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The validity of transverse intermaxillary analysis by traditional PA cephalometry compared with cone-beam computed tomography

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Aim: To assess the validity of using Jugale (J) and Antegonion (Ag) on Posterior-Anterior cephalograms (PAC) as landmarks for transverse intermaxillary analysis when compared with Cone Beam Computed Tomography (CBCT).
Material and methods: Conventional PAC and CBCT images were taken of 28 dry skulls. Craniometric measurements between the bilateral landmarks, Antegonion and Jugale, were obtained from the skulls using a microscribe and recorded as the base standard. The corresponding landmarks were identified and measured on CBCT and PAC and compared with the base standard measurements. The accuracy and reliability of the measurements were statistically evaluated and the validity was assessed by comparing the ability of the two image modalities to accurately diagnose an arbitrarily selected J-J/Ag-Ag ratio. All measurements were repeated at least 7 weeks apart. Intra-class correlations (ICC) and Bland-Altman plots were used to analyse the data.
Results: All three methods were shown to be reliable as all had a mean error of less than 0.5 mm between repeated measurements. When compared with the base standard, CBCT measurements were shown to have higher agreement (ICC: 0.861-0.964) compared with measurements taken from PAC (ICC: 0.794-0.796). When the arbitrary J-J/Ag-Ag ratio was assessed, 18 per cent of cases were incorrectly diagnosed with a transverse discrepancy on the PAC compared with the CBCT which incorrectly diagnosed 8.7 per cent.
Conclusion: CBCT was shown to be more reliable in assessing intermaxillary transverse discrepancy compared with PAC when using J-J/Ag-Ag ratios.
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Introduction

The successful application of orthodontics has always been intrinsically linked with the clinician's ability to assess the soft tissue, bone and dental structures of the face. With the introduction of the cephalometer by Broadbent in the 1930s,[1] a new era of orthodontic diagnosis emerged. It became possible to assess and compare the underlying craniofacial structures using a standardised technique.[2]

Currently, clinicians request cephalometric films as an integral part of diagnosis and treatment planning.[3] Although the PAC is not routinely used by most orthodontists,[4] it still forms a valuable adjunct for the qualitative and quantitative analysis of the craniofacial region; in particular, for assessing transverse discrepancies and asymmetries.[3,5]

However, like all radiographic films, the PAC is a projection of a three-dimensional (3D) object onto a two-dimensional (2D) image. This produces limitations and errors due to superimposition, distortion and landmark identification.[6] Other difficulties include standardising and reproducing head position[7] and maintaining film-object distance.[8] Differences between linear measurements and measurements derived from PACs have been well documented.[8-12] These limitations have been overcome by alternative methods of measurement as a result of 3D imaging.

There have been numerous attempts to incorporate routine 3D imaging into orthodontics but efforts have been hampered by cost, dosage and access factors.[13] Therefore, the development and introduction of CBCT in the late 1990s,[2] as a low dose and relatively-affordable 3D image acquisition method has been beneficial. It has been suggested that CBCT heralds a true paradigm shift from a 2D to a 3D approach for orthodontic data and image processing.[2,13,14] This has resulted in a large acceptance of CBCT by clinicians with a growth from zero to 50% in eight years.[2]

The knowledge of a patients' transverse maxillo-mandibular relationship is important in the treatment planning process. The diagnosis of significant deviations may dictate clinical decisions related to the need for skeletal jaw expansion.[5] Traditionally, the linear measurements between bilateral landmarks on PACs have been used as a clinical aid,[15,16] however, it has been shown that there are increasing errors associated with measuring bilateral landmarks.[6] In contrast, the accuracy of CBCT is well known and documented.[17-22] Nevertheless, studies have not been published demonstrating CBCT to be significantly superior to conventional 2D cephalometry in the diagnosis and treatment planning of transverse discrepancies.

The aim of the present study was to investigate the validity of reference point measurements on CBCT and PAC when compared with base standard (BS) dry skull measurements for the assessment of transverse maxillomandibular relationships.

Material and methods

Ethics approval was sought and granted from the Human Research Ethics Committee, The University of Western Australia in accordance with the requirements from the *National Statement on Ethical Conduct in Human Research* (National Statement) and the policies and procedures of the University of Western Australia.

The sample consisted of 28 undocumented skulls obtained from the Faculty of Human Biology and Anatomy and the Faculty of Medicine, Dentistry and Health Sciences at the University of Western Australia. The skulls were not identified by age, ethnicity or sex and were selected from a larger collection according to the presence of the permanent dentition, the lack of gross asymmetry and a reproducible and stable occlusion.

