UNIVERSITY OF ALBERTA

# ACCURACY AND REPRODUCIBILITY OF DIRECT SONIC DIGITIZATION AND REPRODUCIBILITY COMPARED TO TRACINGS OF CEPHALOGRAMS

BY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled:

"ACCURACY AND REPRODUCIBILITY OF DIRECT SONIC DIGITIZATION AND REPRODUCIBILITY COMPARED TO TRACINGS OF CEPHALOGRAMS"

submitted by Michael P. Bleau in partial fulfilment of the requirements for the degree of Master of Science in Clinical Sciences ( Orthodontics ).

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# INTRODUCTION

## INTRODUCTION

Orthodontics and cephalometrics began a relationship early in the twentieth century when anthropometric techniques from the discipline of Physical Anthropology were introduced to Orthodontics. Holly Broadbent[1] was the first orthodontist to publish on cephalometric techniques when he devised a system to interpret human radiographic images based on craniometric methodology. He was followed by Downs[2] and Steiner[3] along with many other investigators who collectively have developed cephalometric cross sectional, longitudinal, and ethnic norms to aid in the analysis of standardized cephalometric radiographs. Salzmann[4] cautioned that cephalometric variables are not a condition requiring treatment and that other diagnostic material is necessary before formulating a treatment plan. Salzman wrote

> "It is not what we see in the radiogram but the meaning that we attribute to what we see there that counts."

Cephalometrics is currently used by virtually all orthodontists to aid in patient diagnosis and treatment planning.

Clinicians and researchers continue to develop more reliable, valid and efficient ways to analyze craniofacial and dentofacial relationships; however the inherent errors associated with cephalometrics is a basic concern to all orthodontists.

## Projection and Interpretation error

**Projection error**

External validity errors are related to projection and/or positioning errors which include; variable patient position in the cephalostat, central beam divergence, and magnification. The conclusion of numerous investigators[5,6,7,8] who have studied positioning or projection errors is that head position does not significantly affect cephalometric readings for rotational variances of ≤ 5° . Rotations of > 5° should be clinically detectable at the time of positioning of the patient. Spolyar[7] reported that the average angular measurement error related to positioning variability would be <2°, but that the tracing technique of splitting the image of bilateral components compensated for most of the error. He also reported head positioning errors above 5 degrees may induce significant error to any linear measurements that is greater than 10 cm. Cohen et al[5] suggested utilizing video image subtraction with a head holder for the most accurate serial positioning. Central beam divergence results in a non uniform magnification of the subject due to the fact that points further from the central beam and/or further from the film are magnified to a greater extent. Traditionally magnification has been adjusted for using the midsagittal plane as reference.

**Interpretation error**

Internal validity involves accuracy of tracing or landmark identification of the exposed cephalometric radiograph. Validity is the extent to which, in the absence of measurement error, the value obtained represents the specific object of interest. Precision, or reproducibility, is the closeness of successive measurements of the same object. The term reliability is often used as a synonym for reproducibility, but it is better used in a broader sense to include both validity and reproducibility.[9]

Baumrind and Frantz[10] examined both landmark identification errors and the effects these errors have on angular and linear measures. They found that each landmark has its own uniquely characteristic envelope of error. A characteristic envelope of error for specific landmarks was also reported by other investigators.[11,12] When these landmarks are used to derive angular and linear measurements, consideration must be given to how the variables intersect the characteristic envelope to determine potential error of the resultant measurement. They suggested that averaging four independent estimates of each landmarks would decrease any error by half. Gravely and Benzies[13] and Houston[9] also suggested replicated tracings to reduce error and suggested that published data include the number of cephalometric tracings incorporated into the data base. Houston also concluded that authors should discuss how measurement errors can affect the interpretation of result.

Other internal validity factors that influence radiographic landmark identification errors include superimposition protocols associated with various structures, image clarity, and the curvature of the line upon which the landmarks is positioned.

## COMPUTERS AND CEPHALOMETRY

As computerization was expanding in the 1960's, Solow[14] and Barret *et al*[15] advocated the integration of computer technology directly with cephalometrics. Digitized two dimensional data was transferred directly to the computer which was able to derive the desired angular and linear measurements. Solow described the use of computers for superimpositions to study longitudinal growth changes, while also predicting that computers would be able to scan the cephalogram to identify landmarks and interpret the recorded image. Houston[16] reported that digitization of cephalograms could offer the advantage of drawing the clinician's attention to certain parameters or combinations of measurements that might have been overlooked in a more superficial manual analysis. Even though he realized the power and versatility of the digitizer/computer couple, he cautioned that attention must be paid to controlling the quality of data that is entered. Digitization is reported to be as reliable as the traditional techniques of manual tracing and measurement[7,10,17-22]. Richardson found that points on a curved outline defined by terms such as "most anterior", "most posterior", "highest" or "lowest" were actually more accurately located with a digitizer compared to direct manual identification[17]. In contradiction to others Oliver[22] reported that direct digitization of the cephalogram was less precise than both the traditional tracing method and digitization of a tracing.

As Solow[14] had predicted there are now scanners that recognize cephalometric landmarks and input the data directly into the computer for anaylsis[23-25]. The procedure involves image enhancement techniques such as; edgeenhancement, edge-detection, thresholding, grey level transformation, image filtering and noise smoothing. Through the use of computers, image processing algorithms are used to eliminate manual landmark identification by estimating radiographic landmarks based on radiographic densities and location. These systems are in their infancy and current disadvantages are slow scanning speed and high cost.

## RADIATION AND CEPHALOMETRY

### *Ionizing Cephalometric Imaging*

Diagnostic yield of all procedures must be justified against potential risk. During the early 1950's concerns were expressed by the orthodontic community regarding radiation dosage[26,27]. Cohen[28] published a paper that suggested methods for reducing the number of exposures and the amount of radiation for each exposure in a routine orthodontic survey. Tyndall *et al*[29] outlined recent advances whereby radiation exposure could be minimized while retaining high image quality. Within the past decade the use of rare earth screens and filtration techniques along with high speed film emulsions has allowed a decrease in exposure time without affecting the resultant quality.

The dental profession has made considerable advances over the years in reducing the amount of radiation acquired during exposure of diagnostic radiographs[30,31]. Even with this reduction of radiation the profession must still be concerned because there is potential risk with any exposure, even at low-level radiation[32,33,34]. Recent reports indicate that lifetime cancer risk from low levels of radiation may be greater than previously estimated[30,35]. This risk is even greater when the patient is younger[32,33,36,37] and is reported to be approximately twice as great when the patient is exposed during childhood as compared to adulthood[37]. Low level radiation may affect the body's cells in many ways such as carcinogenesis, teratogenesis. genetic mutations, and changes in the immune response[35,38]. Lymphoid tissue is thought to be particularly sensitive to radiation[35,38]. The average annual 3.6 millisievert radiation dose that the population is exposed to is compromised of about 5/6 from natural background radiation while the other 1/6 is the result of man-made radiation[37]. Of the latter portion, over 90% is from medical and dental diagnostic radiographs, of which 30-60% have been reported to be of limited diagnostic value[33]. The radiation dosages of some common orthodontic diagnostic imaging include 10 -16 millisievert for a panoramic film and .05-1 millisievert for a lateral cephalometric film exposure[33]. Even though the exposure from a lateral cephalogram is low as compared to other dental radiographs, the risk of radiation induced cancer produced by cephalometric techniques ranges between 0.3 to 6 cases per million.[39]

Medical and dental diagnostic radiology has been reported to be the most important risk factor identified for parotid gland cancers with approximately 85% of the cumulative dose for the parotid gland to result of dental radiographs[40]. Fifteen percent of parotid gland cancers have been attributed to prior exposure to diagnostic radiographs[40]. The maximum absorbed dose for a cephalogram is in the parotid region[41].

