PHOTOGRAMMETRY AS A TOOL TO AID ORTHODONTIC DIAGNOSIS AND TREATMENT ASSESSMENT

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ABSTRACT

Aim: To present simple photogrammetric techniques that can objectively evaluate standardized digital extra-oral and intra-oral photographs for diagnostic and therapeutic purposes.

Materials and methods: 11 measurements (9 linear and 2 angular) from standardized lateral photographs were compared with analogous measurements from standardized lateral cephalograms. The study was conducted on 60 subjects (n=60, 41 females, 19 males) aged 18-25 years.8 photogrammetric techniques on standardized photographs, linear and angular photogrammetric analysis on lateral photographs, linear photogrammetric analysis on frontal and frontal smile photographs, photogrammetric analysis of occlusal cant, photogrammetric smile analysis and tooth and intra-arch measurements on occlusal photographs are described.

Results: All 11 parameters that were analyzed showed strong correlation. The intraclass correlation coefficients (ICC) and corresponding 95% confidence intervals (CI) of all parameters showed that the reliability of the photographic technique was excellent.

Conclusions: Photogrammetry on standardized photographs used in daily orthodontic practice offers a simple, cost effective solution without the hazard of radiation exposure. The 8 photogrammetric techniques described here show that photogrammetry has multiple applications. However, there is a need to standardize photogrammetric techniques, develop multiple photogrammetric analyses for different needs and obtain mean values for parameters from different populations.

Keywords : Occlusal, photogrammetry, smile analysis, reliability

INTRODUCTION

Photography in dentistry has seen remarkable progress since 1839 when Alexander S Wolcott, a dentist turned photographer, designed and patented the first camera from the Daguerre concept. (Galante, 2009; Humphrey, 1858) Today with continuing technological advancements in digital camera systems and computer software, photography has become an easily available and cost effective diagnostic aid. (Sandler et al, 2012) Photography has been given great importance as a diagnostic aid by many pioneers in orthodontics, such as Simon (Simon, 1924) and Graber (Graber, 1946); the latter who included facial photography as an essential diagnostic aid.

The disadvantage of photographs and cephalograms is that they provide two dimensional images of a three dimensional structure. Some techniques exist which use computed tomography scans, magnetic resonance imaging, destructive scans and laser scans to create three dimensional reconstruction of faces or create three dimensional digital study models(Harrell et al, 2002). However, these techniques require the orthodontist to send the data to a third party image processing facility and involve high costs coupled with the need for dependence on advanced computer processing.

A simpler, cost effective solution would be application of photogrammetry on standardized photographs used in daily orthodontic practice. Photogrammetry may be defined as 'the art, science and technology of obtaining reliable information about physical objects through processes of recording, measuring and interpreting photographic images'. (Chadwick, 1992) The aim of the article is to present simple photogrammetric techniques to objectively evaluate standardized digital extra-oral (Claman et al, 1990) and intra-oral photographs (Bengel, 2006) which could be used in treatment planning and assessment.

Materials and Methods

To determine whether photogrammetry could be used as a reliable tool to help in orthodontic diagnosis, 11 measurements (9 linear and 2 angular) from standardized lateral photographs were compared with analogous measurements from standardized lateral cephalograms.

The study was conducted on 60 subjects (n=60, 41 females, 19 males) aged 18-25 years, with the mean age of 21 years and 6 months, SD 1.4.

Inclusion Criteria

- All teeth till first molars were present.

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Exclusion Criteria

- No previous history of orthodontic or orthognathic treatment.
- No craniofacial trauma.
- No congenital anomalies.
- No neurologic disturbances.

8 photogrammetric techniques on standardized photographs, viz. linear and angular photogrammetric analysis on lateral photograph, linear photogrammetric analysis on frontal and afrontal smile photograph, photogrammetric analysis of occlusal cant, photogrammetric smile analysis and tooth and intra- arch measurements on occlusal photographs, are presented, which coud be used as effective diagnostic and treatment assessment follow up tools.