Direct craniometric measurements were taken of the selected skulls (base standard) as well as a CBCT and a traditional PA cephalogram. For imaging, the skulls were positioned tightly in the machine ear rods with special care to ensure that Frankfort plane was horizontal and parallel to the floor. The mandible was fully seated in the glenoid fossa and the teeth in maximum intercuspation during the imaging process. Jugale and Antegonion, as bilateral landmarks, were chosen to measure the maxillary and mandibular widths respectively. These points were defined as:

- Jugale (J): At the jugal process, the intersection of the outline of the maxillary tuberosity and zygomatic buttress on the left/right side.
- Antegonion (AG): The antegonial notch at the lateral inferior margin of the antegonial protuberance on the left/right side.[11]

The CBCT data was obtained using the Sirona Galileos Cone Beam Imaging System at 85 kVP, 42 mAs (7 mA, 6000 ms) and a 15-inch field of view. High contrast (HC) mode was not used, to optimise image quality. AquariusNET Client software (TeraRecon Inc, San Mateo, CA, USA) was used to process the images. The absolute measurements from the CBCT data were obtained by identifying two point landmarks on the volumetric data and the inter-distance was calculated by the software. The landmarks were identified using a multi-planar reconstruction technique (MPR) following axial, sagittal and coronal reconstructions. The software calculated the measurements to the nearest voxel (0.01 mm). Identification was completed by operator (GC) under the strict guidance of an accredited oral maxillofacial radiologist trained in 3D imaging (BK).

The PA cephalometric images were obtained according to standard procedures using the following radiographic settings: 80 kV, 10 mA, and 0.2 seconds. All images were digitally stored and imported into Quick Ceph Studio (Quick Ceph Systems Inc, San Diego, CA, USA) for landmark identification and measurement.

