# A Comparison of Orthodontic Landmark Reliability and Validity Between Lateral Cephalograms and Hemifacial Lateral Cephalograms Among Orthodontists

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**Acknowledgements**

I would like to thank all the people that have helped me here and there.

## Dedication

This thesis is dedicated to the University of Minnesota Division of Orthodontics.

## Abstract

Lateral cephalometric analysis has been an integral component of orthodontic treatment planning. This study explored a novel approach of hemifacial lateral cephalometric landmark analysis comparing reliability and validity to traditional lateral cephalometric landmark analysis derived from three-dimensional radiographs among experienced orthodontists in symmetric patients. The results showed excellent intraexaminer and interexaminer reliability for both methods, however hemifacial lateral cephalometric analysis proved to be an invalid assessment when compared to traditional lateral cephalometric analysis for multiple orthodontic landmarks assessed. Due to the excellent reliability for both methods and poor overall validity of hemifacial lateral cephalometric analysis for multiple landmarks compared to traditional lateral cephalometric analysis, as well as other limitations, it's use as a supplemental diagnostic tool in symmetric patients by experienced orthodontists cannot be supported.

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## Introduction

Lateral cephalograms have been a diagnostic record in orthodontic treatment for decades, and are used to form orthodontic treatment plans.[1,2,3,4,5] However, some would argue that it is of limited value,[6] in part because landmark identification is a great source of error in two-dimensional (2D) lateral cephalometry.[1]

A variety of methods have been used to analyze orthodontic landmark identification error. Coordinates, linear distances between two points, angular measurements between multiple points, all methods have shown error.[7] Some cephalometric landmarks are more reliable in either the horizontal or vertical plane, making the distribution of errors follow a pattern of a non-circular envelope.[8] These errors have proven to be greater for angles dependent on four landmarks compared to those dependent on three.[9] From this information, it seems that the more points involved in the comparison, the more cumulative error possible.

Validity and reliability of 2D cephalometric analysis is influenced by several factors: image density and sharpness,[5] errors in projection,[4] geometric distortions,[3,4] variations in magnification,[4,10] head positioning of the patient,[1,4,11] superimpositions of structures,[3] facial asymmetry presence,[12] precise definition of the location of a landmark,[5] and operator experience.[1,5]

Cone beam computed tomography (CBCT) is a radiographic imaging technique that has

been used to visualize tissues within the maxillofacial region.[13] These radiographs can provide sub-millimeter resolution, with short scanning times and radiation dosages lower than those of conventional computed tomography.[13] As this technology has become increasingly available, it's use within dentistry has expanded and can provide a three-dimensional (3D) representation of the maxillofacial skeleton and dentition with minimal distortion.[13]

In orthodontics, 3D radiographs can improve diagnosis and treatment planning in specific case types.[14] In fact, it can be immensely helpful when used for evaluating patients with impacted teeth, cleft lip/palate, craniofacial surgery or potential orthognathic surgery.[15] Likewise, 3D radiographs may be additionally helpful when used for evaluating patients with supernumerary teeth, identification of root resorption, evaluating alveolar boundary conditions, temporomandibular joint degeneration and for placement of temporary anchorage devices.[15]

There is a great deal of interest as to how 3D radiographs relate to cephalometric analysis. However, currently there is limited research based evidence on 3D cephalometry.[3] It has been shown that 3D cephalometric analysis minimizes some of the sources of error found in 2D cephalometry,[4] such as head positioning and projections or distortions. There have been developments to measure 3D distances, angles, and volumes and to superimpose 3D craniofacial images.[16,17] While 3D cephalometry is developed and adopted, many practitioners have been continuing 2D cephalometry with lateral

cephalograms derived from 3D radiographs.

Historically, 2D cephalometry was the only method available to the profession for assessing relationships of the dental and skeletal structures,[18,19] as well as determining population distributions of cephalometric values and growth forecasting. The reliance on 2D cephalometry in orthodontics has remained despite the increasing adoption of 3D radiographs in dentistry. Oftentimes, clinicians construct 2D cephalograms from 3D radiographs when forming an orthodontic diagnosis and treatment plan. There are no systematic errors when comparing landmark coordinates in lateral cephalograms derived from 3D radiographs compared to standard 2D cephalograms and they have similar overall landmark identification errors in comparison to conventional digital cephalograms.[1,20] When reconstructing 2D lateral cephalograms from 3D radiographs, 3D radiograph orientation can play a factor in landmark location and analysis.[11,20] To minimize this risk, consistent 3D radiograph orientation is crucial. 3D radiograph orientation, particularly when oriented to intracranial landmarks as opposed to natural head position, has been shown to have excellent reliability regardless of operator experience.[11]

The University of Minnesota Division of Orthodontics' current protocol for cephalometric analysis relies on 2D lateral cephalograms extracted from 3D radiographs. A supplemental 2D hemifacial lateral cephalogram reconstructed from the 3D radiograph, similar to the already utilized 2D lateral cephalogram, may be of value. It

has been shown that multi-planar reconstruction displays of 3D radiographs provide generally more precise identification of traditional cephalometric landmarks.[21] Perhaps utilizing hemifacial lateral cephalograms would likewise lead to an increase in landmark identification precision while requiring less effort than multi-planar interpretation.

The first step in evaluating this would involve determining comparative point identification validity and reliability as compared a 2D lateral cephalogram that is already utilized. Validity assessment, in this situation, is complicated by the fact that cephalometric landmark locations are inherently prone to error.[1] The true values remain unknown. Instead indirect assessments are used, and a new method must be evaluated by comparison with an established technique rather than with the true quantity.[22] Since we do not know the true value, the mean of the two types of measurements is the best estimate we have.[23]

The questions this study explores are:

1. What is the intraexaminer and interexaminer orthodontic landmark reliability of hemifacial lateral cephalograms compared to traditional lateral cephalograms constructed from 3D radiographs among experienced orthodontists in symmetric patients?
2. Is the utilization of hemifacial lateral cephalograms constructed from 3D radiographs a valid method for identifying orthodontic landmarks in comparison to traditional lateral cephalograms constructed from 3D radiographs among

experienced orthodontists in symmetric patients?

**Materials and Methods**

Thirty pre-orthodontic treatment 3D radiographs were retrospectively collected at random from the University of Minnesota Division of Orthodontics. The inclusion criteria for selection comprised of:

1. Consent for treatment was signed after December 2012 with permission to use patient records for research.
2. Patients were between the ages of 6 and 60 at the time of consent.
3. Patients did not have cleft lip, cleft palate, or other craniofacial syndromes.
4. Radiographs had minimal motion artifact, and patients had minimal discernable skeletal or incisor asymmetries.

All identifying information was removed from the radiographs once they were selected for inclusion into the study. Approval by the Institutional Review Board of the University of Minnesota was obtained for the study (Study Number: 1603E85544).

Thirty radiograph volumes of 17 x 23 cm field-of-view were obtained using an i-CAT Next Generation Unit (Model 1-10-1-0, Imaging Sciences International; Hatfield, PA) with a 120 kV voltage, 18.54 mA current, and 8.9 s scan time. These radiographs were exposed as part of the diagnostic records for comprehensive orthodontic treatment per University of Minnesota Division of Orthodontics protocol. The data was saved in Digital Imaging and Communications in Medicine (DICOM) format with an isometric

voxel size of 0.3mm. Radiographs were taken with the patient sitting upright and in natural head position.

Copies of each of the thirty radiographs were organized into 6 collections. These copies were imported at "No Loss" 3:1 single-file compression into Dolphin Imaging Software (Version 11.8, Patterson Dental; St. Paul, MN) and were anonymized. Each of the collections contained the same copies of the thirty radiographs in numerical order. The numerical orders of each individual collection was then randomized without repeats.

Once imported into the Dolphin Imaging Software, the radiographs' hard tissue solid surface segmentation was set to "Default" and the Hounsfield Unit range was unaltered. Soft tissue solid surface segmentation was set to "Default" and the minimum Hounsfield Unit range was reduced to the minimum in Log(y) scale to optimize soft tissue visualization. These settings were identical for each individual radiograph in all 6 collections. These parameters, as well as others following, are specific to Dolphin Imaging Software and were repeated in an individual radiograph specific manner, identical between collections, to ensure standardization.

The radiographs were oriented to individual subject specific coordinates to ensure standardization. The midsagittal plane was defined by the tip of the Anterior Nasal Spine (tip of the bony projection), Nasion (intersection of the internasal suture with the nasofrontal suture), and Basion (midpoint on the anterior margin of the foramen

magnum) serving as reference points. The transverse plane was defined by Right Porion (most superior point of the external auditory meatus), Right Orbitale and Left Orbitale (most inferior point of the external border of the orbital cavity) serving as reference points. The oriented 3D radiographs were used to reconstruct traditional 2D lateral cephalograms and hemifacial lateral cephalograms of the patients' left sides, as defined by the midsagittal plane (Figure 1). Projection type was orthogonal with a 0.0% fictitious magnification factor and 100 mm calibration bar set to the image right to be used for calibration and (X, Y) coordinate definition. No margins were added to the images. Image filter parameters and were set as "Default" except sharpness, which was maximized in all filters. Image filters included: Dolphin 1, Dolphin 2, Dolphin 3, Ray-Sum, Emboss and Maximum Intensity Projection (MIP). Some of these parameters are specific to Dolphin Imaging Software and were repeated in a subject specific manner to ensure standardization.

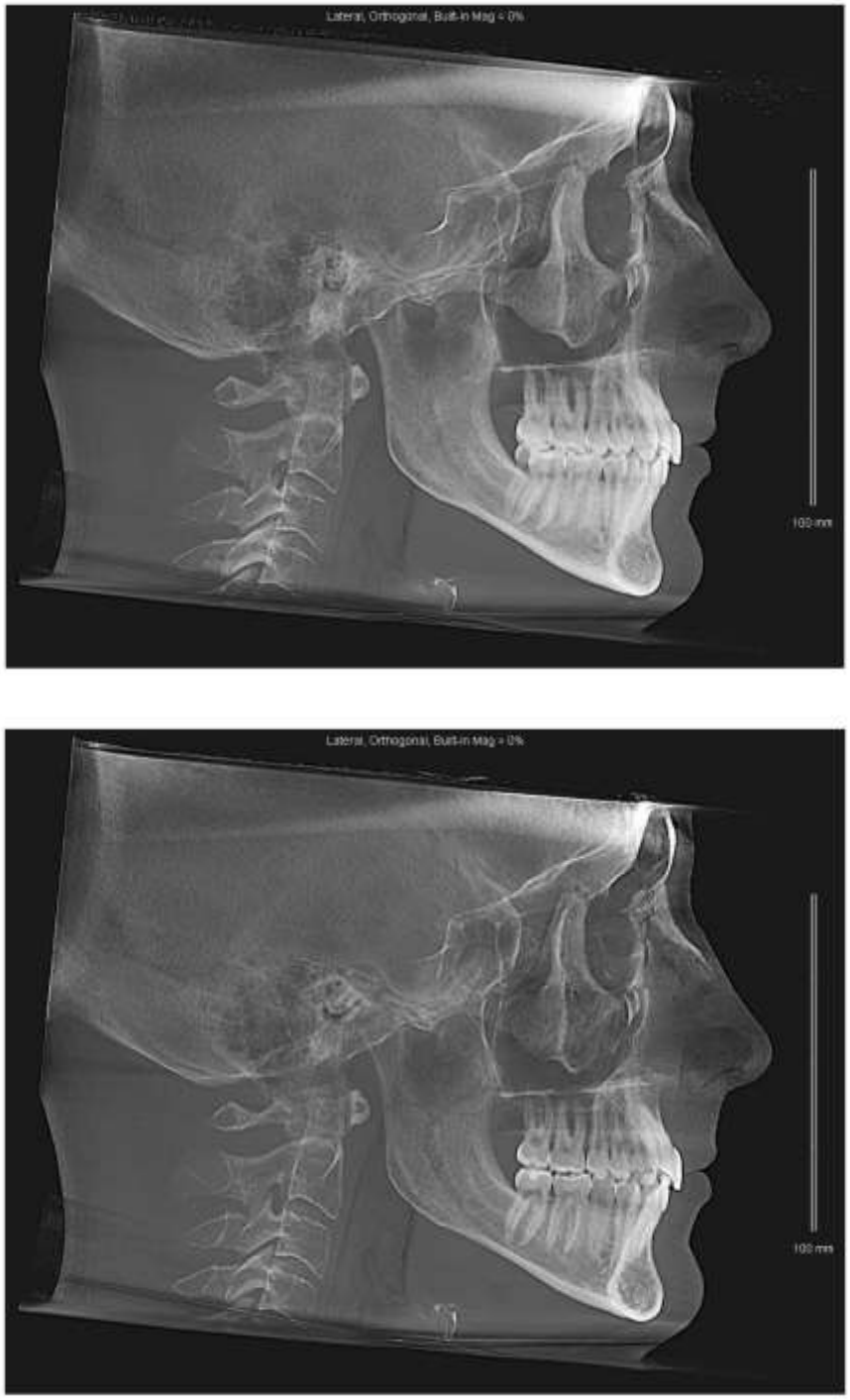


**Figure 1.** Lateral Cephalogram (above) and Hemifacial Lateral Cephalogram (below).

A custom cephalometric analysis was created with the following orthodontic landmarks:

