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# Quantification of maxillary dental midline deviation in 2D photographs: methodology trial

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## ABSTRACT

**Introduction:** Discrepancy of the upper dental midline to the facial midline plays an important role in smile aesthetic assessment. This study presents different reference points to quantify the deviation of upper dental midline to the facial midline in 2D frontal photographs. The aim was to find the most accurate, precise, and practical reference points to measure dental midline discrepancy in 2D photographs.

**Methodology:** A modified headset with a protractor was developed in order to achieve photographs in nine standardised head positions. Six reference points were used to detect the facial midline in the 2D photographs (eyebrows “EB”, inner-canthus of the eyes “ICE”, alae of the nose “AN”, columella “C”, nasolabial folds “NLF”, and the philtrum “PH”). The deviation of the maxillary dental midline from the facial midline was measured and compared with clinical measurements.

**Statistical analysis:** Standard deviations (SD), Root Mean Square Error (RMSE), Method of Moments’ Estimator (MME), 2-way repeated measures ANOVA, and multi-level linear model were used to estimate the true errors.

**Results:** The different reference points responded significantly differently to changes in head position and all showed measurement errors, which increased with greater head rotation. Alae of the nose showed the least measurement error and the greatest precision in all head positions.

**Conclusion:** The alae of the nose are the recommended reference points to identify the facial midline in order to quantify dental midline deviation from frontal photographs.

**Key words:** Dental midline, facial midline, midline deviation, 2D photograph, measurement error, facial landmarks.

## **Introduction:**

Photographs are an important tool in dentistry and have become an essential part of dental records along with study models and radiographs. This is because they are non-invasive and can be used for diagnosis and treatment planning, communication with patients, colleagues, and dental technicians, and are an ideal method to analyse the dental condition before, during and after treatment [1]. The extra oral frontal view smiling photograph is one of the standard dental images [2, 3], and can be used to analyse smile aesthetics [4-6]. One smile aesthetic parameter to be assessed in the frontal view smiling facial photograph is the relation of the upper dental midline relative to the facial midline [6-8], which ideally should be coincident and parallel to the facial midline [8-10].

Some authors suggest that exact coincidence of the upper dental midline with the facial midline can produce an artificial appearance, and a slight discrepancy of about 1.5 to 2 mm is acceptable to provide a natural smile appearance as long as it is parallel to the facial plane and perpendicular to the incisal plane [6, 11-14]. Beyer and Lindauer [14] concluded that 2mm or more midline discrepancy can be easily detected by most individuals. This was supported by Johnston *et al.* [15] who concluded that the majority of orthodontists and laypeople are likely to notice dental and facial midline discrepancies of 2 mm or more. Others found that the maximum acceptable limit of upper dental midline deviation to the facial midline by laypeople is 2.9 mm and one-third of raters were accepting a 4.3mm discrepancy [9]. This increase in the limit of acceptability was also reported in a study [16] where they found that the threshold level of unacceptability by the orthodontists is 4 mm and

neither general dentists nor laypeople were able to find a significant effect of midline deviation at all levels tested.

In order to examine the relationship of the dental midline to the facial midline in 2D photographs a reference point needs to be used to determine the facial midline. The facial midline is defined as the line which splits the face in two approximately equal right and left halves and is ideally perpendicular to the inter-pupillary line passing through glabella, tip of the nose, midpoint of the philtrum, and the midpoint of the chin [17]. The upper dental midline is defined as the line passing through the contact points between the upper central incisors or the midpoint of the space between them in case of presence of the midline diastema and perpendicular to the upper occlusal plane [17]. Many reference points have been used to determine the facial midline, such as the bisector of the pupils, nasion, nose (subnasale and pronasle), philtrum, chin, and corners of the mouth [7, 11, 18-20]. Brown and Monetti [21] (as cited in [7]) stated that the technique for reliably locating the facial midline remains confusing. Arnett and Bergman [18] reported that the philtrum is the best reference point to be used to detect the facial midline due to less risk of asymmetry. Morley and Eubank [7] noticed that prominent facial landmarks such as the eyes, chin and nose can be misleading in locating the facial midline in photographs as they have more chance of asymmetry, and a better approach is to use the line passing through the nasion and base of the philtrum at centre of the upper lip (Cupid's bow). More recently, Bidra *et al.* [20] used the "*The Esthetic Frame*" which uses the exocanthion of the eyes as reference points. They found that the midline of the commissures was the closest landmark to the facial midline and the worst was the tip of the nose.

Previous researchers have not considered the effect of head rotation in detecting the facial midline in photographs, excluding all photographs with a rotation of the head

[20]. This may not represent the real world as head rotation may happen with no possibility to retake the photograph. Excluding these photographs may lead to loss of valuable data such as when photographs are taken in clinical trials.

