Measurements of Progressive addition lenses with interferometry

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Abstract

Objective: Evaluate and measure accurately the dioptric power of progressive addition ophthalmic lenses at specific points on the progressive addition lens surface with interferometry, a Twyman Green interferometer was used, and correlate the results with those taken from automated focimetry. Also progressive addition ophthalmic lenses were measured in order to have a complete presentation of the power distribution and the performance of these lenses.

Method and materials: The progressive addition ophthalmic lenses were inspected, using a Twyman Green interferometer at specific points, and interference patterns were acquired and processed, obtaining the dioptric power that theses lenses presented. Comparison of the respective results was conducted with those taken from an Auto-focimeter (TOMEY TL-100) in order to check if the two types of measurement are interchangeable, and statistical analysis was carried out for both types of measurements.

Results: The data showed, that the two methods Auto-focimeter and Interferometry (Twyman Green) are correlated. The plotting for both measuring techniques were very similar, although the measuring points were not numerical the same. From the statistics and especially the p-value its time taken showed that the two measuring techniques do not different significantly. Also from the Bland and Altman plot it shows that there is a difference of about 0.30 Ds for the spherical component while it was about 0.17 Dc for the cylindrical component between the two methods. With interferometry it was difficult and time consuming to get as many measurements as those taken with the Auto-focimeter due to the manual and laborious nature of the technique.

Conclusions: An alternative method is provided based on interferometry. More specific a Twyman-Green interferometer was set to measure progressive addition ophthalmic lenses. The results showed that it is possible to measure such type of lenses although interferometry it was difficult and time consuming to get as many measurements as those taken with the Auto-focimeter due to the manual and laborious nature of the technique.

Key words: interferometry, Twyman-Green, progressive addition ophthalmic lenses, power.

Introduction

Progressive Addition Lenses are very complicated as ophthalmic lenses. Due to the fact that there are no borders visible for far, intermediate and near vision areas on the lens surface, these lenses are difficult to measure and to access their performance. So far the method for measuring these lenses is the use of Auto-focimetry.

A method technique based on interferometry[1-6] and its validation are presented for measuring the power of progressive addition ophthalmic lenses at specific points on the progressive addition lens surface. A Twyman-Green[7-12] interferometer was preferred and set up, which provided a reference wave front, which was plane. The results taken were correlated with those taken from automated focimetry.

Method and materials

A more precise method is used such interferometry (Twyman-Green interferometer) in providing information about the power distribution on the progressive addition ophthalmic lenses surface. It is well known that so far the performance of such complex lenses is presented by providing contour plots of the power distribution on the lens surface and the unwanted astigmatism distribution that these lenses present outside the progressive corridor. The same way of performance presentation is used here only the data is extracted by using the interferometric method proposed (Twyman-Green interferometer). Such a technique has never so far been used to provide the necessary information for evaluating such lenses. This innovating approach can be used also in the manufacturing sector of these lenses in order to provide the manufacturer data on the surface of the lenses with out the need of subjective observations.

The Twyman-Green interferometer used in order to measure progressive addition ophthalmic lenses produced a plane wave front (parallel rays) which was the reference wave front for comparison with the one produced by any progressive addition ophthalmic lens inserted into the system. The laser was a He-Neon laser (red) having a transmitting wavelength of 632, 8 x 10^{-6} mm and with a beam diameter of 0.8 mm. **Figure 1** is an actual photo of the lab of the experimental set up for such a purpose.

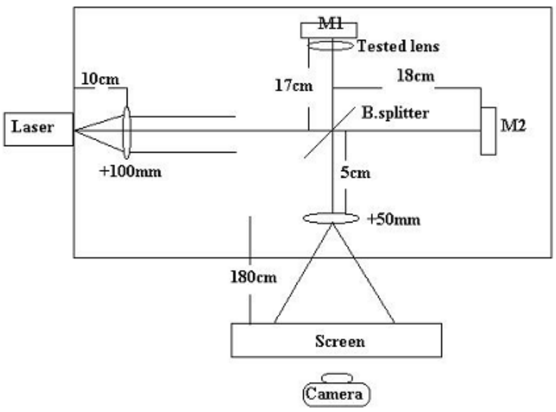


Figure 1. *It is schematic diagram of the Twyman-Green interferometer set up and a photo of the lab for measuring progressive addition lenses.*

