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Research Paper

# Agreement between cephalometric analyses in diagnosing the dento-skeletal characteristics of malocclusion

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ABSTRACT

*Background:* Conflicting results from different cephalometric analyses is a common problem with broader implications but has not received due attention. This study evaluated the agreement between common cephalometric analyses in diagnosing the essential dento-skeletal characteristics of malocclusion.

*Material and methods:* A total of 125 lateral cephalograms were analyzed digitally using Downs, Steiner, Wits, Tweed, Bjork, Ricketts, and McNamara analysis. The diagnosis of sagittal jaw relation (Class 1/2/3), maxillary and mandibular positions (Orthognathic/Prognathic/Retrognathic), growth pattern (Normodivergent/Hypodivergent/Hyperdivergent), and upper and lower incisors positions (Normal/Proclined/Retroclined) were established based on each analysis. The extent of agreement between the analyses was assessed using Kappa statistics.

*Results:* The overall agreement between analyses was moderate for sagittal jaw relationship [k = 0.41 (0.37-0.45)], fair for growth pattern [k = 0.24 (0.20-0.27)], mandibular position [k = 0.25, (0.20-0.30)], upper incisor (k = 0.38, CI = 0.32-0.44) and lower incisor [k = 0.21 (0.17-0.25)] positions, and only slight for maxillary position [k = 0.18 (0.13-0.23)]. For pairwise comparisons of analyses, the agreement was moderate to substantial for the sagittal jaw relationship (except for comparisons involving McNamara analysis) and slight to moderate for other variables. Also, the diagnosis of normal dentofacial relationships (Class 1 and normodivergent skeletal pattern, orthognathic jaw positions, and normal incisor positions) was less consistent than those of deviant subgroups.

*Conclusions:* The agreement between the cephalometric analyses evaluated was moderate for sagittal jaw relation and only fair for most other dento-skeletal characteristics. McNamara's analysis showed less agreement with others. These highlight the need for a more cautious and scientific approach to Cephalometrics.

## 1. Introduction

Cephalometry has long been an indispensable tool in orthodontic diagnosis, treatment planning, and evaluating treatment outcomes. It provides valuable information on the morphology and spatial relationships of the maxillofacial skeleton, dentition, and the associated soft tissues. Since its inception by Broadbent and Hofrath in 1931, cephalometric analysis has undergone significant advancements to refine its diagnostic accuracy and reliability.[1] The cephalometric analyses that have stood the test of time in their utility and popularity include those by Downs, Steiner, Tweed, Bjork, Ricketts, Wits, and McNamara.[2–8]

While each analysis has distinct advantages and inherent limitations, no single method provides a definitive standard for evaluating discrepancies. It is common to observe contradictions in inferences from these analyses, leaving the user perplexed about the correct diagnosis,[10–12] potentially leading to diagnostic inconsistencies and suboptimal treatment planning.[13]

Further, many of these cephalometric methods have not been subjected to rigorous validation protocols characteristic of a diagnostic tool in medicine and dentistry.[9] Ahmed et al.[11] evaluated the agreement between the final diagnosis made from six sagittal variables and the diagnosis based on each. ANB was found to have the highest agreement (k = 0.8) and the Down's Angle of convexity, the least (k = 0.39). For vertical growth pattern, the Sella-Nasion to Gonion-Gnathion angle exhibited the highest agreement with the majority diagnosis established from seven variables.[10] Similarly, the agreement between cephalometric

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variables from eight cephalometric analyses was slight to moderate for incisor inclinations.[12]

Given the paucity and contradictory information in this regard, and as a part of a broader effort at the rational use of cephalometrics as a diagnostic tool, the present study evaluated the agreement between seven widely used cephalometric analyses in diagnosing six essential dentoskeletal characteristics.

## 2. Materials & methods

This cross-sectional study was conducted in the Division of Orthodontics and Dentofacial Orthopedics, Department of Dentistry, Jawaharlal Institute of Postgraduate Medical Education and Research (JIPMER), Puducherry, India. The research proposal was approved by the Institute Scientific Advisory Committee for observational studies, and waiver of patient consent was accorded by the Institute Ethics Committee of the for observational studies of JIPMER, Puducherry. The pre-treatment digital lateral cephalometric radiographs of individuals aged 12–30 years from the department archives were screened for eligibility for inclusion in the study. All the lateral cephalograms were made on the same cephalostat and recorded in centric occlusion with Frankfort Horizontal Plane oriented parallel to the floor. Radiographs with unclear/overlapping structures due to inherent facial asymmetry or faulty positioning (identified as more than 5 mm in the lower or posterior border of the mandible) were excluded from the study. Other exclusion criteria were patients with cleft lip/palate or other craniofacial syndromes, radiographs showing mandible in open mouth position or incorrect head posture, patients with significant developmental delay, and cases where age could not be verified.

