Int Ophthalmol (2019) 39:1955–1963
https://doi.org/10.1007/s10792-018-1028-6

ORIGINAL PAPER

Normative Pentacam anterior and posterior corneal elevation measurements: effects of age, sex, axial length and white-to-white

Ignacio Almorín-Fernández-Vigo · Inés Sánchez-Guillén · José I. Fernández-Vigo · Ana Macarro-Merino · Bachar Kudsieh · Cristina Fernández-Vigo · José A. Fernández-Vigo

Received: 22 April 2018 / Accepted: 21 September 2018 / Published online: 1 October 2018

Abstract
Purpose To provide normal corneal elevation data for a large Caucasian population and to determine the impacts on these data of age, sex, axial length (AXL) and horizontal white-to-white (WW).
Setting Centro Internacional de Oftalmología Avanzada, Madrid, Spain.
Design Retrospective, cross-sectional, observational.
Methods In this retrospective, cross-sectional, observational study, anterior and posterior corneal elevations were measured in 789 right eyes of subjects with no ocular disease at the thinnest corneal location in relation to a fixed 8-mm best-fit sphere using the Pentacam, and AXL and WW were measured with the IOLMaster. A multiple linear regression model was used to assess the effects of age, sex, AXL and WW on the elevation data.
Results Mean subject age was 50.5 ± 15 years (range 17–93 years); 64% were women. Mean anterior and posterior corneal elevations were 1.99 ± 1.75 µm (− 7 to 10 µm) and 7.70 ± 5.7 µm (− 6 to 28 µm). Anterior corneal elevations were higher by 0.165 µm and 0.033 µm for every mm reduction in AXL and every year reduction in age, respectively. Sex and WW were not significant predictors of anterior elevations (R^2 = 7.7%). Posterior corneal elevation increased by 0.186 µm/year of age, 0.707 µm/mm reduction in WW and 0.819 µm/mm reduction in AXL. This variable was also 0.866 µm greater in men (R^2 = 34.4%).
Conclusion Anterior corneal elevations decrease with age and are higher for shorter AXL but are not influenced by sex or WW. Posterior corneal elevations increase with age, decreasing AXL, decreasing WW and are higher in men.

Keywords Cornea · Topography · Pentacam · Corneal elevation · Keratoconus · Population study

I. Almorín-Fernández-Vigo (✉) · I. Sánchez-Guillén · A. Macarro-Merino
Centro Internacional de Oftalmología Avanzada, c/ Godofredo Ortega y Muñoz 22, 06011 Badajoz, Spain
e-mail: ignacioalmorin@gmail.com

J. I. Fernández-Vigo · A. Macarro-Merino · B. Kudsieh · C. Fernández-Vigo · J. A. Fernández-Vigo
Centro Internacional de Oftalmología Avanzada, Madrid, Spain

J. I. Fernández-Vigo
Department of Ophthalmology, Hospital Clínico San Carlos, Madrid, Spain

B. Kudsieh
Department of Ophthalmology, Hospital Puerta de Hierro, Madrid, Spain

J. A. Fernández-Vigo
School of Medicine, Universidad de Extremadura, Badajoz, Spain

Introduction

Corneal refractive surgery is a safe and effective procedure with a fast functional recovery so that is getting more frequently demanded [1]. However, one of the most important concern is the detection of early ectatic disease (subclinical keratoconus) [2] because refractive surgery on these corneas can negatively impact on their biomechanics developing progressive ectasia [3].

Improvements in diagnostic equipment have been developed from Placido disk-based topography, which identifies characteristic topographic patterns, to rotating Scheimpflug camera tomography, which also offers corneal thickness and anterior and posterior elevation measurements [2, 4]. However, despite advances in diagnostic methods, corneal ectasia still occur in operated patients with apparently healthy corneas [5].

Corneal elevation is important for the diagnosis of corneal ectasia [6] and therefore for the screening in refractive surgery [7–9]. Effectively, increased corneal elevation, especially on the posterior surface, has been identified as a sensitive tool for detecting subclinical keratoconus prior to topographic changes [3, 10–12] as it is less affected by tear-film irregularities or epithelium masking [9]. However, anterior and posterior corneal elevations show greater variability among the different measurement devices than corneal thickness or curvature measurements [13]. Further, elevation data depend on the reference surface used [3, 6, 9, 14], which is usually a fixed 8-mm best-fit sphere (BFS) [10, 15] or a best-fit toric aspheric form (BFTA) [16, 17]. In addition, differences in corneal elevation have been recently described between myopic and hyperopic patients [7] and also among different ethnicities [18].