| Orthodontic Landmark | Definition |
|---|---|
| A Point | Most posterior point on the concavity along the anterior border of the maxilla |
| B Point | Most posterior point on the concavity along the anterior border of the mandibular symphysis |
| Pogonion | Most anterior point on the convexity along the anterior border of the mandibular symphysis |
| Menton | Most inferior point of the mandibular symphysis |
| Condylion | Most superior point of the mandibular condyle |
| Maxillary Central Incisor Incisal Tip (U1 Tip) | Incisal edge of the maxillary central incisor |
| Maxillary Central Incisor Root Apex (U1 Root) | Root apex of the mandibular central incisor |
| Mandibular Central Incisor Incisal Tip (L1 Tip) | Incisal edge of the mandibular central incisor |
| Mandibular Central Incisor Root Apex (L1 Root) | Root apex of the mandibular central incisor |

**Table 1.** Orthodontic cephalometric landmarks and their associated definitions.

Radiographs were calibrated with 100 mm standardized distance points and the (X, Y) coordinate system origin was registered to the most right-superior aspect of the ruler point, an arbitrary but radiographic specific location. This location was the same for each individual subject's lateral cephalogram and hemifacial lateral cephalogram to ensure subject specific standardization, however, these points differed between subjects.

Utilizing this coordinate system, more negative values indicate more posterior and inferior locations in the X and Y coordinates respectively.

Three raters, orthodontists each with decades of clinical experience, identified the orthodontic landmarks under similar conditions. The images were projected onto a SMART Board 800 DViT with a SMART UX60 Projector (SMART Technologies; Calgary, AB Canada) with a resolution of 1440 x 900 pixels and refresh rate of 60 Hz. Landmark identification was done in the same relatively isolated, dark room utilizing a mouse-controlled cursor. This was repeated in duplicate with a minimum of two-week washout period between each of the raters' initial session. Raters were free to switch between image filters and to change the location of landmarks within the currently available radiograph until satisfied. No time constraints were given to the orthodontists. After landmark identification had been completed, the (X, Y) coordinates of each landmark was recorded.

**Statistical Methods**

Statistical analysis was performed utilizing SAS 9.3 (SAS Institute Inc.; Cary, NC). A prospective power analysis suggested that a sample size of 30 subjects was recommended to evaluate significant differences in the validity and reliability of landmark detection with the two methods. The power analysis was based on a pilot study completed by the author involving 10 subjects in the same conditions as the study. It was determined that 30 subjects were recommended for study by qualifying an effect size of greater than 0.2 as significant, utilizing an alpha value of 0.025, and power of 0.8.

Intraexaminer and Interexaminer reliability comparisons utilized Intraclass Correlation Coefficient (ICC) evaluating absolute agreement for all radiographs among the three raters. Intraexaminer reliability was performed for each rater by landmark and type of radiograph. Interexaminer reliability was performed for each rater's first reading by landmark and type of radiograph.

Lateral cephalogram and hemifacial lateral cephalogram validity comparisons utilized Bland-Altman testing. For each landmark, the difference between each individual subject specific radiograph reading were plotted against the average of all individual subject specific radiograph reading. Confidence intervals of 95% were calculated. This method of comparison was utilized because the actual landmark coordinates remain unknown, as cephalometric landmark locations are inherently prone to error.[1] For statistical comparison of unknown values, indirect methods of assessment are used, and a new

method has to be evaluated by comparison with an established technique rather than with the actual quantity.[22] The mean of the two measurements, the traditional method of measurement and the new method of measurement, is the best estimate of the actual value that is available.[23] Individual landmark (X, Y) coordinate locations were compared without assessing multipoint linear or angular measurements to eliminate cumulative error inherent in multipoint measurements.[9] In comparing the validity of hemifacial lateral cephalogram to lateral cephalogram, a clinical significance of ± 2.0 mm in either X or Y coordinate was deemed appropriate from previous literature.[24]

**Results**

The intraexaminer variability was small among all points for both methods, with the Intraclass Correlation Coefficient (ICC) ranging from 0.9644 to 0.9999 (Table 1). The interexaminer variability was small among all points for both methods, with the ICC ranging from 0.9847 to 0.9999 (Table 2). This indicates excellent reliability for all landmarks in both hemifacial lateral cephalogram and traditional lateral cephalogram methods.

| | | Rater A | | Rater B | | Rater C | |
|---|---|---|---|---|---|---|---|
| **Landmark** | **Method** | **X** | **Y** | **X** | **Y** | **X** | **Y** |
| A Point | HLC | 0.9965 | 0.9735 | 0.9993 | 0.9919 | 0.9994 | 0.9805 |
| A Point | LC | 0.9988 | 0.9783 | 0.9995 | 0.9934 | 0.9997 | 0.9908 |
| B Point | HLC | 0.9998 | 0.9933 | 0.9997 | 0.9962 | 0.9995 | 0.9912 |
| B Point | LC | 0.9999 | 0.9933 | 0.9999 | 0.9966 | 0.9996 | 0.9927 |
| Condylion | HLC | 0.9933 | 0.9653 | 0.9979 | 0.9884 | 0.9977 | 0.9901 |
| Condylion | LC | 0.9939 | 0.9833 | 0.9979 | 0.9920 | 0.9970 | 0.9867 |
| L1 Root | HLC | 0.9929 | 0.9763 | 0.9967 | 0.9894 | 0.9966 | 0.9791 |
| L1 Root | LC | 0.9963 | 0.9912 | 0.9972 | 0.9886 | 0.9978 | 0.9886 |
| L1 Tip | HLC | 0.9996 | 0.9982 | 0.9998 | 0.9987 | 0.9999 | 0.9978 |
| L1 Tip | LC | 0.9999 | 0.9991 | 0.9997 | 0.9987 | 0.9999 | 0.9988 |
| Menton | HLC | 0.9991 | 0.9998 | 0.9985 | 0.9988 | 0.9957 | 0.9982 |
| Menton | LC | 0.9992 | 0.9998 | 0.9987 | 0.9990 | 0.9950 | 0.9978 |
| Pogonion | HLC | 0.9999 | 0.9967 | 0.9998 | 0.9954 | 0.9998 | 0.9940 |
| Pogonion | LC | 0.9999 | 0.9964 | 0.9998 | 0.9973 | 0.9998 | 0.9958 |
| U1 Root | HLC | 0.9971 | 0.9644 | 0.9978 | 0.9926 | 0.9971 | 0.9914 |
| U1 Root | LC | 0.9967 | 0.9803 | 0.9976 | 0.9915 | 0.9968 | 0.9860 |
| U1 Tip | HLC | 0.9999 | 0.9995 | 0.9998 | 0.9987 | 0.9998 | 0.9986 |
| U1 Tip | LC | 0.9999 | 0.9996 | 0.9996 | 0.9989 | 0.9997 | 0.9989 |

**Table 2.** Intraclass Correlation Coefficient used to assess intraexaminer reliability for each rater by landmark and method. X and Y coordinates are separated. Methods are abbreviated as hemifacial lateral cephalogram (HLC) and lateral cephalogram (LC).

| | HLC | | LC | |
|---|---|---|---|---|
| **Landmark** | **X** | **Y** | **X** | **Y** |
| A Point | 0.9981 | 0.9847 | 0.9991 | 0.9910 |
| B Point | 0.9994 | 0.9876 | 0.9998 | 0.9912 |
| Condylion | 0.9976 | 0.9860 | 0.9976 | 0.9895 |
| L1 Root | 0.9977 | 0.9882 | 0.9979 | 0.9898 |
| L1 Tip | 0.9999 | 0.9984 | 0.9998 | 0.9975 |
| Menton | 0.9971 | 0.9977 | 0.9979 | 0.9978 |
| Pogonion | 0.9999 | 0.9952 | 0.9997 | 0.9945 |
| U1 Root | 0.9975 | 0.9869 | 0.9976 | 0.9905 |
| U1 Tip | 0.9998 | 0.9994 | 0.9998 | 0.9993 |

**Table 3.** Intraclass Correlation Coefficient used to assess interexaminer reliability for raters first reading by landmark and method. X and Y coordinates are separated. Methods are abbreviated as hemifacial lateral cephalogram (HLC) and lateral cephalogram (LC).

In comparing the validity of hemifacial lateral cephalogram to lateral cephalogram, a 95% confidence interval of ± 2.0 mm was deemed appropriate.[24] Utilizing this coordinate system, more negative values indicate more posterior and inferior locations in the X and Y coordinates respectively. The mean differences between the two methods were quite small, ranging from 0.19 to -0.36 mm in the X axis and from 0.21 to -0.24 mm in the Y axis (Table 3). However, confidence interval ranges were wide, with only a few landmarks remaining within the accepted ± 2.0 mm range (Figures 2 – 19). Bland-

Altman plots were calculated to assess validity of hemifacial lateral cephalogram in comparison to lateral cephalogram. For each landmark, the difference between either method was plotted against the average aggregate values of both methods. Individual landmark X and Y coordinates were separated and analyzed independently. On the Bland-Altman plots, the median line represents the average X or Y value of both hemifacial lateral cephalogram and lateral cephalogram aggregate values, respectively. The Bland-Altman plots also illustrate the 95% confidence intervals. For the hemifacial lateral cephalogram to be considered a valid comparison, the 95% confidence intervals would have to be within the accepted ± 2.0 mm range, located at the left of the plot.

