Orthodontic craniofacial pattern diagnosis: Cephalometric geometry and machine learning

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Summary

Efficient and reliable diagnosis of craniofacial patterns (including sagittal and vertical) is critical to orthodontic treatment. Although machine learning (ML) is powerful and time-saving, prior knowledge should validate its reliability. This paper aimed twofold: (1) to propose a geometric model of 56 lateral landmarks with the validation by 408 X-ray cephalograms and (2) to establish ML models for craniofacial pattern diagnosis. After dimension reduction, plane decision boundaries and landmark contribution contours were depicted to demonstrate the consistency with clinical norms, where Multi-layer Perceptron achieved 97.56% accuracy for sagittal within 0.5715 s, and Linear Support Vector Machine reached 90.24% for vertical within 0.0090 s. The Kruskal-Wallis H test was carried out to explore statistical differences in diagnostic accuracy, where the sagittal had no difference, and the vertical showed significance. All the tests indicated that the proposed craniofacial ML workflow was highly consistent with clinical norms and could supplement practical diagnosis.

Introduction

Before the ML application, mainstream clinic diagnoses rely on orthodontists' subjective practice. Thus, discrepant and confusing results inevitably existed among norms and patients of diverse gender, age, or race. Due to its advantages in analyzing high-dimensional features and noise interference, ML has the potential to process orthodontic datasets and diagnose patterns automatically. Various algorithms have recently been applied to landmark detection, surgery planning, growth determination, and postoperative prediction, while few are aimed at craniofacial pattern diagnoses. However, since classifying the deformity pattern is the basis of reliable diagnosis and treatment, it should be studied emphatically. To the authors' knowledge, only three relevant quantitative works have been published currently [1,2,3].

Methods

The 408 X-ray lateral cephalograms with 56 landmarks, from 324 females and 84 males, were collected among Chinese patients in the Department of Orthodontics, Peking University School and Hospital of Stomatology, Beijing, China, from 2017 to 2021. A geometric model was established first to determine the location of landmarks, which were categorized into five zones settled by position benchmarks, such as Figure 1. Subsequently, based on the model, an ML workflow was established and validated for pattern diagnosis. Following, to visualize the consistency and supplements from ML diagnoses towards clinical, plane decision boundaries and contribution contour maps (Figure 2) were depicted.

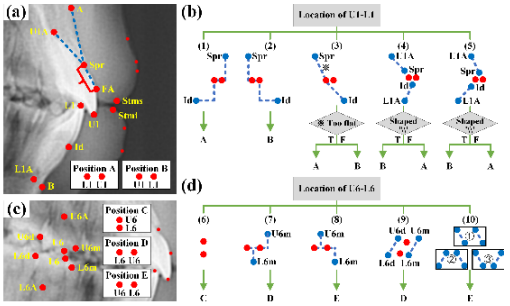

Figure 1: The geometric models: (a)-(b) incisor; (c)-(d) first molar.

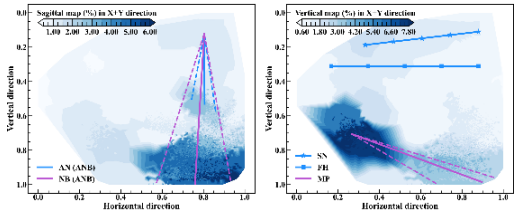

Figure 2: Contribution contours with comparisons between norms.

Results and Discussion

This workflow achieved accuracy at 97.56% for sagittal with the Multi-layer Perceptron and 90.24% for vertical with the Linear Support Vector Machine. Sagittal diagnoses showed higher average accuracy (91.60±5.43)% than the vertical (82.25±6.37)%, significantly affected by the class imbalance. Moreover, discriminative algorithms exhibited superiorly (93.20±3.29)% over the generative (85.98±9.48)% for sagittal. Top contributive landmarks for diagnoses matched clinical norms: the chin, lip, and nose for sagittal, while the mandibular ramus, chin, SN plane, and FH plane for vertical. Plane decision boundaries and contribution contours visualizing the primary landmarks showed that the reliable vertical indicator tended to be MP-SN rather than FH-MP.

Conclusions

This paper established a reliable, time-saving, and generally applicable ML workflow for craniofacial pattern diagnosis. This system exhibited competitive diagnostic performance with relatively small databases of X-ray cephalograms and would provide the clinical reference value, primarily when conflict occurs between various norms.

References

[1] Niño-Sandoval TC et al. (2016). *Forensic Science International*, **261**: 159.e1-e6.
[2] Yu HJ et al. (2020). *Journal of Dental Research*, **99**: 249-256.
[3] Nan L et al. (2023). *Diagnostics*, **13**: 1719.