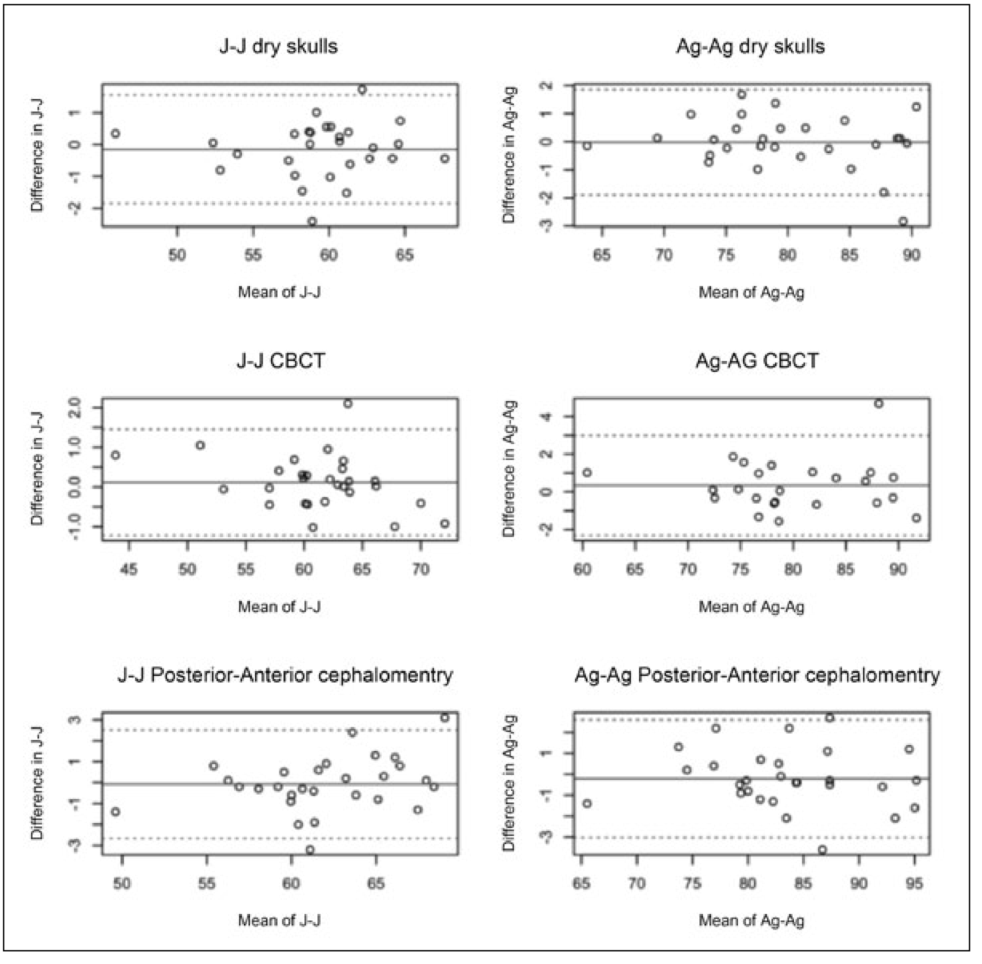

Figure 1. Bland-Altman plots for evaluation of intra-observer reliability between repeats.

The direct craniometric landmarks were digitised using a high-precision microscribe G2X (Immersion Corporation, San Jose, CA, USA). The distances were recorded and calculated using Excel 2010 software (Microsoft, Redmond, WA, USA).

Statistical analysis

The measurements on all image modalities were repeated twice by the same operator (GC) at least seven weeks apart. The intra-observer reliability was calculated using pair-wise intra-class correlation coefficients and Bland-Altman plots. All data were recorded using Excel 2010 software (Microsoft, Redmond, WA, USA) and mean values used for further statistical analysis. Each measurement was assessed at the 95% confidence level ($p < 0.05$) and pair-wise intra-class correlation assessed agreement between corresponding measurements. Reliability was also demonstrated visually using Bland-Altman plots. All statistical analysis was done using Software R (R Foundation for Statistical Computing, Vienna, Austria).

Results

No maximum concavity was identified on the inferior mandibular border of four sample skulls, which created a problem during data collection. Therefore, no antegonial measurements were possible and several samples were reduced to 24 measurements instead of the intended 28.

Intra-observer reliability for the CBCT, BS and PAC measurements was considered acceptable if the mean differences were less than 0.5 mm and excellent intra-class correlation coefficients (ICC) were obtained between repeated measurements (Table