In the X axis, landmarks with validity confidence interval ranges within the range of were: A Point, B Point, Pogonion, Mandibular Central Incisor Incisal Tip, and Maxillary Central Incisor Incisal Tip. In the Y axis, the landmarks with valid confidence interval ranges were: Maxillary Central Incisor Incisal Tip, Mandibular Central Incisor Incisal Tip, and Menton. Central Incisor Incisal Tips were the only landmarks with valid confidence interval ranges in both the X and Y axes. None of the other 9 landmarks confidence intervals fell within the accepted ± 2.0 mm range in both the X and Y axis. This indicates overall poor validity of hemifacial lateral cephalogram in comparison to lateral cephalogram.[25]

| | X | | Y | |
|---|---|---|---|---|
| **Landmark** | **Mean Difference: HLC – LC** | **95% CI** | **Mean Difference: HLC – LC** | **95% CI** |
| A Point | -0.1600 | (-1.8181, 1.4892) | -0.1600 | (-3.0043, 2.6865) |
| B Point | -0.0600 | (-0.9688, 0.8399) | 0.2100 | (-2.5142, 2.9431) |
| Condylion | -0.3500 | (-3.0155, 2.3177) | -0.1300 | (-3.3046, 3.0446) |
| L1 Root | -0.3600 | (-3.1719, 2.4607) | -0.2400 | (-3.4545, 2.9812) |
| L1 Tip | -0.1500 | (-1.0802, 0.7735) | 0.0800 | (-1.2605, 1.4271) |
| Menton | 0.1900 | (-2.6331, 3.0042) | 0.1600 | (-0.9905, 1.3194) |
| Pogonion | -0.0300 | (-0.6410, 0.5854) | 0.1400 | (-1.9663, 2.2508) |
| U1 Root | -0.0600 | (-2.7310, 2.6132) | 0.1500 | (-2.2552, 2.5641) |
| U1 Tip | -0.2000 | (-1.1136, 0.7203) | 0.1000 | (-0.7207, 0.9229) |

**Table 4.** Bland-Altman comparison to assess validity of hemifacial lateral cephalogram (HLC) in comparison to lateral cephalogram (LC). For each landmark, the difference between HLC and LC is plotted against the average of HLC and LC. X and Y readings are separated. More negative values indicate more posterior and inferior locations in the X and Y coordinates respectively. 95% confidence intervals are calculated.

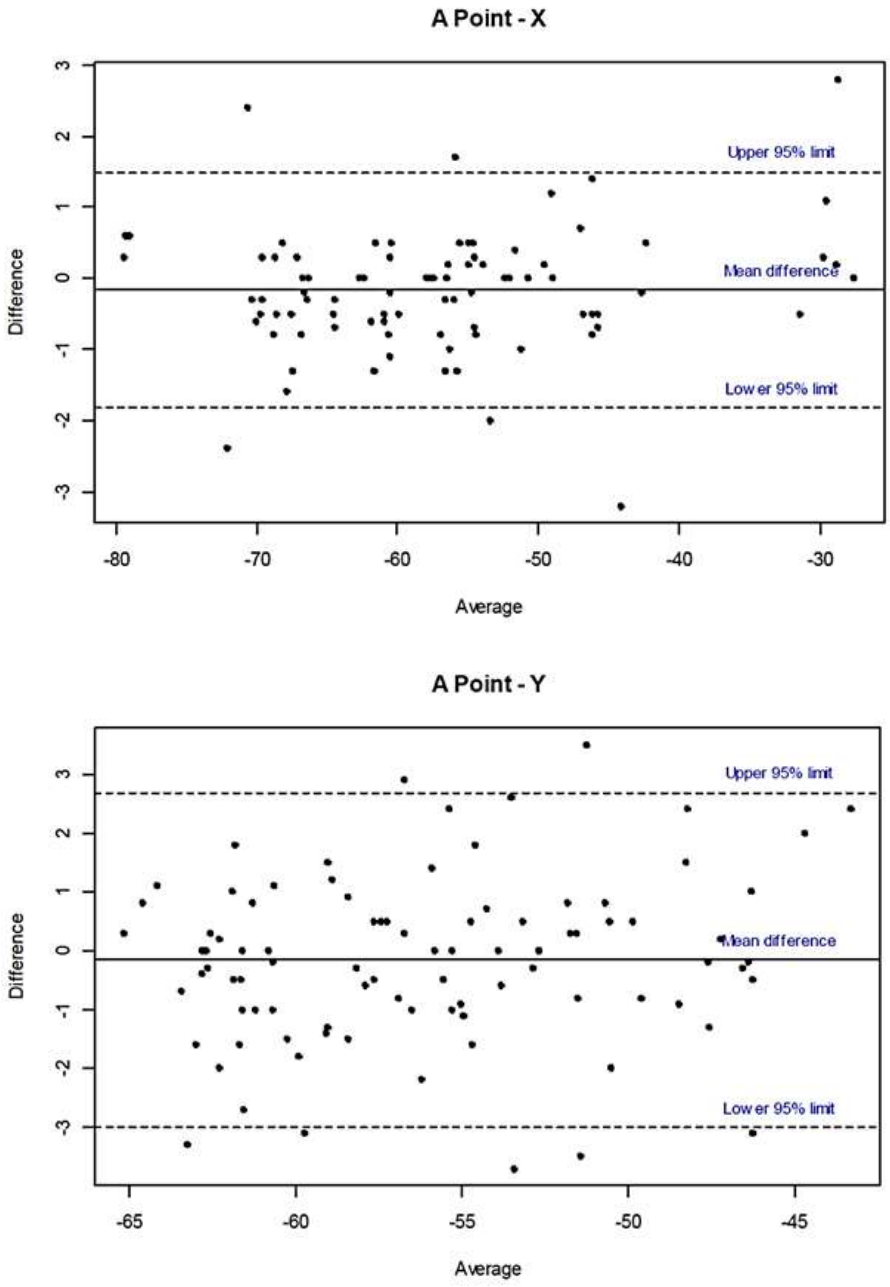


**Figure 2.** Bland-Altman Plot for A Point in both X and Y axes. To assess validity of hemifacial lateral cephalogram (HLC) in comparison to lateral cephalogram (LC). Differences between HLC values are plotted against the average aggregate values of HLC and LC. 95% confidence intervals are plotted.

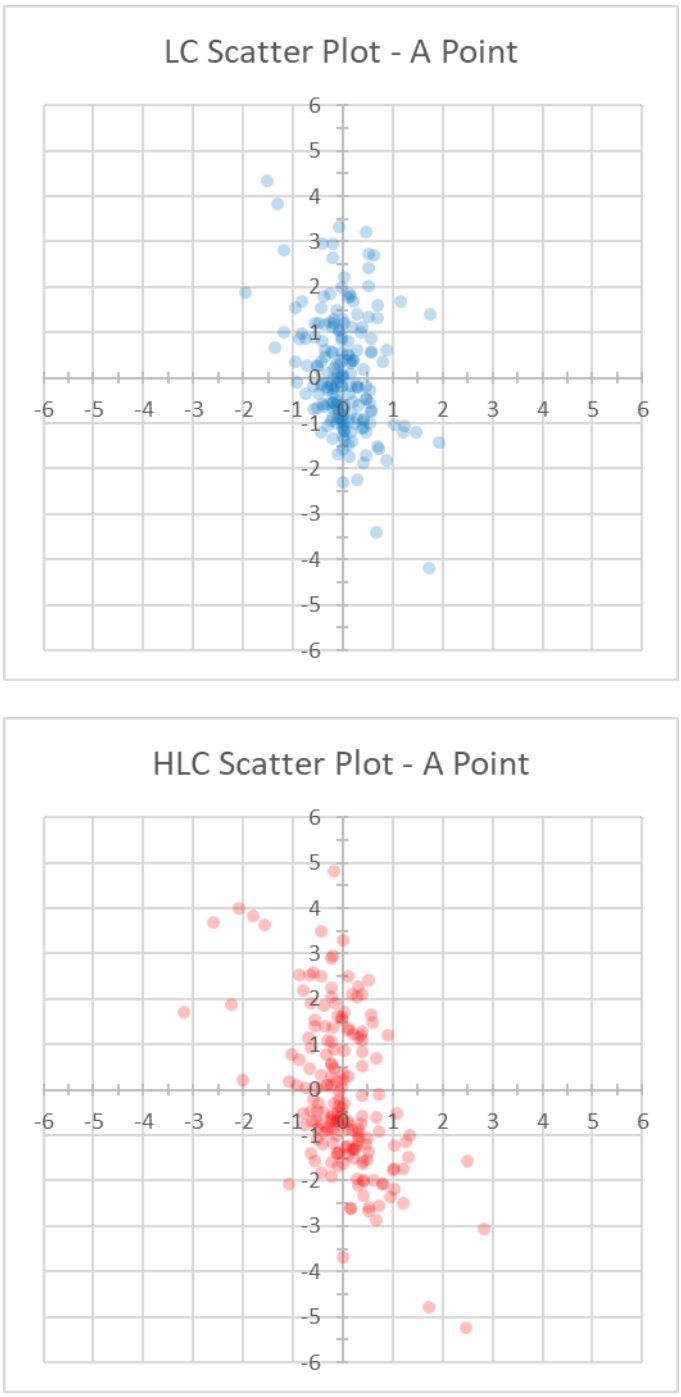


**Figure 3.** Scatter Plots for A Point. Data is organized in both X and Y axes for all raters, timepoints, and radiographs separated by Lateral Cephalogram (above) and Hemifacial Lateral Cephalogram (below) in millimeters from the average of the aggregate values.

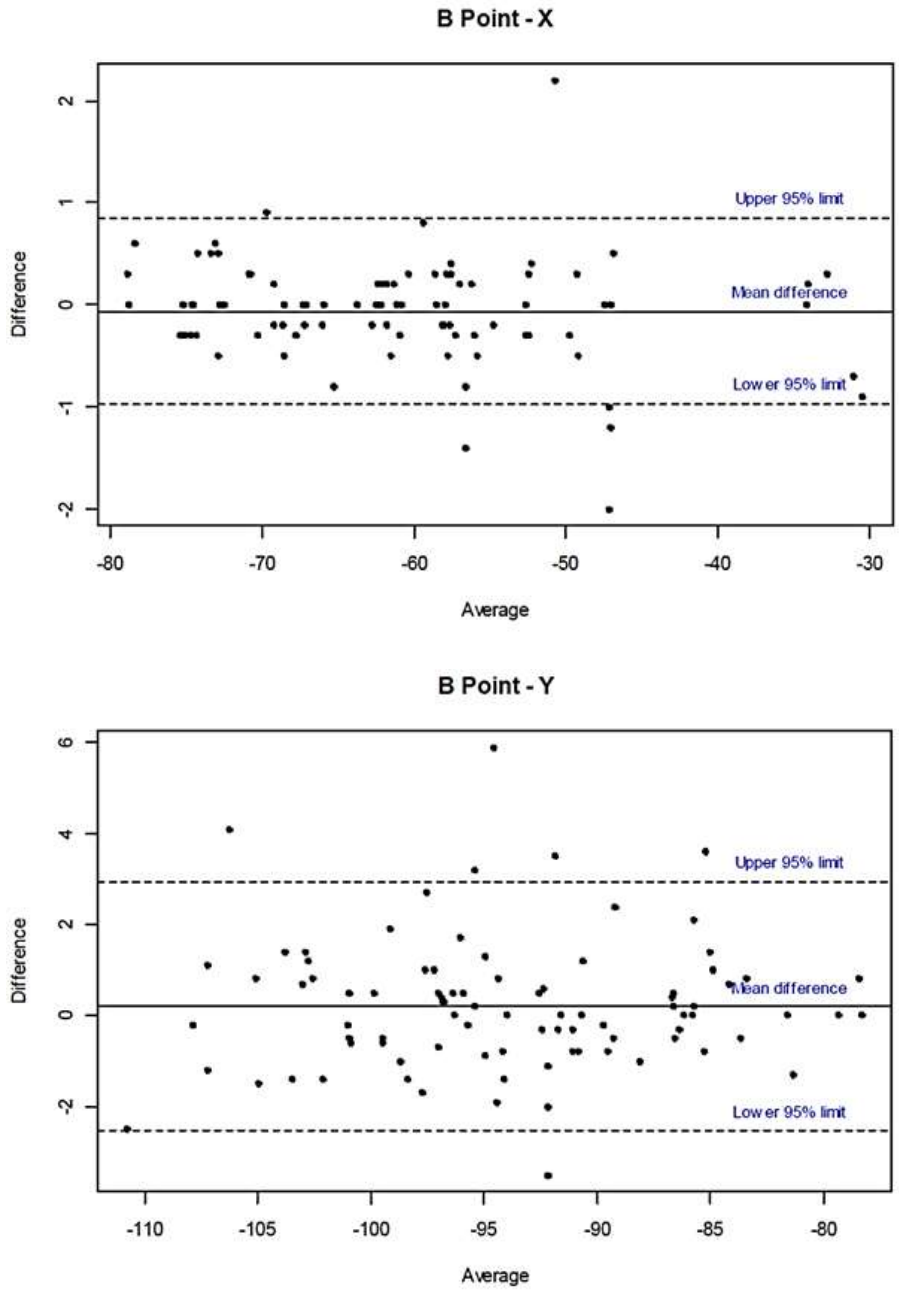


**Figure 4.** Bland-Altman Plot for B Point in both X and Y axes. To assess validity of hemifacial lateral cephalogram (HLC) in comparison to lateral cephalogram (LC). Differences between HLC values are plotted against the average aggregate values of HLC and LC. 95% confidence intervals are plotted.