***Non-ionizing Cephalometric Imaging***

An alternative to radiographs for analysis of craniofacial and dentofacial relationships for orthodontic diagnosis was introduced in 1990[42]. Through the use of sonic digitization, computerization, and video imaging, a system was introduced that can generate a cephalometric analyses without radiation. The principle of sonic digitization is the capture of high frequency sound waves by utilizing temporal calculations to determine the exact spatial relationship. The time between pulse generation and reception by each of the 3 or 4 microphones is measured and the time intervals are used to electronically compute distances. This allows for identification of stylus position and transformation to x, y, and z coordinates within the computer. Previous reports indicate that sonic digitizing is an accurate method for spatial data collection and reported accuracy of sonic digitizers range from +/- 0.125 mm to 0.51 mm[43,44,45].

The system used in this study was the Digigraph Work Station® by Dolphin Imaging Systems* which utilizes direct three dimensional sonic digitization to facilitate cephalometric analysis. The patient is seated and raised into a cephalostat-like head holder to position and maintain the head in a reproducible position that will facilitate current and subsequent digitization. Prior to commencement of digitization a video image of the patient is displayed on the monitor and then cephalometric landmarks are located directly on the patient via

*Dolphin Imaging Systems, Inc., Valencia, CA.

a sonic digitizing handpiece. Sound is emitted from two sources along the top of the handpiece handle and is received by four microphones in the boom assembly of the head holder. Landmark coordinates are calculated and recorded in the computer in 3 dimensions and superimposed on the facial profile image on the video monitor. The computer program allows a variety of traditional cephalometric analyses to be displayed on the screen or printed.

**Research Question:**

The accuracy and reproducibility of cephalometric analysis from direct sonic digitization are important issues. Independent testing of the Digigraph has been limited due to expense and limited availability. One study performed by consultants for the system reported that the Digigraph was as accurate and reliable as traditional radiograph tracings[19]. A second study was a Master's thesis by a student of one of the consultants which concluded that the Digigraph can obtain repeatable and consistent measurements when compared to radiographic tracings.[46]

Independent research is needed to confirm claims of accuracy and reproducibility.

## STUDY OBJECTIVES

The objectives of this study were to determine the accuracy and reproducibility of the Digigraph® by Dolphin imaging systems and to compare the reproducibility to that of digitized radiographs.

The Null hypotheses state that;

1) Digigraphic® linear and angular calculations of template measurements will not be significantly different from direct template measurements

2) Digigraphic® analyses of the same patient at successive time periods will not be significantly different .

3) There will be no significant difference in reproducibility between cephalometric Digigraphic® variables and digitized cephalometric variables obtained from acetate tracings.

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# CHAPTER 2

## Accuracy and Reproducibility of Variables Produced by Direct Sonic Digitization

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## ABSTRACT

A non-radiographic method of taking cephalometric records is evaluated. The purpose of this investigation was to determine the accuracy and reproducibility of direct sonic digitization using the Digigraph® produced by Dolphin Imaging Systems. To determine accuracy, a precisely machined template of ten angular and ten linear variables were digitized 4 times and digitizer calculated values were compared to actual measurements. The mean of each of the 20 variables along with the standard deviation were reported. Standard deviations for all 20 variables were ≤ 1 unit(degree or mm) with ranges from 0.1mm to 1.0mm and from 0.10° to 0.75°. The largest mean discrepancy was 1.03mm and 1.7° for linear and angular measurements respectively. To evaluate reproducibility patients were randomly digitized without prejudice of order once each day on three separate days. Reproducibility was evaluated for 22 variables on each of 20 patients. Six variables were significantly different on repeated digitizations at the p=0.05 level (interincisal angle, upper incisor inclination, upper incisor to FH, MP to FH, gonial angle, and A point to N perpendicular) and 4 at the p=0.01 level (upper incisor inclination, upper incisor to FH, MP to FH, and gonial angle). The mean difference, being the difference of each day, from the mean of the three days, is reported for each variable and ranged from 0.44 to 6.41 units. The standard deviation of the mean difference ranged from 0.28 to 4.30 units. Individual ranges are also reported and ranged from 3.2 to 45.4 and 0.1 to 6.8 units respectively.

**INTRODUCTION**

Orthodontists have been striving to develop cephalometric systems that will, effectively, efficiently, and with low patient risk, give useful information about the patient's skeletal and dental relationships. Traditionally tracings of cephalometric Xrays were manually plotted and then each variable of interest was calculated or derived. External validity of this approach involves patient positioning errors, while internal validity includes landmark identification error along with its characteristic envelope of error and tracing and/or measurement errors. Recent advances in computer technology allows direct digitization of the radiographic image or its tracing and enables the results to be digitally stored for convenient and quick analysis. Research has shown head rotation within the cephalostat is not a significant source of landmark identification error as long as the rotation is less than 5 degrees.[1-4]

In 1990 a commercial direct sonic digitization platform and program was introduced as an alternative to radiographic exposures for analyses of craniofacial and dentofacial relationships.[5] Sonic digitization utilizes sound waves and time calculations to locate a particular point in space. The tip of a digitizing pen or stylus is placed at the point of interest then activated to emit a high frequency sound impulse which is received by 3 or 4 sensitive microphones. The time required for the sound impulse to reach the various microphones allow the computer to calculate the location of the sound source and record its position numerically as X, Y, and Z coordinates.

Previous reports indicated that sonic digitizing is an accurate method for spatial data collection with a reported accuracy that ranges from ± 0.125 mm to 0.51 mm.[6,7,8]

This study utilized the Dolphin Imaging System's Digigraph Work Station®* which incorporates direct three dimensional sonic digitization of the patient to process various cephalometric analysis. Additionally, the Digigraph work station is able to store and retrieve extra and Intra-oral videographic images that allow for composite video and digitized overlays.

Previous published research concerning the accuracy and reproducibility of the Digigraph was a two part study performed by consultants of the manufacturing company.[9] Statistical comparisons of 50 Caucasian patients who each had both sonic digitization and radiographic cephalometric tracings of 5 linear and 7 angular singularly recorded variables reported that there were no significant differences at the p=0.05 level. In the second part of their study, repeatability of consecutive Digigraph recordings was compared to consecutive cephalometric radiograph tracings. Ten patients were digitized consecutively 10 times each and 10 consecutive tracings of cephalograms were performed. The authors state that the sonic data was more repeatable with standard deviations being lower using the sonic system variables investigated.

The purp tudy was to evaluate the accuracy and reproducibility of direct sonic digi it is crucial to determine whether the process is able to

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*Dolphin Imaging Systems, Inc., Valencia, CA.

produce clinically acceptable results consistently. The two part study compared the sonic digitization accuracy against a standardized template and reproducability by comparing repeated analyses of the same patients.

The Null hypotheses assume that Digigraphic linear and angular calculations of template variables will not be significantly different from direct template measurements and that Digigraphic analysis of the same patient at successive time periods will not be significantly different.

## MATERIALS, SUBJECTS AND METHODS

The Digigraphic Work Station houses the computer, video printer, electronic circuitry and also supports the monitor, keyboard, video camera, photographic lamp, as well as the boom assembly of the head holder. The patient is seated and raised into a cephalostat-like head holder to position and maintain the head position for the subsequent digitization. A video image of the patient's head is displayed on the monitor and accessible soft and hard tissue landmarks are digitized directly on the patient. The landmarks are digitally recorded in the computer in 3 dimensions and can be superimposed on the video monitor's facial profile image. A variety of traditional cephalometric analysis can be displayed on the screen or printed.