As corneal elevation data used to screen patients as candidates for refractive surgery may be affected by ethnicity and refractive state, this study was designed to obtain normal anterior and posterior corneal elevation measurements at the thinnest corneal point in a large Caucasian population and to assess how these could be modified by other patient factors such as sex, age, axial length and horizontal white-to-white.

Materials and methods

Study design

Participants for this cross-sectional study were consecutively recruited among those visiting the Centro Internacional de Oftalmología Avanzada (CIOA), Madrid, Spain, for a routine ophthalmology examination over the period November 1, 2012 to June 30, 2013. The number of subjects enrolled was 1006. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of the Centro Internacional de Oftalmología Avanzada.

Inclusion criteria were no history of ocular disease and/or surgery and a willingness and capacity to collaborate with complementary tests. Subjects were excluded if one or more of the following were present: wearing contact lenses (< 1 week for soft and < 1 month for rigid gas permeable) before exploration, under treatment with eye drops (except for artificial tears), a glaucomatous, retinal, inflammatory and/or corneal pathology (congenital or acquired, including leukomas) as seen in the routine examination.

Scheimpflug topography of both eyes was evaluated by the author (IAFV). Subjects were excluded when findings possibly indicating ectasia were detected: asymmetric bow-tie pattern or abnormal steepening or skewed radial axis [2] or the combination of a rate of progression of pachymetry (RPI) of more than 1.2 with a thinnest point less than 450 µm accompanied by a posterior elevation greater than 13.5 µm [18].

Patient examinations

All subjects underwent a complete ophthalmic examination including: visual acuity and cycloplegic refraction, anterior segment biomicroscopy, corneal tomography with the Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany) and biometry with the IOLMaster (Carl Zeiss, Meditec, California, USA), pneumatic non-contact tonometry, and a fundus examination following pupil dilation. Age and sex were also recorded.

Corneal tomography was performed with the Pentacam single rotation Scheimpflug camera (Oculus Optikgeräte GmbH, Wetzlar, Germany): the capture rate was 25 B-scans in 2 s, and the mode was automatic release. Only tomographs with a sufficient quality score and at least 9 mm in diameter without extrapolated data were accepted.

Anterior and posterior corneal elevations were measured at the thinnest point on the cornea in relation to a float BFS calculated at a fixed diameter of 8.0 mm as described in the literature [7, 10, 15, 18, 19]. These parameters can be obtained after exporting data to an excel file (automatically labeled as BAD-LOAD) with the call-all function. Pachymetry at the thinnest point and keratometry of the 3 mm anterior central cornea were also recorded.

Axial length (AXL) and horizontal corneal diameter as white-to-white (WW) were measured by partial coherence interferometry using the IOLMaster (Carl Zeiss, Meditec, California, USA).

Only data for the right eye of each subject were included in this study.

Statistical analysis

The number and percentage of cases in each category (qualitative variables) and mean ± standard deviation (SD), range and percentiles (quantitative variables) were used for a descriptive analysis.

The Kolmogorov–Smirnov test was used to check the normal distribution of data. Mean differences in elevations between myopic (≤ − 0.50 D) and hyperopic (≥ + 0.50 D) eyes were compared using the Kruskal–Wallis test for comparisons with published data.

A multiple regression model was used to identify possible effects of the independent variables (age, sex, AXL and WW) on anterior and posterior corneal elevations. The model steps were: (1) estimation of the variables to be included in the model; (2) individual significance of the variables and the model constant (significance set at $p \leq 0.05$); (3) regression contrast (ANOVA) to assess the overall validity of the model and check that the explanatory variables together provided information about the response variable and goodness-of-fit of the model through the determination coefficient; and (4) confirming the model hypothesis through analysis of residuals.

Results

Of the 1006 subjects enrolled, 217 were excluded mostly because of the presence of extrapolated data in the 9 mm map. This left a study sample of 789 subjects (789 right eyes).

Mean participant age was 50.5 ± 15 years (range 17–93 years); 64% were women. Of the 789 eyes, 304 were myopic, 327 hyperopic and 158 emmetropic. Mean refraction was − 0.41 ± 3.44 D (− 14.5 to + 10.25 D) of sphere and 0.86 ± 0.9 D of astigmatism (0–6 D). Mean AXL and WW were 23.91 ± 1.56 mm (20.24–32.59 mm) and 12.07 ± 0.6 mm (10.9–13.4 mm), respectively. Mean thinnest pachymetry was 546.57 ± 32.45 µm (451–641 µm) and mean anterior keratometry was 43.84 ± 1.42 D (38.84–47.60 D).