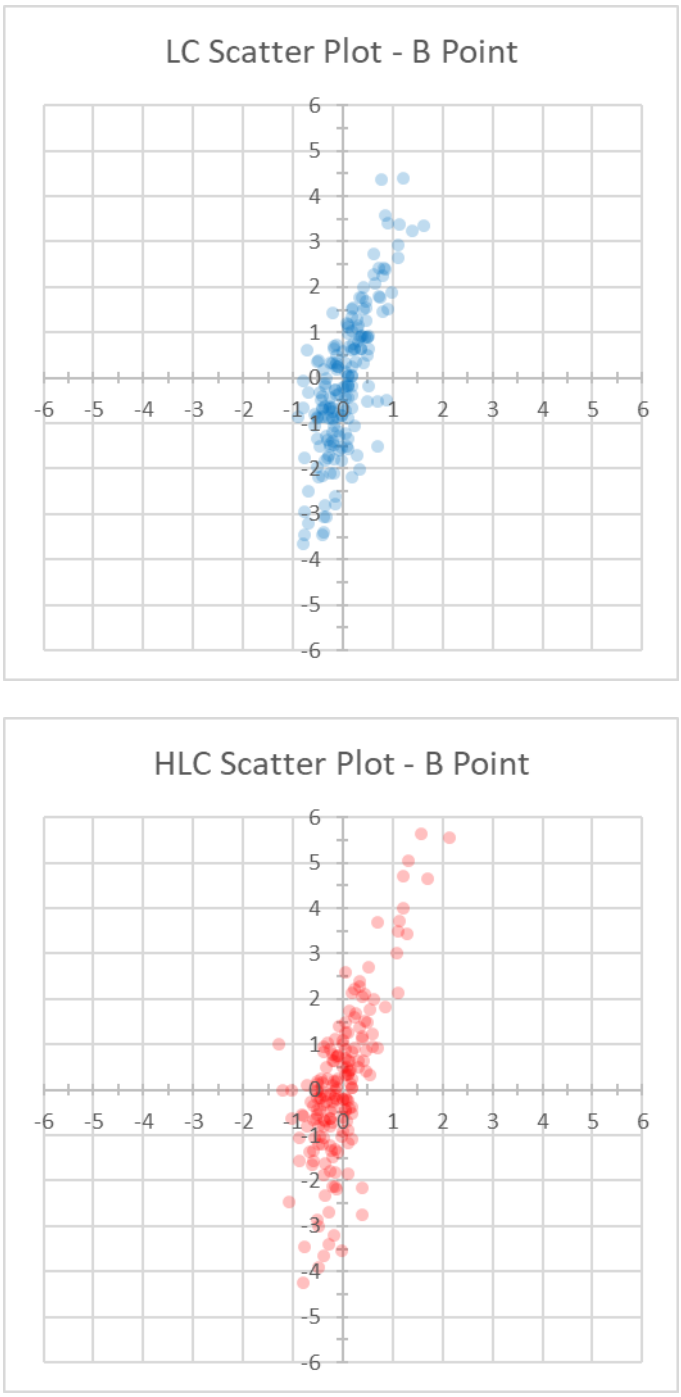


**Figure 5.** Scatter Plots for B Point. Data is organized in both X and Y axes for all raters, timepoints, and radiographs separated by Lateral Cephalogram (above) and Hemifacial Lateral Cephalogram (below) in millimeters from the average of the aggregate values.

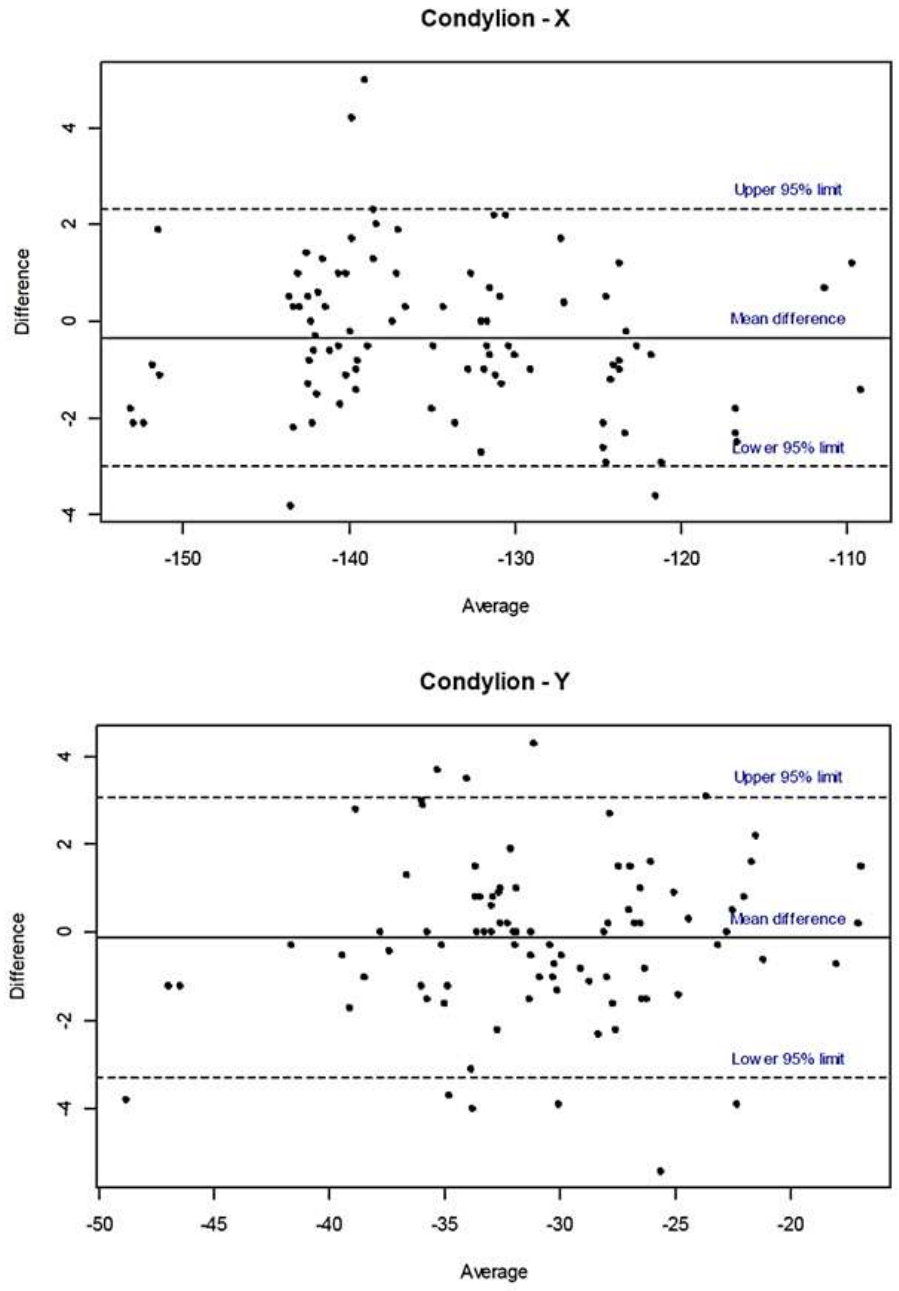


**Figure 6.** Bland-Altman Plot for Condylion in both X and Y axes. To assess validity of hemifacial lateral cephalogram (HLC) in comparison to lateral cephalogram (LC). Differences between HLC values are plotted against the average aggregate values of HLC and LC. 95% confidence intervals are plotted.

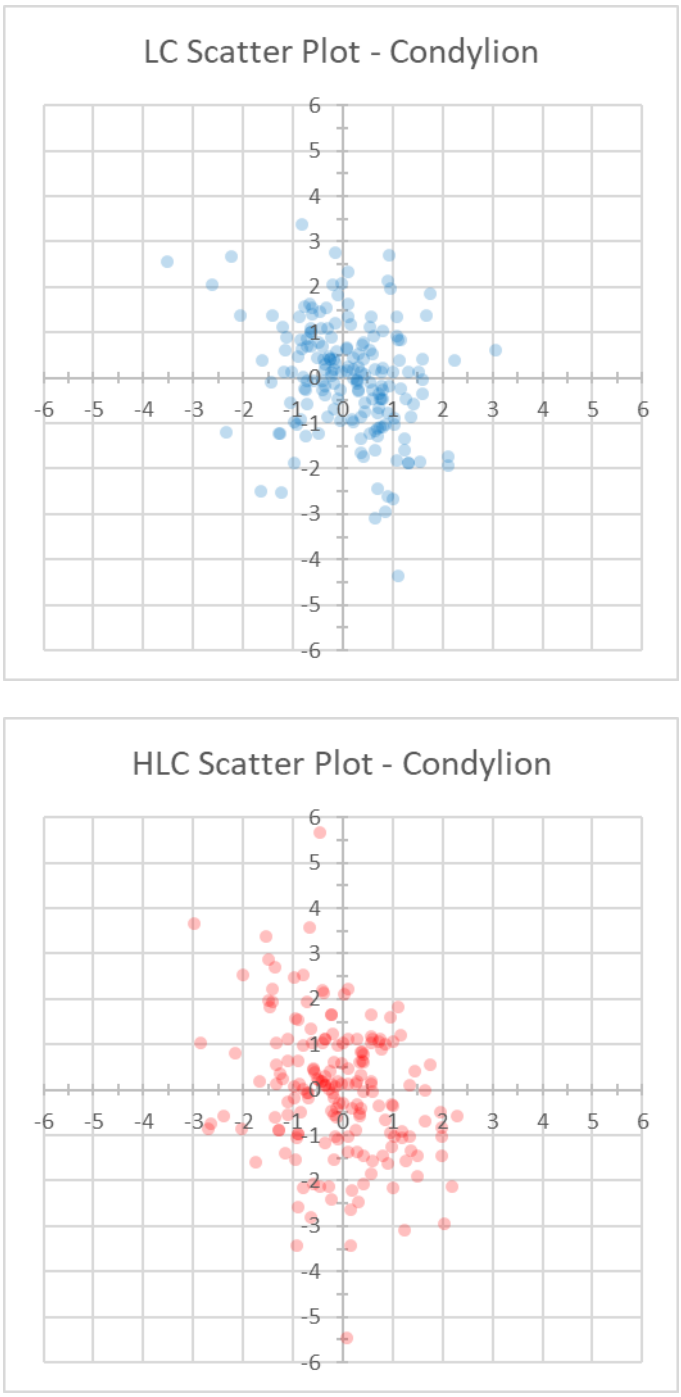


**Figure 7.** Scatter Plots for Condylion. Data is organized in both X and Y axes for all raters, timepoints, and radiographs separated by Lateral Cephalogram (above) and Hemifacial Lateral Cephalogram (below) in millimeters from the average of the aggregate values.

