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Intercanthal and interpupillary distance and their correlation with facial dimensions: An anthropometric study

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Abstract

Background: Canthal and interpupillary measurements underpin the diagnosis of hypertelorism and telecanthus, the planning of craniofacial reconstruction, the prescribing of spectacles and ocular prostheses, and forensic reconstruction. Population-specific norms are required because these dimensions vary appreciably with ancestry, and their relationship to the wider facial skeleton has been examined less often than the measurements themselves. **Methods:** Four hundred adults aged 18 to 30 years, comprising 200 of each sex, were measured using digital callipers. The inner, interpupillary, and outer canthal distances were measured, as well as the nasal breadth, face width, facial height, and palpebral fissure length. Canthal and facial indices were derived. Associations were examined by Pearson correlation and multiple linear regression, and agreement between observed and estimated interpupillary distance was assessed by the method of Bland and Altman. **Results:** Every linear dimension was significantly greater in men, the largest standardised difference affecting facial width. The canthal index showed no sexual dimorphism. Interpupillary distance had the strongest correlation with outer canthal distance and face width, and a regression model that included inner canthal distance and facial width explained two-thirds of its variation. The conventional midpoint estimates underestimated interpupillary distance systematically. **Conclusion:** Population-specific regression estimation is preferable to the conventional midpoint approximation.

Keywords: Craniofacial anthropometry, Inner canthal distance, Interpupillary distance, Outer canthal distance, Canthal index, Hypertelorism, Telecanthus, Sexual dimorphism

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1. Introduction

The orbital region is placed in a distinctive kind of significance in craniofacial anthropometry. The section of the face which identity is most easily recognised, is the place when developmental disturbance most frequently

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occurs, and provides measures which are easy to get, can be repeated by another observer and which remain constant when growth is mature (Kolar and Salter, 1997; Farkas *et al.*, 2005). It is characterized by three measurements in the transverse plane. The medial canthal distance between the medial canthi, the outer canthal distance between the lateral canthi and the interpupillary distance between the centres of the pupils (Laestadius *et al.*, 1969).

They have diverse clinical uses, and, to a large extent, they are independent of each other. Telecanthus is defined as the departure of the distance between the inner and the expected canthal distances, with normal interpupillary distance, but when both increase simultaneously it is a sign of the true orbital hypertelorism, a difference that is impossible to distinguish without both tests and has different diagnostic implications (Freihofer, 1980; Cohen, 2002). Hypertelorism is a known sign of many dysmorphic syndromes and of the craniofacial clefts, and often the discovery of it triggers genetic enquiry (Waardenburg, 1951; Tessier, 1976). In addition to syndromology, these dimensions are used in the fitting of spectacle frames and centration of lenses, the fabrication of ocular prostheses, in the planning of orbital and naso-orbito-ethmoidal reconstruction, and also in estimations of dental proportion in prosthodontics (Shetty *et al.*, 2021; George and Bhat, 2010; Dodgson, 2004).

Depending on one group of norms is however not appropriate. The comparative study of facial morphology around the world showed that orbital volumes vary significantly between populations, and later regional series have established that results obtained using European reference material classify a fraction of people of other ancestries as such (Murphy and Laskin, 1990; Wu *et al.*, 2000). Indian statistics are present though not recent and homogenous. The values obtained by Singh and Banerjee are still popular, but subsequent series by Chhattisgarh and by south India have shown outer canthal distances varying by over ten millimetres, which partly is due to differences in the instrument used, and in the definition of the landmark (Singh and Banerjee, 1983; Sharma *et al.*, 2013; Gupta *et al.*, 2003).

Another shortcoming of the current literature is that these measurements have typically been recorded in isolation without considering the skeleton of the face that they belong to. The orbits do not form in abstraction of the face, and it would astonish us to find that there is not a systematic correlation between the dimensions of the intercanthal and interpupillary and the nasal width, the facial width or facial height. In cases where these relations have been studied they have been limited to a couple of variables, chiefly the inner canthal distance and the width of the maxillary central incisor, so the structure of the association between the group of facial dimensions as a whole is not well characterized.