According to the above photo the set up consisted of: A collimated lens +100 mm, which was placed in front of the laser at a distance equal to its first focal length. This produced the initial *"reference wave front"* which was *plane*. A beam-splitter (50/50) placed oriented at 45° to the laser beam direction in order to divide the initial laser beam into two other components one reflected and the other transmitted. Flat mirrors (one fixed M_2 and the other movable M_1 in terms of three screws for directional movements) were used. The camera was placed exactly behind the semi-transparent screen at 0° angle. The use of a granite table two tones of weight was necessary in order to reduce the interfering of vibrations on the device and on the fringe patterns produced. Even the least noise or air current could affect the fringe patterns producing a breathing phenomenon.

The fringe patterns were photographed and scanned on to a computer in order to calculate the power of progressive addition lenses. The following equation[23] was used in order to find the power of the spherical and cylindrical component at each point measured on the progressive addition lens surface.

$$x_n^2/R = n\,\lambda \;\Rightarrow x_n = \sqrt{n\,R\,\lambda} \;\Rightarrow R = x_n^2/n\,\lambda$$

where x_n is the distance of the *n*th dark fringe R is the radius of curvature of the optical element under test n is the number of the dark fringe from the centre of the fringe pattern while λ is the wave length of the light source used ($\lambda = 632{,}8 \times 10^{-6}$ mm).

Progressive addition lenses were introduced in the system and measured at 15 points. The lenses were measured at points, which are 10 mm apart horizontally. Figure 2. shows on a progressive addition lens surface the points, which were measured.

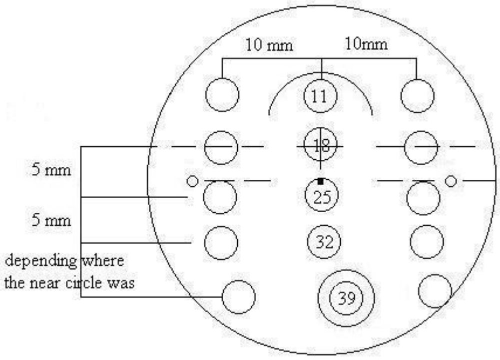


Figure 2. *Points (circles) on a progressive addition lens where measurements with interferometry took place. Each circle is 2,5 mm wide.*

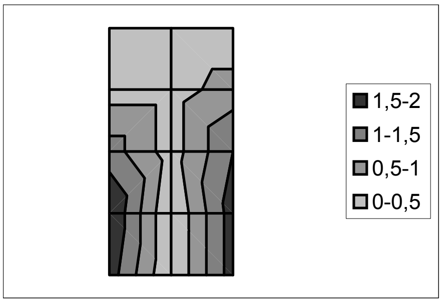
Point 11 represents the semi-circle indicating where the distance power and axis should be checked. Point 18 represents the fitting cross, which is normally located to the patient's pupil. Point 39 represents the circle indicating where the centre of the reading area is. The produced fringes where photographed, measured and the resulting dioptric power was calculated for each point. The plotting for the spherical and the cylindrical component is given in terms of spherical power and unwanted astigmatism distribution. (Each progressive lens was clipped on a stand with verniers horizontally and vertically, in order to ensure that the correct point was measured each time).