To test the accuracy of the sonic digitizer a template was designed and precisely machined to contain 10 angular (ranging from 2 to 180° ) and 10 linear (ranging from 2 to 70mm) variables. Aluminum was chosen for construction of the

10" x 5" template due to it's dimensional stability at room temperature. A Pilot hole drill of approximately the same diameter as the Digigraph probe tip was used to crater the template at the predetermined sites. The crater sites were determined using trigonometry and were machined to an accuracy of .005mm. The template was attached to the head holder of the Digigraph using a nut and bolt assembly. Each of the twenty variables were then digitized 4 successive times and the averaged values obtained were compared to the actual machined value.

The reproducibility portion of the study involved digitization of twenty patients who were selected without discrimination regarding gender, ethnicity, or malocclusion. (see table I). Subjects were randomly digitized one time each on 3 separate days. All digitization was performed by the author who had successfully completed an operators training session at the manufacturer's location (Dolphin Imaging Systems). Prior to each session the sonic digitization system was checked and calibrated according to manufacturer's guidelines. All digitizations were monitored for patient movement using the stream digitization feature of the system which allows for a visual monitor check of the patients head position at the beginning and the end of the digitization procedure. If movement was noted the patient was re-digitized immediately. The "accuracy" digitizing probe, an improved version of the original Digigraph® probe, allowed the computer to refuse the landmark if the probe showed more than the allowable amount of movement or if there was interference of the sound waves by either the operator or the equipment. Landmarks which cannot be digitized directly (upper and lower incisor apex) were

| | Number of Participants | Mean Age ( range in yrs. & mos. ) |
|---|---|---|
| Female Participants | 10 | 25-3 (15-3 to 32-6) |
| Male Participants | 10 | 30-6 (24-1 to 38-5) |
| Total | 20 | 27-11 (15-3 to 38-5) |

**Table I.** *SAMPLE AGE AND GENDER DISTRIBUTION* extrapolated by calculations based on location of other landmarks.

## RESULTS

The results of the accuracy determination portion are shown in *Tables II & III.* Using a raw data plot of actual versus sonic readings, regression analysis was used to determine a best fit straight line for each of the 40 point scattergrams of both linear and angular measurements. The best fit straight line revealed a slope of 1.015 and Y-intercept of +0.039 for linear measurements, while angular measurements demonstrated a slope of 0.996 and a Y-intercept of -0.422. These computations revealed that direct digitization tended to over predict the 10 linear variables by 1.50%, and under predict angular values by 0.40%. The mean standard deviation for all linear variables was 0.52mm within the 0.1 to 1.0mm range. The 10 angular variables that were sonically digitized displayed a mean standard deviation of 0.41° within a 0.10 to 0.80° range. The mean of the 10 linear values ranged was from -0.30mm to +1.03mm while the mean of the 10 angular variables ranged from -1.65° to 0°.

The results of the reproducibility portion are the 22 variables shown in *Tables IV & V.* Interincisal angle and "A" point to Nasion perpendicular were significantly different at the p=0.05 level while four other variables; maxillary incisor inclination, maxillary incisor to Frankfort horizontal, mandibular plane to Frankfort horizontal, and gonial angle, were significantly different at the p=0.01 level. The reported mean difference for each variable is derived by determining the mean of

| LENGTHS (mm) | MEAN | S.D. | RANGE |
|---|---|---|---|
| 2 | 2.05 | 0.35 | 1.7 - 2.4 |
| 5 | 4.70 | 0.35 | 4.4 - 5.2 |
| 9 | 9.53 | 0.83 | 8.9 - 10.7 |
| 14 | 14.27 | 0.44 | 13.8 - 14.7 |
| 20 | 20.27 | 0.10 | 20.2 - 20.4 |
| 30 | 30.60 | 0.55 | 29.8 - 31.0 |
| 40 | 40.58 | 0.24 | 40.4 - 40.9 |
| 50 | 51.03 | 0.59 | 50.2 - 51.6 |
| 60 | 60.80 | 0.73 | 60.1 - 61.8 |
| 70 | 70.95 | 1.00 | 69.7 - 71.9 |
| | | AVE. S.D.=.52 | AVE. RGE.=0.8 |

**Table II** *DIRECT SONIC DIGITIZATION ACCURACY DETERMINATION OF LINEAR VARIABLES* (each variable digitized four times)

| ANGLES (degrees) | MEAN | S.D. | RANGE |
|---|---|---|---|
| 2 | 1.85 | 0.17 | 1.7 - 2.1 |
| 5 | 5.00 | 0.12 | 4.9 - 5.1 |
| 15 | 14.68 | 0.10 | 14.6 - 14.8 |
| 25 | 24.35 | 0.75 | 23.4 - 25.0 |
| 45 | 44.55 | 0.56 | 44.0 - 45.3 |
| 70 | 69.20 | 0.52 | 68.5 - 69.6 |
| 90 | 88.30 | 0.54 | 88.0 - 89.1 |
| 110 | 108.35 | 0.37 | 108.0 - 108.8 |
| 145 | 143.80 | 0.80 | 142.8 - 144.5 |
| 180 | 179.93 | 0.21 | 179.7 - 180.2 |
| | | AVE. S.D.=.41 | AVE. RGE.=0.7 |

**Table III** *DIRECT SONIC DIGITIZATION ACCURACY DETERMINATION OF ANGULAR VARIABLES* (each variable digitized four times)

| VARIABLE | MEAN DIFFERENCE | S.D. | S.E. | MEAN RANGE | INDIVIDUAL RANGE LEAST | GREATEST |
|---|---|---|---|---|---|---|
| Overbite mm | 0.95 | 0.50 | 0.11 | 2.43 | 0.6 | 5.4 |
| Overjet mm | 0.74 | 0.34 | 0.08 | 1.89 | 0.6 | 4.3 |
| Molar Relation mm | 0.44 | 0.33 | 0.07 | 1.17 | 0.1 | 3.2 |
| L1 Protrusion (L1-NB) mm | 0.77 | 0.42 | 0.09 | 1.98 | 0.1 | 5.5 |
| U1 Protrusion (U1-NB) mm | 0.75 | 0.38 | 0.09 | 1.97 | 0.8 | 4.8 |
| Convexity mm | 0.94 | 0.46 | 0.10 | 2.43 | 0.4 | 4.5 |
| A to N perp. mm | 1.46* | 0.84 | 0.18 | 3.83 | 0.5 | 11.0 |
| Pg to N perp. mm | 2.46 | 1.13 | 0.25 | 6.58 | 2.0 | 14.9 |
| Witts mm | 1.37 | 0.46 | 0.10 | 3.56 | 1.3 | 5.7 |
| Lower lip to E plane mm | 0.60 | 0.28 | 0.06 | 1.58 | 0.4 | 3.5 |
| Upper lip to E plane mm | 0.64 | 0.31 | 0.07 | 1.66 | 0.2 | 3.5 |

**Table IV.** *DIRECT SONIC DIGITIZATION LINEAR REPRODUCIBILITY DETERMINATION*
* P=0.05

| VARIABLE | MEAN DIFFERENCE | S.D. | S.E. | MEAN RANGE | INDIVIDUAL RANGE LEAST | GREATEST |
|---|---|---|---|---|---|---|
| Interincisal angle ° | 6.13* | 4.30 | 0.96 | 16.04 | 4.3 | 46.4 |
| L1 Inclination (L1-NB) ° | 2.93 | 2.03 | 0.46 | 7.6 | 1.0 | 18.1 |
| U1 Inclination (U1-NB) ° | 5.05** | 3.53 | 0.79 | 13.32 | 2.6 | 33.3 |
| IMPA ° | 2.94 | 1.71 | 0.38 | 7.68 | 2.4 | 16.1 |
| FMIA ° | 3.17 | 1.54 | 0.35 | 8.4 | 1.6 | 15.9 |
| U1 to FH ° | 5.80** | 3.15 | 0.71 | 14.73 | 4.9 | 36.5 |
| MP to FH ° | 1.87** | 0.96 | 0.21 | 4.87 | 0.2 | 11.4 |
| MP to OP ° | 1.44 | 0.80 | 0.18 | 3.72 | 1.0 | 8.4 |
| OP to FH ° | 1.77 | 0.94 | 0.21 | 4.57 | 0.4 | 10.8 |
| Go angle ° | 6.41** | 4.07 | 0.91 | 16.98 | 6.8 | 44.4 |
| ANB ° | 1.01 | 0.42 | 0.09 | 2.63 | 0.7 | 4.7 |