With a power of 0.90 and assumed true Kappa of 0.21,[12] at a 5 % significance level, the sample size was estimated to be 125. Three orthodontists with over three years of experience selected 125 pre-treatment lateral cephalograms that met the eligibility criteria. Special attention was given to ensure a representative distribution of samples across different dental and skeletal malocclusions. The dental malocclusions were classified according to Angle's classification, and the skeletal sagittal and vertical relationships were classified based on ANB and Frankfort-mandibular plane angle, respectively.

The age (in years) and sex of the individual were noted from the case records. The radiographs were analyzed using Vistadent OC (GAC International) software by the Investigator (US) and cross-verified by one of the co-investigators (BM) before finalization. All radiographs were calibrated using an inbuilt 50-mm ruler. No more than three cephalograms were digitized in one sitting to avoid operator fatigue. The operator was free to apply any image adjustments or filters that were perceived to facilitate landmark localization. The analysis of lateral cephalograms of 30 randomly selected subjects was repeated after 2 weeks to assess intra-rater reliability.

The seven cephalometric analyses evaluated in the study included Downs, Steiner, Tweed, Bjork (Roth-Jarabak), Ricketts, Wits, and McNamara.[2–8] The cephalometric variables included in each analysis are listed in Supplementary Table 1. Based on the published regional norms for the population under consideration,[14–17] the diagnosis of the following four skeletal elements were established by each analysis: sagittal skeletal relation (Class 1/2/3), the position of the maxilla (orthognathic/retrognathic/prognathic), the position of the mandible (orthognathic/retrognathic/prognathic), and growth pattern (normodivergent/hypodivergent/hyperdivergent). The dental elements evaluated were the maxillary and mandibular incisor inclinations (average/proclined/retroclined). Any conflict in the diagnosis categorization was resolved through group discussions involving all investigators.

The data analysis was performed using JASP V 0.19.2, JASP Team, 2024 (https://jasp-stats.org/). Fleiss's Kappa was used to measure the overall extent of agreement between the cephalometric analyses for each diagnostic element. Pairwise agreement between the seven cephalometric analyses and intra-rater agreement were evaluated using the Kappa statistic. The strength of the agreement was categorized according to Landis & Koch.[18]

## 3. Results

The mean age of the samples included in the study was 19.7 (±2.1) years. The demographic and clinical characteristics of participants are presented in Fig. 1. The intra-rater reliability was almost perfect for all the six diagnostic elements evaluated in the study ($k > 0.97$).

The overall strength of agreement was moderate for the sagittal jaw relationship ($k = 0.41$; CI = 0.37, 0.45), while fair for the vertical jaw relationship ($k = 0.24$; CI = 0.20, 0.27), mandibular position ($k = 0.25$; CI = 0.20, 0.30), upper incisor ($k = 0.38$; CI = 0.32, 0.44) and lower ($k = 0.21$; CI = 0.17, 0.25) incisor inclinations, and only slight for maxillary position ($k = 0.18$, CI = 0.13, 0.23).

The results of pairwise comparisons of analysis for the skeletal variables are presented in Table 1. The agreement for the diagnosis of sagittal jaw relationship was least between Downs and McNamara analysis ($k = 0.11$; CI = 0.03, 0.19) and highest between Downs and Steiner ($k = 0.68$; CI = 0.57, 0.79). For the sagittal position of the maxilla, Downs-Steiner had the lowest agreement ($k = 0.11$; CI = 0.01, 0.21) and Downs–Ricketts had the highest ($k = 0.65$; CI = 0.53, 0.76). On the contrary, the Downs- Ricketts pair exhibited the least agreement for the sagittal mandibular position ($k = 0.13$; CI = 0.04, 0.23). For the vertical jaw relationship, McNamara versus Bjork's analysis showed the lowest agreement ($k = 0.08$; CI = 0.00, 0.18) and Steiner versus Bjork, the highest ($k = 0.54$; CI = 0.43, 0.65).

The agreement for pairwise comparisons of analyses for incisor positions is summarized in Table 2. The Steiner-Bjork analyses showed the highest agreement for maxillary incisor position ($k = 0.55$; CI = 0.38, 0.72) and Steiner-Tweed pair for mandibular incisors ($k = 0.54$; CI = 0.40, 0.67).

