Depth-of-field after orthokeratology: a theoretical study

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We evaluated the possible effect of orthokeratology on accommodative response. Using optical modelling we computed the negative half of the depth-of-field (DoFi) for the range of target vengeances from –1.00 D to –3.00 D, of two eye models designed to mimic the levels of primary and secondary spherical aberration found in 24 patients before and after undergoing orthokeratology (ortho-k). Five trained observers were subjected to a resolution task to identify the negative threshold of the depth-of-field of these model eyes by viewing a set of computed images representative of the model eyes trough focus retinal image quality for five target vengeances (TV), from –1.00 to –3.00 D. The differences in the DoFi estimated by the five observers were maximum for a –3.00 D TV (0.21 D), with the post ortho-k model presenting a higher DoFi compared to the pre ortho-k model. Differences were consistent for all five observers and all TV's. In conclusion, the increase in spherical aberration after ortho-k seems to contribute to a small increase in the DoFi. Although small, the benefits might be sufficient to improve retinal image quality in eyes with high accommodative lag.

Keywords: Orthokeratology, lag, depth-of-field, myopia

Introduction

The tolerance of any optical system to focusing errors can be specified by the interval of distances over which the object or image planes can be moved without producing any perceived degradation, with the former being referred to as depth-of-field (DoFi) and the latter as depth-of-focus (DoF). Either term can be used in vision sciences however, DoFi seems a more useful definition since it can be measured by changing the object's vengeance rather than the retina position. Thus, DoFi can be defined as the vengeance range of focusing errors that does not result in perceived deterioration in retinal image quality (RIQ). This deterioration in RIQ is directly linked to final acceptance of the optics worn – e.g. ortho-k treatment – and can be determined according to different subjective and objective measures.[1]

In this work we proposed that the high increase in positive primary spherical aberration (SA) after orthokeratology (ortho-k) might improve the RIQ of eyes with accommodative lag, due to an increase in the DoFi.[2-4]

Figure 1: Trough-focus RIQ simulations for a 5 mm pupil, based on the Navarro accommodative eye model plus a SA phase plate to match the average SA values of our subjects before (top: $C_4^0 = 0.126$ µm; $C_6^0 = 0.001$ µm) and after ortho-k (bottom: $C_4^0 = 0.464$ µm; $C_6^0 = 0.019$ µm), for a -3.00 D target vengeance (TV). Pupil diameter decreases 0.35 mm/D of change in defocus with accommodation.

Methods

Corneal aberrations from *24* patients were averaged to determine the mean value of primary and secondary SA before and after undergoing ortho-k. Two model eyes based on the Navarro schematic eye[5] were designed to mimic the mean amount of corneal *1*st and *2*nd orders SA of the *24* patients, before and after ortho-k. Fourier optics routines were implemented in Matlab to design a trough-focus experience with the purpose of simulating the changes in RIQ as the eye accommodates for five target vengeances (TV; *–1.00 D*, *–1.50 D*, *–2.00 D*, *–2.50 D* and *–3.00 D*). The negative half of the DoFi interval, for the pre and post ortho-k eye models, was determined by five trained observers, who were asked to indicate the first image without considerable degradation in the trough-focus interval. The value yielded by this resolution task simulates the change on the defocus coefficient C_2^0 produced by the lens curvatures needed to produce an acceptable RIQ for the imposed TV, according to our observer's subjective criteria.

Results

Figure 1 illustrates a trough-focus experience similar to the one viewed by five observers, for both pre and post ortho-k eye models. From the present example it is clear the effect of the increased levels of SA. Although the RIQ decreases after ortho-k due to the loss of contrast, image resolution decreases less (left to right) with the imposed defocus, suggesting a greater DoFi in the post ortho-k condition.

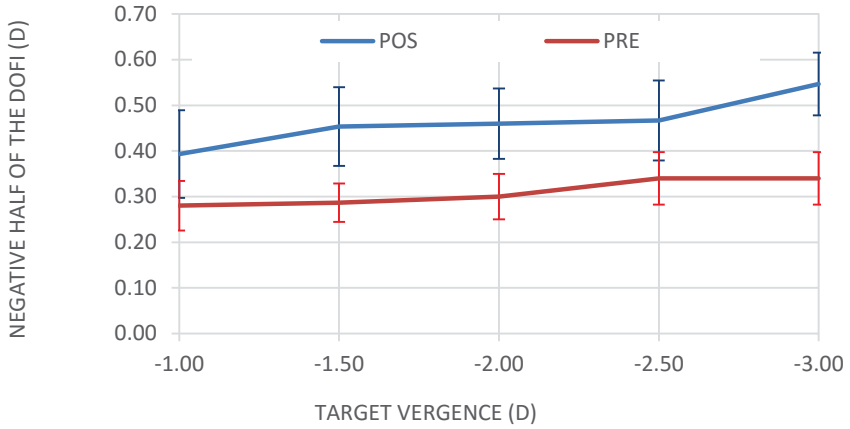

Figure 2: Negative half of the DoFi interval range from –1.00 to –3.00 D TV. These values also represent the highest amount of lag per TV that still allows to maintain an acceptable RIQ, according to the observer's subjective threshold.

This hypothesis is confirmed by our observer's subjective criteria (Figure 2). The observed differences are not constant trough the TV range, but the variation tendency is similar in both conditions, indicating an increased DoFi for higher TV's probably due to the effect of proximal miosis.[6]

Discussion

It has been hypothesized that the increased in positive SA could provide an additional explanation for the myopia control effects obtained different treatments in progressing myopes, due to a change in behaviour of the accommodative system.[3,7] Gambra et al.[4] shown that adding negative *4*th order SA to an aberration-free eye produced a decrease in the accommodative lag, while adding positive *4*th order SA produced an increase in the accommodative lag (less accurate accommodative response). Although the authors do not refer it in their paper, there could be some other effect uncounted for in their conclusions. Adding negative Zernike SA introduces positive Seidel defocus —due to the low-order terms balance in Zernike polynomials— which would help the eye to compensate for the negative defocus produced by the accommodative lag. Even so, from our results illustrated in Figures 1 and 2, it appears that with the increase in positive SA the eye will not need to accommodate as much, for high contrast resolution tasks such as reading. But judging from the trough focus simulated retinal images, this increase in positive SA provides an only a marginal extension of the DoFi in the ortho-k eye models compared to the pre ortho-k results (mean difference = *0.21 D* for a *–3.00 D* TV). Although clinically small, this results seems to agree with experimental findings which showed that the presence of C_4^0 increases the DoFi.[8,9] This observed causal relation might lead to two different results: on one hand, on a patient without accommodative lag it is expected to decrease RIQ due to the loss of contrast induced by the high levels of positive SA; on the other hand, on a patient with accommodative lag – where acuity is compromised during near vision – the extended DoFi might increase retinal image resolution and therefore acuity for high contrast tasks. Taking in to account that the increment in positive C_4^0 after ortho-k is strongly negative correlated to baseline myopia,[10] it is expected that this effect will be more beneficial in moderate myopes with decreased visual acuity at near due to accommodative lag.

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