters such as CCT (with thicker corneas typically found to be associated with higher IOPs). Papastergiou et al (2008) recently investigated NCT IOP readings in keratoconus and did find a significant association between CCT and IOP. However, the relationship between IOP and CCT was noted to be weaker in their keratoconic subjects compared to normal eyes, with a relatively small amount of the variance in IOP accounted for by CCT. The findings of a reduced association between CCT and NCT IOP by Papastergiou et al, and no significant correlation in our current study suggests that corneal characteristics aside from the central corneal thickness may also have an influence on applanation IOP readings in keratoconus (e.g. corneal biomechanical characteristics). Liu & Roberts (2005) suggested that corneal biomechanical factors potentially have a much larger influence on applanation tonometry than corneal thickness. It therefore appears that there is not a simple direct relationship between central corneal thickness and corneal structural and biomechanical changes in keratoconus as evidenced by the fact that associations between corneal biomechanical measures such as corneal hysteresis typically exhibit only relatively weak associations with corneal thickness in keratoconus (Shah et al 2007).

An interesting finding from our current study was the significant correlations found between $IOP_{DCT-NCT}$ and the measures of corneal thickness and topography in our keratoconic population. The difference in IOP readings between the DCT and NCT appears to provide a relatively strong correlation with

a wide range of measures describing the severity of keratoconus. Previous studies of both normal (Tonnu et al. 2005; Pelit et al. 2009) and keratoconic subjects (Edmonds 1993; Papastergiou et al. 2008) have found IOP measures with NCT appear to be influenced by corneal parameters to a greater degree than other tonometers. We postulate that because NCT's IOP measures appear to be relatively dependant upon corneal biomechanical factors, and DCT measures appear to be relatively independent of these factors, the difference between the readings from the two instruments may therefore be providing a measure of the cornea's biomechanical properties. Hence the $IOP_{DCT\text{-}NCT}$ exhibited strong correlations with a number of measures of the severity of keratoconus, which is known to lead to changes in corneal biomechanics (Edmund 1989; Luce 2005; Shah et al. 2007; Touboul et al. 2008). There has been considerable recent interest in the ophthalmic community in identifying corneas that are biomechanically compromised, and therefore at risk of developing keratoconus or iatrogenic keratoectasia following laser refractive surgery (Pallikaris et al. 2001; Randleman et al. 2003; Rad et al. 2004; Klein et al. 2006; Rabinowitz 2006). Whilst further study is required, if $IOP_{DCT\text{-}NCT}$ is providing a metric of corneal biomechanics, it may prove useful as a screening tool to identify corneas that are biomechanically weaker and hence at risk of developing ectatic changes.

The accurate determination of IOP is of particular clinical importance in the diagnosis and monitoring of glaucoma (Brandt et al. 2001; Boland & Quigley

2007). In subjects with substantially altered corneal characteristics such as keratoconus, errors with traditional tonometric techniques could therefore potentially lead to difficulties in the accurate diagnosis of glaucoma in these patients. We found that the DCT instrument appears to be providing reliable measures of IOP in patients with keratoconus that do not appear to be influenced by altered corneal biomechanics. We found no significant relationship between IOP as measured with the DCT and the severity of keratoconus. The difference in IOP readings between the DCT and NCT appears to correlate strongly with a number of parameters describing the severity of keratoconus. This difference in measures may therefore be providing a useful estimation of corneal biomechanical properties.

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Figure Legends:

Figure 1: Mean IOP with the NCT and DCT instruments from the keratoconic and age-matched control subjects. The difference between the keratoconic and control subjects was non-significant for DCT measures ($p=0.885$) but was highly significant for NCT measures ($p<0.0001$).

Figure 2: The relationship between the difference in IOP measures from the DCT and NCT ($IOP_{DCT-NCT}$) and measures of anterior corneal topography (steepest axial curvature within the central 4mm), posterior corneal topography (steepest axial curvature within the central 4mm) and corneal thickness (thinnest corneal thickness) in the keratoconic population.