Mean anterior and posterior elevations at the thinnest location were 1.99 ± 1.75 µm (− 7 to 10 µm) and 7.70 ± 5.7 µm (− 6 to 28 µm), respectively. The 97.5 percentiles for the anterior and posterior elevations were 6 and 21 µm. Neither variable was normally distributed ($p < 0.0001$). Anterior corneal elevations were similar between myopic and hyperopic subjects (2.03 ± 1.47 µm vs 1.94 ± 2.00 µm, respectively, $p = 0.478$), though posterior elevations were greater in hyperopic eyes (5.03 ± 4.99 µm vs 9.95 ± 5.60 µm, respectively, $p < 0.0001$). Figure 1 shows the distributions of anterior and posterior corneal elevations in myopic and hyperopic patients.

The multivariate regression model data for anterior and posterior elevations are provided in Tables 1 and 2, respectively. Anterior elevation was 0.165 µm higher for every mm reduction in AXL and 0.033 µm lower for every 1-year increase in age. Sex and WW did not emerge as significant predictors of anterior corneal elevation ($R^2 = 7.7\%$). Posterior corneal elevation increases were 0.186 µm/year of age, 0.707 µm/mm reduction in WW and 0.819 µm/mm reduction in AXL. This variable was also 0.866 µm higher in males than in females ($R^2 = 34.4\%$) (see Fig. 2).

Discussion

Normative corneal elevation data can be used to identify candidates for refractive surgery, and thus diminish the risk of potential complications such as

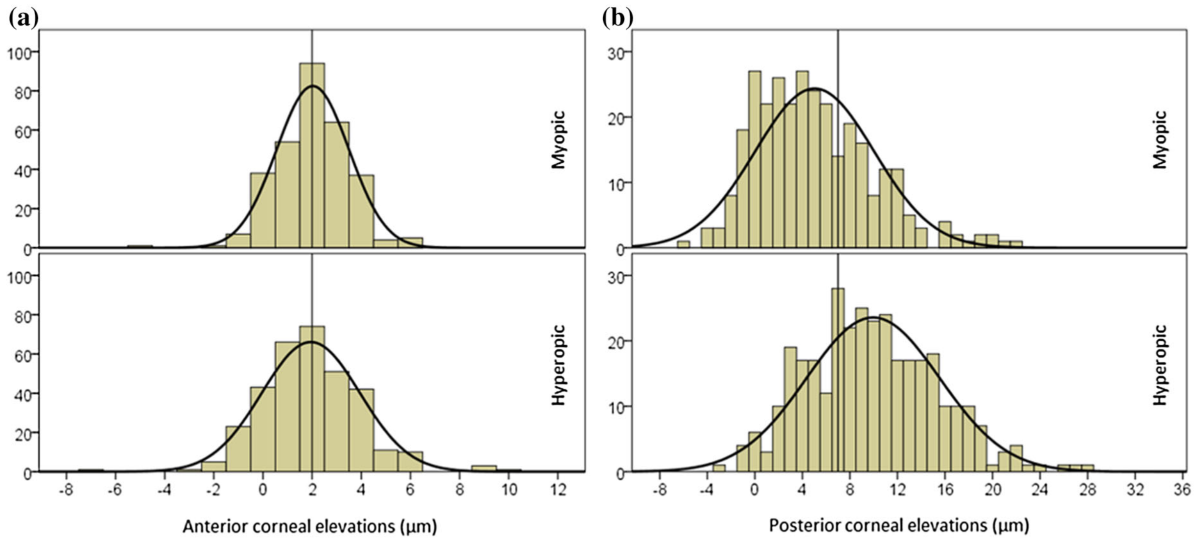

Fig. 1 Distributions of corneal anterior (**a**) and posterior (**b**) elevation data in myopic and hyperopic subjects. Vertical black line represents the median of the whole sample

Table 1 Multivariate regression model of factors affecting anterior corneal elevation measured at the thinnest corneal point

Anterior elevation: model summary R^2 (%) 7.7				
Variable	*B* (*E*)	*β*	*t*	*p*
Sex	0.238 (0.130)	0.065	1.83	0.107
Age (years)	− 0.033 (0.004)	− 0.273	− 7.60	< 0.001
WW (mm)	− 0.019 (0.106)	− 0.007	− 0.18	0.078
AXL (mm)	− 0.165 (0.042)	− 0.147	− 3.90	< 0.001
(Constant)	7.664 (1.517)		5.05	< 0.001

Table 2 Multivariate regression model of factors affecting posterior corneal measured at the thinnest corneal point