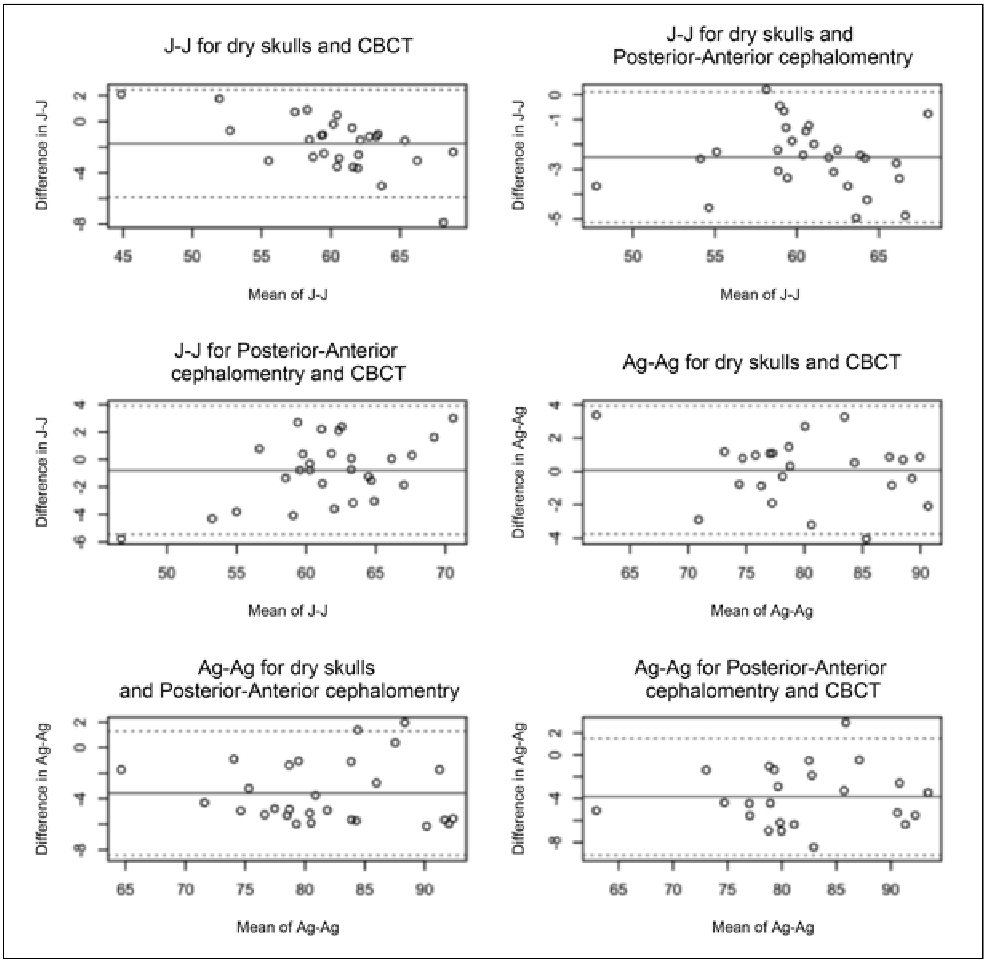

Figure 2. Bland-Altman plots for evaluation of the reliability of difference methods for measuring Jugale and Antegonion.

I). A 95% confidence interval was used and there were no statistically significant differences between the measurement types. There was a maximum of one value outside the limits of agreement for each repeated measurement and the Bland-Altman plots demonstrated no obvious signs of bias or pattern between repeats (Figure 1).

No statistically significant differences could be found for most measurements which indicated good reliability related to the measurement techniques. The exceptions were J-J for PA Ceph-CBCT and Ag-Ag for CBCT-BS (Table II) which demonstrated poorer reliability and less statistical significance.

There was a greater difference noted in landmark measurements between points Ag-Ag compared with J-J. In particular, the biggest difference was evident between measurements obtained from PA Ceph–CBCT and PA Ceph-BS. The exception was CBCT-BS, which demonstrated the smallest mean difference (-0.108) and highest ICC (0.964). Most results were in high agreement, with ICC ranging from 0.793 to 0.964. The Bland-Altman plots (Figure 2) demonstrated that values obtained from PAC had larger mean differences and tended to overestimate results. Values derived from CBCT showed smaller mean differences without overestimation.

In order to evaluate the relationship between J-J and Ag-Ag, the ratios J-J/Ag-Ag from the two imaging modalities were plotted against each other and with BS on three graphs (Figure 3). The Pearson's correlation coefficient was 0.87 for CBCT-BS, 0.81 for PAC-BS and 0.80 for PA-CBCT. An arbitrary value of 77% for J-J/Ag-Ag was chosen as an indicator of transverse discrepancy and the imaging modalities were assessed for their diagnostic validity against this value. When compared with the BS ratios, five skulls (18%) measured using PAC were shown to be incorrectly

Table I. Intra-observer reliability expressed as mean differences, 95% CI and Intra-class correlations.

	J-J					Ag-Ag				
	Mean difference	SD	Lower CL	Upper CL	ICC	Mean difference	SD	Lower CL	Upper CL	ICC
CBCT	0.12	0.67	-0.13	0.36	0.99	0.34	1.33	-0.19	0.871	0.98
Base standard	-0.15	0.83	-0.46	0.16	0.98	0.02	0.92	-0.36	0.324	0.99
PA cephalometry	-0.07	1.30	-0.55	0.41	0.96	-0.21	1.41	-0.73	0.310	0.98

Table II. Mean Difference, Standard deviation, 95% CI and Intra-class correlation between BS, PAC and CBCT.

	J-J					Ag-Ag				
	Mean Difference	SD	Lower CL	Upper CL	ICC	Mean Difference	SD	Lower CL	Upper CL	ICC
PA Ceph – CBCT	0.79	2.34	-0.08	1.65	0.88	3.77*	2.67	2.70	4.84	0.79
CBCT- BS	1.14*	1.72	0.50	1.78	0.86	-0.11	1.92	-0.88	0.66	0.96
PA Ceph – BS	2.51*	1.31	2.03	3.00	0.80	3.57*	2.43	2.67	4.47	0.79

*statistically significant

valued. Four measurements indicated a value lower than 77% and one greater. In comparison, CBCT incorrectly valued two skulls (8.3%) and all indicated a value above 77%. Of note, the direct comparison of PAC and CBCT ratios indicated that five subjects (21%) were incorrectly valued. Four of these were found to have ratios below 77% on PAC but not on CBCT. Only one subject was undervalued on PAC compared with CBCT.