Methodology for Assessing Reliabilty of the Photogrammetric Method

Photographic Setup and Procedure

A digital camera (Canon EOS 600D) mounted with a macro portrait lens (EF 105 mm f/2.8, 1:1 OS, Sigma) was used to obtain photographic records. A distance of 5 feet was maintained between the camera and the subject. The subject was made to face a mirror placed 120 cm away to aid in obtaining Natural Head Posture (NHP). A metal scale attached to a plumb line was secured just in front of the subject. A modified protractor (Moate, 2007) resting on the tip of the nose and the soft tissue pogonion was used to record NHP (Fig.1a)

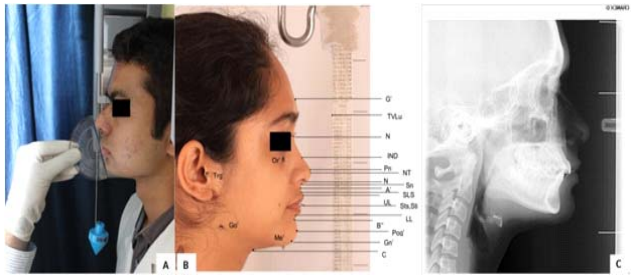

Fig.1 A. Modified protractor on tip of the nose and soft tissue pogonion to assess natural head position. B. Soft tissue landmarks used in the study. Metal ruler with steel spokes separated at 50 mm placed in front of the subject indicates the true vertical (VER). C. Standardized digital lateral cephalograms of the same patient with the metal scale in place. Metal scale is used to calibrate both images.

Orbitale, Menton, Gonion and Tragus points were palpated directly on subjects and marked with a micro metallic ball for clear representation in the photographs(Fig.1b). Subsequently, right lateral profile photographic views were taken for all subjects in maximum intercuspation with lips at rest.

Radiographic Procedure

Digital lateral skull radiographs were taken with a Cranex D® X- Mind Pano Ceph D+ (Acteon group, Satelec, Soredex, Finland) cephalostat. Cephalometric radiographs were obtained in Natural Head Position following the same procedure as used for photographs. The modified protractor was used to achieve a similar angle obtained during photographic record taking(Fig.1c)

24 landmarks were used in the study (Table 1)

Sl no	Soft Tissue Landmark	Ab*	Radiographic landmark	Ab*
1.	Soft tissue Glabella	G'	Glabella	G
2.	Soft Tissue Nasion	N'	Nasion	N
3.	Nasal Crown	IND	Nasal Crown	IND
4.	Pronasale	Pn	Pronasale	Pn
5.	Nasal Tip	NT	Nasal Tip	NT
6.	Nasale Medium Columella	NM	Nasale Medium Columella	NM
7.	Subnasale	Sn	Subnasale, Anterior nasal spine	Sn,ANS
8.	Soft Tissue subspinale	A'	Subspinale	A
9.	Labrale Superius (upper lip anterior)	UL	Labrale Superius (upper lip anterior)	UL
10.	Superior Labial Sulcus	SLS	Superior Labial Sulcus	SLS
11.	Stomion superior	Sto	Stomion superior	Sto
12.	Stomion inferior	Sti	Stomion inferior	Sti
13.	Labrale inferius (Lower lip anterior)	LL	Labrale inferius (Lower lip anterior)	LL
14.	Inferior Labial sulcus	ILS	Inferior Labial sulcus	ILS
15.	Soft tissue submentale	B'	Submentale	B
16.	Soft tissue Pogonion	Pog'	Pogonion	Pog
17.	Soft tissue Gnathion	Gn'	Gnathion	Gn
18.	Soft tissue Menton	Me'	Menton	Me
19.	Cervical point	C	Cervical point	C
20.	Soft tissue Orbitale	Or'	Orbitale	Or
21.	Tragion	Trg'	Articulare, Condylion,Sella	Ar,Co,Se
22.	Soft tissue Gonion	Go'	Gonion	Go
23.	True Vertical line (upper point)	TVLu	True Vertical line (upper point)	TVLu
24.	True Vertical line (lower point)	TVLi	True Vertical line (lower point)	TVLi

Table 1. Soft tissue landmarks and their corresponding analogous radiographic landmarks used in the study. Ab* = Abbreviation

Computerized landmark identification and comparison

Digital photographic and radiographic records of 60 subjects were uploaded into Nemoceph 10.4.2 (Nemotec Dental Systems, Madrid, Spain) software program for Windows and were analysed using a customized analysis configured in the software. The soft tissue and analogous hard tissue landmarks were digitally identified by a single examiner (Fig.2) The 2 spokes of the ruler separated by a distance of 50 mm were used as the reference distance for both photographic and cephalometric records.