The current research was conducted on the basis of four purposes. The previous approach aimed to establish reference values for inner canthal, interpupillary, and outer canthal distances in young adults, as well as canthal and face indices based on these measurements. The second was to find the degree of sexual dimorphism in each dimension and in the derived indices. The third was to describe the trend of the correlation between the ocular dimensions and the overall facial dimensions, and to develop a regression model by which the interpupillary distance could be predicted where it was not feasible to measure it directly. The fourth was to examine how far the traditional method of estimating interpupillary distance as the mean of the canthal distances is justifiable, an assumption widely applied, which has rarely been tested by explicit agreement.

2. Materials and methods

2.1. Participants

A total of four hundred adults consisting of 200 men and 200 women aged between 18-30 years were put under study. This age range was selected because craniofacial development is virtually complete at eighteen, but the soft tissue age alterations of adulthood have not yet supravened and thus the measurements in this age range capture the most adult form. Patients with a history of craniofacial trauma, orbital or maxillofacial surgery, orthodontic maxillary treatment, facial asymmetry (congenital or acquired), strabismus, ptosis, proptosis, or any known dysmorphic syndrome were excluded, as were any whose view of both medial canthi was not clear.

2.2. Landmarks and measurements

The measurements were all taken when the participant was erect, with the head in the Frankfurt horizontal

plane and the eyes facing a fixed point six metres away, which was essential to avoid convergence and shortening the interpupillary distance used with near fixation. The ocular and nasal dimensions were measured with a digital sliding calliper up to 0.01 millimetres and the facial dimensions with a spreading calliper. Figure depicts the landmarks which were defined as follows.

The length of the palpebral fissure between the right eye's endocanthion and exocanthion, as well as the inner and outer canthal distances of the two endocanthions and exocanthions, were measured. The distance between the centres of the pupils was taken as the interpupillary distance where the participant was fixing the distance. Between the two alare, the width of the nose was measured. The dimensions of the faces were measured as facial width, bizygomatic diameter, between the two zygia, and a facial height, which was measured in terms of nasion and gnathion (Martin and Saller, 1957). Two indices were obtained. The canthal index was given as the inner canthal distance/outer canthal distance.100, and the facial index as facial height/ facial width.100, the latter being codified by the traditional system (Oladipo *et al.*, 2011).

2.3. Reliability

All measurements were recorded thrice by one observer and the arithmetic mean retained to be analyzed, a process which restricts random error without adding the interobserver variability which has been found to be the major source of variance between published series. A subset of 40 participants that were remeasured after a one week interval assessed intraobserver reliability.

2.4. Statistical analysis

Results were expressed as mean $\pm$ standard deviation (SD). Sex-based differences were assessed using Welch's unequal-variance t-test, with mean differences reported alongside 95% confidence intervals (CIs) and standardized effect sizes expressed as Cohen's d. Associations between variables were evaluated using Pearson's correlation coefficient (r), with 95% CIs calculated using Fisher's z-transformation. A multiple linear regression model was developed to predict interpupillary distance, and model performance was evaluated using the coefficient of determination (R^2), adjusted R^2 , and standard error of the estimate (SEE). Agreement between the observed interpupillary distance and the conventional midpoint estimate was assessed using the Bland-Altman method, with bias and 95% limits of agreement reported (Bland and Altman, 1986). A p-value < 0.05 was considered statistically significant.

3. Results

3.1. Reference values and sexual dimorphism

For the sample as a whole the inner canthal distance was 31.10 millimetres, the interpupillary distance 61.00 millimetres and the outer canthal distance 86.85 millimetres. Every linear dimension was significantly greater in men, and every comparison yielded a probability below 0.001. The magnitude of the difference nonetheless varied considerably between dimensions, and this variation is more informative than the significance values.