Posterior elevation: model summary R^2 (%) 34.4				
Variable	*B* (*E*)	*β*	*t*	*p*
Sex	− 0.866 (0.358)	− 0.072	− 2.416	0.016
Age (years)	0.186 (0.012)	0.475	15.698	< 0.001
WW (mm)	− 0.707 (0.291)	− 0.074	− 2.427	0.015
AXL (mm)	− 0.819 (0.117)	− 0.223	− 7.025	< 0.001
(Constant)	26.995 (4.179)		6.459	< 0.001

ectasia. However, as these variables show variation according to ethnic group [18], local normative data are needed to minimize false positive or negative test results. Normal corneal elevation Pentacam data reported by the authors of population studies are provided in Table 3. Our Pentacam anterior corneal elevations at the thinnest location were similar to reported values. The variation seen was minimal (− 0.1 to 3 μm) despite differences in age, refraction and nationality of the populations [7, 18–24]. Lower values were only reported in two studies [7, 21]. In the first of these studies by Kim et al. [7], lower anterior elevations were detected in an older hyperopic population, yet differences with myopic subjects disappeared when the data were corrected for age, suggesting a diminishing effect of age on anterior elevation which is in agreement with our results. The data provided in the study by Hashemi [21] showed lower anterior elevations along with the narrowest SD found in the literature. These authors used the same reference BFS suggesting their lower anterior corneal elevations were attributable to racial differences.

Published data for posterior corneal elevation show wider variation (0–19.8 μm) than for anterior elevations [3, 7, 10, 11, 18–25]. This can be mainly explained by differences between studies in the diameter of the BFS used, the site of elevation measurement and population characteristics. Larger BFS diameters [3] give rise to higher elevations, as this larger reference surface is flatter due to asphericity [9, 26], while measurements at the thinnest corneal location are larger than at the apex [7, 18, 19, 23, 24],