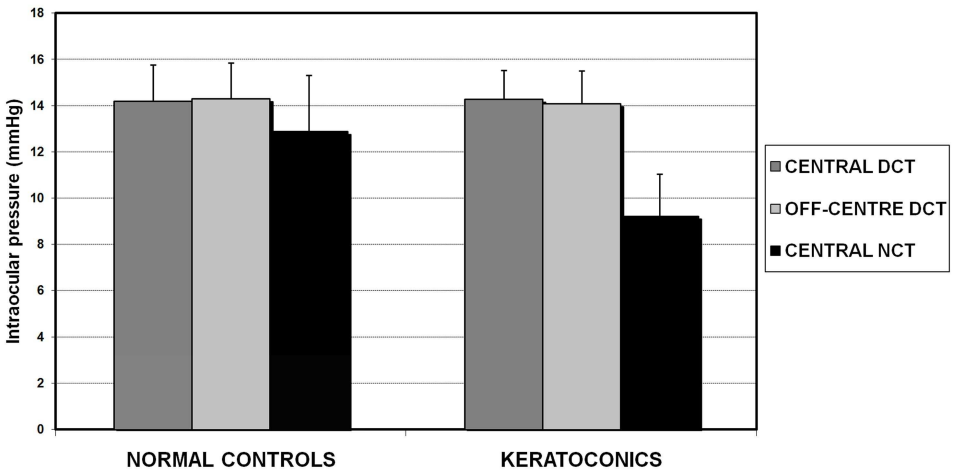

Figure 1: Mean IOP with the NCT and DCT instruments from the keratoconic and age-matched control subjects. The difference between the keratoconic and control subjects was non-significant for DCT measures (p=0.885) but was highly significant for NCT measures (p<0.0001)
130x67mm (600 x 600 DPI)

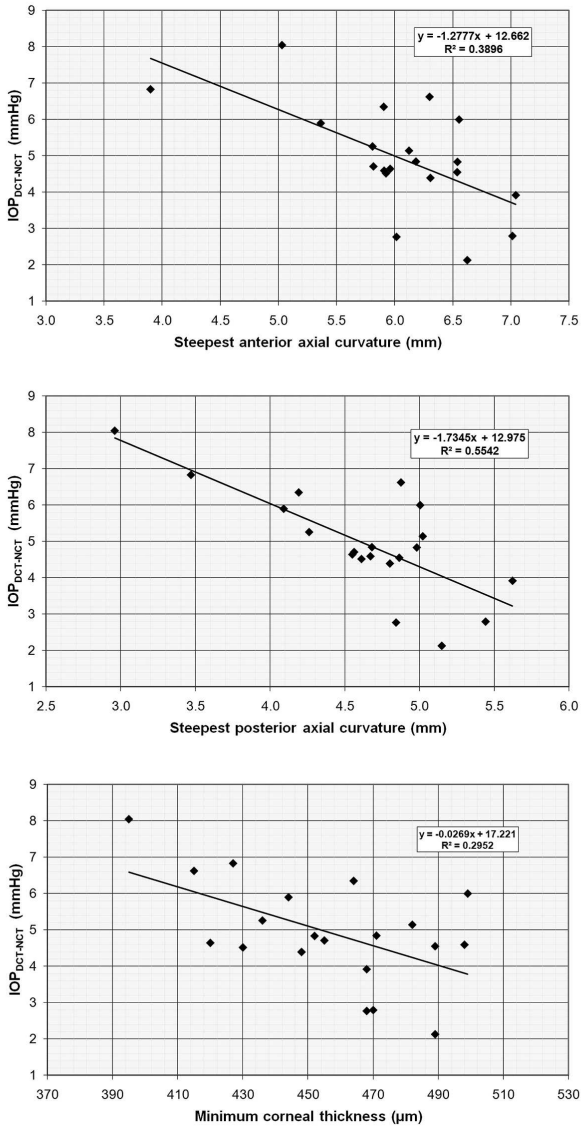

Figure 2: The relationship between the difference in IOP measures from the DCT and NCT (IOPDCT-NCT) and measures of anterior corneal topography (steepest axial curvature within the central 4mm), posterior corneal topography (steepest axial curvature within the central 4mm) and corneal thickness (thinnest corneal thickness) in the keratoconic population.
116x203mm (600 x 600 DPI)