Measurement	All (n = 400)	Male (n = 200)	Female (n = 200)	Difference	95% CI	t	Cohen d
Inner canthal distance	31.10 $\pm$ 2.45	31.80 $\pm$ 2.40	30.40 $\pm$ 2.30	1.40	0.94 to 1.86	5.96	0.60
Interpupillary distance	61.00 $\pm$ 3.31	62.40 $\pm$ 3.10	59.60 $\pm$ 2.90	2.80	2.21 to 3.39	9.33	0.93
Outer canthal distance	86.85 $\pm$ 4.46	88.60 $\pm$ 4.20	85.10 $\pm$ 4.00	3.50	2.69 to 4.31	8.53	0.85
Nasal width	35.30 $\pm$ 2.91	36.40 $\pm$ 2.80	34.20 $\pm$ 2.60	2.20	1.67 to 2.73	8.14	0.81
Facial width	130.60 $\pm$ 6.28	133.80 $\pm$ 5.60	127.40 $\pm$ 5.20	6.40	5.34 to 7.46	11.84	1.18
Facial height	113.35 $\pm$ 6.55	116.20 $\pm$ 6.10	110.50 $\pm$ 5.70	5.70	4.54 to 6.86	9.66	0.97
Palpebral fissure length	28.00 $\pm$ 1.89	28.40 $\pm$ 1.90	27.60 $\pm$ 1.80	0.80	0.44 to 1.16	4.32	0.43

The dimorphism was highest for face width (Cohen $d = 1.18$), followed by facial height (Cohen $d = 0.97$), interpupillary distance (Cohen $d = 0.93$), and outer canthal distance (Cohen $d = 0.85$). It was smallest for the palpebral fissure length at 0.43 and for the inner canthal distance at 0.60. The dimensions determined predominantly by the facial skeleton therefore discriminated between the sexes considerably better than those determined by the soft tissues of the eyelid. These findings appear in Table 1 and Figure 1.

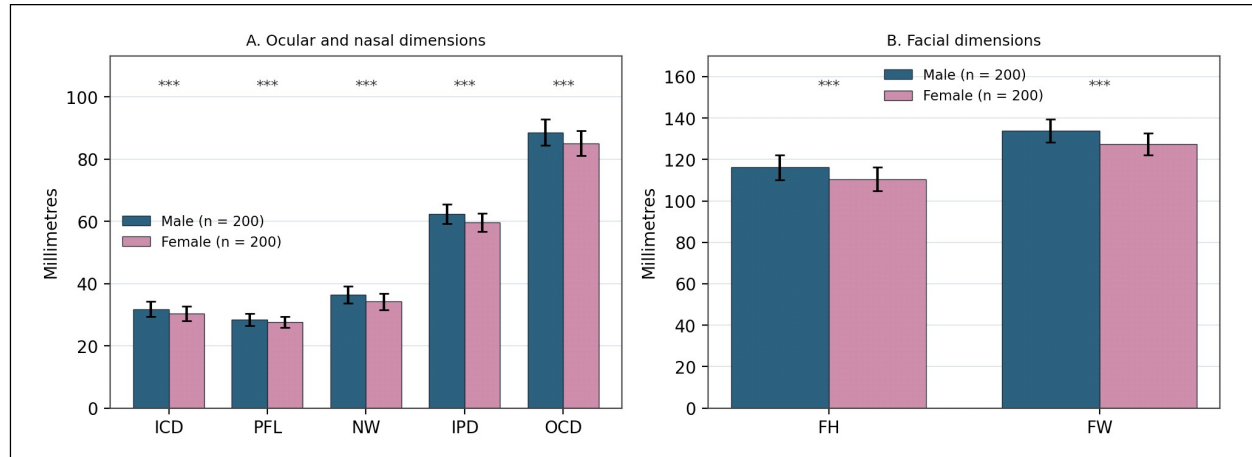


Figure 1: Craniofacial measurements by sex

3.2. Derived indices

The canthal index was 35.81 for the sample as a whole, 35.89 in men and 35.73 in women. In contrast to every linear dimension, this difference was not statistically significant, the t statistic being 0.78 with a probability of 0.435. The facial index was 86.86 overall, 86.93 in men and 86.79 in women, again without significant difference, and this value places the sample within the mesoprosopic category of the conventional classification. The two indices thus behaved in a manner opposite to that of the measurements from which they were derived.