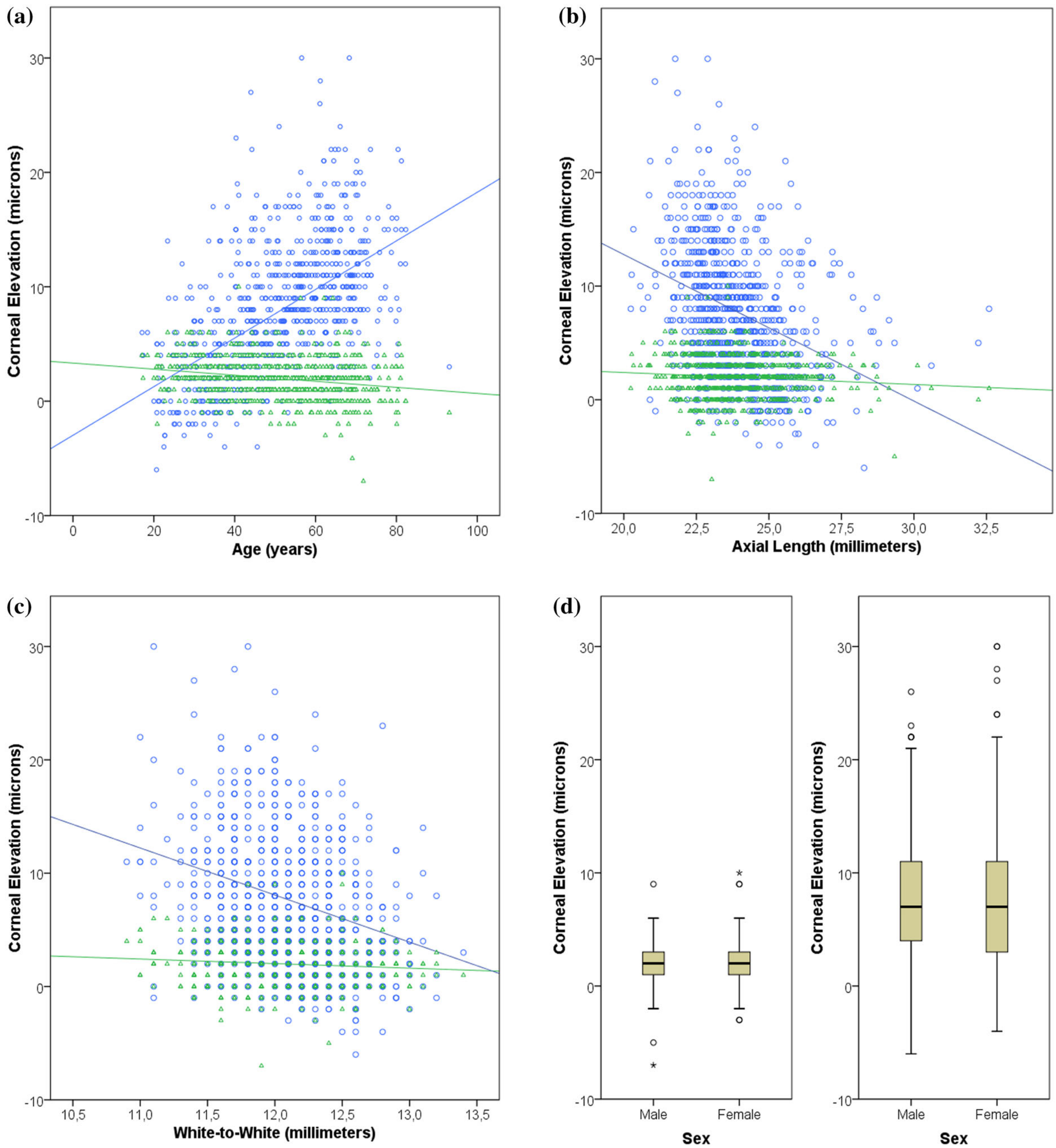

Fig. 2 Dispersion diagrams for corneal elevations by age, AXL and WW with interpolation lines. Green triangles and blue circles represent anterior and posterior corneal elevations, respectively (**a–c**). Box plot of anterior (left) and posterior (right) corneal elevations recorded in men and women (**d**)

as this region is the most protruding point of the posterior surface. Studies in myopic populations [18, 19, 23, 24] tend to find lower posterior elevations than in hyperopic populations, as described by Kim et al. [7]. In the present study, posterior corneal elevations were 4.1 µm greater in hyperopics than in myopics (9.7 ± 5.6 µm vs 5.6 ± 5.1 µm, $p < 0.001$) as a shorter AXL is associated with a higher posterior thinnest corneal elevation. Feng et al. [18] described ethnic variability in posterior elevations such that, for

Table 3 Thinnest corneal location anterior elevations measured using the Pentacam reported in the literature [3, 7, 10, 11, 18–25]

Author	Device	Year	N	Country	Age	Range	Refraction	BFS	Ant thin elev	Post apex elev	Post thin elev
De Sanctis et al. [3]	Pentacam	2008	64	Argentina	43 ± 14	–	Myopic	9	–	–	19.8 ± 6.37 (max 5 mm)
Feng et al. [18]	Pentacam	2011	555	International[a]	–	25–65	Myopic/ Emmetropic	8	2 (median)	1 (median)	3 (median)
Kim [7]	PentacamHR	2011	100	–	53.5 ± 9	27–68	Hyperopic	8	− 0.10 ± 2.2 (− 6 to 4)	5.7 ± 3.6 (− 1 to 14)	10.6 ± 5.7 (− 2 to 30)
Correia et al. [23]	PentacamHR	2012	200	Brazil	33 ± 12	12–65	–	8	1.57 ± 2 (− 6 to 7)	1.75 ± 2.81 (− 5 to 12)	3.55 ± 4.18 (− 4 to 16)
Gilani et al. [19]	PentacamHR	2013	341	N. America	–	18–68	Myopic	8	1.69 ± 1.54 (− 2 to 8)	1.09 ± 3 (− 8 to 10)	3.99 ± 4.1 (− 7 to 18)
Muftuoglu et al. [11]	Pentacam	2013	82	Turkey	29.8 ± 7	19–53	Myopic	9	–	6.87 ± 2.14 (3 to 15)	–
Ruiseñor-Vazquez et al. [20]	PentacamHR	2014	299	Argentina	32.5 ± 12	14–65	–	8	3.00 ± 2 (3 to 14)	–	4 ± 5 (7–37)
Henriquez et al. [10]	Pentacam	2014	107	Peru	30.6 ± 6	–	–	8	–	–	9.98 ± 5.33 (max 5 mm)
Orucoglu and Toker [22]	PentacamHR	2015	268	Turkey	33	8–74	Mean − 0.88D	8	2.29 ± 1.8 (− 6 to 8)	–	6.41 ± 3.83 (− 2 to 28)
Muftuoglu et al. [25]	PentacamHR	2015	67	Turkey	29.0 ± 6	18–41	Myopic	8	–	7.7 ± 2.6	–
Hashemi et al. [21]	PentacamHR	2016	4177	Iran	50.5 ± 6	40–64	–	8	0.42 ± 0.04	–	8.16 ± 0.11
Ying et al. [24]	PentacamHR	2016	1500	China	–	18–48	Myopic	8	2 (median)	0.0 (median)	3 (median)
Almorin Fernández-Vigo	Pentacam	2018	789	Spain	50.5 ± 15	17–93	Mixed	8	1.99 ± 1.75 (− 7 to 10)	–	7.70 ± 5.7 (− 6 to 28)

[a]Brazil, China, Egypt, Germany, India, Japan, New Zealand, US

example, Chinese, Egyptian, or Indian patients might benefit if a different upper limit were used to screen for ectasia, though these authors did not specify population characteristics such as age, AXL or refraction that could affect results' variability. Our population sample offered a wide age range as well as a distribution of refractive errors that well represents the Caucasian population.

