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# Photogrammetric reliability of frontal facial photographs with radiographs and anthropometric measurements

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ABSTRACT

*Aim:* To evaluate relationships between frontal cephalograms and photographic measurements of Indian population with anthropometric measurements and if frontal photographic analysis could be utilized with precision for orthodontic diagnosis.
*Material and methods:* A cross-sectional ex vivo study was conducted on 300 subjects with age range of 18–25yrs. Standardized frontal cephalograms and photographs were obtained for all subjects and were analysed with Nemoceph 10.4.2 (Nemotec Dental Systems, Madrid, Spain) software program. Linear anthropometric measurements were recorded with the help of a digital Vernier caliper. 21 linear measurements were made, of which 10 were horizontal and 11 were vertical. Repeated measures of ANOVA followed by Bonferroni's Post hoc Analysis was used to compare mean values of horizontal and vertical parameters between 3 different methods. The level of significance was set at $p < 0.05$.
*Results:* Statistically significant differences were found with most parameters. Between the analogous photographic, cephalometric and anthropometric measurements, only N′-Me' showed reliability with all three methods ($p = 0.53, 0.53, 0.53$).
*Conclusion:* The photographic method has proven to be a repeatable and reproducible tool for only few parameters. Therefore, it cannot be considered a reliable diagnostic tool.

## 1. Introduction

One critical factor in planning orthodontic treatment and assessment of treatment changes is evaluation of hard and soft tissues. The early days of orthodontic practice were largely based on Angle's philosophy, with major emphasis on dental and skeletal components.[1] With a paradigm shift from dentoskeletal to soft tissue evaluation, researchers included soft tissue parameters in cephalometric analysis. Some remarkable contributions in the field of cephalometrics were use of filters that enabled visualization of the soft tissue in radiographs by Downs,[2] Steiner's[3] S line, Merrifield's[4] Z angle, Ricketts[5] Esthetic plane (E-plane), Burstone's[6,7] esthetic analysis of the facial profile and Holdaway's[8] harmony line (H-line).

With cephalometrics contributing to orthodontic diagnosis and treatment planning, facial photographs as propagated by Graber,[9] are also an integral diagnostic aid. Facial photographs being essential diagnostic tools can offer valuable information in case of unavailability of cephalometric equipment. Photogrammetry, as defined by the American Society of Photogrammetry is 'the art, science and technology of obtaining reliable information about physical objects through processes of recording, measuring and interpreting photographic images'.[10] In the1940s, Sheldon, suggested that accurate anthropometric measurements could be recorded from standardized photographs[11] and in 1955, Stoner[12] introduced the concept of photogrammetry into orthodontics.

Various authors[13,14] examined the reliability of photogrammetry and cited several advantages of using it over direct measurements, including the fact that photographs provided a permanent patient record permitting multiple measurements. Innumerable studies on soft tissue facial analysis using lateral cephalograms with consistent relationships between facial overlying tissues and skeletal structures have been found. However, due to technical limitations on radiographs, especially when analyzing the frontal view, studies on frontal cephalograms have not been undertaken till date.

Using photographs as a means of soft tissue analysis has been proved reliable in literature with digital technology making assessment easy and accurate. Relationships between frontal cephalograms and photographic measurements of Indian population with anthropometric measurements to determine if photographic analysis could be utilized

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with precision for orthodontic diagnosis was the primary aim of this study.

## 2. Methods

### 2.1. Study population

The subjects signed an informed consent form adapted from the guidelines given by WHO (World Health Organization) which is available at www.who.int/rpc/research_ethics/informed_consent/en.

Frontal cephalograms and frontal facial photographs were obtained for 300 subjects, aged between 18 and 25 years. The sample size was selected by power analysis. A test power of 80% with a level of significance of 5% and sample size of 300 was obtained. Inclusion criteria was: (1) Subjects with Class I occlusion with well-balanced faces (short and long faces were excluded), (2) subjects were of Indian origin with BMI under normal range (18.5–22.9 $kg/m^2$), (3) all teeth present till 1st molars, (4) no facial and/or dental asymmetry on visual examination, (5) no history of orthodontic or orthognathic treatment and (6) no history of craniofacial trauma or congenital anomalies.