Discussion

The present study measured cephalometric reference points J-J and Ag-Ag on 28 dry skulls. The corresponding craniometric measurements obtained from the dry skulls were considered to be the base standard. Comparable measurements were obtained from either PAC- or CBCT- derived volumetric data. The results were compared to determine their validity in assisting the clinical diagnosis of an intermaxillary transverse discrepancy. The correct assessment of the transverse dimension is essential as a skeletal deficiency could potentially change treatment and may even require surgery.[5]

Numerous factors require consideration by the clinician prior to applying the results of the present study. The use of dry skulls meant that there was no soft tissue attenuation of the images. This allowed for greater contrast and easier identification of specific bony landmarks. Secondly, the dry skulls were fastened tightly to the machine, which meant that there was no movement during imaging. Thirdly, head positioning was controlled and not influenced by anatomic factors. Therefore, Frankfort plane was easily visualised and positively aligned parallel to the X-ray beam. Head positioning has been a well-documented problem which has a significant impact on the identification of bilateral landmarks[6,7] and therefore on cephalometric measurements.[7,8,10] The above factors meant that a much clearer and more accurate picture was obtained using the dry skull than would otherwise have been possible on a real patient.

Several of the skulls examined in this study had pre-existing springs and screws attached which could not be removed. These attachments had not been placed in an anatomical area related to the measurements. However, decreased measurement accuracy due to radiological artefact could not be eliminated. A comparable situation may be identified in patients with a large number of metallic restorations or with unremoved earrings.

A comparative strength of the present study was the use of the microscribe in digitising and measuring

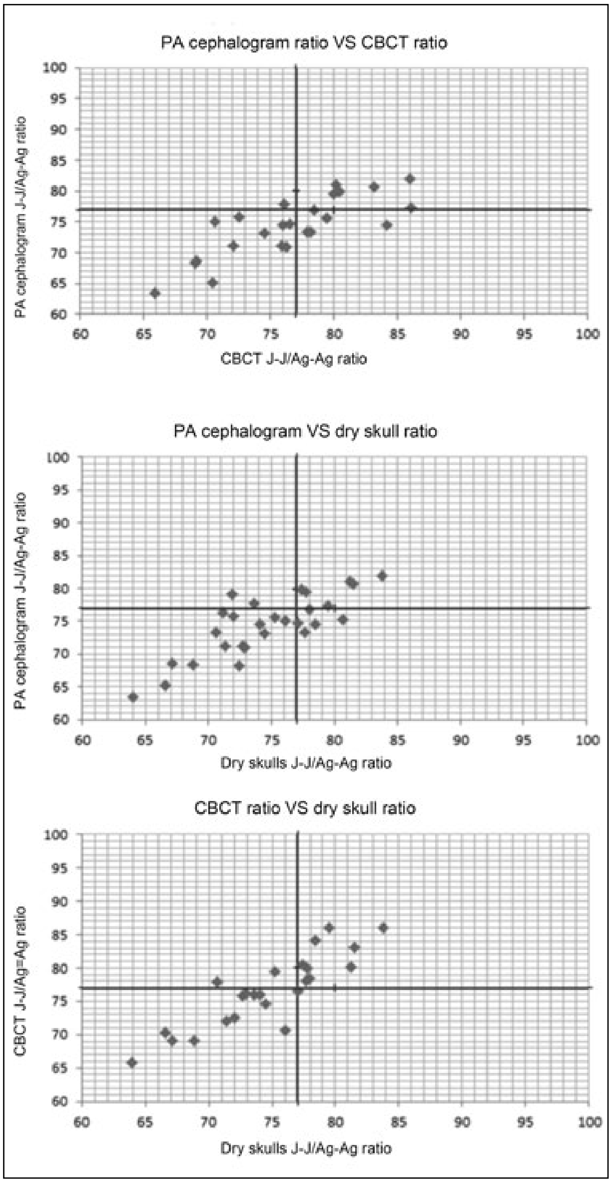

Figure 3. Linear regression of intermaxillary width ratios of J-J/Ag-Ag for evaluation of diagnostic concordance.

the craniometric landmarks. Comparative studies have used digital callipers in traditional manual anthropometry craniometry.[9,18,21] Research has suggested that 3D digitisation methods minimise errors, are less time consuming and are more accurate when compared with traditional methods.[23]

It was not possible to find Ag-Ag point on the CBCT volumetric data on 4 of the 28 skulls. Further observation determined that the inferior mandibular border of the specimens had a mostly convex outline compared with the expected flat or concave outline (Figure 4).