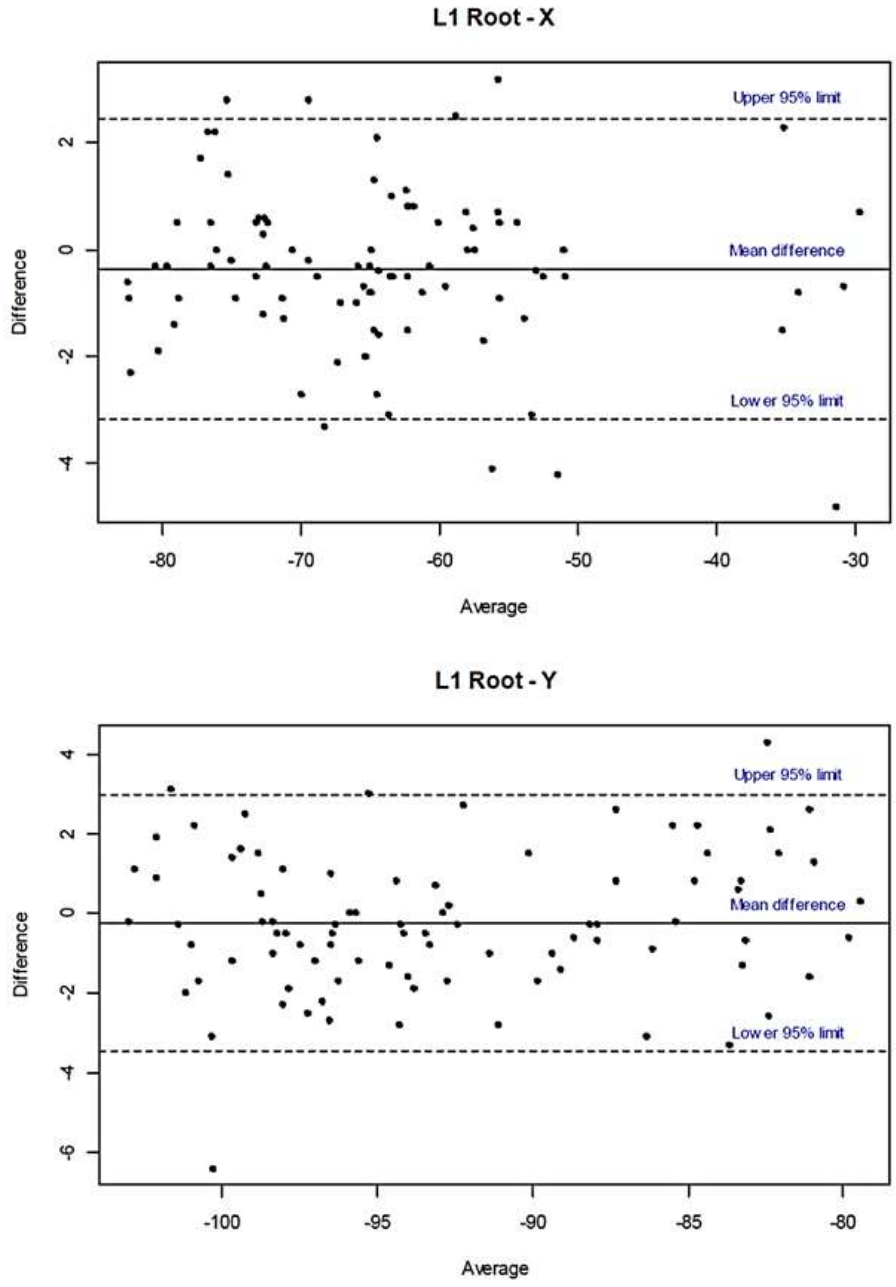


**Figure 8.** Bland-Altman Plot for Mandibular Central Incisor Apex in both X and Y axes. To assess validity of hemifacial lateral cephalogram (HLC) in comparison to lateral cephalogram (LC). Differences between HLC values are plotted against the average aggregate values of HLC and LC. 95% confidence intervals are plotted.

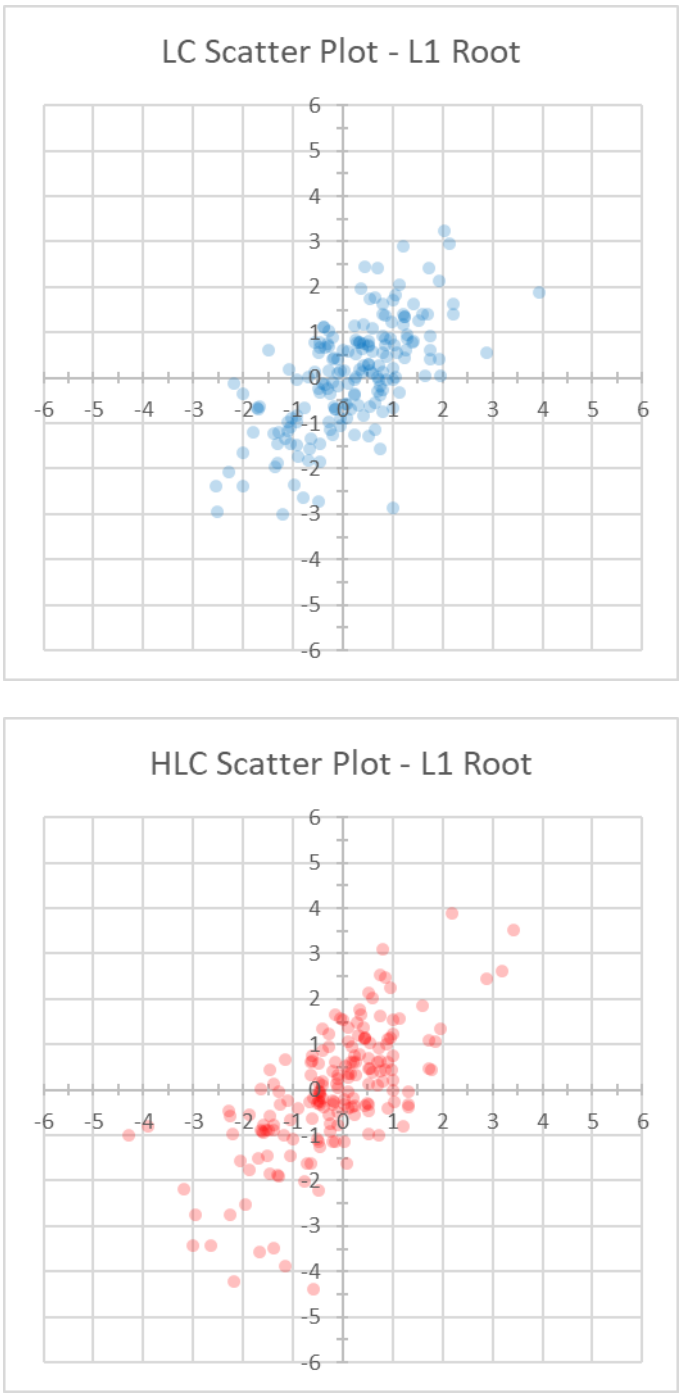


**Figure 9.** Scatter Plots for Mandibular Central Incisor Apex. Data is organized in both X and Y axes for all raters, timepoints, and radiographs separated by Lateral Cephalogram (above) and Hemifacial Lateral Cephalogram (below) in millimeters from the average of the aggregate values.

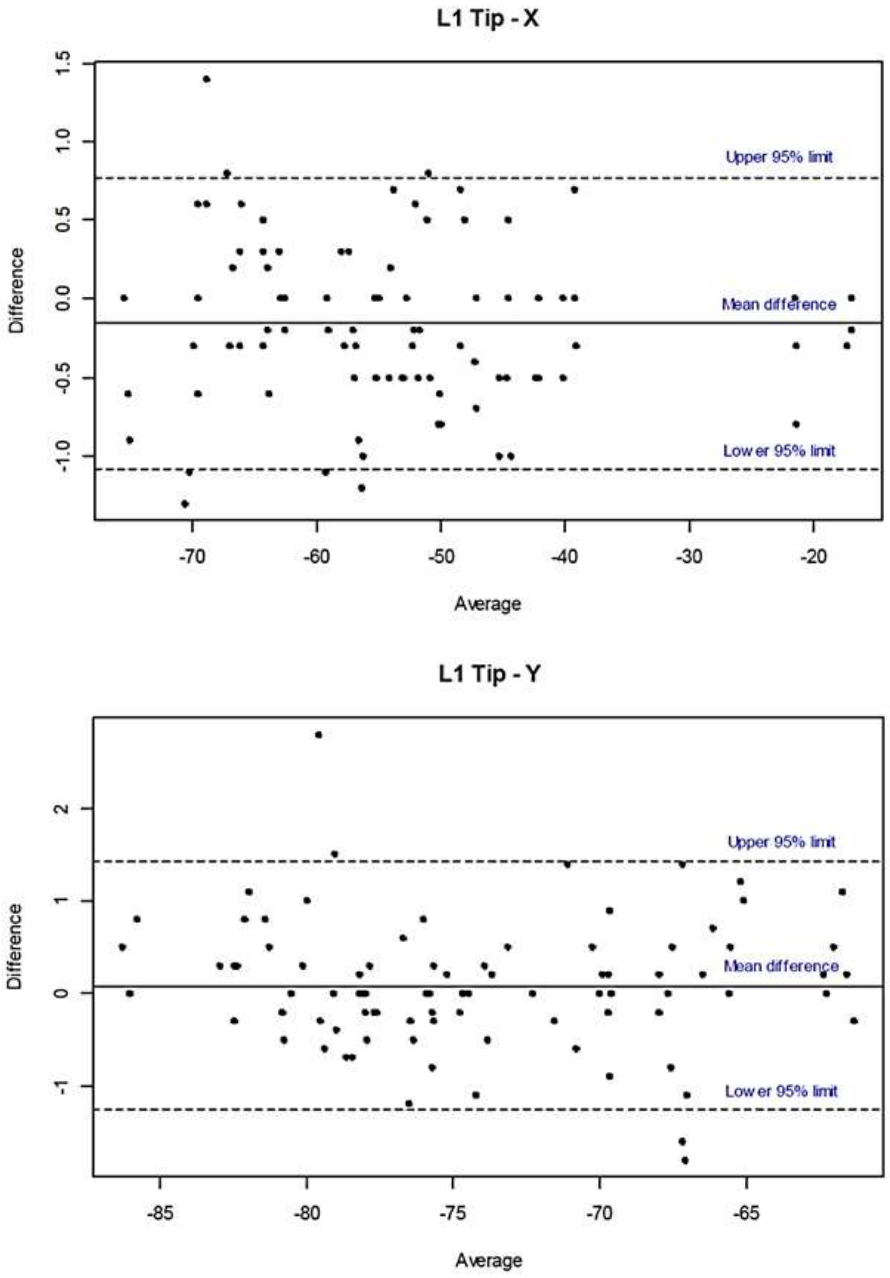


**Figure 10.** Bland-Altman Plot for Mandibular Central Incisor Tip in both X and Y axes. To assess validity of hemifacial lateral cephalogram (HLC) in comparison to lateral cephalogram (LC). Differences between HLC values are plotted against the average aggregate values of HLC and LC. 95% confidence intervals are plotted.