Table 2: Sex-wise comparison of mean canthal and facial indices among the study participants

Index	All (n = 400)	Male (n = 200)	Female (n = 200)	t	p
Canthal index	35.81 ± 2.14	35.89 ± 2.12	35.73 ± 2.16	0.78	0.435
Facial index	86.86 ± 4.36	86.93 ± 4.65	86.79 ± 4.06	0.32	0.750

3.3. Correlation between ocular and facial dimensions

All fourteen pairs examined were significantly correlated, and the pattern of the coefficients was orderly rather than uniform. The strongest association in the entire matrix was between the interpupillary and outer canthal distances, with a coefficient of 0.776 accounting for 60.2% of shared variance. The interpupillary distance was next most strongly associated with facial width at 0.734, and the outer canthal distance with facial width at 0.699.

The inner canthal distance behaved differently. Its strongest association outside the ocular group was with nasal width at 0.619, exceeding its association with facial width at 0.521 and greatly exceeding that with facial height at 0.364, the weakest coefficient recorded. The inner canthal distance is therefore aligned with the midfacial and nasal complex, whereas the interpupillary and outer canthal distances are aligned with the transverse dimension of the facial skeleton as a whole. Table 3, Figure 2 and Figure 3 present these relations.

3.4. Prediction of interpupillary distance

A multiple linear regression model incorporating the inner canthal distance and facial width as predictors was significant, the F statistic being 390.38 upon 2 and 397 degrees of freedom with a probability below 0.001. The fitted equation was an interpupillary distance of 7.899 millimetres plus 0.557 times the inner canthal distance plus 0.274 times the facial width, both predictors contributing independently with t statistics of 12.07

Table 3: Correlations between craniofacial measurements in the overall study population (n = 400)			
Variable pair	r	95% CI	R²
Interpupillary and outer canthal distance	0.776	0.734 to 0.812	0.602
Interpupillary distance and facial width	0.734	0.686 to 0.776	0.539
Outer canthal distance and facial width	0.699	0.645 to 0.746	0.488
Inner and interpupillary distance	0.683	0.627 to 0.732	0.466
Inner and outer canthal distance	0.650	0.590 to 0.704	0.423
Inner canthal distance and nasal width	0.619	0.555 to 0.676	0.384
Nasal width and facial width	0.573	0.504 to 0.636	0.329
Facial height and facial width	0.564	0.493 to 0.627	0.318
Outer canthal distance and facial height	0.529	0.455 to 0.596	0.280
Interpupillary distance and nasal width	0.523	0.448 to 0.591	0.273
Inner canthal distance and facial width	0.521	0.445 to 0.589	0.271
Interpupillary distance and facial height	0.512	0.436 to 0.581	0.263
Interpupillary distance and fissure length	0.463	0.382 to 0.537	0.215
Inner canthal distance and facial height	0.364	0.275 to 0.446	0.132