The results of agreement on the diagnosis of these variables by subgroups are presented in Table 3. The agreement was least for the orthognathic maxillary position ($k = 0.02$; CI = 0.00, 0.09) and highest for the Class III sagittal jaw relationship ($k = 0.57$; CI = 0.51, 0.62).

The Quick comparison of the agreement between the analyses for the six variables (based on Kappa Values) and their sub-groups (based on Fleiss Kappa Values) is presented in Fig. 2.

## 4. Discussion

The current study evaluated the agreement between different cephalometric analyses in diagnosing various skeletal and dentoalveolar characteristics in 125 subjects. The results revealed varying levels of agreement between and within the analysis for the six diagnostic elements, reflecting the limitations of these techniques. For instance, the agreement between Downs and Steiner was good for the sagittal jaw relationship, moderate for the vertical jaw relationship, fair for upper and lower incisor positions and poor for assessing the position of the maxilla and mandible.

Steiner's ANB and Wits appraisal showed good agreement for the sagittal skeletal pattern, which aligns with previous studies reporting a statistically significant correlation between these.[11,19] It was also observed that the agreement between Downs and Steiner's analyses with McNamara was weak, indicating that the latter was less aligned with others in diagnosing the sagittal relationships. A similar finding was also noted for vertical skeletal relations, where McNamara's analysis showed low agreement with Tweed and Ricketts' analyses. In an earlier study, Benedicto et al.[20] reported that the lowest agreement for vertical relation was between Jarabak and Steiner. Overall, the agreement for vertical skeletal relation was lower than sagittal relation.

Guerrero M et al.[21] found a moderate agreement between Ricketts and McNamara's analysis in diagnosing the sagittal position of the maxilla ($k = 0.59$) and mandible ($k = 0.46$). However, this was only

