J Forensic Sci, July 2002, Vol. 47, No. 4
Paper ID JFS2001341_474
Available online at: www.astm.org

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Facial Approximation: Globe Projection Guideline Falsified by Exophthalmometry Literature*

ABSTRACT: The projection of the cornea from the bony orbit has been determined, in facial approximation, by centrally locating the eyeball in the orbit and positioning the cornea so that its most anterior point falls in line with a tangent dropped from the mid-superior to the mid-inferior orbital rim. However, there appears to be no scientific evidence to justify this guideline; yet, there have been numerous studies that measure globe projection in living subjects, from the lateral orbit using an exophthalmometer. The aim of this study was to determine if the traditional facial approximation guideline is consistent with the exophthalmometry literature. MRI research shows that corneal projection is underestimated using the traditional facial approximation guideline. An underestimation is also strongly supported by statistical comparisons of globe projection measures taken using more traditional instruments (e.g., Hertel's exophthalmometer) to skull morphology ($p < 0.006$). It is suggested that the traditional facial approximation guideline not be used in future facial approximations since it appears to under-predict anterior globe projection by 4 mm on average. It is also suggested that average exophthalmometer values be used until more accurate and precise ways of determining globe projection have been determined.

KEYWORDS: forensic science, forensic anthropology, facial reconstruction, facial reproduction, eyeball, cornea, skull, face, anthropometry

Besides the placement of average soft tissue pegs, one of the first procedures in any facial approximation is to locate the eyes within the orbit. Globe positioning takes place in three planes: (i) the medial-lateral plane; (ii) the superior-inferior plane; and (iii) the anterior-posterior plane. Traditionally, globe location in the medial-lateral and superior-inferior planes has been accomplished by central positioning of the pupil (1–4). In the anterior-posterior plane, the globe has been placed by aligning the most anterior part of the cornea with an "imaginary" tangent from the superior to the inferior orbital rim (1–4).

Despite the publication and promotion of these positioning guidelines, there appears to be no published tests of these methods, by the original authors or by any other authors, in the scientific literature. It therefore appears that these guidelines have been based on untested observations, and other facial approximation practitioners have followed the method blindly, e.g., (2–4). Consequently, the accuracy and reliability of these facial approximation guidelines are unknown. Experience of the author indicates that adherence to these globe-positioning guidelines results in an under-representation of globe projection and distance between the pupils. However, this paper concerns itself only with projection of the globe in the anterior-posterior plane.

It seems worthy to note that while palpebral ligament attachments (5) and the canthi of the eyelid (Angel and Krogman cited in (6)) may be useful to some extent for globe positioning in the medial-lateral plane, these features offer little use for determining globe position in the superior-inferior and anterior-posterior planes because these structures are not directly associated with the globe itself. If the palpebral ligament attachments and the locations of the canthi are used to position the eyeball in these two planes, unjustifiable assumptions must be made concerning curvatures of eyelid borders (for globe positioning in the superior-inferior plane) and eye proptosis (for anterior-posterior globe positioning).

Exophthalmometry appears to be useful in determining globe positioning in the anterior-posterior plane since it involves the measurement of the anterior protrusion of the globe in living subjects using standard instruments and methods. Exophthalmometry studies began as early as the 1870s (7,8), 25 years before scientific facial approximations began in 1895 (9).

In exophthalmometry, globe projection measures are most commonly taken using a Hertel's exophthalmometer (see (10) for images). However, other instruments such as Luedde's exophthalmometer have been used (see (11–12) for images). Both exophthalmometers are used to measure the projection of the globe from the deepest point on the lateral orbital rim/s to the anterior most point of the cornea (10,13,14).