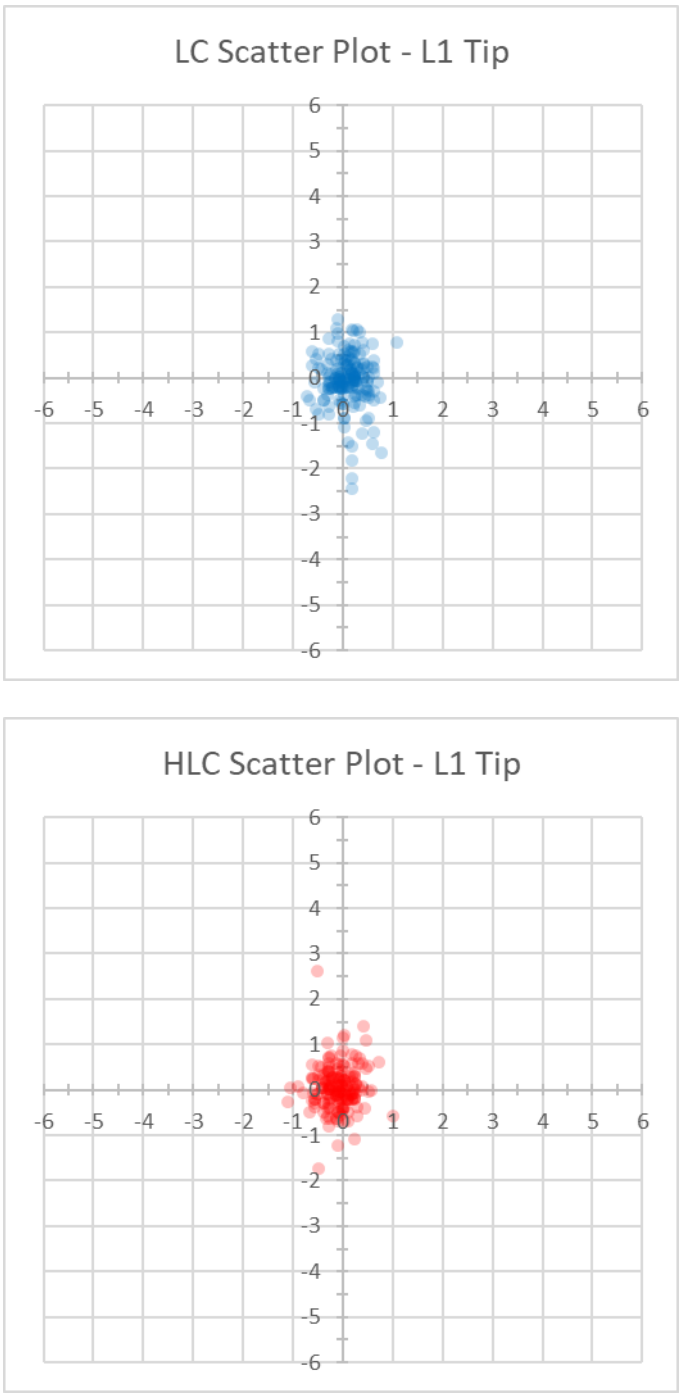


**Figure 11.** Scatter Plots for Mandibular Central Incisor Tip. Data is organized in both X and Y axes for all raters, timepoints, and radiographs separated by Lateral Cephalogram (above) and Hemifacial Lateral Cephalogram (below) in millimeters from the average of the aggregate values.

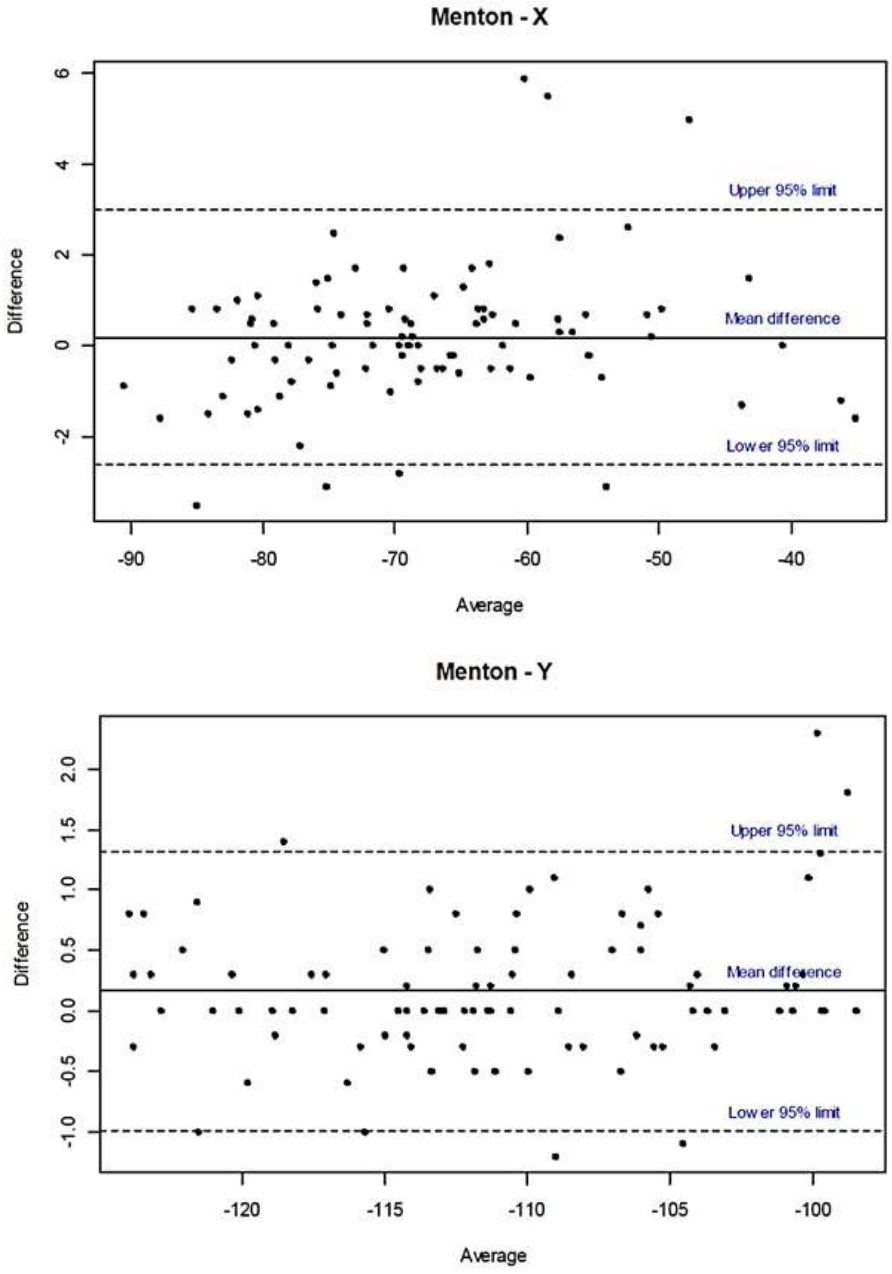


**Figure 12.** Bland-Altman Plot for Menton in both X and Y axes. To assess validity of hemifacial lateral cephalogram (HLC) in comparison to lateral cephalogram (LC). Differences between HLC values are plotted against the average aggregate values of HLC and LC. 95% confidence intervals are plotted.

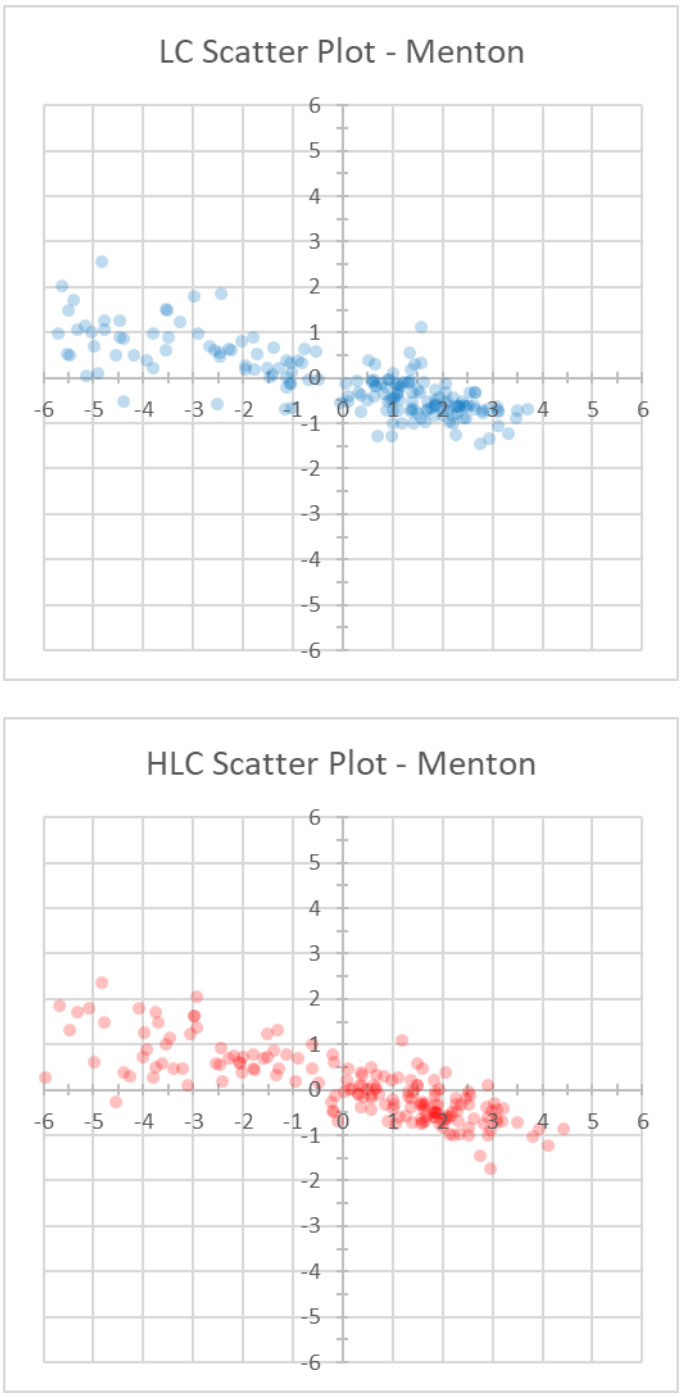


**Figure 13.** Scatter Plots for Menton. Data is organized in both X and Y axes for all raters, timepoints, and radiographs separated by Lateral Cephalogram (above) and Hemifacial Lateral Cephalogram (below) in millimeters from the average of the aggregate values.