### 2.2. Photographic procedure

Standardized frontal photographs of the subjects were taken in natural head position (NHP) with maximum intercuspation and lips at rest. A digital SLR camera (Canon Rebel T6, Canon, Japan) mounted with a 100 mm macro 1:1 lens was mounted on a tripod. The photographic room was designed such that the distance between the photographer and the subject was 5 feet. A metallic ruler was placed parallel to the mid-sagittal plane of the subject with the help of an adjustable rod. The stainless-steel spokes were attached to the ruler at 5 mm, which helped in indicating the true vertical and was used to calibrate images (Fig. 1).

To achieve NHP, the patient was asked to look straight in front of the camera to obtain "orthoposition". A modified protractor[15] with a plumb line was used to ensure parallelism of the interpupillary line with the floor (Fig. 2A). The protractor was placed to the interpupillary distance and the head was adjusted such that the plumb line was at 90°. The protractor was also placed on the nose tip and soft tissue pogonion and a plumb line recorded the NHP angle (Fig. 2B).

Facial landmarks were identified without using any landmark identification marks. It was done to reduce landmark identification bias and obtain inter and intra-observer reliability. The soft tissue landmarks which were used in the study are described under Table 1 and Fig. 3A.

### 2.3. Radiographic procedure

Digital frontal radiographs were taken with an X-Mind Pano Ceph D + (Acteon, Spain) with exposure parameters of 73kv, 10 mA and 0.6sec. Cephalometric radiographs were taken in NHP with maximum intercuspation and lips at rest. Cephalostat interference while achieving NHP was negated by using a protractor modified with a plumb line placed on the tip of the nose and soft-tissue pogonion which was kept parallel to the interpupillary line, to check if the same position achieved during photography had been obtained during radiography as well. A 30 cm ruler attached to a plumb line was suspended in the midsagittal plane to register the true vertical. The ruler was also used to calibrate images. Corresponding photographic landmarks mentioned in Table 1 were marked on frontal radiographs (Fig. 3B).

### 2.4. Direct facial measurements

Facial landmarks were palpated manually by the investigator. Linear measurements were recorded on subjects faces with the help of a digital Vernier caliper in maximum intercuspation with relaxed lips and natural head orientation. 10 horizontal and 11 vertical measurements were recorded for each subject.

**Fig. 1.** Photographic room used in the study.

### 2.5. Computerized assessment of frontal cephalograms and photographs

Photographic and radiographic records were evaluated with Nemoceph 10.4.2 (Nemotec Dental Systems, Madrid, Spain) software program for Windows. The images were calibrated, and measurements obtained with minimum error. The cephalometric parameters and their soft tissue analogous photographic and direct parameters are summarized in Table 2.

### 2.6. Statistical analysis

Data was subjected to statistical analysis using the Statistical Package for Social Sciences [SPSS] for Windows Version 22.0 released 2013. Armonk, NY: IBM Corp. Inter and intra-class correlation analysis to assess inter and intra-observer reliability for different horizontal and vertical parameters was done.

Repeated measures of ANOVA followed by Bonferroni's Post hoc Analysis was used to compare mean values of horizontal and vertical parameters between 3 different methods. The level of significance was set at $P < 0.05$.

## 3. Results (Tables 3 and 4)

300 standardized frontal cephalograms and frontal photographs were taken and subsequently digitally analysed using Nemoceph software by two examiners at $T_1$ and $T_2$ time intervals.