**Table V** *DIRECT SONIC DIGITIZATION ANGULAR REPRODUCIBILITY DETERMINATION*
* P=0.05, **P=0.01

each variable for each patient, then the absolute difference of each individual measurement from that of the mean was calculated. Three differences from the mean values for each variable on every patient were recorded which yielded a sample of 60 difference values that were averaged to find the mean difference of that variable. The mean difference for the linear variables ranged from 0.44 to 2.46mm while the mean difference of the angular variables ranged from 1.01 to 6.41°. Standard deviation for the linear measurements ranged from 0.28 to 1.13mm while the standard deviation for the angular measurements ranged between 0.42 and 4.30°. The standard error of the mean is also reported for all variables and ranges from 0.06 to 0.25mm and 0.09 to 0.96° for linear and angular variables respectively. Since there was a large spread for the variables, the range is also included as part of *tables IV & V.*

**DISCUSSION**

When the average standard deviation of the linear and angular variables, 0.52mm and 0.41 degrees respectively, are compared to reported accuracies of other two dimensional digitizers used for cephalometric analysis of radiographs (0.10 - 0.38mm)[10-13] the Digigraph values exceed those of the two dimensional sonic digitizers. Digigraph variables include machine sources of error in addition to the digitizer recording error. Other sources of machine error for the Digigraph would include; accuracy of the probe tip, movement of the probe tip shaft within the probe handle, accuracy of the probe sound emitters, allowable movement of the probe handle during sound emission, and accuracy of machine calibration prior to digitization. Another source of interpretation error inherent to digitization is operator varibility.

Digigraph® average standard deviation values compare favourably to manual measurement from tracings where the measurement error is reported to be approximately 0.5mm in each of the two planes of space.[14] The consistent pattern of over-prediction of linear values (1.5%) and under prediction of angular values (0.40%) is a concern. This source of systematic error may be due to calibration. More precise pre-session calibration may reduce this apparent calibration error or the error may be due to the precision of the factory values that are entered during the calibration process. A suggestion for improvement during the calibration process would be to include specific linear and angular values to be digitized and a comparison of the actual and digitized values made.

All angular variables involving the upper incisor were significantly different from each other over three trials. Three points for the lower incisor and four points for the upper incisor were digitized to approximate crown morphology. Root angulation was then calculated based on standards, the source of which is not divulged by the manufacturer. Slightly different placement of the probe during digitization of these points results in a different crown shape being determined and thus a different root angulation. Interincisal angle was found to have a mean difference of 6.13° and a mean range of 16° and have an individual range as high as 46° over the three trial sessions. Lower incisor coronal inclination was found not to be as variable as the upper incisor and was not significantly different over the trial sessions. This may be due to greater visual referencing of landmarks on the lower incisor during digitization and the fact that there is less curvature to the lower incisor crown.

Present research revealed that maxillary incisor angulation determination is the major weakness of the sonic digitizing. Rather than point reference, the technique of stream digitizing the entire profile contour of the incisor crowns would likely yield a more accurate and reproducible determination of crown morphology and thus allow for serial comparison. It still may not accurately reveal root angulation but it should give a more acceptable determination of crown angulation. Root angulation has been used as an assessment of ideal crown positioning for proper occlusion.[15,16] According to Andrews crown angulation is a more important determinant of occlusion than root angulation.[17] The relationship of the contour and angulation of the lingual aspect of the maxillary incisor determines the degree of incisal guidance in protrusive jaw movement.[17,18] Stream digitized incisor crowns may derive valuable diagnostic information for ideal crown angulation for functional occlusion. Lower incisor root angulation is considered important as a determinant of long term stability. It may be possible to use lower incisor crown angulation as a reference for this stability determinant.

Gonial angle was another measurement that revealed high variability with a mean difference of 6.41°, and a mean range of almost +17° and individual variations that ranged from 7° - 44°. This variation is due mainly to the extraoral determination of articular point as well as the determination of gonion. Gonial angle measured from radiographs has been used as one indicator of growth pattern.[19,20,21] The extreme variability of this sonic measurement renders it non diagnostic. Until there is a better extraoral reference point any attempted correlation of this variable to growth vectors and amounts should be avoided. A suggestion may be to not use articulare at all and replace it with the more reproducible superior curvature of the external auditory meatus. Thus a new "gonial angle" could be derived that would be much more reproducible due to less variability of locating the external auditory meatus.

In view of radiation hygiene concerns it now appears to be appropriate to further investigate sonic digitization as a possible alternative to exposure of ionizing radiation used in cephalogram analysis.

Future research should be directed toward utilizing the strengths of direct three dimensional sonic digitizing of facial and skeletal characteristics so that facial asymmetry, among other variables, may become more reliable. There are many soft tissue landmarks other than profile landmarks, that could be utilized in a three dimensional facial analysis. As an example, malar ridge prominence may be correlated to soft tissue "A" point prominence as a measure of mid-face deficiency. Another example could be that intercanine width may correlate with mandibular width.

The ultimate goal of cephalometrics is to provide accurate diagnostic information so that decisions can be made to optimize aesthetics, stability and function of the craniofacial complex.

## CONCLUSIONS

Sonically digitized measurements of variables involving the angular relationship of the upper incisor and gonial angle are not reliably determined. Direct sonic digitization does have the advantage of non-ionizing imaging and warrents further investigation and research to develop tighter ranges of reproducibility.

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# CHAPTER 3

## Reproducibility Comparison of Cephalometric Values obtained by Direct Sonic Digitization and Digitization of Lateral Cephalometric Radiograph Tracings.

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**ABSTRACT**

Reproducibility of direct sonic digitization is compared to reproducibility of digitizations of repeated tracings of cephalometric radiographs. The reproducibility of 22 variables were examined on 20 patients and 20 lateral cephalometric radiographs, which were each randomly digitized once each day on three separate days. The standard deviation of the differences between replicate measurements is reported for both groups for all 22 variables. For 7 of 22 variables digitized tracings were significantly more reproducible than direct sonic digitizing. All 5 variables that were more reproducible using sonic digitization were linear variables and included, Pg - N perpendicular, Witts, lower lip to E plane, upper lip to E plane, and upper incisor protrusion. Most variables that were more reproducible using digitization of repeated tracings were angular variables, which include inter-incisal angle, upper incisor inclination, upper incisor to FH, MP to FH, gonial angle, and ANB. The 10 variables in which there was no significant difference between the two methods were; over-jet, molar relation, lower incisor protrusion, lower incisor inclination, IMPA, FMIA, MP-OP, OP-FH, convexity, and A -N perpendicular.

## INTRODUCTION

Orthodontically, cephalometrics has utilized ionizing radiographic techniques to study both longitudinal and cross sectional growth as well as treatment changes associated with the craniofacial complex. From the composite data come population norms as well as individual variants that are useful adjuncts in the orthodontic treatment planning process.

With any cephalometric analysis there is always concern about the validity of the chosen landmark location as well as the reliability of repeated measures of the same image. Errors associated with radiographic cephalometric analysis include external validity errors such as patient positioning and image projection as well as internal validity errors from landmark and tracing variables.