Results

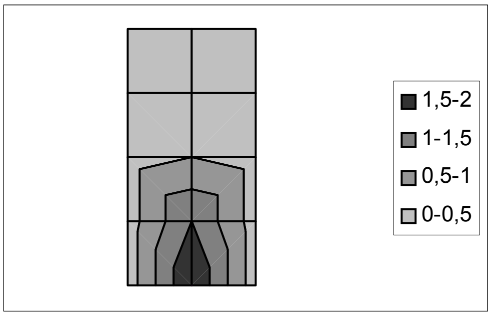
The progressive addition lenses selected for the research were taken from the Greek market representing companies' products, which are widely used nowadays. From Essilor it was selected to measure *Comfort* and the new lens design under the trademark *Panamic*. From the company Hoya the lenses *GP* and Summit *Pro* lens designs were selected. From Aoptical the lenses selected were *AO Pro* and the *Compact*. From Zeiss the *Gradal HS*, Rodenstock *Progressive S* and from Nikon *Presio* were selected. These 9 lens designs represent the majority of the progressive lenses marketed in Greece. All these lens design are very similar to each other belonging to the major category of *ultra soft* designs. The only different one is the *AO Compact* which is a design produced to fit in small frames (B vertical dimension of the frame B< 35 mm). All the lenses were measured having plano distance vision zone and addition 2.00 D which represents the mean value of additions used from presbyopic wearers.

Also all the above mentioned lenses were measured with an Auto-focimeter (Tomey) at the same points in order to compare the two methods in their results of measuring such complex lenses. With the Auto-focimeter besides the same 15 points measured other 34 points were measured in order to have a complete presentation of the power distribution and the performance of these lenses. So there were a total of 49 points measured on the surface of such lenses covering all the area representing a viewing angle of 35°.

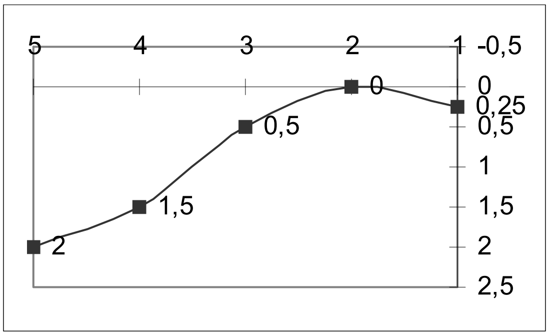
The results are given for one of the above-mentioned lenses in the following plots.



a)



b)

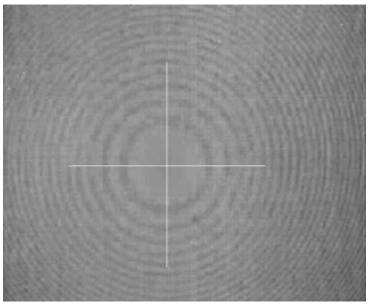


c)

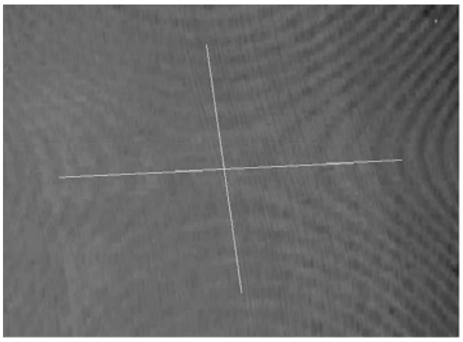
1	Far (point 11)
2	Cross (point 18)
3	5 mm below cross (point 25)
4	10 mm below cross (point 32)
5	Near vision circle (point 39)

Figure 4. *a) Diagram showing the distribution of the unwanted astigmatism presented by the lens b) diagram showing the spherical power distribution c) plot of the power progression at the progression corridor. All the above results are for Hoya GP plano/add 2.00 D. Measurements taken with interferometry.*

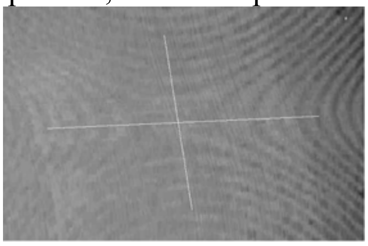
The photographs of the fringes taken for Hoya GP at the progression corridor are given below



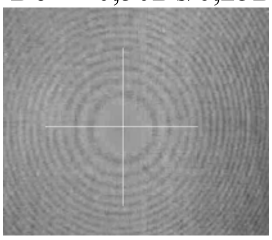
0,25 Ds at point 11



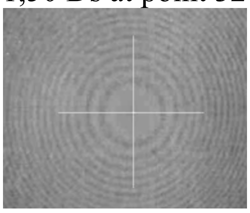
plano/0,25 Dc at point 18



0,50 Dc/0,75 Dc → 0,50Ds/0,25Dc at point 25



1,50 Ds at point 32



2,00 Ds at point 39

Figure 5. *Photographs of the fringes taken for Hoya GP at the progression corridor*

For comparison the same lens was measured with the Auto-focimeter but this time the points were 49 on the lens surface. These points are seen in the following figure.