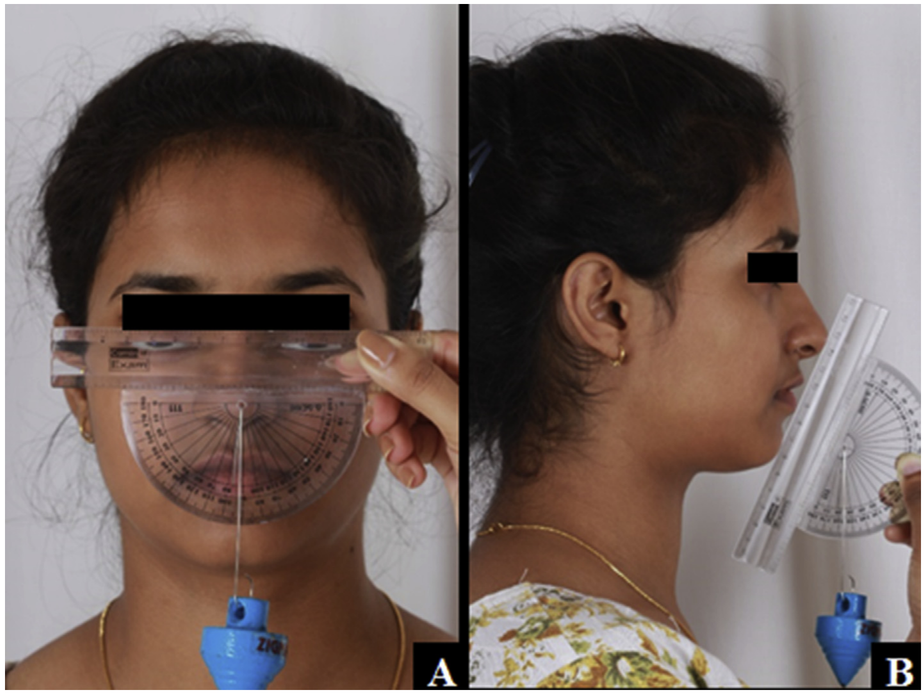


**Fig. 2.** (a) Modified protractor to ensure parallelism of interpupillary line with the floor. (b) Modified protractor on the tip of the nose and the soft tissue pogonion to assess NHP.

### 3.1. *Reliability of cephalometric measurements with analogous photographic and direct measurements*

A statistically insignificant difference was found with 1 parameter of 11 vertical parameters. Only N′-Me' showed insignificant difference with ($p$ = 1.00) all the three methods i.e. radiographic, photographic and direct (Table 3).

On evaluating pair wise comparisons (Table 4), statistically significant correlations were found between N′-Me' when radiographic versus photographic, radiographic versus direct and photographic versus radiographic ($p$ = 0.53, 0.53, 0.53) measurements were analysed.

### 3.2. *Evaluation of reliability of photogrammetric analysis*

To check the reliability of the photogrammetric method, measurements were analysed twice, by two examiners at two intervals ($T_1$ and $T_2$), for all 21 parameters. The inter and intraclass correlation coefficients (ICC) and corresponding 95% confidence intervals (CI) were estimated to measure reliability of repeated tracings and demonstrated excellent to good reliability ranging between 0.86 to 1.00 and 0.89 to 1.00 which is statistically significant at $p < 0.001$.

## 4. Discussion

To evaluate feasibility and determine reliability between frontal photographs and cephalograms, a pilot study was conducted in mid-2016.[16] Statistically insignificant differences were found between frontal photographic, radiographic and anthropometric measurements. Subjects between 18 and 25yrs were included as there would be no variability due to aging. The study included subjects with Body Mass Index (BMI[17]) ranging between 18.5 and 22.9 $kg/m^2$ to eliminate soft tissue bias to order to reduce overestimation of photographic measurements. Though BMI was taken into consideration, some patient's thick soft tissue integument in the subnasal area and soft tissue pogonion could lead to lower correlations between cephalograms and photographs. The study could not be carried out on obese individuals as thick facial soft tissue overlying bony structures masks actual measurements, creating bias in recording measurements.