Projection errors are those that occur when a three - dimensional object is projected on a two - dimensional radiograph. Points that are further away from the central beam and/or further from the film will be magnified to a greater extent than points that are closer. Not all points of interest are midsagittal points nor are all midsagittal points magnified to the same degree.[1,2,3] Positioning errors are reported to be clinically insignificant when rotations in any plane is 5 degrees or less.[4-7] Rotations of greater than 5 degrees should be clinically detected at the time of positioning of the patient and are avoidable.[6]

Studies that have been performed to evaluate the magnitude and pattern of landmark and tracing errors found that errors of certain landmark identification point errors are too large to be ignored and that each landmarks has it's own characteristic pattern or envelope of error.[8-12] Studies suggest that this error can be decreased by replicated landmark identification and averaging the landmark position.[9,11,13]

Direct sonic digitizing for cephalometric assessment was introduced in 1990.[14] This non ionizing source utilizes ultrasonic sound waves, audible sensors, and time computer calculations to derive a spatial three - dimensional relationship that is then transformed into computer coordinates. Both two and three dimensional digitizers have been used in research and reported accuracy lies within the range of 0.125 mm to 0.51 mm.[15,16,17]

The system used in this study is the three dimensional sonic Digigraph Work Station®* that has been independently assessed with average standard deviations of 0.52mm and 0.41° for linear and angular variables respectively.[18]

Investigations performed on reproducibility comparing direct sonic digitization and digitization of lateral cephalometric radiograph tracings are limited. Chaconas *et al* published an article which involved the comparison of Digigraph Work Station® records to those of lateral cephalometric radiographs.[19] In the "Study 1" (part 1) portion of their investigation five orthodontists took radiographic lateral oriented headfilms and then immediately afterwards digitized the ten patients in their subset. The headfilm was later traced and compared to the sonic variables. Of the 5 linear and 7 angular variables evaluated they found no significant differences at the p=0.05 level between radiographic or sonic values. It appears

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*Dophin Imaging Systems, Inc., Valencia, CA.

from the article that only one digitization and one tracing was performed for each patient. Also the utilization of F-tests to report no significant differences at the $p=0.05$ level in standard deviations may not be the most appropriate statistical test.

In the "Study 2" (part 2) portion of their article they evaluated repeatability of consecutive Digigraph recordings versus consecutive cephalometric radiograph tracings. Each of the 10 patients was digitized 10 times and each radiographic lateral cephalometric image was traced 10 times. They reported that the sonic data was more repeatable with 7 of the 12 sonic digitized standard deviations lower than those of the radiograph assessment.

This investigation was designed to compare the reproducibility of direct sonic digitization to digitization of tracings of a cephalogram.

## MATERIALS, SUBJECTS, AND METHODS

Twenty patients between 15 and 38 years, (*table I*) selected without discrimination regarding gender, ethnicity, and malocclusion, were randomly digitized one time each on 3 separate days by the author who had successfully completed an operators training session at the manufacturer's location (Dolphin Imaging Systems). The sonic system was checked and calibrated prior to each session according to manufacturer's guidelines. All digitizations were monitored for patient movement using the stream digitization feature of the system which allows for a visual monitor check of the patients head position at the beginning and the

| | Number of Participants | Mean Age ( range in yrs. & mos. ) |
|---|---|---|
| Female Participants | 10 | 25-3 (15-3 to 32-6) |
| Male Participants | 10 | 30-6 (24-1 to 38-5) |
| Total | 20 | 27-11 (15-3 to 38-5) |

**Table I.** *SAMPLE AGE AND GENDER DISTRIBUTION OF SONIC DIGITIZATION PARTICIPANTS* end of the digitization procedure. If movement was noted the patient was re - digitized immediately. The "accuracy" digitizing probe, an improved version of the original Digigraph® probe, allowed the computer to refuse the landmark if the probe showed more than the allowable amount of movement or if there was interference of the sound waves by either operator or equipment position. Landmarks which cannot be digitized directly (upper and lower incisor apex) were extrapolated by calculations based on location of other landmarks.

Twenty sequential lateral headfilms of 17 to 38 year old patients, all exposed using a Siemens®** model OP-10 radiographic unit, were acquired from a private practicing orthodontist without discrimination regarding gender, ethnicity, and malocclusion. (*table II*) All lateral headfilms were exposed under standard conditions with source-patient and source-film distances of 60 and 75 inches respectively. Headfilms were randomly traced and digitized one time each on 3 separate days by the author. The computer program used to digitize the radiographs was Orthodontic Treatment Planner®*** (OTP) by Computer Diagnostic Information, INC. The hardware used was an IBM compatible 386DX33 computer with a math co-processor and a Kurta®**** IS/ONE digitizing tablet. The Kurta tablet has a manufacturer reported accuracy (precision) of +/- 0.9mm.

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**Siemen Electric Limited, Dental Division, Benshein, Germany

***Computer Diagnostic Information, Inc., Burlingame, CA.

****Kurta, Phoenix, AZ.

| | Number of Participants | Mean Age ( range in yrs. & mos. ) |
|---|---|---|
| Female Participants | 12 | 27-6 (17-9 to 38-0) |
| Male Participants | 8 | 25-11 (17-9 to 32-8) |
| Total | 20 | 26-11 (17-9 to 38-0) |

**Table II.** *SAMPLE AGE AND GENDER DISTRIBUTION FOR RADIOGRAPHIC TRACING PARTICIPANTS*

**RESULTS**

Standard deviations of differences between replicate linear and angular measurements as well as statistically significant differences between methods are shown in *tables III & IV.* Standard deviations of the differences between replicate measurements was chosen over mean differences to better demonstrate the reproducibility of both systems. Mean differences between replicate measurements would reveal accuracy concerns.

Of the 22 variables evaluated there was significant difference between the two methods in 12 instances. Four of the differences were at the p=0.05 level and eight at the p=0.01 level. Of the 12 differences 7 were lower when the variable was traced from a lateral cephalogram, and 5 were lower when the patient was digitized sonically. The variables that digitized tracings reproduced more significantly were; interincisal angle, upper incisor inclination, upper incisor - FH, MP - FH, gonial angle, ANB, and over-bite. The variables that sonic digitization reproduced more significantly were; upper incisor protrusion, Pg - N perpendicular, Witts, lower lip - E plane, and upper lip - E plane.

**DISCUSSION**

This study has shown that when measuring traditional radiographic cephalometric variables, digitization of lateral cephalogram tracings is more reproducible than direct sonic digitization of patients. There is a bias towards the

| VARIABLE | SONICALLY DIGITIZED MEASUREMENTS | P= LEVEL | DIGITIZED TRACINGS MEASUREMENTS |
|---|---|---|---|
| Overbite mm | **0.50** | ◆◆ | **0.33** |
| Overjet mm | **0.34** | | **0.43** |
| Molar Relation mm | **0.33** | | **0.46** |
| L1 Protrusion (L1-NB) mm | **0.42** | | **0.21** |
| U1 Protrusion (U1-NB) mm | **0.38** | ◆ | **0.73** |
| Convexity mm | **0.46** | | **0.45** |
| A to N perp. mm | **0.84** | | **0.95** |
| Pg to N perp. mm | **1.13** | ◆ | **1.29** |
| Witts mm | **0.46** | ◆◆ | **1.26** |
| Lower lip to E plane mm | **0.28** | ◆ | **0.71** |
| Upper lip to E plane mm | **0.31** | ◆◆ | **0.82** |

**Table III.** *STANDARD DEVIATIONS OF DIFFERENCES BETWEEN REPLICATE LINEAR MEASUREMENTS*

◆ = 5% level ◆◆ = 1% level

N.B. Wilcoxon pairs signed ranks test for investigation of statistical significance

| VARIABLE | SONICALLY DIGITIZED MEASUREMENTS | P= LEVEL | DIGITIZED TRACINGS MEASUREMENTS |
|---|---|---|---|
| Interincisal angle ° | **4.30** | ◆◆ | **1.64** |
| L1 Inclination (L1-NB) ° | **2.04** | | **1.68** |
| U1 Inclination(U1-NB) ° | **3.54** | ◆◆ | **1.40** |
| IMPA ° | **1.71** | | **1.64** |
| FMIA ° | **1.54** | | **1.44** |
| U1 to FH ° | **3.12** | ◆◆ | **1.19** |
| MP to FH ° | **0.96** | ◆ | **0.50** |
| MP to OP ° | **0.80** | | **0.90** |
| OP to FH ° | **0.94** | | **0.95** |
| Gonial angle ° | **4.07** | ◆◆ | **0.89** |
| ANB ° | **0.92** | ◆◆ | **0.40** |

**Table IV.** *STANDARD DEVIATION OF DIFFERENCES BETWEEN REPLICATE ANGULAR MEASUREMENTS*

◆ = 5% level ◆◆ = 1% level

N.B. Wilcoxon pairs signed ranks test for investigation of statistical significance tracing technique in that traditional cephalometric variables, which favour the lateral cephalometric radiograph, were chosen for validity and convenience. Another reason for bias is that repeated tracings of the same cephalogram are compared to three separate sonic recording sessions that have the potential to introduce variable head position. Error due to operator variability is another concern but effort was made to reduce the error by having the same operator for both digitizations.