Table 1: Average corneal topography and thickness parameters for the keratoconic and age-matched control populations. Axial curvature, average CT and HO RMS parameters calculated across a 4 mm corneal diameter. P-values are derived from independent sample t-tests comparing mean keratoconic parameter to mean age-matched normal parameter.

Corneal parameter	Mean ± SD		P-value
	Keratoconic subjects (n = 20)	Age-matched control subjects (n = 20)	
Average anterior axial curvature (mm)*	7.04 ± 0.56	7.83 ± 0.23	P< 0.001 for all parameters
Steepest anterior axial curvature (mm)*	6.04 ± 0.70	7.63 ± 0.26	
Anterior Corneal HO RMS (µm)*	1.34 ± 0.64	0.10 ± 0.03	
Average posterior axial curvature (mm) †	5.61 ± 0.56	6.55 ± 0.23	
Steepest posterior axial curvature (mm) †	4.63 ± 0.62	6.13 ± 0.27	
CCT (µm)†	473 ± 25	529 ± 33	
Min CT (µm) †	456 ± 29	527 ± 33	
Average CT (µm) †	493 ± 23	539 ± 33	
Temporal CT (2.0mm) (µm) †	500 ± 28	541 ± 34	
% Thickness increase (8mm)†	47.93 ± 11.80	28.40 ± 3.96	

*Parameter derived from data from Medmont E300 videokeratoscope

†Parameter derived from data from Pentacam HR rotating Scheimpflug camera

Table 2: Overview of correlation analysis exploring association between IOP measures and corneal topographical and thickness parameters for the keratoconic population. Pearson's correlation coefficient (r) and significance displayed for the correlation between each corneal parameter.

Corneal parameter		IOP MEASURE		
		IOP_{DCT_AVE}	IOP_{NCT}	$IOP_{DCT-NCT}$
Average anterior axial curvature (mm)*	r (p-value)	-0.179 (0.449)	**0.447 (0.048)**	**-0.617 (0.004)**
Steepest anterior axial curvature (mm)*	r (p-value)	-0.233 (0.323)	**0.624 (0.003)**	**-0.624 (0.003)**
Anterior Corneal HO RMS (µm)*	r (p-value)	0.156 (0.512)	-0.358 (0.122)	**0.505 (0.023)**
Average posterior axial curvature (mm)†	r (p-value)	-0.221 (0.349)	**0.502 (0.024)**	**-0.712 (0.0004)**
Steepest posterior axial curvature (mm)†	r (p-value)	-0.359 (0.120)	0.404 (0.078)	**-0.744 (0.0002)**
CCT (µm)†	r (p-value)	-0.339 (0.144)	0.116 (0.627)	**-0.438 (0.05)**
Min CT (µm)†	r (p-value)	-0.344 (0.138)	0.216 (0.360)	**-0.543 (0.013)**
Average CT (4mm) (µm)†	r (p-value)	-0.25 (0.287)	-0.012 (0.476)	-0.226 (0.338)
Temporal CT (2.0mm) (µm) †	r (p-value)	-0.326 (0.16)	-0.138 (0.563)	-0.174 (0.464)
% Thickness increase (8mm)†	r (p-value)	0.235 (0.319)	**-0.474 (0.035)**	**0.697 (0.001)**

*Parameter derived from data from Medmont E300 videokeratoscope

†Parameter derived from data from Pentacam HR rotating Scheimpflug camera