Besides race and refractive state, other patient factors could also influence corneal elevations. Here, we examined the impacts of age, sex, WW and AXL on anterior and posterior corneal elevations by constructing a multivariate regression model. We observed that sex and WW were not correlated with anterior elevations and only had a weak effect on posterior elevations. Thus, the clinical relevance of these factors is less important than age and AXL. Indeed, only Ying et al. [24], in a multivariate analysis, detected slightly higher thinnest corneal anterior elevations in women ($r = 0.086$, $p = 0.001$), but not posterior elevations.

In our model, age and AXL were significant predictors of corneal elevations, especially posterior elevations. Age was the most important factor and was noted to correlate inversely with anterior elevation and directly with posterior elevation. Older subjects showed slightly diminished anterior elevations at a rate of 0.029 μm/year. This would mean a 0.87 μm change in 30 years, which has no clinical significance. In contrast, with age, posterior elevations rose at a rate of 0.186 μm/year, determining that every 5.4 years posterior elevation increases by 1 μm. A few studies have evaluated the relationship between age and Pentacam HR corneal elevations. Mahroo et al. [27] detected no correlations between age and anterior ($r = -0.11$, $p = 0.22$) or posterior ($r = 0.13$, $p = 0.12$) elevations at the thinnest location in their population of 138 twins. Probably, the narrower age range (34–81 years) and smaller sample size made the slight effect of age non-detectable. Contrasting with our results, a large study on over 4177 patients by Hashemi et al. [21] found that maximum anterior elevations in the central 6 mm of the cornea slightly increased with age in the 40–64 year range ($r = 0.114$, $p < 0.001$) but not maximum posterior elevations ($r = 0.011$, $p = 0.476$). Results cannot be directly compared as these authors measured maximum corneal elevations. Ying et al. [24] described no changes in anterior elevation in their Chinese population but, through multivariate analysis, a weak decrease in posterior elevations at the thinnest location was observed with age ($r = -0.068$, $p = 0.009$), inconsistent with our findings. We propose ethnic variability as a possible explanation for these differences. An increasing age has been proposed as a protective factor for ectasia due to progressive stiffening of the cornea [2]. This, combined with our finding of higher posterior elevation with increasing age in normal subjects, suggests a higher upper limit should be considered in older individuals who decide to undergo corneal refractive surgery for the first time [28] or after multifocal intraocular lens implantation. This effect of age found in our cross-sectional study will need to be confirmed in longitudinal studies.

In our model, AXL emerged as the second most important predictor of corneal elevation, with an inverse relationship observed between AXL and anterior and posterior elevation, such that every mm reduction in AXL gave rise to increases of 0.166 and 0.819 μm in anterior and posterior elevation, respectively. Ying et al. also reported negative correlation with AXL of anterior and posterior elevation at the thinnest corneal point ($r = -0.167$ and -0.13, $p = 0.000$) [24]. This association has been previously described by Kim et al. [7] for refractive state in that hyperopic corneas showed greater anterior and posterior elevations than myopic corneas in a normal population. Based on this finding, a separate reference database has been established for myopic and hyperopic normal subjects in the Pentacam's Belin–Ambrosio Enhanced Ectasia Display (BAD) software. However, the variation in posterior elevation normality values when selecting the myopic or hyperopic reference database is independent of the amount of refraction, so a + 1 D and a + 4 D patients are treated the same. Thus, a progressive increase in normal posterior elevations in subjects with greater hyperopia would be more suitable. Moreover, as near-emmetropia refraction also depends on keratometry, low-hyperopic or low-myopic refraction could give rise to a similar AXL, making between-group comparisons less reliable than when considering the continuous effect of AXL as shown in our regression model. Contrary to our findings, Hashemi et al. [29] observed no differences in maximum posterior elevations at the central corneal 4 mm measured with the Pentacam, but there was considerable asymmetry between groups (20 hyperopic and 242 myopic) and

BFS diameter was variable rather than fixed. These are significant limitations of the study conducted by Hashemi's group.

Given the assumption that initial changes in ectasia affect the posterior corneal surface [6], posterior corneal elevations have been proposed as a sensitive diagnostic marker for ectasia screening in refractive surgery [10]. Two different methods are generally used to establish cutoffs for relevant elevations. The first is to calculate an upper limit for a normal population based on percentiles or SD like the Tukey method (1.5 of the interquartile range above the third quartile, which is a nonparametric approximation of a 2.7 standard deviation (SD) cutoff in a normal distribution) [18]. Based on 2.7 SD, upper limits of 6 and 13.5 µm were proposed for thinnest corneal anterior and posterior elevations by Feng et al. [18] for myopic subjects, and based on 2 SD, upper limits of 4.3 and 22.1 µm were proposed by Kim et al. [7] for hyperopic individuals. In our study, these SD of 2.7 and 2 SD yielded differences with those limits of less than 1.6 µm for anterior elevation and 2 µm for posterior elevations in myopic or hyperopic subjects, indicating that the international upper limits published by Feng [18] could be applied to Caucasian populations despite discrete racial variations.