The antegonial notch was poorly defined but still identifiable by palpation. However, it was impossible to visually identify the landmark on the CBCT. The position of Antegonion on the PAC is believed to be an artefact of superimposition and parallax error (Figure 5) produced by the posterior section of the inferior border of the mandible being broader than the anterior part. This creates the false impression of a concavity on the lateral-inferior mandibular border when in reality, no concavity exists. This raises the question of whether any landmark identified on the PAC for Antegonion is truly representative of the definition on the dry skull. It has been suggested that Antegonion as a landmark is invalid when measured on posterior anterior cephalograms.[24]

A major aim of the present study was to assess the accuracy and consistency of landmark identification. The intra-observer reliability for all measurements was free of any obvious bias and pattern, indicating favourable reliability. It was found that measurements on PAC and the J-J measurement on CBCT had statistically significant differences from actual measurements. However, the absolute differences compared favourably with other studies[18,25,26] and was small in comparison with total measurements. This statistical significance likely did not translate into clinical relevance which was further confirmed by the high ICC values.

The measurements errors varied, depending on the landmark and the imaging modality which matched previous reports.[6,9,12] It has been previously established that points located at an intersection are easier to identify than points located on broad curves.[12,25,27] Jugale was defined by an intersection whereas Antegonion was located on a curve. El-Mangoury et al.[28] reported that Jugale had a significantly smaller envelope of error compared with Antegonion and this might explain why Ag-Ag distances had generally larger differences compared with J-J distances. An alternative explanation may be found in the classical definitions for landmarks which are inadequate for use with volumetric data. While the landmarks Ag-Ag and J-J are routinely identifiable on a PAC, most clinicians are not acutely aware of each landmark's 3D location. For example, Jugale is defined as 'at the jugal process, the intersection of the outline of the maxillary tuberosity and zygomatic buttress on the left/right side'.[11] This definition is inappropriate when used in 3D imaging, as the intersection between the

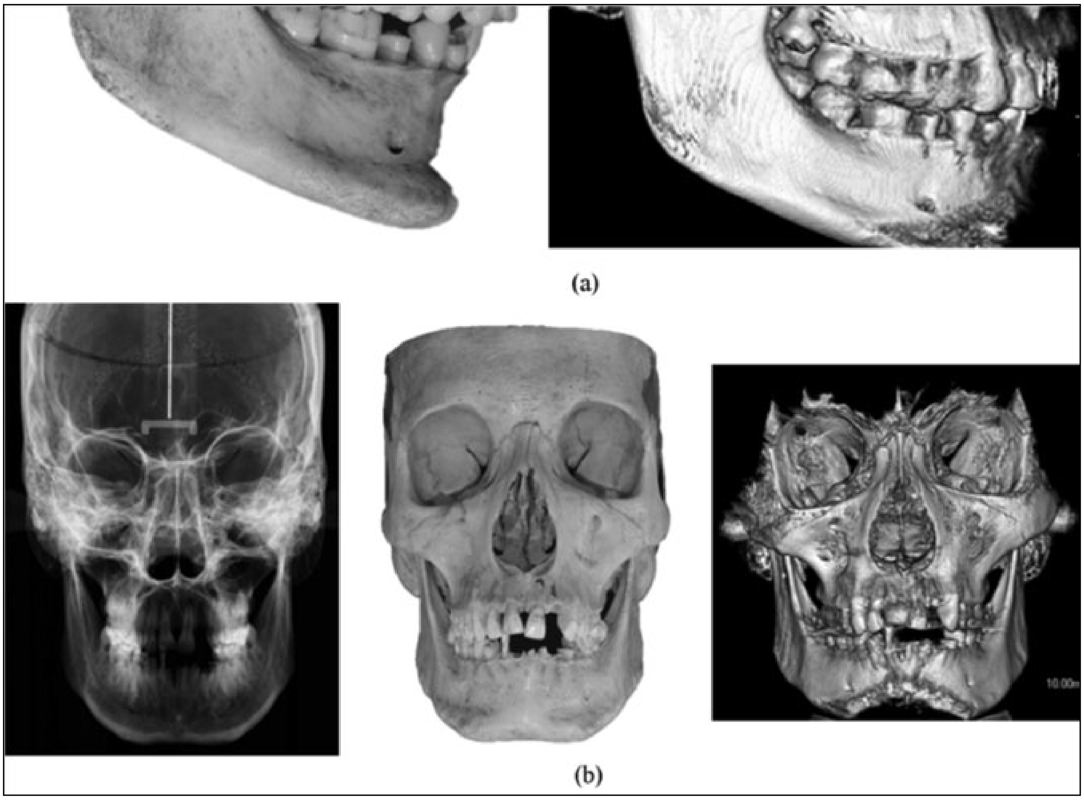

Figure 4. Comparative close-up of a skull for which no measurement was possible. (a) Lateral views in photograph (left) and surface rendering from CBCT (right); (b) Frontal views in PA cephalogram, photograph and surface rendering from CBCT (left to right).

tuberosity only exists in two dimensions. Previous studies have found similar problems with 3D landmark identification.[25,29] The exception is the Antegonion location on dry skulls as the landmark was identifiable by palpation and hence demonstrated a much lower intra-observer error than other measurements.