The current study standardizes NHP in frontal photographs as well as cephalograms by using a modified protractor in frontal and lateral views, as used in the Sydney diagnostic system.[15] This standardization helped in correlating photogrammetric measurements to frontal cephalograms with better accuracy.

The photographic room was designed such that the distance between the photographer and the subject was always maintained at 5

**Table 1**
Definitions and abbreviations of the soft tissue landmarks used in the photogrammetric analysis.

| S. no | Soft Tissue Landmark | Ab* | Definition |
|---|---|---|---|
| 1. | Ala | Al | the most lateral point of the alar contour of the nose |
| 2. | Antegonial notch | Ag’ | the deepest point on the curvature of the antegonial notch. |
| 3. | Endocanthion | En | the midpoint of the medial orbital margin |
| 4. | Exocanthion | Ex | the midpoint of the lateral orbital margin |
| 5. | Soft tissue Menton | Me’ | most inferior point of the soft tissue chin, in the midsagittal plane |
| 6. | Soft tissue Nasion | N′ | concave or retruded point in the tissue overlying the area of the frontonasal suture. |
| 7. | Soft tissue Orbitale | Or’ | the lowest point on the bony orbit found by palpation |
| 8. | Subnasal | Sn | point where the lower margin of the nasal septum is confluent with the integumental upper lip. |
| 9. | Zygoma | Zyg’ | most lateral aspect of zygomatic arch |

(Ab* = abbreviations).

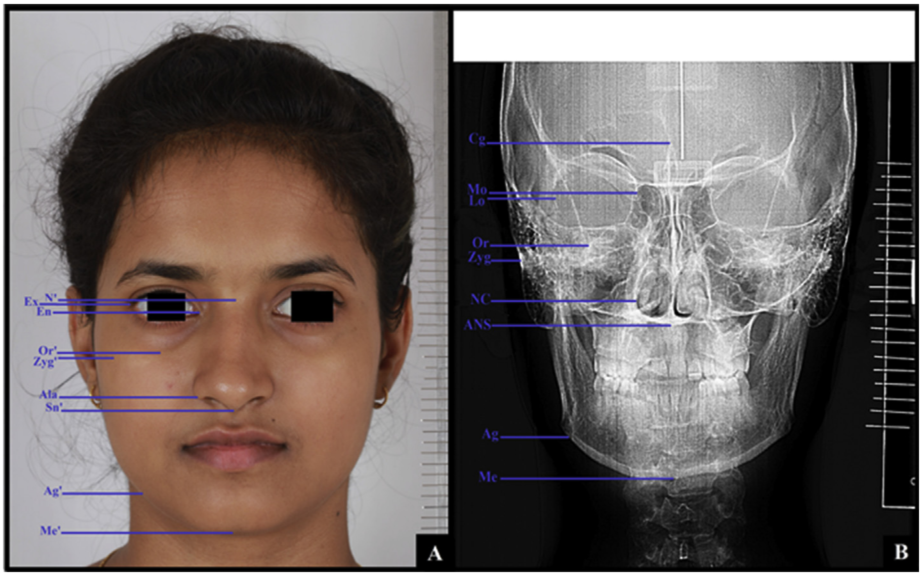


**Fig. 3.** (a) The soft tissue landmarks. (b) Radiographic landmarks.

feet. This distance was chosen to maintain similarity to the radiographic setup to produce bias free photographic and radiographic images. Gomes et al.[18] recommended the use of a digital SLR camera with 1:1 macro lens for the photographic records to obtain a life size image, thereby reducing photographic measurement errors or image deformation. In this study, a digital SLR camera was used to eliminate image distortion and reduce photographic measurement error. The frontal photographs and frontal cephalograms used in this study were 2-D representation of 3-D structures. These individually should not be used to judge aesthetics of an individual. Additionally, the Vernier calipers can cause pressure on soft tissues while recording measurements, giving rise to inaccurate readings.

Of 21 parameters, 20 parameters showed statistically significant differences with $p$ value $< 0.005$, except N′-Me' ($p = 1.00$).