Statistical Analysis

Data was statistically analysed using the Statistical Package for Social Sciences, version 23 (SPSS Inc, Chicago, Ill). Cephalometric measurements were compared with analogous photographic measurements to assess Pearson correlation coefficients. Intra class correlation coefficient was calculated for photographic (independent variable)

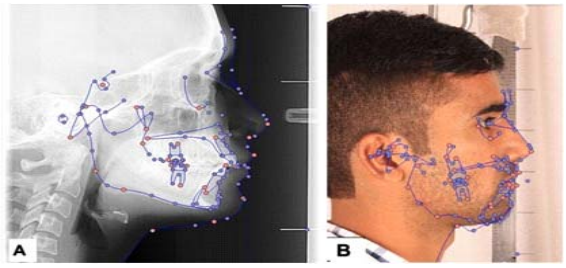

Fig.2 Landmarks are digitally identified for lateral cephalograms. A. and photograph B. using Nemoceph 10.4.2 software with control points shown.

measurements to determine the reliability of photogrammetric evaluation of soft tissues.

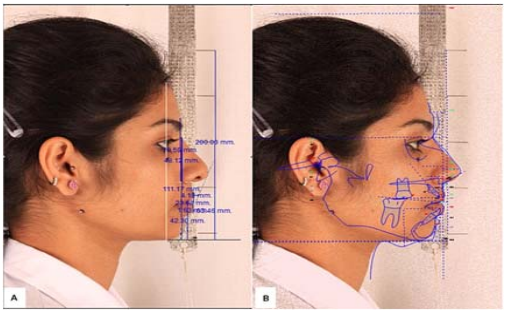

Fig.3 Landmarks are digitally identified for lateral cephalograms. A. and photograph B. using Nemoceph 10.4.2 software with control points shown.

Methodology for Extra- Oral Photogrammetry techniques

Linear and angular analysis on lateral photographs

Landmarks which were recorded in the study (Table1) were digitally identified in Photoscape®software (Copyright (C) 2001-2017 MOOII TECH). The metal scale can be taken as the True vertical and horizontal planes perpendicular to True Vertical were drawn from Sn and Me. A straight line connecting the nasal tip and soft tissue pogonion is constructed. The image was then uploaded in Nemotec software for linear photogrammetric measurements (Fig 3a). The angular analysis can be performed similarly in the Nemotec software from customized cephalometric analysis (Fig 3b)

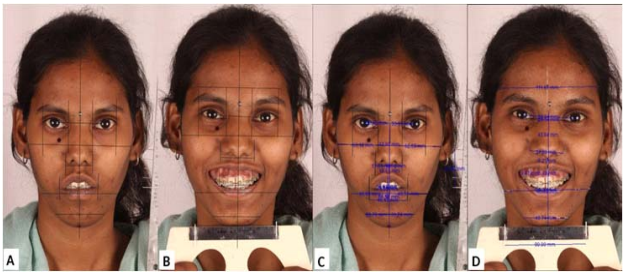

Fig.4 A,B. Frontal photograph and Frontal smile photograph marked with vertical and horizontal planes in Photoscape. C,D. Photogrammetric analysis performed on both photographs in Nemotec software.

Linear photogrammetric analysis on frontal and frontal smile photographs

For frontal photogrammetric analysis, a patient with unilateral scissor bite involving 44 – 47 was selected. The patient was instructed to hold a modified fox plane with a 90 mm metal scale trimmed and bonded on its surface for the purpose of calibration. The frontal photograph obtained was uploaded into Photoscape software and horizontal planes (90 mm calibration, mental width, bigonial width, bizygomatic width, bitemporal width, interpupillary distance, line connecting two upper cuspids, alar base width) were marked. The facial midline and vertical lines on both side of face connecting outer canthus, inner canthus, ala of nose, and lip commissures were drawn. The image with marked planes was uploaded in Nemotec software for linear photogrammetric measurements (Fig 4a, 4b).

Occlusal cant analysis

To assess the presence of occlusal cant, the patient was instructed to place a wooden tongue blade inter-occlusally as posterior as possible and bite on it. The modified fox plane as well as the vertical ruler can be used for calibration purposes. Similar planes as constructed in frontal photographs can be used in this analysis. The vertical distance from pupil and outer ala of nose are measured on both sides to determine occlusal cant (Fig 5a).