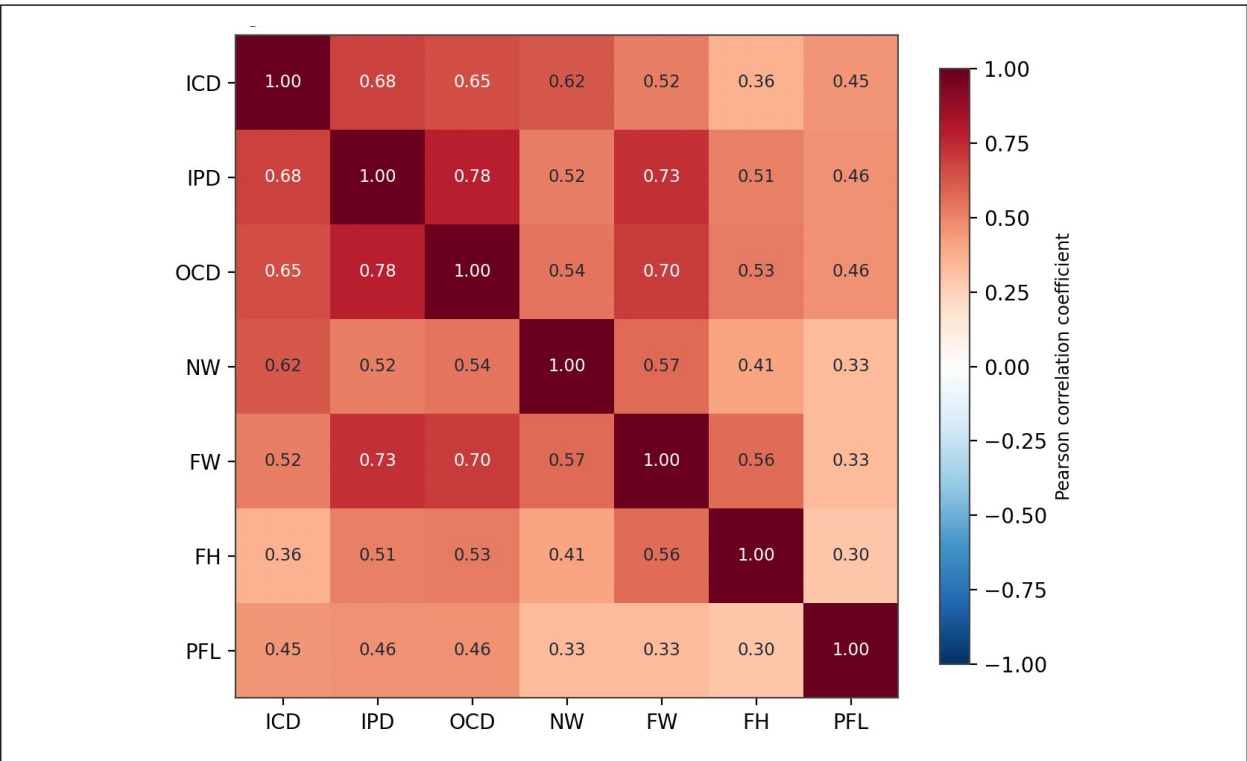
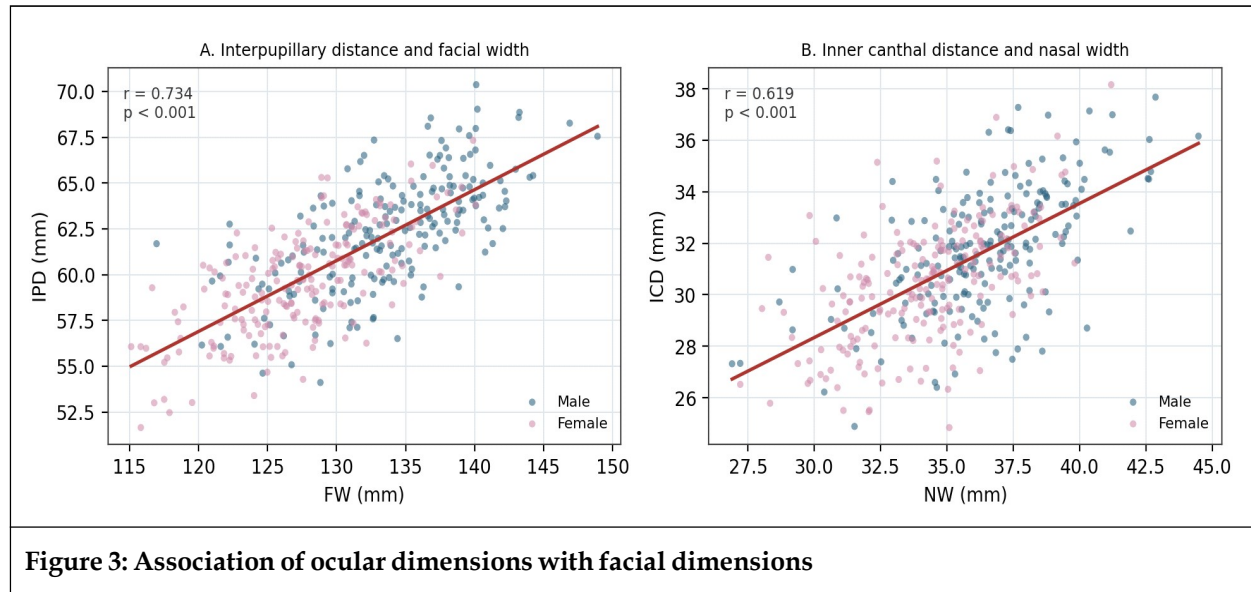