The mean values for N′-Me' between the 3 methods of assessment was found to be statistically insignificant at $p = 1.00$. On pair wise comparison, it was observed that the 3 methods were statistically insignificant at $p = 0.53$, 0.53, 0.53. Hence, the radiographic versus photographic versus anthropometric measurements for N′-Me' were in concordance with each other.

In contrast to this study, Gomes et al. found no correlations amongst photographic and anthropometric measurements for N′-Me'.[18]

On pair wise comparison, it was observed that photographic versus direct pair for Endo(R)-Endo(L) was statistically insignificant at $p = 1.00$. Hence, the photographic versus direct measurements for Endo(R)-Endo(L) were in concordance with each other. No significant concordance was found between radiographic versus photographic and radiographic versus direct measurements.

Fraser and Pashayan[19] and Farkas, Bryson and Klotz's found Endo'(R)-Endo'(L) to be a reliable measurement which was similar to our study.[20]

Aksu, Kaya and Kocadereli[21] found good reliability for Ex(R)-Ex(L) and Endo(R)-Endo(L) reference distances. Farkas et al.[20] found Ex(R) -Ex(L) was not reliable while Endo(R)-Endo(L) was reliable. These

**Table 2**
List of horizontal and vertical measurements and their analogous cephalometric and photographic parameters.

| Sl. no | Horizontal measurement | Direct facial point | Cephalometric point | Photographic point |
|---|---|---|---|---|
| 1. | Inter-orbital distance | Or'(R)-Or'(L) | Or(R)-Or(L) | Or'(R)-Or'(L) |
| 2. | Medial canthal distance | Endo'(R)-Endo'(L) | Mo(R)-Mo(L) | Endo'(R)-Endo'(L) |
| 3. | Lateral canthal distance | Ex'(R)-Ex'(L) | Lo (R)-Lo(L) | Ex'(R)-Ex'(L) |
| 4. | Medial-lateral canthal distance-right | Endo'-Exo' (R) | Mo-Lo(R) | Endo'-Exo'(R) |
| 5. | Medial-lateral canthal distance-left | Endo'-Exo' (L) | Mo-Lo(L) | Endo'-Exo'(L) |
| 6. | Bi-zygomatic width | Zyg'(R)-Zyg'(L) | Zyg(R)-Zyg(L) | Zyg'(R)-Zyg'(L) |
| 7. | Orbitale-Zygoma-right | Or'-Zyg'(R) | Or-Zyg(R) | Or'-Zyg'(R) |
| 8. | Orbitale-Zygoma-left | Or'-Zyg'(L) | Or-Zyg(L) | Or'-Zyg'(L) |
| 9. | Alar base distance | Ala(R)-Ala(L) | C (R–C(L) | Ala (R-Ala(L) |
| 10. | Antegonial notch distance | Ag'(R)-Ag'(L) | Ag (R–Ag(L) | Ag'(R)-Ag'(L) |
| Sl. no | Vertical measurements | Direct facial point | Cephalometric point | Photographic point |
| 1. | Anterior facial height | N′-Me' | Cg-Me | N′-Me' |
| 2. | Nasion-Subnasale | N′-Sn' | Cg-ANS | N′-Sn' |
| 3. | Lower facial third | Sn'-Me' | ANS-Me | Sn'-Me' |
| 4. | Zygoma-antegonial notch-right | Zyg'-Ag'(R) | ZA-Ag(R) | Zyg'-Ag'(R) |
| 5. | Zygoma-antegonial notch-left | Zyg'-Ag'(L) | ZA-Ag (L) | Zyg'-Ag'(L) |
| 6. | Orbitale-antegonial notch-right | Or'-Ag'(R) | Or-Ag(R) | Or'-Ag'(R) |
| 7. | Orbitale-antegonial notch-left | Or'-Ag'(L) | Or-Ag(L) | Or'-Ag'(L) |
| 8. | Antegonial notch-exocanthion-right | Ag'-Exo'(R) | Ag-Lo(R) | Ag'-Exo'(R) |
| 9. | Antegonial notch-exocanthion-left | Ag'- Exo'(L) | Ag- Lo(L) | Ag'- Exo '(L) |
| 10. | Ala-endocanthion-right | Ala'-Endo'(R) | NC-Mo(R) | Ala'-Endo'(R) |
| 11. | Ala-endocanthion-left | Ala'-Endo'(L) | NC-Mo(L) | Ala'-Endo'(L) |