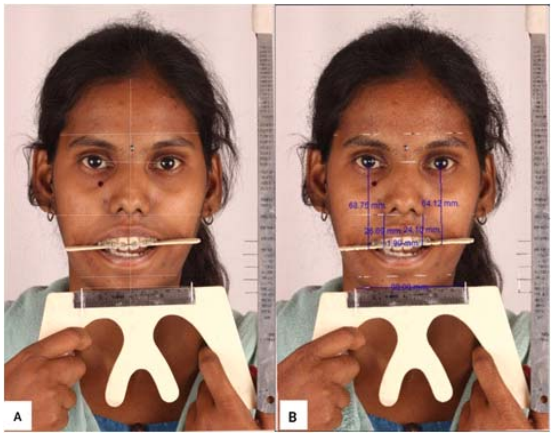

Fig. 5 The modified fox plane with metal spokes separated by 90 mm can be used for calibration purposes. The linear distance from pupil and outer ala of nose to base of tongue blade is measured on both sides to metrically determine the occlusal cant.

Smile analysis

For the smile analysis a magnification ratio of 1:2 was maintained. The patient was asked to hold a metal ruler beneath the lower lips and instructed to produce a full natural and relaxed smile. Vertical lines corresponding to the dental midline and demarcating the buccal smile corridor were drawn using Photoscape® software (Fig 6a).

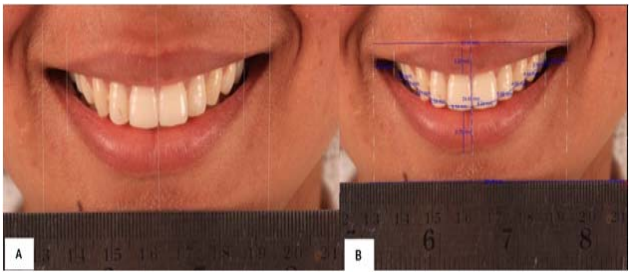

Fig. 6 A. A metal scale is used to calibrate the picture. Vetrical lines representing the buccal corridor space and the dental midline are drawn in Photoscape software. B. The measurements obtained in the smile analysis are shown.

Methodology for Intra- Oral Occlusal Photogrammetry

Photographic Setup and Procedure

In this technique, a modified intra oral combination mirror (Prakash *et al*, 2016) was used. A 35 mm trimmed metal scale bonded on the front surface of an occlusal cheek retractor was used for calibration purposes. The image was subsequently uploaded into Nemotec software to photogrammetrically measure mesiodistal width of all teeth up to first molars and intra arch widths (Fig 7a, 7b)

RESULTS

Analysis of 11 parameters that were analyzed showed strong correlation (Table2).

Sn	Nt	A. Measurement	Ceph point	Photo point	(r)*	I
1.	Nma	Nasomental a	IND N'NTPog'	IND N'NTPog'	.823	S
2.	Nbp*	NB ^ LsPog'	NB-Ls-Pog'	N'B'-Ls-Pog'	.787	S
3.	Tfh	Total facial height	TVLu TVLi- N' Me'	TVLu TVLi- N' Me'	.920	S
4.	Nsn	N' to Sn	TVLu TVLi- N' Sn	TVLu TVLi- N' Sn	.883	S
5.	Snme	Sn to Me´(LTH)	TVLu TVLi – Sn Me'	TVLu TVLi – Sn Me'	.852	S
6.	Mth3	Middle Third	TVLu TVLi – G' Sn	TVLu TVLi – G' Sn	.850	S
7.	Llsme	Lower lip length	TVLu TVLi- Sti Me'	TVLu TVLi- Sti Me'	.835	S
8.	Stsme	Sts to Me´ (D)	TVLu TVLi- Sts Me'	TVLu TVLi- Sts Me'	.800	S
9.	Ltl	Lip to lip	TVLu TVLi- UL LL	TVLu TVLi- UL LL	.754	S
10	Uep	UL:En-Pog'	NT-Pog'-UL	NT-Pog'-UL	.815	S
11	Plab	Protrusión Labial	NT Pog' – LL	NT Pog' – LL	.802	S

Table 2: 11 parameters that showed strong correlation. 1-2 (angular measurements), 4-9 vertical measurements and 10-11 are horizontal measurements.

Lateral photographs of 20 subjects were randomly selected and analyzed twice. The intraclass correlation coefficients (ICC) and corresponding 95% confidence intervals (CI) were estimated to measure the reliability of the repeated tracings.(Table 3).