The other method often used compares elevation values between a group of ectatic eyes and a healthy control group, so a cutoff value based on receiver operating characteristic (ROC) curves is obtained. Using this method, cutoffs fully depend on the characteristics of the groups, so a large variability of reported values is seen in the literature [10–12, 20, 22, 23, 25]. As we here describe that age and AXL significantly influence elevation values, these should be taken into account to properly evaluate and compare corneal elevation cutoff points among these studies.

Finally, as age information is readily available and AXL and WW measurements can be taken almost automatically using modern tomographers equipped with low-coherence interferometers and iris cameras, these data could help improve the performance of ectasia risk algorithms to better individualize patient risks.

Our study has several limitations. As it was cross-sectional, the effects of age can only be inferred, and longitudinal studies should be designed to assess this effect. WW is a highly variable measurement between instruments, so it would be desirable to have evaluated it with two different instruments. In addition, we could have inadvertently included cases of subclinical ectasia as there are still no definitive topographic criteria to exclude this, especially at a younger age (younger subjects are more likely to have non-detectable ectasia).

In conclusion, our study provides normative anterior and posterior corneal elevation data for a Caucasian population that are comparable to values reported in the literature. Anterior corneal elevations did not vary substantially according to age, sex, WW or AXL. In contrast, posterior corneal elevations were mainly influenced by age and AXL in that an older age and shorter AXL gave rise to a greater posterior corneal elevation.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

References

1. Wen D, McAlinden C, Flitcroft I et al (2017) Postoperative efficacy, predictability, safety, and visual quality of laser corneal refractive surgery: a network meta-analysis. Am J Ophthalmol 178:65–78. https://doi.org/10.1016/j.ajo.2017.03.013
2. Santhiago M, Giacomin N, Smadja D, Bechara S (2016) Ectasia risk factors in refractive surgery. Clin Ophthalmol 10:713–720. https://doi.org/10.2147/opth.s51313
3. de Sanctis U, Loiacono C, Richiardi L et al (2008) Sensitivity and specificity of posterior corneal elevation measured by Pentacam in discriminating keratoconus/subclinical keratoconus. Ophthalmology 115:1534–1539. https://doi.org/10.1016/j.ophtha.2008.02.020
4. Ambrósio R, Faria-Correia F, Ramos I et al (2013) Enhanced screening for ectasia susceptibility among refractive candidates: the role of corneal tomography and biomechanics. Curr Ophthalmol Rep 1:28–38. https://doi.org/10.1007/s40135-012-0003-z
5. Bae GH, Kim JR, Kim CH et al (2014) Corneal topographic and tomographic analysis of fellow eyes in unilateral keratoconus patients using Pentacam. Am J Ophthalmol