When measuring, the exophthalmometer is placed firmly against the orbital rim and the projection of the cornea read off the scale. The lateral rim is chosen since it appears to have a thin covering layer of soft tissue regardless of the size or weight of the body (15). However, using the lateral rim as a reference point is somewhat dubious because, in reality, it is not fixed (10) (i.e., the lateral orbital rim position varies across individuals due to variation in skull growth; consequently, a normal globe projection may, for example, be interpreted as being pathological if the lateral orbital rim is posteriorly displaced in comparison to the rest of the skull). Cohn (16), who is reported to be the first to construct an exophthalmometer (10), originally used the lateral orbital wall; however, he found it not to represent the "ideal plane" since it was often asymmetric between left and right sides, so he built a new exophthalmometer two years later that used the superior orbital margin as the reference (17). However, others have reported that the supraorbital rim is just

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* Portions of this work have been previously presented at the 16th International symposium on the Forensic Sciences, Canberra, Australia.

Received 6 Oct. 2001; and in revised form 20 Dec. 2001; accepted 4 Jan. 2002; published 14 June 2002.

as variable as the lateral orbital rim (18). Several other reference points have also been proposed (14); however, the lateral orbital wall is the most commonly used today because of the advantages listed above.

Although the accuracy of Hertel's Exophthalmometer has been challenged (10), it is one of the most commonly used instruments to measure globe proptosis and has the advantages that: it is easy to operate; it measures both eyes simultaneously; and has cross hairs that allow correction for parallax (19). Despite the most likely source of error being misplacement of the instruments foot plates (10), both the Hertel's and Luedde's exophthalmometers are reported to have a measurement accuracy of about 1 mm (14,20,21), with the lowest reported error being 0.5 mm (14). However, the accuracy of the Hertel instrument starts to decrease if the transverse bar is not parallel to the frontal plane (usually caused by asymmetrical orbits) (14).

The aims of this paper are: (i) to determine if there are any previously published papers that directly support, or refute, the facial approximation guideline for determining globe projection; and (ii) to determine if reported measures of globe projection from the lateral orbit correspond to the tangent from the superior and inferior orbital rims as predicted by the traditional facial approximation method.

Material and Methods

A search of the ophthalmology and related literature was conducted for papers reporting globe projection values in normal healthy adults. Searches were conducted using Medline, Current Contents, and reference lists of exophthalmometry papers. Of those papers found, exophthalmometry values were collated in a database. Table 1 summarizes those papers and displays, where possible, sex specific averages, sample sizes, standard deviation, and type of exophthalmometer used. Decimal places, as presented in reviewed articles, are presented in Table 1.

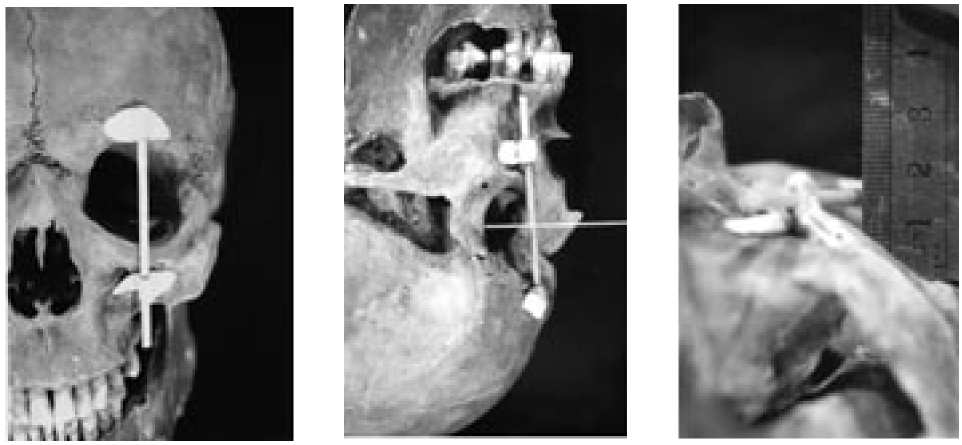
To establish if exophthalmometry values, as measured from the lateral orbital rim, correspond to the guideline used in facial approximation, measurements were also taken on crania from the deepest point of the lateral orbital rim to the tangent from the mid-superior to the mid-inferior orbital rim. Twenty-eight Caucasoid adult crania (as determined using standard osteological methods) were used in the analysis. No attempt was made to separate this sample into sexes or ages because of its small size.