The correct technique for obtaining measurements from CBCT data has yet to be established. Different visualisation techniques have been proposed and include a volume-rendered (VR), shade surface display (SSD) and multi-planar reconstruction (MPR).[21,30] MPR has been proposed as a method of choice as it is considered to have the greatest accuracy.[31] The present results provided confirmation by demonstrating highly accurate measurement on CBCT. However, it must be taken into account that reliability and accuracy was only possible after a long period of training under a qualified oral maxillofacial radiologist (BK). The addition of the extra dimension resulted in an increased likelihood of error and there was difficulty in obtaining the correct segmentation and windowing. The extra training required is obviously not feasible for all clinicians. Therefore, the establishment of CBCT as the new standard, requires not only standardisation, but also simplification of the measurement technique. This deficiency has been recognised by the formation of reference groups, such as the Joint Cephalometric Expert Group (JCEG), charged with the creation of standards to ease the transition from 2D to 3D analysis.[2]

The results of the present study indicated that CBCT is superior to PAC for measuring points Jugale and Antegonion. CBCT achieved greater ICC and smaller mean differences when compared with base standard values. This is in agreement with previous literature which demonstrated CBCT to be an accurate imaging modality for the measurement of the craniofacial complex,[22] whereas PAC remained affected by head positioning and other errors.[6] These differences were further exaggerated by the difficulty in the identification of J-J and Ag-Ag landmarks which are susceptible to distortion from head positioning.[6-8]

Traditionally, Rickett's Rocky Mountain analysis[32] has been popular for the diagnosis of intermaxillary dimensions due to the inclusion of normal values for