Sl no	Measurement	Intraclass correlation	95 % confidence interval	
			Upper bound	Lower bound
1.	Nasomental Angle	.977	.991	.942
2.	NB LsPog' Angle	.988	.995	.969
3.	UL:En-Pog'	.986	.995	.965
4.	Lower lip length	.991	.996	.977
5.	Middle 1/3 height	.985	.994	.962
6.	LL:En-Pog'	.974	.990	.934
7.	Lip to lip	.980	.992	.949
8.	Sts to Me'	.988	.995	.970
9.	Protrusión Labial	.974	.990	.934
10.	Sn to Me'	.985	.994	.962
11.	Nsn (N' to Sn)	.973	.989	.932

Table 3: Intraclass correlation and 95% confidence intervals of the 11 parameters.

The intraclass correlation coefficients (ICC) and corresponding 95% confidence intervals (CI) of all 11 parameters showed that the reliability of the photographic technique was excellent. All the parameters showed ICCs > .973. Lower lip length showed the highest ICC value with .991.

Linear and angular analysis on lateral photographs

The values obtained for the 9 linear parameters and 2 angular parameters for 60 subjects are shown in Table 4.

Sl no	Measurement	Mean	SD
1.	Nasomental Angle	124.50	4.52
2.	NB LsPog' Angle	14.97	3.75
3.	UL:En-Pog'	-2.88	2.12
4.	Lower lip length	41.80	5.75
5.	Middle 1/3 height	73.66	9.61
6.	LL:En-Pog'	-2.02	2.31
7.	Lip to lip	-2.71	1.70
8.	Sts to Me'	45.36	7.13
9.	Protrusión Labial	-2.02	2.31
10.	Sn to Me'	64.82	9.07
11.	Nsn (N' to Sn)	48.31	6.34

Table 4: The mean values for the 9 linear and 2 angular parameters. (n = 60)

The average value of Nasomental angle (N-Prn/ N-Pog) obtained in the study is 124.50 ± 4.5, which is similar to the average value of nasomental angle in the North Indian population obtained by Reddy et al (2011). In the current study the nasal height (N'-Sn) value of 48.312 ± 6.3479, was similar to the value obtained by Fernandez-Riveiro et al (2002) (N-Sn: males 52.5 ± 4 mm and females 49.8 ± 4 mm). The interlabial gap at rest (mean value 0.38 mm) was similar to the value obtained by Fernandez-Riveiro et al (2002). The upper lip length obtained in the study (21.5 ± 6.7) was more than the value obtained by Park and Burstone (18 ± 2 mm).

Linear photogrammetric analysis on frontal and frontal smile photographs

The photogrammetric measurements obtained from frontal smile and frontal photographs are shown in Table 5. (fig 4c, 4d)

Parameter (Frontal smile)	Value (mm)	Parameter (Frontal)	Value (mm)
Bimental width	53.61	N'-Sn	43.90
Bigonial width	92.40	Sn-Me'	66.56
Bizygomatic width	124.20	Dental Midline shift	1.53
Bitemporal width	93.94	Inter commissural width	46.13
Inter pupillary distance	59.30	ULS-LLS	25.54
Inner canthal distance	28.36	Sti-Sto	6.81
Outer canthal distance	88.72	Sn- ULS	10.91
Alar base width	37.98	N'-Me'	110.46
Gingival exposure	7.01		

Table 5: The values obtained for the linear parameters measured in frontal smile and frontal photographs.

Additionally, the frontal photograph can be used to determine facial asymmetry by measuring the bimental, bigonial,bizygomatic, inter-pupillary and alar base width on right and left sides as divided by the facial midline. The examined patient showed increased width on the right side in all widths [inter – pupillary .42 mm, bizygomatic .49mm, alar base 1.43 mm, bigonial .16mm except bimental width which decreased by .54 mm] (Fig 4d).

Occlusal cant analysis

The occlusal cant analysis shows that the patient described (Fig. 5b) has an increased occlusal cant towards the right side as evinced by the increased vertical distance from inter pupillary (4.63 mm) and alar base (1.99) width to the base of the tongue blade.

Smile analysis

Smile analysis can help to objectively quantify buccal corridor space, distance between the vermillion border of upper and lower lip and upper and lower stomion respectively, as well as ratios of mesiodistal width and height of the teeth to digitally evaluate patients smile (Fig. 6b).