The mid-orbital tangent was represented on the skulls using a plastic rod, fixed in the mid-saggital plane of the left orbit using Bostik Blu-Tack®, placed over the plastic rod (Fig. 1*a*). A metal

TABLE 1—*Reported measures of average globe projection, from the lateral orbital rim, for normal healthy adults.*

Author (Date Published)	White American		Black American		Not Specified/Other		Exophthalmometer Used
	Male	Female	Male	Female	Male	Female	
Bolanos-Gil-de Montes et al. (1999)					15.18 ± 2. 16 (*n* = 116)	14.82 ± 1.98 (*n* = 185)	Hertel
Barretto and Mathog (1999)	17.00 ± 2.65 (*n* = 34)	15.98 ± 2.22 (*n* = 31)	18.23 ± 2.26 (*n* = 33)	17.27 ± 1.44 (*n* = 28)			Hertel and Luedde
Goldberg et al. (1999)					15.2 ± 2.8 (*n* = 79)		MRI
Quant and Woo (1992)					16.66 ± 1.86 (*n* = 120)	16.57 ± 1.78 (*n* = 123)	Hertel
Dunsky (1992)			18.20 ± 2.97 (*n* = 139)	17.46 ± 2.64 (*n* = 170)			Hertel
Majekodunmi and Oluwole (1989)					13.5	15	Hertel
Borgren et al. (1986)	16 (*n* = 53)		18 (*n* = 47)				Hertel
Fledelius and Stubgaard (1986)					16.51 ± 2.26 (*n* = 102)	16.01 ± 1.73 (*n* = 101)	Rhodenstock apperatus
Migliori and Gladstone (1984)	16.51 ± 2.59 (*n* = 127)	15.41 ± 2.34 (*n* = 200)	18.49 ± 3.08 (*n* = 113)	17.82 ± 2.57 (*n* = 241)			Hertel
de Juan et al. (1980)	16.0 ± 2.30	14.7 ± 1.92	17.9 ± 2.86	17.1 ± 2.71			Luedde
Brown and Douglas (1975)	14.7 ± 1.7 (*n* = 51)	17.0 ± 2.9 (*n* = 87)					Hertel
Drescher-Benedict (1950)*					17.3 (*n* = 100)		Hertel
Knudtzon (1949)	17.1 ± 2.08 (*n* = 263)	16.8 ± 2.05 (*n* = 99)					Hertel
Gormaz (1946)					14–16		Own
Soley (1942)†					15.9 (*n* = 65)		Hertel
Ruedemann (1936)*					18.8 (*n* = 1000)		Hertel
Wagener (1934)					18.0 (*n* = 200)		Hertel
Lee (1930)†					14.4 (n = 324)	14.8 (*n* = 76)	Hertel
Jackson (1921)*					16–17 (*n* = 4500)		Own
Helmbold (1916)†					16.67 (*n* = 300)	15.68 (*n* = 225)	Hertel
Woods (1915)†					12–14 (*n* = 200)		Hertel
Birnbaum (1915)†					15 (*n* = 120)	14.5 (*n* = 30)	Hertel
Geraud (1912)†					13.6 (*n* = 12)		Rollet-Durand
Birch-Hirschfeld (1900)†					14 (*n* = 24)		Satler and Hering
Emmert (1870)					12–14 (*n* = 200)		Own

* As cited in (13).
† As cited in (14).