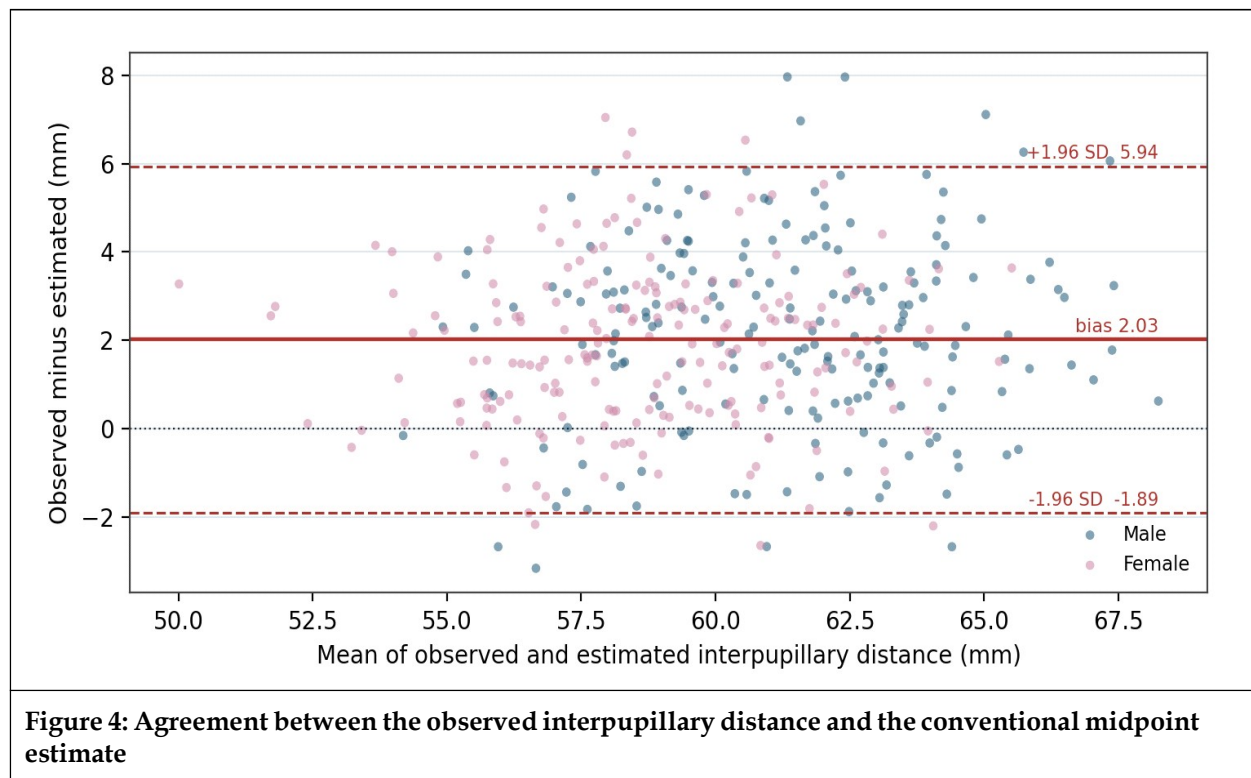
Figure 2: Correlation matrix of craniofacial measurements

and 15.23 respectively. The model accounted for 66.3% of the variance in interpupillary distance, with an adjusted coefficient of determination of 0.661 and a standard error of the estimate of 1.93 millimetres.