Of the variables examined in this study, sonic digitization was significantly more reproducible for soft tissue variables and significantly less reproducible for variables which included extrapolated points such as upper and lower incisor apices. Patients seeking orthodontic treatment are motivated by a desire for improvement in facial esthectics as well as masticatory function. Orthodontic treatment can alter facial esthectics via both hard and soft tissue changes. Patients see and are mainly concerned with soft tissue contour as well as the obvious dental changes. A truly relevant and complete analysis should include soft tissue variables.

Orthodontists and patients are becoming increasingly aware of hazards from cummulative low - levels of ionizing radiation. It is not only the responsibility of the practitioner to ensure that patients receive as low as reasonably achievable (ALARA) dose levels[20], but it is also his/her responsibility to consider alternative methods of diagnosis that may not carry with it radiation risk.

A recent article that evaluated the contribution of pretreatment radiographs to orthodontists' decision making, found that orthodontists were on average 75.2% confident of their diagnosis before reviewing any radiographs.[21] These same orthodontists were then allowed to order any radiographs they wanted to supplement the data base. Radiographs increased average diagnostic certainty by only 12.3% and thirty percent of the orthodontists certainty level never changed at all. Since 74% of the radiographs did not cause a change in either diagnosis or treatment plan the diagnostic yield of such procedures must be questioned. Radiographs may be ordered to supplement patient records for medical-legal reasons. Radiographs should be taken only when patient benefit outweighs risk.

When a new technique is introduced it may not be as proficient at measuring the "traditional" variables, but consideration must be given to alternate ways that may yield comparable diagnostic information. Alternatives to ionizing radiation imaging should be evaluated and ways to improve the quality of the analysis must be developed. This will involve the determination of new landmarks that are valid, sonically digitizable and reproducible. New variables may have limited similarity to traditional radiographic variables, but may be equally or more valid in assessing craniofacial and dentofacial relationships.

## CONCLUSIONS

It is concluded that sonic digitization cephalometric reproducibility using the Digigraph® is significantly lower than digitization of cephalogram tracings for 7 of 22 variables. Variables that were more reproducible for sonic digitization system were; Pg - N perpendicular, Witts, lower lip to E-plane, upper lip to E-plane, and upper incisor protrusion. It is therefore suggested that sonic digitizing systems should have an analysis or analyses which utilizes the strengths of the system rather than trying to perform a "radiographic" analysis. Once new sonographic cephalometric analyses are derived, population norms will need to be gathered to establish validity.

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# Chapter 4

## Final Discussion

This study into direct sonic digitization revealed that standard deviations of linear and angular values (0.52mm and 0.41° respectively) obtained sonically are higher than reported accuracies of digitizers used for radiographic cephalometric analysis (+/- 0.10 - 0.38)[1-4] but are not frightening. Manual tracing or measurement error is approximately equal to pencil lead thickness (0.50mm)[5] and sonic digitization values compare well with this figure. Sources of machine error for the Digigraph® include; accuracy of the probe tip, movement of the probe tip shaft within the probe handle, accuracy of the probe sound emitters, allowable movement of the probe handle during sound emission, and accuracy of machine calibration prior to digitization. These sources of error are independent of landmark identification error and operator variability which would apply to both systems.

Reproducibility of cephalometric variables was also researched in this study and the sonic system was found to have strengths and weaknesses. Variables which involved the extrapolation of landmarks (incisor apicies) were found to be highly variable. This is due to the variation in locating landmarks on the crown of the incisor that were required to be digitized in order to calculate root angulation. Three points for the lower incisor and four points for the upper incisor were digitized to approximate crown morphology. The standards from which root angulation was calculated, based on average crown shape are not reported by the manufacturer. Slightly different placement of the probe during digitization of these points results in a different crown shape being determined and thus a different faciolingual root angulation. Interincisal angle in this study was found to have a mean difference of 6.13° and range between sessions an average of 16° with individual variations as high as 46° and as low as 4°. Lower incisor inclination was found not to be as variable as the upper incisor and was not significantly different between trial sessions. This may be due to greater visual referencing of the landmarks on the lower incisor during digitization or the fact that there is less curvature to the lower incisor crown.

Maxillary incisor angulation determination is a weak point of sonic digitizing. One way to improve reproducibility of this measurement may be to stream digitize the entire profile contour of the incisor crowns. Stream digitization would allow for more accurate and reproducible determination of crown morphology and thus allow serial comparison. Even if root angulation is not adequately determined, crown angulation will be accurately recorded. Root angulation has been used as an assessment of ideal crown positioning for proper occlusion[6,7]. According to Andrews crown angulation is a more important determinant of occlusion than root angulation[8]. The relationship of the contour and angulation of the lingual aspect of the maxillary incisor determines the degree of incisal guidance in protrusive jaw movement[8,9]. Lower incisor root angulation is considered important as a determinant of long term stability. Sonic digitization of lower incisor crown angulation may provide an adequately reliable assessment of stability.

Gonial angle revealed high variability with a mean difference of 6.41° and a mean range of nearly 17° and demonstrated individual variations that ranged from 7 - 44°. It is speculated that this variation is due mainly to the extraoral determination of articulare point. Gonial angle measured from radiographs has been used as an indicator of growth pattern[10,11,12]. The high variability using the Digigraph renders values using Gonial angle as non diagnostic. It may be possible that a new sonic system variable could be introduced that would be highly correlated to growth direction and may be utilized instead.

Replacing articulare with the superior most position of the external auditory meatus would be much more reproducible and sonically accessible. This new variable could then provide diagnostic information on growth direction so that appropriate treatment decisions could be implemented.

When reproducibility of certain cephalometric variables was compared between repeated sonic digitizations and digitization of repeated tracings, both systems were found to have advantages.

Of the 22 variables examined 9 were found to be significantly more reproducible using radiographic tracings, and 3 significantly more reproducible using sonic digitization. Sonic digitization performed better for soft tissue variables and was less reproducible for variables which included extrapolated points.

An ideal craniofacial and dentofacial analysis would have the following objectives;

- ability to serially compare records to study the process of craniofacial growth and assess orthodontic treatment progress and results
- provide information to identify individual deviations from

population norms

- provide valid and reproducible diagnostic data to facilitate orthodontic treatment planning to achieve the most stable, functional, and esthectic result
- provide diagnostic data to accurately predict growth and treatment changes
- analyze the craniofacial complex in three dimensions
- be of no risk to the patient
- allow intra and interdiciplinary communication

At the present time these objectives are not all met by any one method of diagnosis alone. There are many systems being researched and developed that may have future potential in the area of craniofacial analysis[13-16].