(a) (b) (c)

FIG. 1—(a) *Representation of the tangent (connecting the superior and inferior orbital rims in its saggital plane) by plastic rod and held in place with Bostik Blu-Tack® placed over the rod;* (b) *measurement of the distance from the deepest portion of the lateral orbital rim to the tangent;* (c) *close up inferior-oblique view of the orbit showing the scale directly beside the rod and touching the lateral orbit while being held in the saggital plane. In this case the projection of the tangent would be read as 13 mm.*

TABLE 2—*Comparison of exophthalmometry measures taken on Caucasoid adults to the tangent-orbit measures made in this study using two-sample t-tests.*

Study	Sex	n	Average	SD	Degrees of Freedom	t	$p <$ normal (Bonferroni Adjusted)
Goldberg et al. (1999)	All	79	15.20	2.80	105	6.48	0.0005 (0.0055)
Barretto and Mathog (1999)	Male	34	17.00	2.65	60	8.48	0.0005 (0.0055)
Barretto and Mathog (1999)	Female	31	15.98	2.22	57	7.21	0.0005 (0.0055)
Fledelius and Stubgaard (1986)	Male	102	16.51	2.26	128	11.16	0.0005 (0.0055)
Fledelius and Stubgaard (1986)	Female	101	16.01	1.73	127	10.64	0.0005 (0.0055)
Migliori and Gladstone (1984)	Male	127	16.51	2.59	153	11.05	0.0005 (0.0055)
Migliori and Gladstone (1984)	Female	200	15.41	2.34	226	8.95	0.0005 (0.0055)
Brown and Douglas (1975)	Male	51	14.70	1.70	77	6.06	0.0005 (0.0055)
Brown and Douglas (1975)	Female	87	17.00	2.90	113	10.76	0.0005 (0.0055)
Knudtzon (1949)	Male	263	17.10	2.08	289	14.76	0.0005 (0.0055)
Knudtzon (1949)	Female	99	16.80	2.05	125	12.31	0.0005 (0.0055)
Total	All	1174	16.20	2.30			
Tangent-orbit measures made in this study	All	28	12.43	1.53			

ruler was then used to measure the distance of the midpoint of the rod from the deepest point on the lateral orbital rim (Fig. 1*b* and 1*c*). Before measuring, all skulls were inverted but placed in a position equivalent to the natural head position (splanchnocranium rotated superiorly by ~5 degrees in comparison to the Frankfort horizontal). The skull was also placed as symmetrically as possible according to methods of Drews (14) using the intermaxillary suture, the foramen magnum, and the two glenoid fossae.

The metal ruler was wide enough to be placed, simultaneously, on the lateral orbital rim and directly beside the rod (Fig. 1*c*). Measures were rounded to the nearest millimeter. This technique is similar to that employed when using Luedde's Exophthalmometer. Every effort was made to ensure the ruler was in the sagittal plane, as any deviation from it would introduce error, as would be the case if using Luedde's exophthalmometer (10,14).

Exophthalmometry values were then compared to the tangent-orbit measures made. For exophthalmometry studies that were conducted on adult Caucasoid samples, and reported means, sample sizes, and standard deviations, two-sample t-tests were used to determine if statistically significant differences existed in comparison to the tangent-orbit measures made in this study. Significance was initially set at $p < 0.05$ but altered according to the Bonferroni adjustment (i.e., since eleven tests were conducted, significance was taken at $p < 0.0045$).

Results

A paper by Goldberg et al. (22), using MRI techniques and a sample of 79 individuals, found that the anterior corneal surface falls, on average, 3.6 ± 3.3 mm anterior to the superior orbital rim and 11.3 ± 3.3 mm anterior to the inferior orbital rim. This observation shows that the facial approximation guideline of the tangent from the superior to inferior orbital rims under-represents actual globe projection in the vast majority of cases.

The average distance from the left lateral orbital rim to the tangent connecting the superior and inferior mid-sagittal orbital margins, as measured on 28 Caucasoid adult skulls, was 12.5 ± 1.5 mm. This value was less than the average globe projection (16.2 ± 2.3 mm) reported by the exophthalmometry literature (Table 2). Comparisons of tangent-orbit measures made in this study to reports of exophthalmometry in similar samples showed highly statistically significant differences ($p < 0.006$) in each case (Table 2). This further supports the conclusion that the facial approximation guideline for anterior globe projection is inaccurate. The magnitude of this difference (4 mm) also appears to be considerable in relation to other orbital measures like eye fissure length and height.