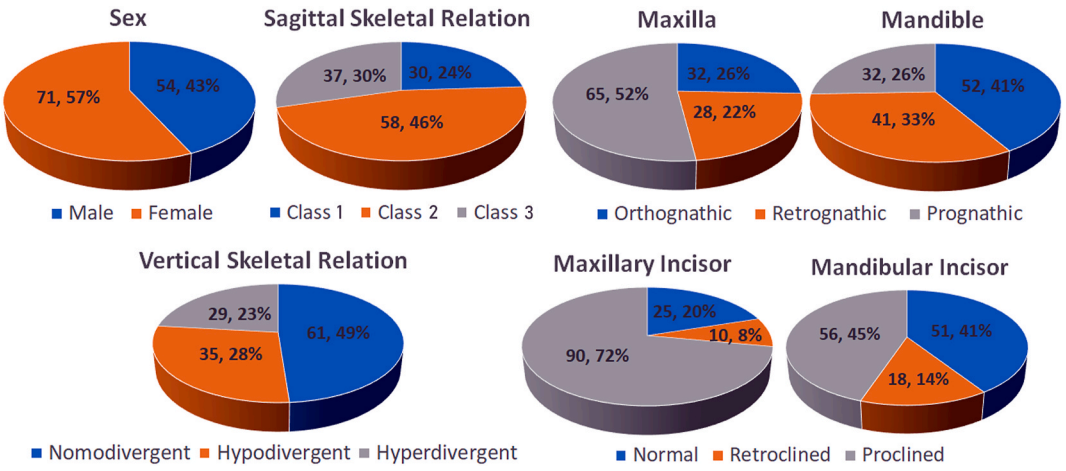


**Fig. 1.** The demographic and clinical characteristics of the sample (n, %).

**Table 1**
Agreement between the cephalometric analyses for the skeletal variables.

| | | | | |
|---|---|---|---|---|
| **Sagittal skeletal relation** | | | | |
| | Downs | McNamara | Ricketts | Steiner |
| McNamara | 0.11 (0.03–0.19) | | | |
| Ricketts | 0.58 (0.47–0.69) | 0.23 (0.12–0.35) | | |
| Steiner | 0.68 (0.57–0.79) | 0.16 (0.06–0.26) | 0.67 (0.56–0.78) | |
| Wits | 0.55 (0.43–0.67) | 0.19 (0.08–0.30) | 0.59 (0.47–0.69) | 0.62 (0.50–0.73) |
| **Sagittal position of the maxilla** | | | | |
| | Downs | McNamara | Ricketts | |
| McNamara | 0.14 (0.05–0.23) | | | |
| Ricketts | 0.65 (0.53–0.76) | 0.15 (0.05–0.25) | | |
| Steiner | 0.11 (0.01–0.21) | 0.3 (0.15–0.44) | 0.05 (0–0.16) | |
| **Sagittal position of the mandible** | | | | |
| | Downs | McNamara | Ricketts | |
| McNamara | 0.41 (0.26–0.54) | | | |
| Ricketts | 0.13 (0.04–0.23) | 0.36 (0.25–0.46) | | |
| Steiner | 0.15 (0.04–0.23) | 0.28 (0.16–0.40) | 0.37 (0.24–0.50) | |
| **Vertical skeletal relation** | | | | |
| | Bjork | Downs | McNamara | Ricketts | Steiner |
| Downs | 0.19 (0.08–0.31) | | | | |
| McNamara | 0.08 (0.00–0.18) | 0.23 (0.08–0.37) | | | |
| Ricketts | 0.15 (0.04–0.26) | 0.21 (0.07–0.35) | 0.12 (0.00–0.26) | | |
| Steiner | 0.54 (0.43–0.65) | 0.46 (0.36–0.56) | 0.18 0.09–0.28) | 0.16 (0.08–0.25) | |
| Tweed | 0.43 (0.30–0.55) | 0.34 (0.20–0.47) | 0.12 (0.00–0.24) | 0.23 (0.07–0.38) | 0.35 (0.25–0.46) |

**Table 2**
Agreement between the cephalometric analyses for the dental variables.

| | | | | |
|---|---|---|---|---|
| **Maxillary incisor position** | | | | |
| | Bjork | Downs | McNamara | |
| Downs | 0.15 (0.00–0.32) | | | |
| McNamara | 0.36 (0.21–0.51) | 0.37 (0.22–0.51) | | |
| Steiner | 0.55 (0.38–0.72) | 0.38 (0.20–0.56) | 0.48 (0.33–0.63) | |
| **Mandibular incisor position** | | | | |
| | Bjork | Downs | Ricketts | Steiner |
| Downs | 0.08 (0.01–0.15) | | | |
| Ricketts | 0.09 (0.01–0.18) | 0.14 (0.01–0.26) | | |
| Steiner | 0.23 (0.11–0.36) | 0.40 (0.29–0.52) | 0.21 (0.09–0.33) | |
| Tweed | 0.44 (0.30–0.58) | 0.30 (0.20–0.40) | 0.11 (0.00–0.22) | 0.54 (0.40–0.67) |

**Table 3**
Agreement between the cephalometric analyses for the sub-groups within variables.

| Sagittal skeletal relation | | | |
|---|---|---|---|
| Class I | Class II | Class III | Overall |
| 0.23 (0.18–0.29) | 0.43 (0.37–0.48) | 0.57 (0.51–0.62) | 0.41 (0.37–0.45) |
| **Sagittal position of the maxilla** | | | |
| Orthognathic | Retrognathic | Prognathic | Overall |
| 0.02 (0.00–0.09) | 0.35 (0.27–0.42) | 0.22 (0.15–0.30) | 0.18 (0.13–0.23) |
| **Sagittal position of the mandible** | | | |
| Orthognathic | Retrognathic | Prognathic | Overall |
| 0.10 (0.03–0.17) | 0.16 (0.08–0.23) | 0.55 (0.48–0.62) | 0.25 (0.20–0.30) |
| **Vertical skeletal relation** | | | |
| Normodivergent | Hypodivergent | Hyperdivergent | Overall |
| 0.10 (0.06–0.15) | 0.33 (0.29–0.38) | 0.31 (0.27–0.36) | 0.24 (0.20–0.27) |
| **Maxillary incisor position** | | | |
| Normal | Retroclined | Proclined | Overall |
| 0.29 (0.22–0.37) | 0.47 (0.39–0.54) | 0.43 (0.36–0.51) | 0.38 (0.32–0.44) |
| **Mandibular incisor position** | | | |
| Normal | Retroclined | Proclined | Overall |
| 0.08 (0.02–0.13) | 0.46 (040–0.51) | 0.20 (0.15–0.26) | 0.21 (0.17–0.25) |