Kobayashi et al,[13] have developed a three - dimensional analysis of facial soft-tissue morphology. Reference points were marked on the face with black eye-liner, and the head positioned in a reference metal frame which included standardized three dimensional values. Two photographs were exposed simultaneously at an angle of approximately 25 degrees from the right and left sides of the face. Perspective transformation was accomplished using the two - dimensional values from the photographs of the known three - dimensional standard points. A three - dimensional wire frame model of the face could then be displayed on a monitor from any direction. Volumetric determination of the face was possible and could be compared before and after orthognathic surgery. They also suggest that it may be possible to predict three-dimensional post operative change in facial soft tissue associated with surgical movement of the mandible. A disadvantage of this system is the large amount of manual input required.

Stereo photogrammetry is a method of topographically mapping the face. Using photographs a contour map of the face can be produced with certain intervals between contour lines[14,15]. Burke and Beard[15] accomplished this using two aerial survey "multi-plex" projectors for both the stereo camera and plotting instrument. Modification of the projectors allowed photograhic plates to be inserted and lowered to the focal plane. Synchronized exposure is made by electronic flash and the sliding doors close to complete the photographic recordings. The photographs are taken with the patient in a supine position after he/she has been raised into position using a vertical Frankfurt plane and ear rods on the head positioner as a guide. All measurements are taken from a horizontal plane coincident with the upper surface of the ear rods, which are are mounted flush with the head positioner frame referred to as the datum plane. When the instrument is used for plotting the head positioner is removed and the projectors are lowered the amount the head positioner was above the table. The light housing on the projectors are replaced and the photographs which were processed as positive transparencies (diapositives) are projected. A small mobile tracing table is then used to record the contour lines. A point source of light is set in the center of this table and appears to float above or below the surface, depending on table height. The correct height is registered on a vernier gauge when the "floating spot" just rests on the surface of the three -

dimensional image. A hard pencil directly below the spot is then lowered to register a contour line on paper. The contour line is completed by moving around the image at this one level. Dimensions can then be measured from the facial plot between known landmarks. Vertical and horizontal profiles can be obtained through sections of the plot as well as to give three - dimensional measurements. This technique requires special cameras, plotters, and contour mapping techiques, as well as being labour intensive and not widely used clinically.

Direct digital radiographic technology is being developed as a alternative to conventional radiography[16]. Radiographic sensors are able to digitally capture images with substantially decreased radiation exposure dosages[16]. (Approximately 60% reduction on current intraoral films). Images are displayed on a video monitor and there is potential for expediting transfer of records through electronic mail (teleradiology)[17]. Digital imaging in dentistry is currently still in a pioneering stage and the only commercially available sensors are small area intra - oral units[16]. It would be anticipated that similar units will be produced for extra - oral use but exposure reduction may not be as substantial for cephalometrics. Exposure reduction techniques discussed are already being used for extra oral imaging which are not available intra - orally.

Computed tomography (CT) is another radiographic method, that utilizes a moving X -ray source and sensors to image a "slice" of the desired anatomy. Unlike conventional radiographs where X - rays are detected by film, in CT they strike radiations detectors and the amount of radiation that penetrates the body is stored digitally in a computer. The image is then reconstructed by the computer using a mathematical process of converting X - ray penetration data into a numerical, or digital, image. This imaging process allows for a "slice" view without superimposition of anatomy and slice thickness can be varied usually between 1 - 10mm. Contrast levels can be changed using the computer to facilitate visualization. The radiation exposure dose of CT is reported to be similar to or higher than conventional radiography[18-21]. Although CT has an advantage in contrast resolution as the detectors are more sensitive than film, spatial resolution (fine detail) of CT is inferior to that of standard radiography[22]. Three - dimensional images reconstructed from two - dimensional scans are possible but has limitation due to artifacts in reconstructed images, increased radiation exposure, and increased cost[23].

Magnetic resonance (MR) imaging instruments are scanners which include a large magnet into which the patient is placed. Once placed in the scanner a strong magnetic field is employed to align the atomic nuclei with significant magnetic moments within an area of the patients body. Hydrogen, sodium, and phosphorus nuclei are affected and the alignment is momentarily disturbed by a pulse of radio waves of the frequency appropriate to the particular element under study, and the rate of return to the stable state is measured from the emission of radio waves. From this, images of elemental distribution can be produced. MR images are similar to CT in that they image a "slice" of the body and can be varied in thickness accordingly. Three - dimensional imaging is possible with MR, and performs best with nonossifed structures[24].

Advantages of MR are; no ionizing radiation is used, fewer artifacts from dense bone and metal clips as compared to CT, imaging in multiple planes is possible without moving the patient, signals from tissues are dependant on several chemical and physical properties, which may be studied independently.

Current limitations of MR are; ferromagnetic material close to the image sight may affect image quality, movement artifact is frequent in young children, claustrophobic reactions are seen in some patients, high cost, unknown affects of high magnetic fields and inability to image patients with cerebral aneurysm clips or cardiac pace makers.

With the development of new systems and radiation concerns such as;

a) low dose ionizing radiation maybe more detrimental over the life span of an individual than previously thought

b) there is a carcinogenic risk from any exposure to radiation and this risk is increased when the patient is younger

c) cells are affected in many ways causing carcinogenesis, teratogenesis, genetic mutations, and changes in the immune response

d) 90% of artificial radiation is from diagnostic radiographs of which 30 - 60% are unnecessary (74% of orthodontic radiographs do not change the orthodontists' diagnosis or treatment plan - unnecessary?)

e) even with low exposures from cephalograms there is a definite risk of cancer induction from 0.3/million - 6/million

f) 13% of parotid gland cancers may be attributed to dental radiographs and cephalograms maximum absorbed dose is in the parotid region

g) it is the practitioners responsibility to see that patients receive as low as reasonably achievable dose levels (ALARA)

it is in the patients best interest for new avenues of diagnostic information gathering to be explored.

A recent article that evaluated the contribution of pretreatment radiographs to orthodontists' decision making, found that orthodontists were on average 75.2% confident of their diagnosis before reviewing any radiographs[25]. These same orthodontists were then allowed to order any radiographs they wanted to supplement the data base. Radiographs increased average diagnostic certainty by only 12.3%, and 30% of the orthodontists' certainty level never changed at all. The majority of radiographs (74%) did not cause a change in either diagnosis or treatment plan. This implies that 74% of orthodontic radiographs are unnecessary or that information found on these radiographs was available from other non-radiographic sources. Radiographs are often ordered to supplement patient records for medical-legal reasons. In this case the benefit of the radiograph does not outweigh the risk to the patient and should not be obtained. The requirement of pre and post - treatment radiographs may have become a "tradition" in orthodontics. Radiation dose from a cephalogram is small but it must be remembered that patients have radiation exposure from other sources and it is not known when a particular individual will exceed their threshold level. It has been suggested that cancer risk from cephalometric techniques alone is approximately 3 in a million and must be considered carefully.

Research must be continued in all areas that have potential for future benefit. Direct sonic digitization has non-ionizing advantages over conventional radiographic techniques. What is needed now is a method to extract diagnostic information of the patient in a form that is meaningful, valid, and reliable. Sonic digitization has three dimensional capability that could prove to be very useful. A reliable and validated new technique of data gathering that measures the face in three dimensions would be of more value than a two dimensional analysis of a lateral cephalogram. There is potential to develop a three dimensional facial analysis that could be coupled with three dimensional computer graphics for growth and treatment predictions.

Many people seeking orthodontic treatment are motivated by a desire for improvement in facial esthectics as well as masticatory function. Orthodontic treatment can produce both hard (dental and skeletal) and soft tissue changes for an individual. It is only the dental and soft tissue changes that the patients can see and thus are mainly concerned with. Soft tissue covering of the craniofacial complex has been shown previously to vary in thickness and consequently does not correspond uniformly to the hard tissue framework[26,27,28]. A truly relevant and complete analysis should include soft tissue variables. Future research into facial soft tissue changes due to weight loss/gain and hormonal fluctuations for example, need to be undertaken.