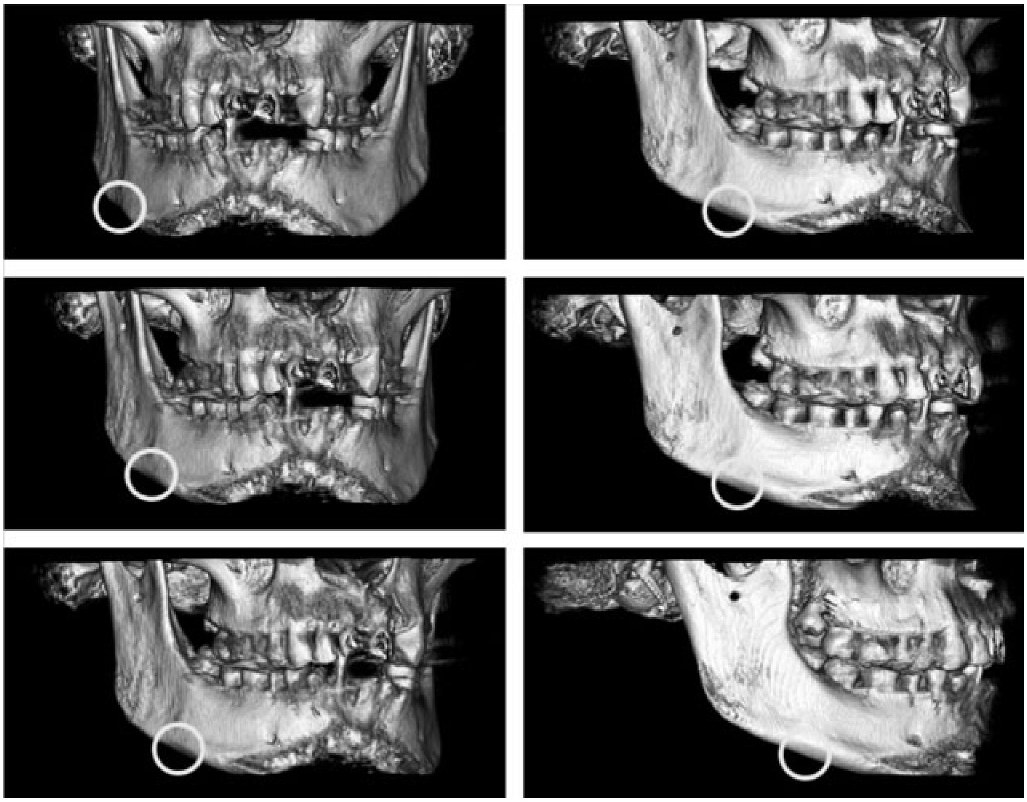

Figure 5. CBCT image of one of the skulls on which we were unable to obtain Ag values. The skull is rotating from the frontal view to the lateral view. The white circle highlights the landmark known as the right Ag on the frontal view as it rotates to its lateral position.

various ages.[3] However, it has recently been suggested that, because of the errors with PAC measurements, the ratio J-J/Ag-Ag[33,34] is a more accurate assessment of intermaxillary relationships. It has been further shown that measurements from single landmarks are inaccurate representations of mandibular or maxillary dental or skeletal width.[33] With 3D data now available, a future direction for research may be the abandonment of the idea of using fixed landmarks and the consideration of using maxillary and/or mandibular volumes for analysis. Kau et al.[35] suggested that orthodontics should consider a shift from landmarks, lines, distances and angles to surfaces, areas and volumes.

In this regard, it has been shown that CBCT provides an accurate measurement of volume[36] and therefore the maxilla and mandible may be volumetrically compared and evaluated. Deguchi et al. found significant differences between the volumetric maxillomandibular ratio of different skeletal classes[37] and hypo- or hyper- divergent subjects.[38] An alternative approach by Stratemann et al.[30] used a combination of volumes and landmark measurements to develop volumetric norms. Currently, no published papers have used volumes to assess transverse discrepancies.

An additional suggested approach is the use of CBCT-constructed posterior-anterior cephalograms. Although it has been documented that measurements from constructed cephalograms have comparable accuracy to conventional films,[39-41] constructed radiographs possess the same problems as conventional PACs and involve errors in head position and superimposition.[15] This is at best a temporary measure until superior volumetric 3D analyses are developed.

The accurate diagnosis of intermaxillary transverse discrepancy requires detailed clinical and radiographic evaluations.[5] Traditionally, this has been assessed radiographically using either absolute measurements or ratios on PACs.[3] The results from the present study indicated that the use of PAC incorrectly diagnosed several skulls (five out of 28, or 18%) with a transverse discrepancy. By comparison, CBCT had more acceptable agreement with the base standard as only two out of 24 skulls (8.3%) were incorrectly diagnosed. This questions the validity of using PAC for the diagnosis of an intermaxillary transverse discrepancy using J-J/Ag-Ag ratios. Importantly, a similar error of five out of 24 skulls (21%) was found when comparing CBCT to PAC. Further studies are necessary to investigate whether, and to what degree, similar errors occur in real patients. While CBCT has demonstrated superior results, its role is inconclusive in the diagnosis of intermaxillary discrepancies and other orthodontic problems. Despite the recent popularity of CBCT, opinions regarding its use are divided and range from routine in all patients to limited use in specific cases.[31] A recent position statement by the American Dental Association Council on Scientific Affairs has expressed the need for caution.[42] Nevertheless, the volumetric data from CBCT has the potential to aid in diagnosis due to its ability to represent 'anatomical truth'. The problem is the adequacy of assessment and use of this data for better diagnosis and treatment planning. The results from the present study therefore highlight that the diagnosis of intermaxillary discrepancies from radiographical data should only act as a guide which is best supported by other clinical indicators.

Conclusions

In the present study, the accuracy and reliability of measurements on the conventional PAC and CBCT images with respect to the standard microscribe-based measurements, while performing transverse intermaxillary analysis using bilateral landmarks Jugale (J) and Antegonion (Ag) on dry skulls, were evaluated. It was found that:

- Landmark identification for point Ag showed greater deviation than point J.
- CBCT landmark identification demonstrated better correlation with BS than PAC results and was accompanied by smaller mean differences and overestimation.
- CBCT imaging was more reliable than PAC in assessing an intermaxillary transverse discrepancy using J-J/Ag-Ag ratios, as fewer skulls were incorrectly diagnosed.

Despite the above results, the lack of 3D analyses and standardisation hinders the use of CBCT as a routine diagnostic tool. Further research on live patients will be beneficial to confirm the findings of the present study.

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Conflict of Interest

There was no conflict of interest between the authors and results from this study.

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