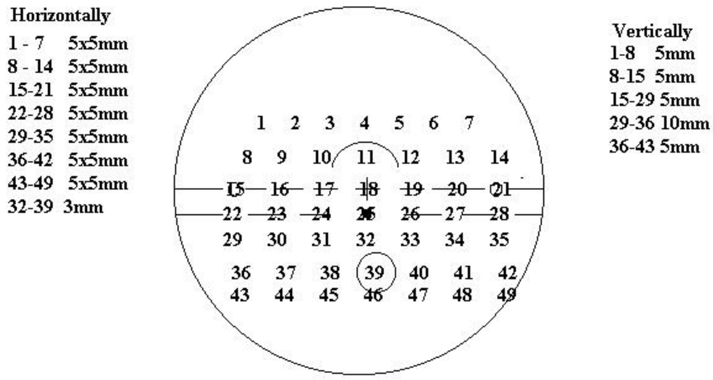


Figure 6. *Points on a progressive addition lens where measurements with an auto-focimeter took place.*

Figure 5. shows the results taken with an auto-focimeter for comparison with the results taken with interferometry.

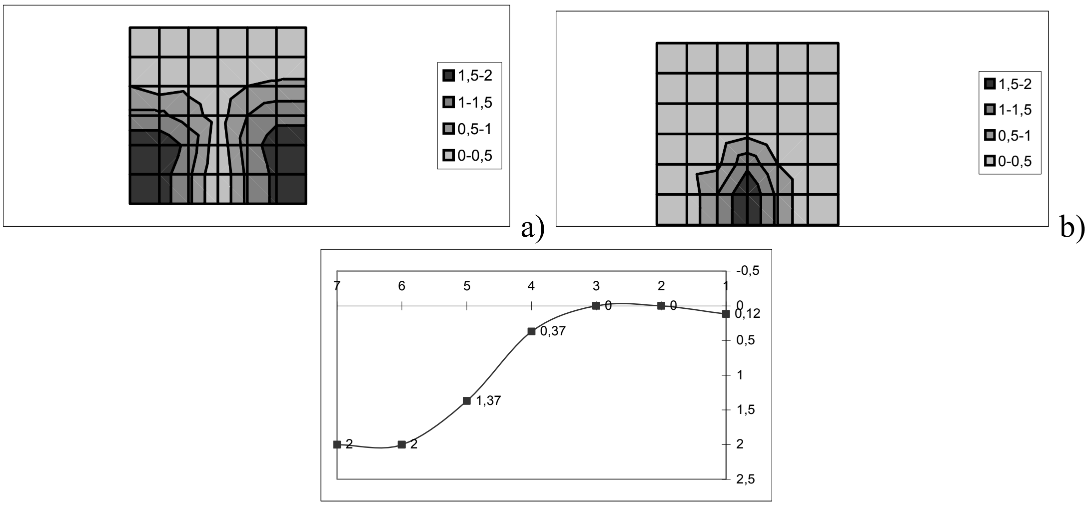


Figure 6. *a) Diagram showing the distribution of the unwanted astigmatism presented by the lens b) diagram showing the spherical power distribution c) plot of the power progression at the progression corridor. All the above results are for Hoya GP plano/add 2.00 D. Measurements taken with auto-focimeter.*

The statistical analysis is done for the measurement of one progressive lens Hoya GP at the lens corridor. The lenses were measured once with an Auto-focimeter (TOMEY TL-100) and with the interferometric technique described in chapter 4. The results are given in the table below.

Table 1.