To develop an analysis using direct sonic digitizing reference planes and landmarks should be chosen that do not rely on extrapolated points[29]. Firstly a stable reference plane is needed from which to measure and compare variables. Ideally the reference plane should be stable over time, valid, reproducible, reliable, and allow for comparison between individuals. Traditional cephalometric analysis have used reference lines such as Sella-Nasian (SN) or Frankfurt Horizontal (FH)[30-33] which have been shown to have considerable biological variation (SD 4 to 6°)[34-37]. Some researchers are concerned that this biological variation does not allow for an accurate assessment of the individual from population norms[30,38-42]. The cant of the traditional reference planes could either mask a legitimate concern or make a normal situation appear abnormal. The natural head position (NHP) is a standardized orientation of the head with the eyes focused on a distant point at eye level. NHP has been previously investigated and found to be reproducible with an approximate SD of 2° [36,39,43-48]. Being that NHP has less variability than the biological variation of SN and FH it may allow for more precise comparison of an individual to population norms.

The use of NHP as a logical reference and orientation for patient evaluation has been previously advocated[35,36,45,47,48,49-54]. NHP is a true life everyday appearance of the individual and again this appearance is precisely what interests the patient. When using NHP as a reference position "true horizontal" and "true vertical" reference planes can be used to measure variables. Previous analysis have utilized a plumb line hung from above the patient as a reference for "true vertical" and a "true horizontal" can be constructed perpendicular to this.

The following analysis suggestions will relate to a sonic system although the principles may be applied to other 3D analysis systems. NHP position can be achieved using a mirror[43,55]. Using a plumb line as a guide, the mirror can be positioned in a true vertical relationship. The patient is instructed to look into their pupil reflection in the mirror. Two points would be digitized from the surface of the mirror as a reference coodinates for "true vertical". A "true horizontal" would be constructed perpendicular to the "true vertical". Both the true horizontal and vertical could be superimposed on the patient video image through any landmark or position chosen and variable measurements made. Ideal position of the true vertical reference would require substantial research and longitudinal studies, but a true vertical through nasion would be informative (Nasion True Vertical = NTV). The position of the true horizontal line may also be chosen through nasion (Nasion True Horizontal = NTH). The position of the reference planes will only matter for linear measurements as angular measurements will not change if the plane is moved parallel to itself. Using direct sonic digitization, valid and reproducible landmarks need to be chosen that are accessible for direct digitization, and extrapolated landmarks should be avoided.[29] There are many possible landmarks and variables that could be investigated and the following is certainly not an all inclusive list, but may prove to provide a thorough assessment of an individual. (*Table I*)

| VARIABLE | LANDMARKS FOR DETERMINATION | DIAGNOSTIC INFORMATION DERIVED |
|---|---|---|
| Interincisal crown angulation | stream digitization of most prominent upper and lower incisors | angular relation of upper and lower incisors |
| U1 - NTV degrees | | angular determination of incisor crowns to reference planes -allows for comparison to norms and serial records |
| U1 - NTH degrees | | |
| L1 - NTV degrees | | |
| L1 - NTH degrees | | |
| U1 - NTV mm | | anterio-posterior relation of incisors to reference plane |
| L1 - NTH mm | | |
| Over-jet | | anterio-posterior relation of incisors to each other |
| Overbite | | vertical relation of incisors to each other |
| U6 - L6 mm | a point in the buccal embrasure that approximates the mesial contact point for each molar | anterio-posterior relation of molars to each other |
| OP - NTH degrees | computer derived midpoint of OB and the occlusal most point on the cuspal inclines between the MB and DB cusps for U6 and L6 | angular relation of OP to reference plane |
| MP - NTH degrees | soft tissue (S.T.) menton and gonion | angular relation of MP to reference plane |
| OP - MP degrees | see above | angular relation of MP - OP |
| S.T. Apoint - NTV mm | S.T. Apoint | AP relation of mid-face to reference plane |
| S.T. Bpoint - NTV mm | S.T. Bpoint | AP relation of lower face to reference plane |
| H.T. Apoint - NTV mm | H.T. Apoint | AP relation of maxilla to reference plane |
| H.T. Bpoint - NTV mm | H.T. Bpoint | ap relation of mandible to reference plane |
| S.T. Pg - NTV mm | S.T. Pg | AP relation of S.T. chin to reference plane |

| | | |
|---|---|---|
| H.T. Pg - HTV mm | H.T. Pg | Ap relation of H.T. chin to reference plane |
| S.T. B - S.T. Pg | S.T. B and Pg | S.T. chin button |
| Malar eminence - NTV mm | S.T. orbitale | AP relation of lateral portion of mid-face |
| Upper Lip - E plane | Upper and Lower Lip midpoint, nasal tip, and Pg | relation of lips to nose and chin |
| Lower Lip - E plane | | |
| Nasal tip - Alar base : Alar base - N | N, Nasal tip, and Alar base | assessment of nose size and projection |
| Upper Lip thickness and taper | S.T. Apoint, H.T. Apoint, Upper lip, and Upper 1 | relation of lips to teeth<br>- diagnose lip strain and predict post treatment lip position |
| Lower Lip thickness and taper | S.T. Bpoint, H.T. Bpoint, Lower Lip, and Lower 1 | |
| VERTICAL FACIAL THIRDS - L:M:U | menton, subnasale, glabella, and superior limit of frontalis muscle | vertical facial proportions |
| Lower = menton - subnasale | | |
| Middle = subnasale - glabella | | |
| Upper = glabella - superior limit of frontalis m. | | |
| TRANSVERSE FACIAL FIFTHS | right and left<br>alar base<br>inner and outer canthus<br>ear extreme | transverse facial proportions |
| Medial = alar width | | |
| R lateromedial = R intracanthal width | | |
| L lateromedial = L intracanthal width | | |
| R lateral = R outer canthus - R ear extreme | | |
| L lateral = L outer canthus - L ear extreme | | |

**Table I.** *PROPOSED SONIC DIGITIZATION ANALYSIS*

The above proposed sonic analysis would be a starting point from which the analysis would be investigated and very likely additions, deletions, and or modifications of the variables would be implemented. Validation would involve studies to determine accuracy of landmark identification as well as reproducibility of variables. Landmarks and variables that are not reliable would not be used. Once a comprehensive analysis was validated, data concerning the reliability of the chosen landmarks and variables should be published. The next step would be to gather data for population norms. Subjects would need to be chosen by a panel of experienced experts for "normality". Many subjects would be needed and population norms should be gathered for different ethnicity, gender, and ages. Longitudinal studies would then be conducted to gain information on growth patterns.

Eventually all of this information could be organized and entered in a computer system to give specific information of an individual's deviation from his/her specific population norms. Using age, gender, and ethnicity related norms growth and treatment predictions would be more accurate and useful. Predictions could be further improved by classifying the individual and norms to facial patterns and facial size. Incorporating the three - dimensional aspect of facial size and shape into an analysis is very thought provoking and would require practitioners to evaluate their patients in a more conceptual manner.

Systems such as MRI and radiographics require patient immobility for at least a short period of time. Using sonics it may be possible to perform a functional analysis if sound emitters were placed directly on the face at certain landmark positions. The patient could then be asked to perform mandibular movements for example and the movements could be continually monitored. This information could prove to be very useful for TMJ dysfunction as well as mandibular posturing diagnosis. These functional movements could be recorded videographically at the same time and reviewed later as necessary for example to determine more exactly the postion of a TMJ "click" and/or asymmetry of opening.

Sonic digitization warrants further investigations and research. Currently sonic systems are "young" and need patience, effort, and ideas to "mature" into a comprehensive analyzing systems.

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