This study examined different reference points to determine the facial midline in order to quantify the deviation of upper dental midline in 2D photographs compared to the clinical measurement. The aim of the study was to find the most accurate, precise, and practical reference points to determine facial midline for the purpose of assessing dental midline discrepancy in 2D photographs.

### **Principal research questions**

1. What are the best reference points to determine the facial midline on 2D frontal photographs to assess the maxillary dental midline?
2. What is the impact of changes in head position on accuracy of 2D photographic dental midline measurement?

### **Null hypothesis to be tested**

There is no significant difference between the different reference points used to determine the facial midline when measuring dental midline in 2D photographs, and all methods respond similarly to change in head position.

### **Methodology and subjects recruitment**

Institutional ethical approval (UREC 15054) was obtained from the Research Ethics Committee at University of Dundee. Students and staff at Dundee Dental School were invited via email to participate voluntarily. A brief description of the project was included, and those interested were contacted and provided with an information

sheet and consent form which was completed prior to taking the photographs. The exclusion criteria were subjects with craniofacial abnormalities, or with obvious craniofacial asymmetry.

### **Preparation of the digital photographs**

Full face photographs were taken for the five subjects in 9 different standardised head positions, using a modified headset with a protractor (Figures 1, 2, and 3). This headset was held on the head via disposable single use silicon ear buds (Figure 2).

The photographs were taken for the subjects in nine head positions (right 20°, right 15°, right 10°, right 5°, 0°, left 5°, left 10°, left 15°, and left 20°) (Figure 3). The mesio-distal width of upper right central incisor and the dental midline deviation to the facial midline were measured clinically in mm for each subject.

The photographs were transferred to image processing software (Adobe Photoshop CS3) and adjusted so the inter-pupillary line was parallel to the horizontal plane, and cropped to only show the face.

The upper dental midline was identified with a line passing through the contact point between the upper central incisors and perpendicular to the inter-pupillary line (Figure 4). The facial midline was identified using six different reference points (eyebrows (EB), inner-canthus of the eyes (ICE), alae of the nose (AN), columella (C), nasolabial folds (NLF), and the philtrum (PH)) (Table 1) by finding the midpoint between the right and left reference point or at the centre of the midline reference points (Figure 4).

The deviation of upper dental midline from the facial midline was recorded independently in pixels for each subject fifty-four times (6 methods in 9 head

positions). Individual correction factors were calculated from the previously known mesio-distal widths of the upper right central incisors, and all measurements converted to mm.

Error scores (deviation from the value of the dental midline shift measured clinically) were calculated for each measurement for each subject in all positions (54 times), and the absolute measurement error calculated in order to avoid left side and right side errors cancelling each other out.

## **Results and Data analysis**

### **Descriptive statistics**

The measurement error increased with head rotation to both sides and greater error was noticed with rotations to the right than to the left side (Figure 5, 6).

In order to quantify the error in measuring upper dental midline deviation absolute values were used and the mean absolute measurement errors (M), standard deviation (SD), and bootstrapped 95% confidence interval (CI) were calculated for each reference points in all head positions and at each head position for all reference points (Figure 7-9).

All reference points used to detect the facial midline showed some measurement error in measuring dental midline compared to the clinical measurement, with the lowest mean absolute measurement error found with alae of the nose,  $M= 1.70\text{mm}$  ( $SD = 1.18$ ), bootstrapped 95% CI [1.36, 2.07], while the highest error value was found with columella,  $M= 5.50\text{ mm}$  ( $SD = 3.86$ ), bootstrapped 95% CI [4.44, 6.75], and the hierarchy of the reference points closest to the zero error is: (1) alae of the nose, (2)



philtrum, (3) eyebrows, (4) nasolabial folds, (5) inner-canthus of the eyes, and (6) columella (Figure 7) (Table 2).

The lowest mean absolute measurement error was found with left 5° head position, M= 1.24mm (SD =0.80), bootstrapped 95% CI [0.97, 1.55], and the error increased steadily with increasing head rotation, with the highest error found with right 20° head position, M= 6.18 mm (SD = 4.15), bootstrapped 95% CI [4.74, 7.67] (Figure 8) (Table 3).

### **Assessment of random error (Precision)**

Standard deviation was used as a measure of precision (i.e. how stable a measurement was) (Table 4). For each head position the highest and lowest standard deviations are highlighted. It can be seen that (with the exception of right 10°) alae of the nose consistently had the lowest standard deviation. This result was consistent with the narrowest bootstrapped 95% CI of the alae of the nose (Figure 7). This indicates that alae of the nose had the lowest variability in its scores and can be considered as the most precise reference point.