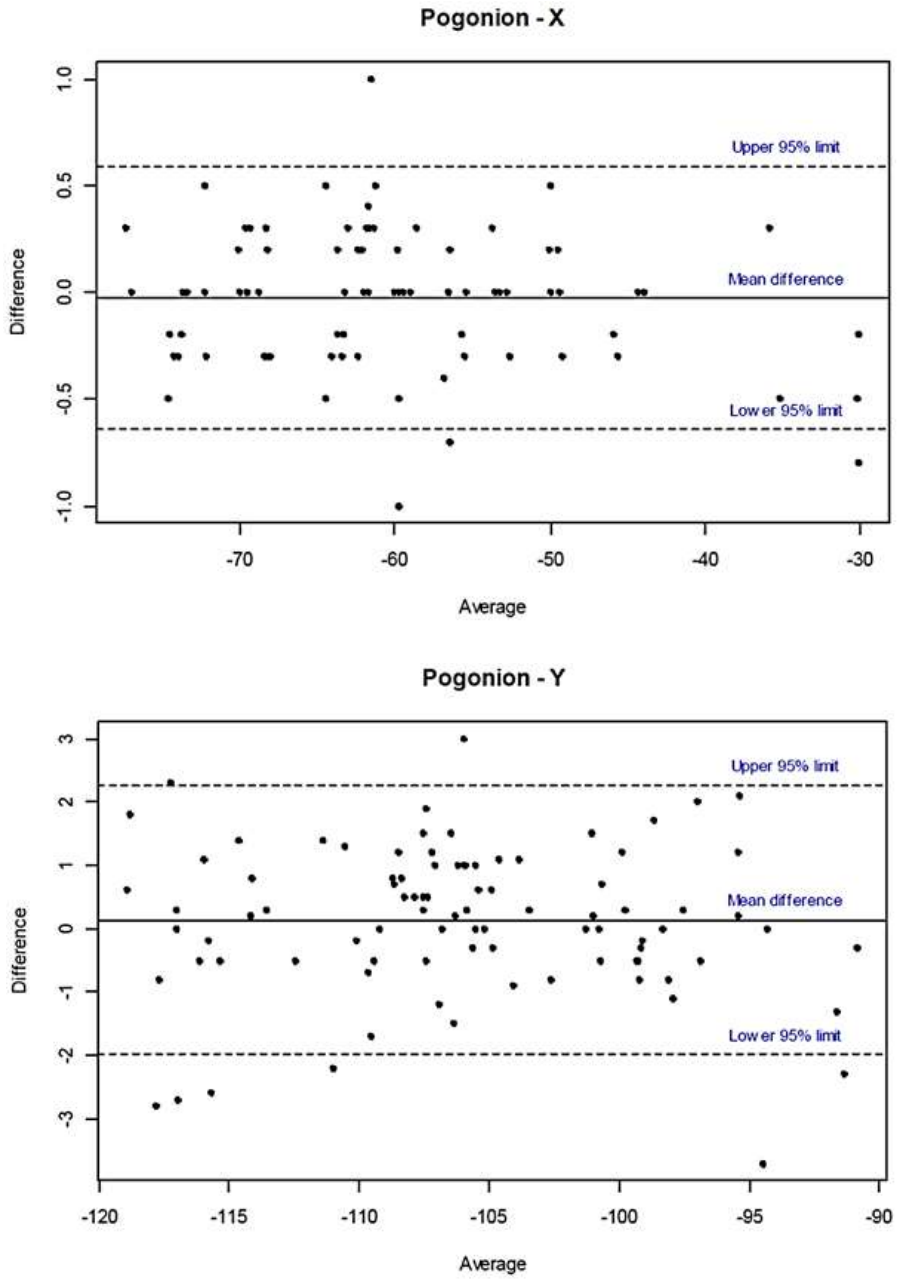


**Figure 14.** Bland-Altman Plot for Pogonion in both X and Y axes. To assess validity of hemifacial lateral cephalogram (HLC) in comparison to lateral cephalogram (LC). Differences between HLC values are plotted against the average aggregate values of HLC and LC. 95% confidence intervals are plotted.

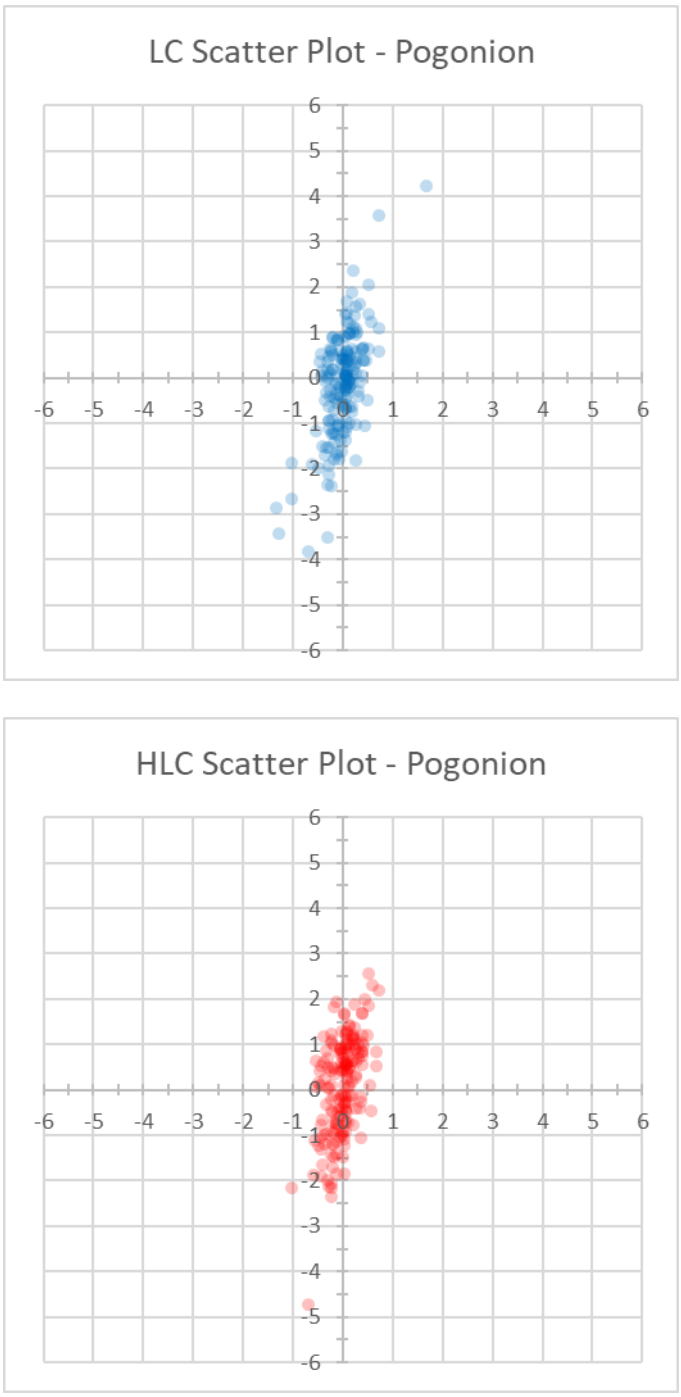


**Figure 15.** Scatter Plots for Pogonion. Data is organized in both X and Y axes for all raters, timepoints, and radiographs separated by Lateral Cephalogram (above) and Hemifacial Lateral Cephalogram (below) in millimeters from the average of the aggregate values.

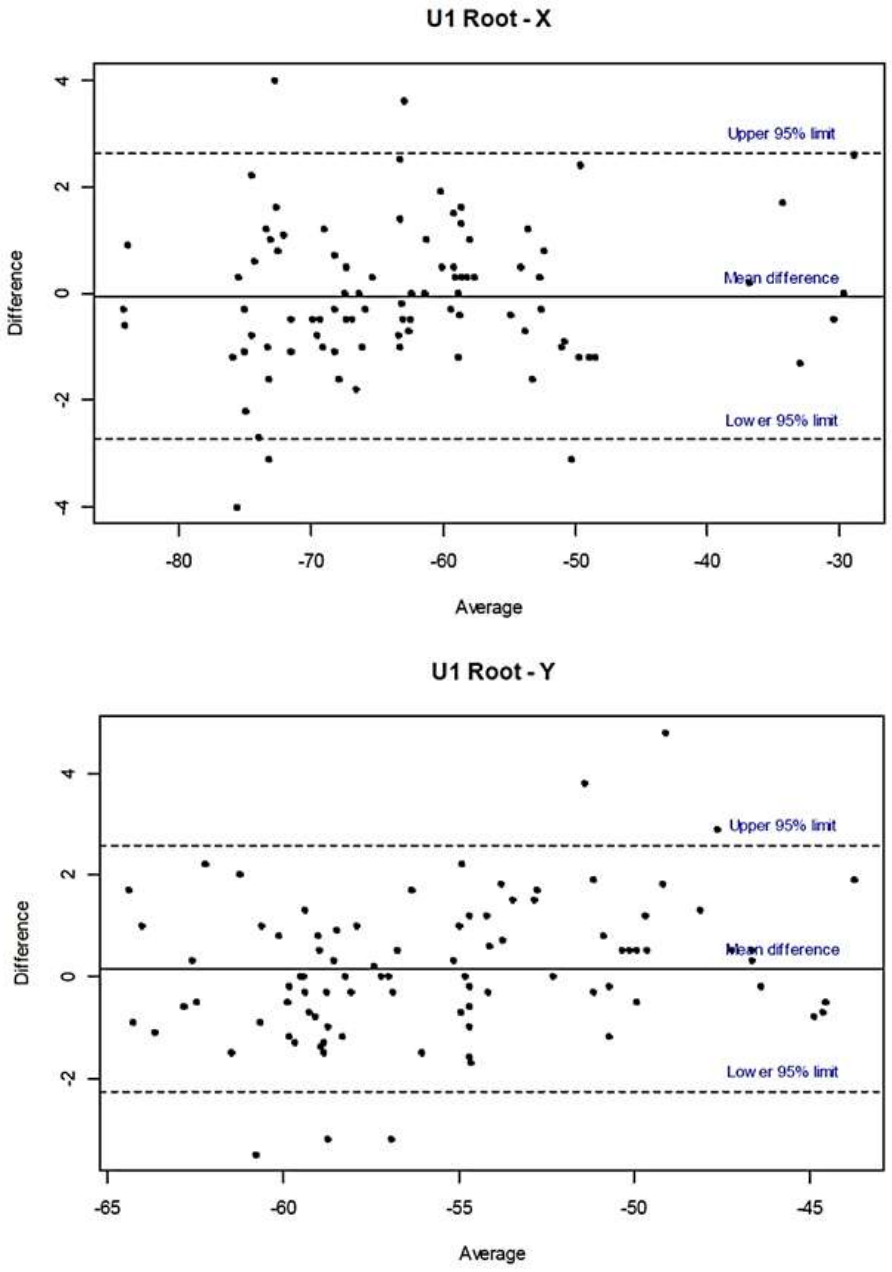


**Figure 16.** Bland-Altman Plot for Maxillary Central Incisor Apex in both X and Y axes. To assess validity of hemifacial lateral cephalogram (HLC) in comparison to lateral cephalogram (LC). Differences between HLC values are plotted against the average aggregate values of HLC and LC. 95% confidence intervals are plotted.

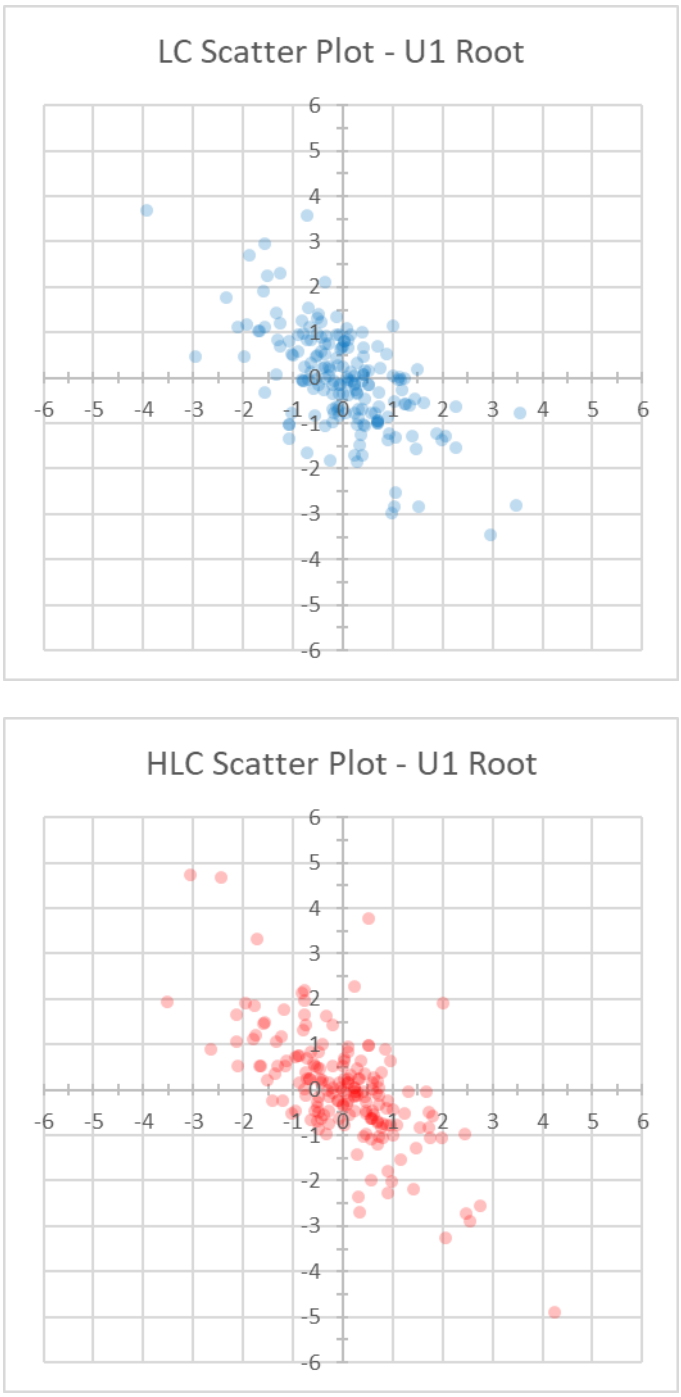


**Figure 17.** Scatter Plots for Maxillary Central Incisor Apex. Data is organized in both X and Y axes for all raters, timepoints, and radiographs separated by Lateral Cephalogram (above) and Hemifacial Lateral Cephalogram (below) in millimeters from the average of the aggregate values.