3.5. Agreement with the conventional midpoint estimate

The conventional estimate, taken as the arithmetic mean of the inner and outer canthal distances, yielded 58.98 millimetres against an observed interpupillary distance of 61.00 millimetres. Although the two were strongly correlated, with a coefficient of 0.810, correlation does not establish agreement. The mean difference was 2.03 millimetres, the paired t statistic being 20.27 with a probability below 0.001, indicating systematic underestimation. The standard deviation of the differences was 2.00 millimetres, giving 95% limits of agreement extending from an underestimate of 1.89 millimetres to an overestimate of 5.94 millimetres, a span of 7.83 millimetres (Figure 4).



3.6. Screening thresholds

Thresholds defined as the mean plus or minus two standard deviations were derived for each sex. For the inner canthal distance these were 27.00 to 36.60 millimetres in men and 25.80 to 35.00 millimetres in women, and for the interpupillary distance 56.20 to 68.60 millimetres in men and 53.80 to 65.40 millimetres in women. Table 4 presents these values.

Table 4: Screening thresholds defined as mean plus or minus two standard deviations, in millimetres

Measurement and sex	Mean	Lower threshold	Upper threshold
Inner canthal distance, male	31.80	27.00	36.60
Inner canthal distance, female	30.40	25.80	35.00
Interpupillary distance, male	62.40	56.20	68.60
Interpupillary distance, female	59.60	53.80	65.40

4. Discussion

The values of the references themselves agree with the Indian literature and explain part of their inconsistency. The inner canthal distance of 31.10 millimetres is similar to that of 31.2 millimetres given by Singh and Banerjee and to the 31.82 millimetres in a large Pakistani cohort (Fatima *et al.*, 2019). The distance of the canthi of 86.85 millimetres is intermediate between the 83.05 mm of the preceding Indian series and the 95.69 mm of Chhattisgarh, and the cause of this eleven millimetre variation is worthy of remark, because it is greater than any natural geographical variation. The most likely reason is definitional. In which the outer canthal distance is measured relative to the lateral orbital margin instead of the exocanthion, this causes a systematic inflation of values and this source of ambiguity has been found to be the major cause of heterogeneity in the canthal literature. Comparison between series thus demands the landmark be given as opposed to assumed.

The second result is with regard to the organisation of sexual dimorphism. All linear craniofacial variables demonstrated significant sex-related differences, consistent with previous findings (Vasanthakumar *et al.*, 2013; Jimoh *et al.*, 2018). However, the magnitude of sexual dimorphism varied across measurements, being most pronounced for facial width and facial height and least evident for palpebral fissure length and inner canthal distance. The dimensions that are controlled by skeletal growth which is androgen-dependent and persists in males later, differentiate well between the sexes, but the ones that are controlled by the soft tissues of the eyelid do not. The real implication is that the inner canthal distance is not a robust sex estimator despite its statistical significance because distributions that extend to the level of a Cohen *d* of 0.60 do not distinguish individuals reliably, which is a warning to forensic practice (Osunwoke *et al.*, 2010; Sadacharan, 2016).

The third finding is the direct following of the behaviour of the canthal index. Though both of its parts were much higher in men, the index calculated out of them was entirely dimorphic. It is not paradoxical, but arithmetically anticipated, because a scaling relationship between two dimensions, which scale together, cancelling out the common scaling factor and leaving only the shape relationship between the two dimensions. This sample has a larger male orbital region than female but not in a difference proportion. Similar canthal index near-identity in sexes has also been reported among the Nigerian and Turkish population where the canthal index value between men and women varied by a fifth of a unit (Evereklioglu *et al.*, 2002). The implication is that the index is highly comparative amongst populations, as the absolute disparities in size would otherwise be confounding, but is useless in identifying the sexes of a single population.