Points of measurement	Autofocimeter		Interferometry	
	sph	cyl	sph	cyl
Point 11	0	0	0.25	0
Point 18	0	0.12	0	0.25
Point 25	0.37	0.25	0.50	0.25
Point 32	1.37	0.12	1.50	0
Point 39	2.00	0	2.00	0

Statistics for the Spherical component

The sample size for progressive addition lenses (spherical component) measured with the interferometric technique using Twyman-Green interferometer was 5 having arithmetic mean 0,8500 Ds (95% CI for the mean -0,2163 to 1,9163) the standard deviation was SD=0,8588 having a standard error of the mean of SE=0,3841). Kolmogorov-Smirnov test for Normal Distribution showed that the data is normally distributed (accept Normality P=0,835).

The sample size for progressive addition lenses measured with the Auto-focimeter was 5 having arithmetic mean 0,7480 Ds (95% CI for the mean -0,3654 to 1,8614) the standard deviation was SD=0,8967 having a standard error of the mean of SE=0,4010). Kolmogorov-Smirnov test for Normal Distribution showed that the data is normally distributed (accept Normality P=0,817).

Comparing now the two methods Auto-focimeter and Interferometry the Pearsons correlation coefficient shows high statistical significant correlation between the two methods showing that the data are highly associated (r = 0,9937 P=0,0006 having a 95% confidence interval for r = 0,9045 to 0,9996). Conducting the Paired t-test for the two methods this showed that there is no bias between the two methods (Two-tailed probability P = 0,0961). The Mean difference was MD = 0,1020 while the Standard deviation SD= 0,1052 with 95% CI = -0,0286 to 0,2326. The Variance ratio test (F-test was = 1,0903 with P = 0,935.

In order to compare better the two measuring methods the Bland & Altman plot[13-14] is used. With this method the differences between the two measuring methods are plotted against the averages of the two methods.

BLAND AND ALTMAN PLOT

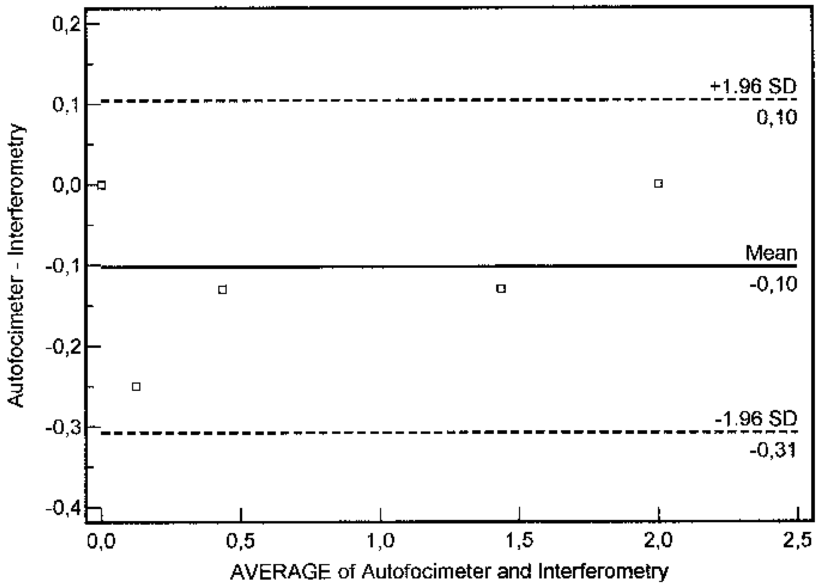


Figure 7. *Is the Bland & Altman Plot where "Interferometer" and "Auto-focimeter" are the two measuring methods that are compared for the results on progressive addition lenses and more specifically on the spherical component.*

From the plot it is concluded that the limits of agreement between the two methods are (Lower limit = -0,3082 Ds and Upper limit = 0,1042 Ds).

Statistics for the Cylindrical component

The sample size for progressive addition lenses (spherical component) measured with the interferometric technique using Twyman-Green interferometer was 5 having arithmetic mean 0,1000 Ds (95% CI for the mean -0,0700 to 0,2700) the standard deviation was SD=0,1369 having a standard error of the mean of SE=0,0612). Kolmogorov-Smirnov test for Normal Distribution showed that the data is normally distributed (accept Normality P=0,416).