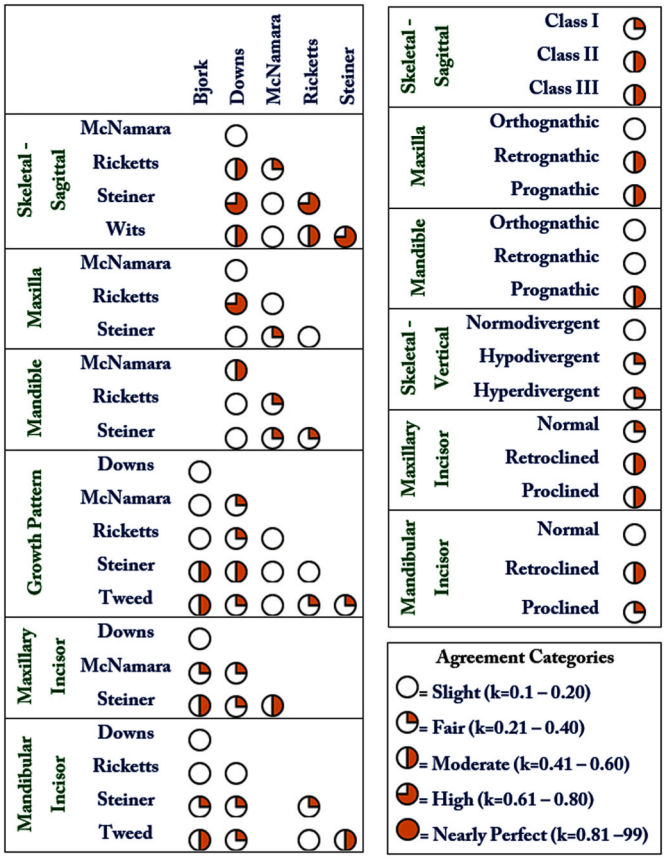


**Fig. 2.** The agreement between analyses for the six diagnostic elements and their subgroups.

slight for the maxilla (k = 0.15) and fair for the mandible (k = 0.36) in our study. This difference could have resulted from variations in the sample, including inherent differences in craniofacial characteristics, demographic factors (ethnicity, age, gender), and the sample size. While their sample was 44 individuals (18–27 years) from Ecuador,[21] ours included a higher number (n = 125, 54 males, 71 females) and relatively younger individuals from India. For upper and lower incisor positions, we noted slight to moderate agreement, consistent with the results of Gómez-Medina et al.[12]

The sub-category agreement analysis revealed an interesting trend of normal dento-skeletal relations (Class 1 skeletal base, normodivergent pattern, orthognathic jaw positions, normal position of incisors) showing lesser agreement than deviant relationships. This situation was also evident in the data of Gómez-Medina et al.[12] for incisor inclinations. The norms denoting normal relations are sandwiched between and seamlessly merge with the values of the deviant categories on either side, making the categorical diagnosis more difficult in these cases. This is common and especially true for borderline cases.

The wide variation in the agreement between cephalometric analysis evaluated in the study could be attributed to the inherent variations and limitations in the landmarks used in these. Methodological differences in the interpretation of values also contribute to the inconsistency as the diagnosis established using only the mean value may differ from that achieved with the mean and range or mean and standard deviation.

## 5. Clinical implications

The study results indicate that the practice of assessing a case with individual analysis and arriving at a corroborative diagnosis may not improve the diagnostic validity. Using composite analysis that derives relevant variables from multiple analyses is a potential solution, though this may not mitigate the problem completely. The conjunctive use of variables with higher prediction accuracy and floating norms has also been suggested as an alternative. Irrespective of the method, it is recommended that normative thresholds for these variables be derived using Receiver Operating Characteristic (ROC) curve analysis rather than the conventional approach of using norms from a few individuals with ideal occlusion and well-balanced faces. Further, these should be subjected to rigorous scrutiny, akin to medical diagnostic tests, before adoption for clinical use.

The wide variability and suboptimal level of agreement between these cephalometric analyses argue against the analysis-based approach to diagnosis and reiterate the need for a more rational and scientific approach to the use of cephalometrics as a diagnostic tool.

## 6. Limitations

It is important to note that this study was intended only to assess the method agreement and not to validate the different cephalometric analyses. Hence, it is impossible to comment on the accuracy of the diagnosis established using these analyses or identify the deviant ones in cases of poor agreements, both of which are currently being evaluated in another study.

## 7. Conclusions

The following are the salient conclusions from the study:

1. The agreement between the cephalometric analyses evaluated in the study was moderate for the sagittal skeletal pattern [k = 0.41 (0.37-0.45)] and fair for the vertical skeletal pattern [k = 0.24 (0.20-0.27)], mandibular position [k = 0.25, (0.20-0.30)], and incisor positions [k = 0.38 (0.32-0.44); k = 0.21 (0.17-0.25)].
2. McNamara's analysis often exhibited less agreement with other analyses for sagittal and vertical skeletal patterns.
3. The agreement between the analyses was relatively poorer for cases with normal dento-skeletal relations than for deviant ones.

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Nil.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jobcr.2025.04.012.

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