Discussion

Previously published MRI data (22), and measurements taken from skulls in this study in conjunction with published exophthalmometry studies (Tables 1 and 2), indicate that the traditional facial approximation guideline for determining globe projection is inaccurate and is likely to underestimate the position of the cornea by more than 2.5 mm (average underestimation = 3.7 mm). It is, therefore, suggested that the traditional facial approximation guideline should be replaced by exophthalmometry values as measured from the lateral wall of the orbit.

Exophthalmometry values, as measured from the lateral orbital wall, appear to be useful to facial approximationists since they have been comprehensively studied. Values have been calculated for numerous adult populations including: Chinese (19); Mexican (23); white American (13); black American (13); and African (24). Studies also cover a relatively wide range of age groups. Fledelius and Stubgaard (25) give values for children from 5 to 20 years, Nucci et al. (24) give values for children aged 3 to 10 years, and Gerber et al. (12) provide values from 10 to 14 years of age. Although not shown in Table 1, many of the samples used by these studies have also been divided into age groups. Furthermore, globe projection has been shown to increase up until the late teenage years (about 17 years of age) when they reach adult values (25). Values also appear to be slightly greater (1 to 2 mm) for American blacks than whites (Table 1). Average male values appear to be consistently larger than females; however, the differences are generally not more than 1 mm (27), being about the same as published instrument errors (14,20,21), indicating that this difference may not be real. It is also commonly reported that globe projection is larger on the right side (12,14,15,19,28), but this asymmetry is not usually more than about 2 mm in whites (11,15,19,25,26,29,30) and Mexicans (23), and about 3 mm in blacks (11,31). Asymmetries of 3 to 4 mm have, however, been recorded in normal healthy subjects (24,32). Majekodunmi and Oluwole (24), and Fledelius and Stubgaard (25) report more proptosis of the left rather than the right side. However, other authors report that the difference between the sides is not statistically significant (29,30).

In general, weak to no correlation in exophthalmometry values have been found for height (11,19,24,29), head length (19), head width (19), temple width (19), and weight (11,24). But stronger correlations have been found for skull size (31), inter-orbital distance (19,21), and corneal pituitary distance (32).

Bertelsen (21) has suggested, from measurements he made, that proptosis can be predicted by adding 1 mm to 15 mm for every 4 mm that pupillary distance increases beyond 61 mm (and to remove 1 mm from 15 mm for every 4 mm that the pupillary distance is less than 61 mm); however, error rates are not reported. It has been suggested that globe projection increases with shallower orbits (7,29,30) and this has been proposed as a possible determinant of the higher exophthalmometry measures in blacks (7,29,30). The possibility exists that correlated measures may be useful in predicting individual values of globe projection, however, more research in this area is needed.

It seems illogical that some previous exophthalmometry studies report distances to two decimal places (see Table 1) considering that the error of measurement is about 0.5 to 1 mm (14,20,21). It is, therefore, suggested that in facial approximation exophthalmometry values only be used to 0.5 mm accuracy. It is also unlikely that eyeballs can be located beyond this precision in three-dimensional clay approximations anyway.

It may be considered by some that the inaccuracy of the traditional guideline, probably not much more than about 4 mm on average, is quite small and may not be of significance if it does not affect facial approximation recognition. However, this appears not to be the case. Firstly, a difference of 4 mm is fairly large when dealing with small features of the face such as the eyes. For example, it is equal to ~13% of the eye length, en-ex (33) and ~37% of eye height, ps-pi (33). Secondly, errors are introduced into the facial approximation each time a feature is built. Therefore, this error will accumulate as many features are approximated and cause the final facial approximation to largely differ from the actual target individual, probably resulting in misidentifications (34). Consequently, it is important to limit the error introduced in all facial approximation guidelines to make facial approximations as exact and recognizable as possible.