The sample size for progressive addition lenses measured with the Auto-focimeter was 5 having arithmetic mean 0,0980 Ds (95% CI for the mean -0,0312 to 0,2272) the standard deviation was SD=0,1040 having a standard error of the mean of SE=0,0465). Kolmogorov-Smirnov test for Normal Distribution showed that the data is normally distributed (accept Normality P=0,927).

Comparing now the two methods Auto-focimeter and Interferometry the Pearsons correlation coefficient shows high statistical significant correlation between the two methods showing that the data are highly associated (r = 0,9937 P=0,0006 having a 95% confidence interval for r = 0,9045 to 0,9996). Conducting the Paired t-test for the two methods this showed that there is no bias between the two methods (Two-tailed probability P = 0,9621). The Mean difference was MD = 0,0020 while the Standard deviation SD= 0,0884 with 95% CI = -0,1078 to 0,1118. The Variance ratio test (F-test was = 1,7329 with P = 0,607.

BLAND AND ALTMAN PLOT

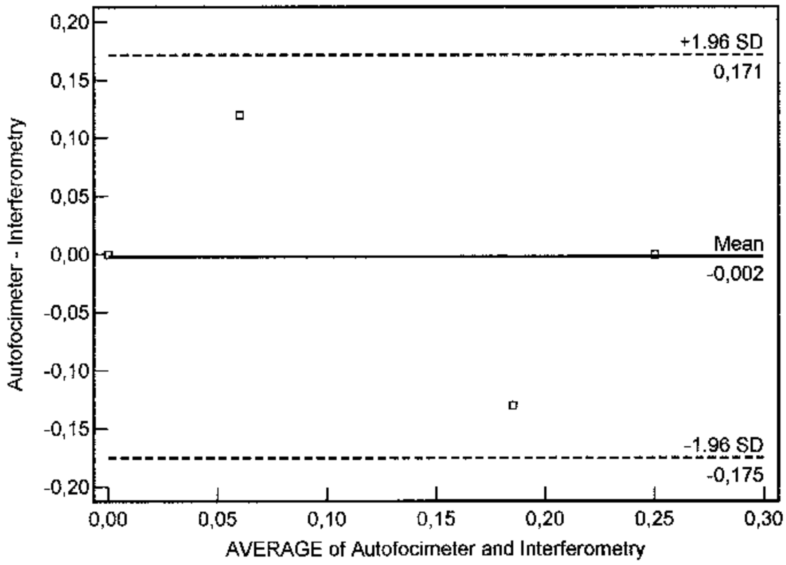


Figure 8. *Is the Bland & Altman Plot where "Interferometer" and "Auto-focimeter" are the two measuring methods that are compared for the results on progressive addition lenses and more specifically on the cylindrical component.*

From the plot it is concluded that the limits of agreement between the two methods are (Lower limit = -0,1753 Ds and Upper limit = 0,1713 Ds).

Conclusions

A Twyman-Green interferometer was utilized to take measurements on progressive addition lenses. Although at the beginning the fringe pattern of the whole lens was taken in order to assess the performance of these lenses due to the fact that the pattern it was impossible to interpret then specific points on the lens surface were measured and the power of these points was calculated from the fringe pattern being photographed.

The results were presented in a way that always, progressive addition lenses performance is done. Using contour plots, the power and the unwanted astigmatism distribution is presented. The measuring points on the lens surface contained the progressive corridor the far and near vision points and points 10mm away from the corridor (15 points in total). These results were compared with measurements taken with an Auto-focimeter and (49 points in total) and contour plots again were presented for power and astigmatism distribution. The plotting for both measuring techniques were very similar, although the measuring points were not numerical the same. From the statistics and especially the p-value its time taken (p should be in all cases $p > 0,05$) showed that the two measuring techniques do not different significantly. Also from the Bland and Altman plot it shows that there is a difference of about 0.30 Ds for the spherical component while it was about 0.17 Dc for the cylindrical component between the two methods. With interferometry it was difficult and time consuming to get as many measurements as those taken with the Auto-focimeter due to the manual and laborious nature of the technique. The technique can be improved, in order of time needed, if a computer with the analogous software could analyze the fringe pattern.