157(103–109):e1. https://doi.org/10.1016/j.ajo.2013.08.014

6. Gomes JA, Tan D, Rapuano CJ et al (2015) Global consensus on keratoconus and ectatic diseases. Cornea 34:359–369
7. Kim JT, Cortese M, Belin MW, Ambrosio R Jr, Khachikian SS (2011) Tomographic normal values for corneal elevation and pachymetry in a hyperopic population. J Clin Exp Ophthalmol 2:130. https://doi.org/10.4172/2155-9570.1000130
8. Ambrósio R, Randleman JB (2013) Screening for ectasia risk: what are we screening for and how should we screen for it? J Refract Surg 29:230–232. https://doi.org/10.3928/1081597x-20130318-01
9. Kovács I, Miháltz K, Ecsedy M et al (2011) The role of reference body selection in calculating posterior corneal elevation and prediction of keratoconus using rotating Scheimpflug camera. Acta Ophthalmol (Copenh) 89:e251–e256. https://doi.org/10.1111/j.1755-3768.2010.02053.x
10. Henriquez MA, Izquierdo L, Dañin D (2014) Corneal elevation values in normal eyes, forme fruste keratoconus and keratoconus at different stages measured by Scheimpflug imaging. Int J Keratoconus Ectatic Corneal Dis 3:36–39. https://doi.org/10.5005/jp-journals-10025-1075
11. Muftuoglu O, Ayar O, Ozulken K et al (2013) Posterior corneal elevation and back difference corneal elevation in diagnosing forme fruste keratoconus in the fellow eyes of unilateral keratoconus patients. J Cataract Refract Surg 39:1348–1357. https://doi.org/10.1016/j.jcrs.2013.03.023
12. de Sanctis U, Aragno V, Dalmasso P et al (2013) Diagnosis of subclinical keratoconus using posterior elevation measured with 2 different methods. Cornea 32:911–915. https://doi.org/10.1097/ico.0b013e3182854774
13. Hernández-Camarena JC, Chirinos-Saldaña P, Navas A et al (2014) Repeatability, reproducibility, and agreement between three different Scheimpflug systems in measuring corneal and anterior segment biometry. J Refract Surg 30:616–621. https://doi.org/10.3928/1081597x-20140815-02
14. Khachikian SS, Belin MW (2009) Posterior elevation in keratoconus. Ophthalmology 116:816
15. Guilbert E, Saad A, Grise-Dulac A, Gatinel D (2012) Corneal thickness, curvature, and elevation readings in normal corneas: combined Placido–Scheimpflug system versus combined Placido–scanning-slit system. J Cataract Refract Surg 38:1198–1206. https://doi.org/10.1016/j.jcrs.2012.01.033
16. Smadja D, Santhiago MR, Mello GR et al (2013) Influence of the reference surface shape for discriminating between normal corneas, subclinical keratoconus, and keratoconus. J Refract Surg Thorofare NJ 29:274–281. https://doi.org/10.3928/1081597x-20130318-07
17. Mostafa EM (2017) Comparison between corneal elevation maps using different reference surfaces with Scheimpflug–Placido topographer. Int Ophthalmol 37:553–558. https://doi.org/10.1007/s10792-016-0291-7
18. Feng MT, Belin MW, Ambrósio R et al (2011) International values of corneal elevation in normal subjects by rotating Scheimpflug camera. J Cataract Refract Surg 37:1817–1821. https://doi.org/10.1016/j.jcrs.2011.04.030
19. Gilani F, Cortese M, Ambrósio RR et al (2013) Comprehensive anterior segment normal values generated by rotating Scheimpflug tomography. J Cataract Refract Surg 39:1707–1712. https://doi.org/10.1016/j.jcrs.2013.05.042
20. Ruiseñor Vázquez PR, Galletti JD, Minguez N et al (2014) Pentacam Scheimpflug tomography findings in topographically normal patients and subclinical keratoconus cases. Am J Ophthalmol 158(32–40):e2. https://doi.org/10.1016/j.ajo.2014.03.018
21. Hashemi H, Beiranvand A, Khabazkhoob M et al (2016) Corneal elevation and keratoconus indices in a 40- to 64-year-old population, Shahroud Eye Study. J Curr Ophthalmol 27:92–98. https://doi.org/10.1016/j.joco.2015.10.007
22. Orucoglu F, Toker E (2015) Comparative analysis of anterior segment parameters in normal and keratoconus eyes generated by Scheimpflug tomography. J Ophthalmol 2015:1–8. https://doi.org/10.1155/2015/925414
23. Correia FF, Ramos I, Lopes B et al (2012) Topometric and tomographic indices for the diagnosis of keratoconus. Int J Keratoconus Ectatic Corneal Dis 1:92–99
24. Ying J, Wang Q, Belin MW et al (2016) Corneal elevation in a large number of myopic Chinese patients. Contact Lens Anterior Eye J Br Contact Lens Assoc 39:185–190. https://doi.org/10.1016/j.clae.2016.01.005
25. Muftuoglu O, Ayar O, Hurmeric V et al (2015) Comparison of multimetric D index with keratometric, pachymetric, and posterior elevation parameters in diagnosing subclinical keratoconus in fellow eyes of asymmetric keratoconus patients. J Cataract Refract Surg 41:557–565. https://doi.org/10.1016/j.jcrs.2014.05.052
26. Gatinel D, Malet J, Hoang-Xuan T, Azar DT (2011) Corneal elevation topography: best fit sphere, elevation distance, asphericity, toricity and clinical implications. Cornea 30:508–515. https://doi.org/10.1097/ico.0b013e3181fb4fa7
27. Mahroo OA, Oomerjee M, Williams KM et al (2014) High heritability of posterior corneal tomography, as measured by Scheimpflug imaging, in a twin study. Invest Ophthalmol Vis Sci 55:8359–8364. https://doi.org/10.1167/iovs.14-15043
28. López-Montemayor P, Valdez-García JE, Loya-García D, Hernandez-Camarena JC (2017) Safety, efficacy and refractive outcomes of LASIK surgery in patients aged 65 or older. Int Ophthalmol. https://doi.org/10.1007/s10792-017-0614-3
29. Hashemi M, Falavarjani KG, Aghai GH et al (2013) Anterior segment study with the Pentacam Scheimpflug camera in refractive surgery candidates. Middle East Afr J Ophthalmol 20:212. https://doi.org/10.4103/0974-9233.114793