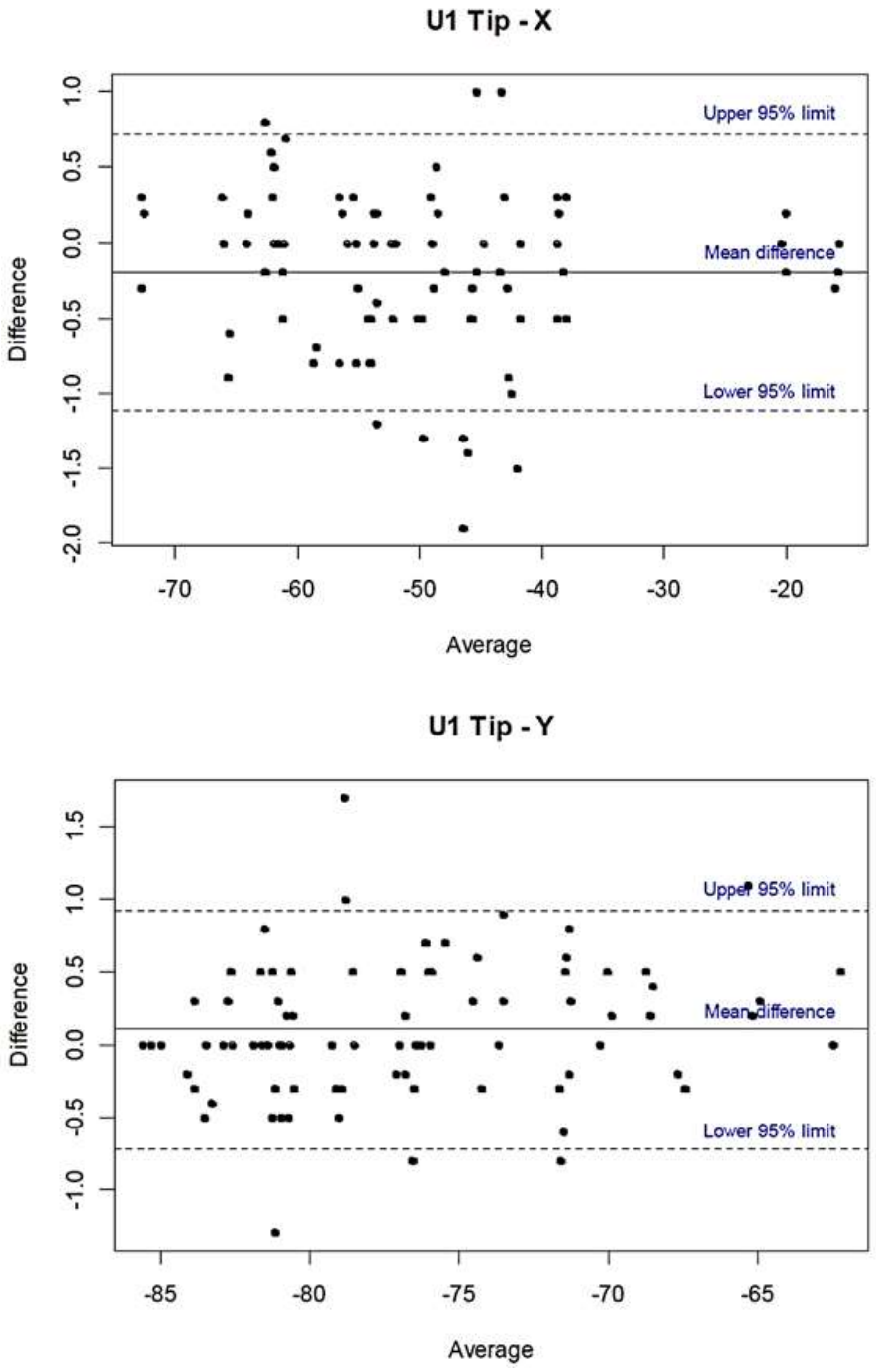


**Figure 18.** Bland-Altman Plot for Maxillary Central Incisor Tip in both X and Y axes. To assess validity of hemifacial lateral cephalogram (HLC) in comparison to lateral cephalogram (LC). Differences between HLC values are plotted against the average aggregate values of HLC and LC. 95% confidence intervals are plotted.

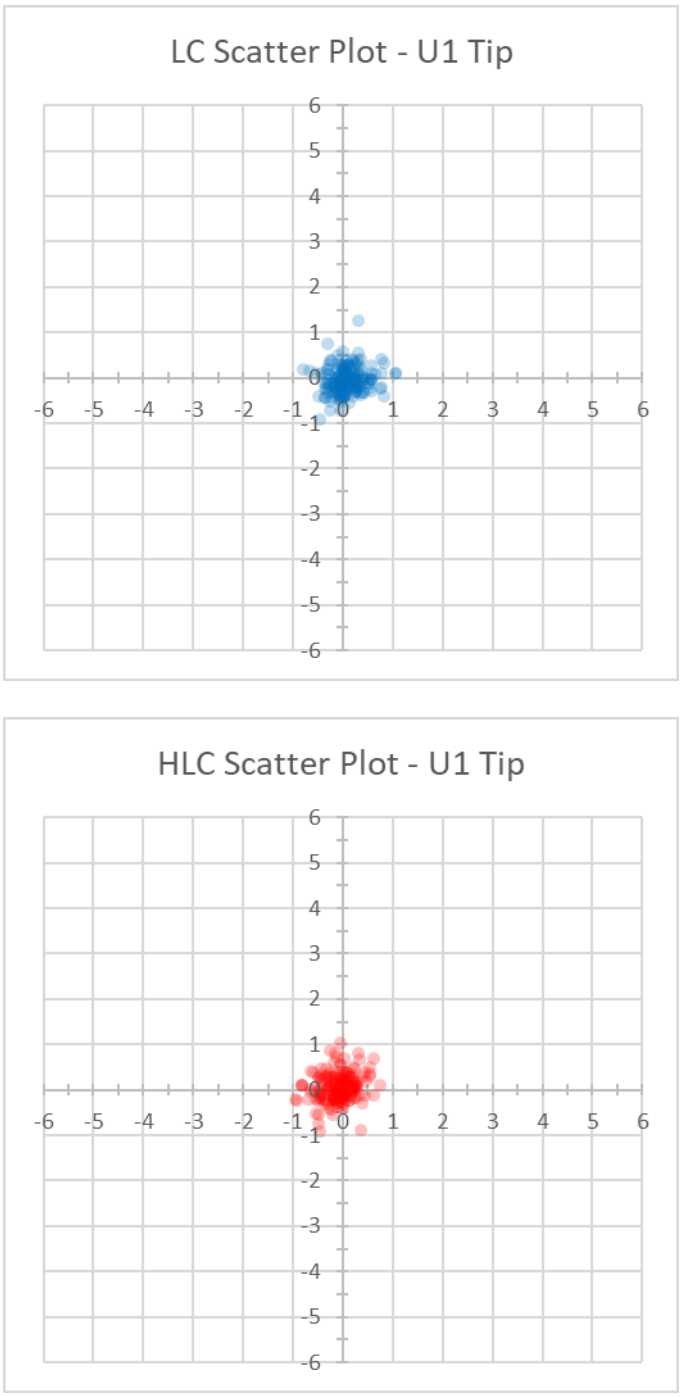


**Figure 19.** Scatter Plots for Maxillary Central Incisor Tip. Data is organized in both X and Y axes for all raters, timepoints, and radiographs separated by Lateral Cephalogram (above) and Hemifacial Lateral Cephalogram (below) in millimeters from the average of the aggregate values.

**Discussion**

This study showed hemifacial lateral cephalograms to be highly reliable, yet invalid for several landmarks when utilized with experienced orthodontists in comparison to lateral cephalograms.[25] The overall invalidity of several landmarks assessed, combined with the excellent reliability of lateral cephalogram landmarks, dismisses the utility of hemifacial lateral cephalogram in symmetric patients among experienced orthodontists.

There are several potential issues with this study. Clinical significance was defined as ± 2.0 mm range. The selected range of clinical significance has been suggested in the literature,[24] but the argument can be made that clinical significance depends on level of accuracy required for the type and complexity of the potential treatment plan, not an absolute blanket value for all landmarks, although a benchmark range is required for comparison. This can make interpretation of the utility of hemifacial lateral cephalograms subjective and difficult.

Landmarks were only evaluated by comparing their (X, Y) coordinates, as opposed to linear measurements or angles. This was done to reduce the amount of cumulative error that two point linear and multi-point angular measurements introduce.[9] Lateral cephalometric analysis does not, however, involve any individual point measurement, all measurements are linear or angular. This is a deviation of applicability. However, the goal of this study was to assess reliability and validity of individual landmarks which should be done in a manner minimizing cumulative error.

Due to the overall invalidity of the hemifacial cephalogram analysis, applying craniofacial/dental assessments extrapolated from lateral cephalogram analysis would be inappropriate.[25] If hemifacial cephalogram analysis was to be utilized, it would require additional development, standardization, and assessment of population variations, as extrapolating historical data from lateral cephalogram analysis would be inappropriate. This effort would likely be better spent developing 3D cephalometric analysis.

Further weaknesses include that hemifacial lateral cephalogram was only utilized in symmetric patients and only intended as a supplement to lateral cephalogram, which can make its applicability limited and requires additional time to evaluate.

Limitations of the study include its retrospective, convenience sample design, possibly introducing bias and making population generalizations problematic. Although radiographs were randomized and anonymized, differences between hemifacial lateral cephalogram and lateral cephalogram are inherently observable, leading to further possible introduction of bias and an inability for effective blinding. Symmetry was also weakly defined and difficult to quantify. Orientation of 3D radiographs, although much better defined, may have not been an absolute reflection of symmetry. Tracing sessions were long and may have led to rater fatigue and introduced error. Landmark identification was also performed by experienced orthodontists on a projector in relative isolation. This is not always the case in clinical setting.

Hemifacial lateral cephalogram analysis may hold some value while 3D cephalometric analysis is developed, standardized, and population variations assessed. However, this study failed to illustrate validity for multiple landmarks compared to lateral cephalogram analysis. Further investigation of utilizing hemifacial lateral cephalogram analysis into asymmetric patients, involving less experienced raters, additional landmarks, or alternative methods may provide useful information.

## Conclusions

Hemifacial lateral cephalogram and lateral cephalogram both have excellent reliability, however the validity of hemifacial lateral cephalogram was poor for many of the landmarks evaluated in comparison to traditional lateral cephalograms constructed from 3D radiographs. The excellent reliability of either method, combined with the poor validity of hemifacial lateral cephalogram, and limitations of applicability, does not support the use of hemifacial lateral cephalogram as a supplemental diagnostic tool in symmetric patients among experienced orthodontists.

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