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Περίληψη

Στόχος: Η αξιολόγηση και η μέτρηση με ακρίβεια της διοπτρικής δύναμη των πολυεστιακών οφθαλμικών φακών σε συγκεκριμένα σημεία, πάνω στην προοδευτικής αύξησης της δύναμης επιφάνεια του φακού, με την χρήση συμβολομετρίας (Twyman-Green), καθώς και στατιστική συσχέτιση των αποτελεσμάτων με εκείνα που λαμβάνονται από ένα αυτοματοποιημένο φακόμετρο. Επίσης, οι πολυεστιακοί οφθαλμικοί φακοί μετρήθηκαν για να παρουσιαστεί πλήρως η κατανομή της διοπτρικής δύναμης πάνω στην επιφάνεια του φακού και να αξιολογηθούν ως προς την απόδοση τους οι φακών αυτοί.
Μέθοδος και υλικά: Οι πολυεστιακοί οφθαλμικοί φακοί ελέγχθηκαν σε συγκεκριμένα σημεία, χρησιμοποιώντας ένα συμβολόμετρο Twyman Green και τα συμβολογραφήματα που αποκτήθηκαν κατόπιν φωτογράφησης τους υποβλήθηκαν σε επεξεργασία και αξιολόγηση, για την μέτρηση της διοπτρική δύναμης που αυτοί φακοί παρουσιάζουν. Η σύγκριση των αντίστοιχων αποτελεσμάτων έγινε με εκείνα που λαμβάνονται από ένα αυτοματοποιημένο φακόμετρο (Tomey TL-100), προκειμένου να ελεγχθεί αν οι δύο τύποι μετρήσεων είναι εναλλάξιμοι, καθώς και στατιστική ανάλυση πραγματοποιήθηκε και για τους δύο τύπους μετρήσεων.
Αποτελέσματα: Τα στοιχεία έδειξαν, ότι οι δύο μέθοδοι το αυτοματοποιημένο φακόμετρο και η συμβολομετρία (Twyman-Green) συσχετίζονται. Η κατανομή της διοπτρικής δύναμης πάνω στην επιφάνεια του φακού και για τις δύο τεχνικές μέτρησης ήταν πολύ παρόμοια, αν και τα σημεία μέτρησης δεν έδωσαν αριθμητικά το ίδιο αποτέλεσμα. Από τα στατιστικά στοιχεία και ειδικά το p-value έδειξαν ότι οι δύο τεχνικές μέτρησης δεν διαφέρουν σημαντικά. Επίσης από το Bland & Altman σχεδιάγραμμα φάνηκε να υπάρχει μια διαφορά της τάξης του 0,30 Ds για το σφαιρικό στοιχείο, ενώ ήταν περίπου 0,17 Dc για το κυλινδρικό στοιχείο μεταξύ των δύο μεθόδων. Η συμβολομετρία ήταν δύσκολη και χρονοβόρα σε σχέση με το αυτοματοποιημένο φακόμετρο λόγω του χαρακτήρα της τεχνικής.
Συμπεράσματα: Μία εναλλακτική μέθοδος μέτρησης πολυεστιακών οφθαλμικών φακών παρουσιάζεται βασιζόμενη στην συμβολομετρία. Πιο συγκεκριμένα ένα συμβολόμετρο Twyman-Green χρησιμοποιήθηκε για τη μέτρηση πολυεστιακών οφθαλμικών φακών. Τα αποτελέσματα έδειξαν ότι είναι δυνατή η μέτρηση αυτού του τύπου φακών παρόλο που η συμβολομετρία ήταν δύσκολη και χρονοβόρα με πολλές μετρήσεις.
Λέξεις κλειδιά: συμβολομετρία, Twyman-Green, πολυεστιακοί οφθαλμικοί φακοί, δύναμη.