### **Root Mean Square Error (RMSE)**

The statistical method commonly used to estimate the random error of measurements is the Root Mean Square Error [22, 23] given by the Dalberg formula [24] as cited in Houston [22]

$$\sqrt{\frac{\sum_{i=1}^n d_i^2}{2n}}$$

Alae of the nose showed the lowest RMSE value (Table 5).

**The Method of Moments Estimator (MME)**

The method of moment's estimator (MME) was also used to estimate the random error given by the formula [25]:

$$\sqrt{\frac{\sum_{i=1}^n (d_i - \bar{d})^2}{2(n-1)}}$$

Alae of the nose showed the lowest MME value (Table 6).

### **Assessment of systematic error (accuracy)**

Absolute means and significance were analysed using SPSS (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp) and R-project [26] software. A 2-way repeated measures ANOVA was performed on the square-root transformed absolute error data at different reference points (6 levels) and different head positions (9 levels). There was a significant interaction between reference point and head position ( $F(40, 160) = 2.178, p < 0.001$ , effect size (partial eta squared) = 0.35). This reflects a difference in how the reference points respond to head position. The results were checked by performing multilevel linear modelling which confirmed a significant interaction between reference point and head position ( $\chi^2(58) = 84.52, p < 0.0001$ ).

These results were further explored using Bonferroni corrected post-hoc t-tests. Alae of the nose differed significantly from columella ( $p < 0.001$ ), nasolabial folds ( $p = 0.001$ ) and inner-canthus of the eyes ( $p = 0.012$ ), but not from the others. In terms of head position, position  $0^\circ$  was found to differ significantly from right  $20^\circ$  ( $p < 0.001$ ), right  $15^\circ$  ( $p < 0.001$ ), right  $10^\circ$  ( $p < 0.001$ ), right  $5^\circ$  ( $p = 0.001$ ) and left  $20^\circ$  ( $p = 0.036$ ).

For each reference point and each head position, it was calculated whether the estimated absolute measurement error obtained exceeded the previously discussed clinically acceptable limit of 2 mm (Table 7). Values below this threshold are highlighted in green, whereas values exceeding 2 mm are highlighted in red. It can be seen that alae of the nose and philtrum perform best across all levels of head rotation, and acceptable error was with the use the alae of the nose in head positions right  $5^\circ$ ,  $0^\circ$ , and left  $5^\circ$ .

## Discussion

This study shows that the choice of reference points to determine the facial midline significantly affects the error of the measurement of the upper dental midline deviation in 2D photographs. This may be attributed to the fact that a 2D photograph does not exactly represent the 3D object. The errors were different when different methods were used, increased when the head was not centred in zero position, and the different methods responded differently to the change in head position.

It appears that the main reason for the different reference points responding differently to the change in head position is the difference in the sagittal position of the reference points relative to the labial surface of the upper incisors. The closer the reference point sagittally to the incisors the less error. The result of this study was consistent with result of Bidra *et al.* [20] that high error was associated with the use of the tip of the nose and the columella as a reference points.

Researchers have advised using the philtrum as a reference point for the facial midline due to less risk of asymmetry [7, 18]. However, according to this study the alae of the nose better, and the philtrum may be better used as an alternative method when there is obvious nasal asymmetry.

In the study of Bidra *et al.* [20], although the photographs were taken in a standardised way and care was taken to ensure that the subject did not have any head rotation, they excluded some photographs due to head rotation along the vertical axis. This confirms that this can happen even with the presence of strict standardisation. A better approach is to find a method that minimises the error to within an acceptable limit, and this study shows that the error when using alae of the nose as the reference points for facial midline are within acceptable limits for a 5 degree rotation either side of the ideal head position.

The data showed a systematic difference between right and left sided rotations of the head with greater error being present to the right side. One possible explanation for this is that a systematic error was present in the camera positioning at the zero degree position of the headset. Alternatively, there may have been asymmetry across the sample of 5 subjects used for this study. However, neither of these invalidate the finding that the alae of the nose are the best reference points to determine facial midline from 2D frontal photographs.

## **Conclusions**

Within the limitations of the study we can conclude the following:

1. In all head positions and with all reference points, there were measurement errors.
2. The error increases with the increase in the sagittal distance of the reference points from the labial surface of the upper incisors.
3. The error increases with increase in head rotation.
4. Alae of the nose has the lowest estimated absolute measurement errors in all head positions, and can be regarded as clinically acceptable when the head is not rotated more than 5°.
5. Philtrum can be used as an alternative method if there is obvious nasal asymmetry.
6. Columella and nasolabial fold are not satisfactory reference points to be used to detect the facial midline in 2D photographs.

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## **Conflict of Interest**

The authors declare no conflict of interest.

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