The entire absence of papers referencing exophthalmometry studies in the facial approximation literature, and the use of a guideline that deviates from and is unsupported by mainstream ophthalmology, is rather surprising. It seems to indicate that facial approximation practitioners have blindly followed methods suggested by others, ignoring relevant exophthalmometry literature that uses accurate and reliable methods (14,20,21). This is surprising for two reasons: (i) a major priority of "facial approximationists" would appear to be comprehensive and up-to-date knowledge and understanding of the anatomy and soft/hard tissue relationships of *all* facial features; and (ii) "facial approximationists" should (if facial approximation is really a blend of science and art as it is reported to be (4)) be conducting frequent literature reviews in an attempt to keep pace with new scientific knowledge and review it in a logical and scientific manner. It appears that the lack of a thorough literature review and/or logical assessment of it has, in this case, led to the use of an inaccurate technique for the last 40 years despite more reliable and accurate scientific methods that have existed for the last 80+ years. Data directly refuting the facial approximation guideline for globe projection have also been available since 1999 (22).

Previous findings from scientific tests that facial approximation recognition is low (34) may not be surprising if facial approximation guidelines are inaccurate. This study has shown that the traditional subjective guideline used to determine globe projection is not accurate. Farkas (35) has also demonstrated that the height of the ear is not equal to the height of the nose as some authors report (1,2,36,37). Although it is unknown if the many other untested (and/or tested but unpublished) subjective guidelines (like: mouth width is equal to interpupillary distance (1) or the junctions between the canines and the first premolars (1,2,4,38); eyeballs are centrally positioned in the orbits (1,2); nose projection is equal to 3X the length of the nasal spine (1,2) or equal to the junction of tangents following the nasal spine and the last one third of the nasal bones (36–39); height of lips equals the height of central incisor enamel (2,37); superciliare falls inline with the lateral border of the iris (4), etc.) fall into the same category, it seems probable that they will as they have been subjectively determined without any empirical evidence.

Since few specific facial feature prediction guidelines used in facial approximation have been scientifically evaluated (i.e., published studies are limited to those that assess width of nose (40); average soft tissue measures, e.g., (41–45); gross anatomy of the nose (46–48); palpebral ligament attachment (5); and muscle insertion at the mouth angle (49)) many facial features are left open to unrestricted subjective interpretation or use of subjective guidelines (see examples above). Therefore, it appears that the scientific rigor of the method is often over emphasized since subjective interpretation plays such a large role. It cannot be expected that a face, which is representative of the individual in question, can be reliably built from the skull using the few scientifically tested guidelines above. Consequently, the facial approximation method, in its entirety, appears to be more appropriately described as a pseudo-science until it can be demonstrated that the majority of the method is composed of scientific (i.e., tested) methods that result in faces that are reliably recognized correctly.

With more research in the future, facial approximation may become a scientific technique that relies upon little subjective interpretation. However, the ability of facial approximation methods to achieve purposeful, specific and reliable facial identification remains to be seen. If it is to be demonstrated, it must be done under controlled conditions since forensic casework success may be due to factors other than facial recognition, e.g., chance (34) or contextual information (50).

Conclusion

The facial approximation guideline that uses the inferior and superior orbital rims to determine globe projection has been falsified by MRI evidence that shows that the facial approximation guideline gives values of globe projection that are not equal to measures taken on living people. An examination of skull morphology and comparison to exophthalmometry measures also indicates that this is the case. It is, therefore, suggested that exophthalmometry values be used in facial approximation techniques instead of the current guideline. Exophthalmometry has the advantage that it measures living individuals, has been widely scientifically tested, its accuracy and reliability are known, and knowledge of the effects of age, population, symmetry, and its variability is rather comprehensive. This study demonstrates the need for other "traditional," subjectively determined, facial approximation guidelines to be scrutinized since they may not be as accurate as thought.

Acknowledgments

Much thanks is due to my supervisors Prof. Maciej Henneberg and Prof. John Clement, who have provided me with endless support in all my work. Also thanks to Tim Anson for permitting use of the St-Mary's Cemetery skeletal collection in this study. Special thanks are also extended to Rachel Norris, who provided valuable comments on this paper.

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