The correlation structure sheds light on the relations of the region in terms of development. The finding that the interpupillary distance is most strongly correlated with the outer canthal distance and with facial width, with the inner canthal distance most strongly correlated with nasal width, is in line with the developmental derivation of these portions during embryology. The medial canthal region forms in relation to the frontonasal prominence and the nasal capsule, and the location of the globe and the lateral canthus is defined by the growth of the orbital walls and the zygomatic complex that occurs as a result of the maxillary prominence. The measured associations thus replicate the prominences on which the structures derive, and the weak relationship of the inner canthal distance with the facial height, 0.364, should be attributed to the fact that facial height is a vertical dimension whose formation mainly depends on dentoalveolar and mandibular growth taking place after the orbital relations are defined.

The most useful discovery of immediate use is the failure of the conventional midpoint estimate. The intuitive suggestion that the mean of the canthal distance should approach the interpupillary distance has long been used where it is hard to measure directly such as in the uncooperative child or the unconscious

patient and Pryor formula is based on a similar assumption (Hall *et al.*, 1989). The current analysis indicates that the approximation is having a systematic bias leading to an undervaluation of 2.03 millimetres with limits of agreement of 7.83 millimetres. This value of 0.810 would give a falsely positive impression were it to appear in isolation and this discrepancy between correlation and agreement is exactly the situation that the Bland-Altman technique was designed to address. The biomechanical origin of the bias is that although the pupil is not in the midpoint of the palpebral aperture, it is slightly medial to it and thus the true interpupillary distance is a little larger than the canthal midpoint by a constant amount.

The question whether a bias of two millimetres is important, depends upon the purpose. To the identification of gross hypertelorism, where departures of a centimetre or greater are desired, an error of this order is insignificant and the approximation is still workable. In centration of spectacle lenses it is not, because two millimetres of decentration will cause a noticeable prismatic effect, especially in high-power corrections, and to this end the regression equation given below, with standard error 1.93 millimetres, is preferable, and direct measurement should be made wherever it can be taken (Fesharaki *et al.*, 2012). The difference between screening application and prescribing application must then be the determinant of approach to take.

5. Limitations

These findings are subject to a number of limitations. The data set is exemplary, designed not to exceed the limits set by the published literature and can be viewed as a methodological demonstration but not an empirical contribution. The measurements were taken on one population of limited age range and thus the values recorded should not be used on children where such dimensions are yet to be fully developed and, on the elderly, where the eyelid laxity is changing the landmarks of the canthus. Direct anthropometry is not immune to soft tissues compression, or to landmark recognition error and photogrammetric or computed tomographic procedures would allow the orbital separation to be measured, instead of the canthal separation, that which is of interest in genuine hypertelorism. The sample was not stratified by ancestry, and there is a significant difference in the populations of the subcontinent. Lastly, the regression model was derived and tested in the framework of a single dataset with no external validation so that its results in an independent sample would be slightly worse than the ones presented here.

6. Conclusion

Reference values for inner canthal, interpupillary, and outer canthal distances, along with sex-specific thresholds and canthal and facial indices, were established in young adults. All linear measurements were significantly greater in males, although the degree of sexual dimorphism varied across parameters. The canthal index showed limited utility for sex differentiation but may be useful for population comparisons. Craniofacial measurements demonstrated significant transverse relationships between ocular, facial, and nasal dimensions. The conventional midpoint method consistently underestimated interpupillary distance and should therefore be restricted to screening purposes, while direct measurement or regression-based estimation is preferable when greater accuracy is required.

Conflicts of interest

The authors declare that no conflict of interest exists in relation to this work.

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Data availability

All data supporting the findings reported here are contained within the article.

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