**Table 3**
Comparison of mean values of horizontal and vertical parameters obtained from three different methods using Repeated Measures of ANOVA.

| Horizontal Parameters | Radiograph | | Photograph | | Direct | | p-Value |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | |
| Ag(R)-Ag(L) | 81.82 | 3.98 | 107.92 | 7.75 | 114.45 | 7.23 | < 0.001* |
| Or(R)-Or(L) | 63.27 | 5.4 | 65.84 | 3.93 | 64.59 | 3.34 | < 0.001* |
| Zyg(R) -Zyg(L) | 120.18 | 4.05 | 118.57 | 7.3 | 118.45 | 7 | 0.009* |
| Ala(R)-Ala(L) | 31.27 | 3.26 | 40.61 | 3.71 | 43.41 | 4.16 | < 0.001* |
| Ex(R) -Ex(L) | 92.76 | 5.54 | 104.25 | 4.92 | 103.14 | 5.31 | < 0.001* |
| Endo(R)-Endo(L) | 23.64 | 4.25 | 30.64 | 5.38 | 30.65 | 3.94 | < 0.001* |
| Endo-Exo (R) | 35.11 | 3.73 | 38.76 | 3.6 | 40.75 | 3.63 | < 0.001* |
| Endo-Exo (L) | 33.88 | 4.04 | 37.96 | 3.44 | 39.65 | 3.25 | < 0.001* |
| Or-Zyg (R) | 28.68 | 5.48 | 28.1 | 3.88 | 30.09 | 3.92 | 0.005* |
| Or-Zyg (L) | 28.09 | 3.71 | 26.88 | 5.12 | 28.51 | 4.77 | 0.006* |
| **Vertical Parameters** | | | | | | | |
| N′-Me' | 116.59 | 6.54 | 116.75 | 7.17 | 116.62 | 7.14 | 1 |
| Sn'-Me' | 64.88 | 5.68 | 63.65 | 7.34 | 62.45 | 7.37 | < 0.001* |
| N′-Sn | 51.37 | 6.71 | 52.91 | 6.31 | 53.69 | 6.51 | < 0.001* |
| Zyg-Ag (R) | 68.28 | 7.92 | 58.41 | 8.71 | 61.73 | 11.05 | < 0.001* |
| Zyg-Ag (L) | 68.99 | 7.45 | 58.76 | 7.89 | 61.73 | 11.05 | < 0.001* |
| Or-Ag (R) | 68.88 | 8.7 | 60.67 | 7.91 | 66.88 | 14.91 | < 0.001* |
| Or-Ag (L) | 67.13 | 8.98 | 62.21 | 8.72 | 68.3 | 14.82 | < 0.001* |
| Ag'-Lo (R) | 85.2 | 7.66 | 81.34 | 8.15 | 82.07 | 9.32 | < 0.001* |
| Ag'-Lo (L) | 85.23 | 8.05 | 82.19 | 8.03 | 83.33 | 8.9 | < 0.001* |
| NC-Mo (R) | 40.34 | 6.45 | 38.8 | 5.27 | 38.41 | 5.36 | < 0.001* |
| NC-Mo (L) | 39.35 | 6.78 | 38.67 | 5.3 | 38.13 | 5.34 | < 0.001* |

* - Statistically Significant.