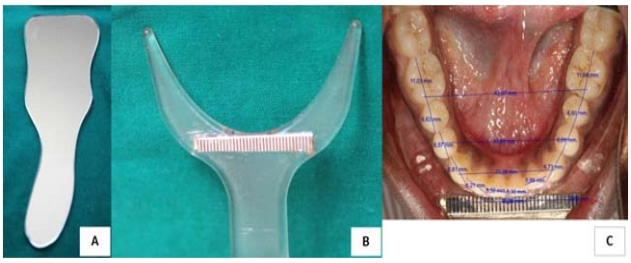

Fig. 7 A. Single combination mirror used in the procuring occlusal photographs. B. A 35 mm metal scale is trimmed and bonded on both sides of the cheek retractor. C. A mandibular occlusal photograph showing scale used for calibration and the mesiodistal width and intra arch widths measured in Nemotec software.

Occlusal photogrammetric analysis

Nemotec software can be used to measure the mesiodistal widths of all teeth up to the first molar and the inter premolar width, inter canine width and inter molar width (Fig. 7c).

DISCUSSION

A proper diagnosis undoubtedly forms the cornerstone in constituting sound orthodontic treatment. It is pertinent that the orthodontist follows a thorough and proper diagnostic protocol to obtain consistent and predictable results. With advances in technology and increased use of computers in the daily orthodontic practice, newer tools are becoming popular to help us intelligently analyze and interpret diagnostic data. Photogrammetry is one such tool that can be easily used and has a relatively low learning curve.

The present study shows that photogrammetry is a reliable tool which could be used as an adjunct to other diagnostic aids like cephalometric analysis. Jorgensen (1991) in his study to quantify facial changes that occur between 4 and 13 years of age concluded that, in general, landmark identification on photographs was reproducible.

Goodlin (2005, 2011) and Calamia et. al (2007) have discussed the use of photography assisted diagnosis and treatment planning, with the latter designing a smile evaluation form which is used in New York University College of Dentistry (NYUCD). Stereophotogrammetry has been used to analyze the contours of surgically corrected faces by Berkowitz (1971) and Burke (1971) to monitor growth of facial soft tissues.

Lateral and frontal photogrammetric analysis

Epker (1992) took his records in NHP, using the true vertical (TV) as the reference line on which he defined proportional measures as the following: the upper lip (Sn-Sto) was 30% of the inferior third of the face (Sn-Gn), the inferior lip (Sto-Sm) was 28% of the inferior third of the face, the height of the chin was 42% of the inferior third and nasal depth (Sn-Prn) was 40% of the nasal length (N-Sn). Arnett and Bergman (1993) described an analysis of the soft tissue facial profile on photographic records in NHP. Their analyses of the symmetry, both vertical and horizontal, contour of the smile line, facial middle lines, and facial contour were important.

Riveiro et al. in 2002, digitally analyzed the soft tissue facial profiles of a European

white population of young adults by means of linear measurements made on

standardized photographic records taken in natural head position.

Smile analysis

Ackerman and Ackerman in 2002, performed a smile analysis in a program called SmileMesh, which measured 15 attributes of the smile. More recently, Sodagar et al. in 2010 designed a software for smile analysis and McLaren et al in 2013, have described the various applications of digital dentistry with the help of Photoshop® software.

Occlusal photogrammetric analysis

Occlusal photogrammetric analysis can be used as an adjunct to dental study model analysis and to assess treatment progress. In cases where expansion appliances are used, the inter premolar, inter – canine and inter – molar width can be periodically assessed quantitatively to determine treatment change. The mesiodistal dimensions of teeth can also help calculate Bolton's discrepancy and can be helpful in planning correction of midline discrepancies. Normando *et.al* (2011) in their study, found that with the exception of the mesio-distal width of upper first molar, photogrammetric method on standardized occlusal photographs are a reliable instrument for clinical and scientific application to measure dental arch dimensions and tooth size.

CONCLUSION

In the present digital age where the gamut of diagnostic aids is ever increasing, we need to recognize the need to prevent a "cookbook approach" to therapeutic decisions. It is imperative that diagnostic aids employed by orthodontists should be reliable and easy to use. Photogrammetric evaluation of facial photographs is a simple method which has endless possibilities. However, there is a need to standardize photogrammetric techniques, develop multiple photogrammetric analyses for different needs and obtain mean values for parameters from different populations. With greater importance to the soft tissue paradigm today, increasing emphasis is being given to soft tissue and the face in orthodontic diagnosis and treatment planning. Hence, it is only logical that photogrammetry from standardized photographs should evolve to take an ever increasing application as a diagnostic aid and patient education tool. Moreover photogrammetry promises to be a relatively easy and cost effective tool to use in epidemiologic studies or in cases where conventional diagnostic aids like cephalometry are impractical.

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