**Table 4**
Pair-wise comparison of horizontal and vertical parameters by Bonferroni's Post hoc Analysis.

| Horizontal Parameters | Radiographic Vs Photographic | Radiographic Vs Direct | Photographic Vs Direct |
|---|---|---|---|
| Ag(R)-Ag(L) | < 0.001* | < 0.001* | < 0.001* |
| Or(R)-Or(L) | < 0.001* | 0.02* | < 0.001* |
| Zyg(R) -Zyg(L) | 0.04* | 0.02* | 0.003* |
| Ala(R)-Ala(L) | < 0.001* | < 0.001* | < 0.001* |
| Ex(R) -Ex(L) | < 0.001* | < 0.001* | < 0.001* |
| Endo(R)-Endo (L) | < 0.001* | < 0.001* | 1.00 |
| Endo-Exo (R) | < 0.001* | < 0.001* | < 0.001* |
| Endo-Exo (L) | < 0.001* | < 0.001* | < 0.001* |
| Or-Zyg (R) | 1.00 | 0.08 | < 0.001* |
| Or-Zyg (L) | 0.08 | 1.00 | < 0.001* |
| **Vertical Parameters** | | | |
| N′-Me' | 0.53 | 0.53 | 0.53 |
| Sn'-Me' | < 0.001* | < 0.001* | < 0.001* |
| N′-Sn | < 0.001* | < 0.001* | < 0.001* |
| Zyg-Ag (R.) | < 0.001* | < 0.001* | < 0.001* |
| Zyg-Ag (L) | < 0.001* | < 0.001* | < 0.001* |
| Or-Ag (R) | < 0.001* | < 0.001* | 0.006* |
| Or-Ag (L) | 0.003* | 0.10 | < 0.001* |
| Ag'-Lo (R) | < 0.001* | < 0.001* | 0.006* |
| Ag'-Lo (L) | < 0.001* | < 0.001* | < 0.001* |
| NC-Mo (R) | 0.004* | < 0.001* | 0.43 |
| NC-Mo (L) | 0.006* | 0.006* | 0.36 |

* - Statistically Significant.

results were similar to the results of the present study where Ex(R) -Ex (L) was not reliable while Endo(R)-Endo(L) was reliable when photographic versus anthropometric measurements were analysed.

### *4.1. Clinical implications*

The present study could not prove photogrammetry as a reliable tool for diagnosis even after following standardized photographic protocols. Therefore, orthodontic treatment planning should not be solely dependent on photographs, especially in cases where aesthetics is compromised. Treatment planning for cases like antero-posterior jaw discrepancy and facial asymmetry, cannot be based on photographs alone. It is an absolute requirement for every clinician to thoroughly examine patients clinically with radiographs if required.

### *4.2. Future implications and scope for additional research*

The present study was an attempt to evaluate reliability of frontal photographs in diagnosis. Direct measurements were included to eliminate image bias. In the current study, all three methods were found to be repeatable and reproducible at T1 and T2 intervals but lagged concordance with each other. This was contrary to findings of other studies conducted on Indian population for lateral cephalograms.[22–24] Although photographs assume equal importance as essential diagnostic aids, radiographic or anthropometric analysis cannot be replaced with photographs.

Very few studies have been conducted correlating analogous measurements from frontal cephalograms and photographs, and this could be identified as an area for future research. Further studies utilizing frontal photogrammetry to evaluate correlation with frontal radiographs with additional inclusions of angular variables could be carried out. Also, gender dimorphism can be considered.

## Conclusion

Frontal photogrammetry cannot be used as an alternative to frontal cephalograms. This indicates that frontal radiographic landmarks cannot be located on facial photographs consistently. Therefore, photogrammetric analysis cannot be used as an alternative to radiography in epidemiological studies or during clinical examination before planning orthodontic or ortho surgical treatment.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jobcr.2019.06.011.

## Ethics approval

The study protocol was approved by the Ethics Committee of the Army College of Dental Sciences, Secunderabad, India (ACDS/IEC/11/Dec 2016).

## Conflicts of interest

None.

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