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Morphological integration of mandible and cranium: Orthodontic implications

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ABSTRACT

Objectives: This study aimed at clarifying the morphological interactions among the cranial base, face, and mandible, to improve the assessment and treatment of skeletal malocclusions involving the mandible.
Design: Untreated adult subjects ($n = 187$) were grouped according to standard cephalometric criteria of vertical and sagittal relationships. Geometric morphometrics were used to test the null hypothesis that integration patterns between the mandible and its associated basicranial and upper midfacial counterparts would be similar among various vertical and sagittal facial patterns.
Results: The null hypothesis was rejected for vertical groups, because the dolicho- and brachyfacial subjects showed significantly different integration patterns, but was accepted for sagittal groups, which showed identical covariation patterns. The morphological integration between the cranium-face and mandible were similarly high in the three skeletal classes, which explained the similarly large covariance between the two structures (57.80% in Class II to 60% in Class III).
Conclusions: Dolicho- and brachi-facial subjects showed specific and different cranium-face and associated mandible configurations. The cranium-face configuration may have an important influence (~60%) on the generation of sagittal (anteroposterior) skeletal malocclusions. The remaining morphological component of the skeletal malocclusion (~40%) would be independent of this particular integration (PLS1) between the cranium-face and mandible.

1. Introduction

The term morphological integration (MI)[1–3] implies that an evolutionary change in the morphology of one anatomical element is reflected by morphological changes in other elements.[4] MI comprises a set of mechanisms that connect (integrate) elements of an anatomical system, quantify the associations between them, and provide measures of covariation to infer developmental or functional relationships.[5] Many orthodontic treatments seek to affect the growth of the mandible.[6–10] However, differences in cranium and mandible MI patterns between patients, depending on their sex, jaw skeletal relationship, or facial pattern, could result in divergent responses to orthopaedic treatment. Therefore, accurate knowledge about the interdependence among craniofacial

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structures (e.g., mandible, face, and cranial base) is critical for therapeutic planning.

It is still unclear whether orthopaedic treatments can alter the mandibular growth to a clinically significant degree. For example, the effect of functional appliances over condylar growth is a topic of long-standing controversy.[7] The MI between the mandible and craniofacial system could be partially responsible for the basic skeletal setting that leads to a given sagittal or vertical malocclusion. It could also explain the relatively limited response of the mandible to orthopaedic appliances.

Several quantitative studies have investigated MI in the human face.[11–14] Some studies found significant features of integration between the cranium and mandible or some of its elements.[15] However, the idea that the mandible is relatively independent of the cranium remains pervasive. In a study of adolescents without major malocclusion, McKane and Kean[14] found minor or no covariation among the shapes of parts of the facial skeleton. Recent research about the MI of the modern human mandible during ontogeny concluded that the mandible has maintained a passive role in hominin skull evolution, playing "follow the leader" with the cranium.[16] Enlow offered a compromise between these extreme viewpoints, proposing that a brain-to-basicranium-to-face (mandible) cascade of morphological influence leads to integration.[17,18] Later studies partially confirmed some of these spatiotemporal interconnections.[19,20] More recently, Wellens et al.[21] found that the mandible and maxilla constitute one module, independent of the skull base.

The fact that a high integration degree between the mandible and the cranium could exist in some cases, but not in others, raises some questions: For example, what are the morphological pattern (i.e., shape-coordinated variation) and the quantitative pattern (i.e., the degree of covariation) of the mandible–cranium integration, and do these integration patterns differ among various craniofacial configurations (e.g., occlusal and facial patterns)?

The aim of this study was to quantify patterns of morphological covariation between the mandible and cranium in adult subjects with skeletal Class I, II, and III malocclusions, on the one hand, and meso-, dolicho-, and brachyfacial configurations, on the other hand. The overall goal was to improve the assessment and treatment of skeletal malocclusions involving the mandible. Because conventional distance-angle cephalometric approaches present limitations for shape assessment,[22,23] this study employed geometric morphometrics, which have been shown to be useful for investigating MI.[24–26] The null hypothesis was that there would be no difference in the craniofacial-mandibular integration pattern between groups.

2. Material and methods

2.1. Data sample

This study included 187 Caucasian adult subjects (92 males; 95 females, age range, 20–30 years; mean, 25.6 ± 4.2 years) from Granada (southern Spain) who were randomly selected from a private dental office. Exclusion criteria included: craniofacial disorders such as cleft anomalies, craniosynostoses, or other syndromal diseases or congenital malformation, congenitally missing, supernumerary, or extracted teeth; and previous or current orthopaedic or orthodontic treatment.

For all subjects, standard lateral cephalometric radiographs with the teeth in centric occlusion and with the head oriented horizontally with the Frankfort plane were taken with a cephalostat in accordance with standard cephalometric procedures. The same digital X-ray device (Planmeca PM-2002 EC Proline Dental Pan X-Ray Machine, Helsinki, Finland), technician, focus-median (150 cm), and film-median (10 cm) plane distances were used for all radiographs. A reference ruler was shown on the cephalostat for exact measurement of the magnification factor.

Cephalograms were imported into tpsDIG 2.12 software (tpsSeries, J.F. Rohlf, SUNY Stony Brook; http://life.bio.sunysb.edu/morph/) to digitize 38 landmarks (2D) representing the morphology of the cranial floor, the midline cranial base, and the face, and 31 semilandmarks representing the morphology of the lower surface of the mandibular body and the contour of the bony chin-symphysis (Table 1 and Fig. 1). All of these localizations were performed by the same examiner (J.A.A.). Paired bilateral landmarks were digitized by averaging the left and right sides.

Measurement errors were evaluated by multivariate analysis of variance (MANOVA) by repeated data recordings of 10 randomly selected subjects on 4 different days. No significant differences were found between the repeated samples (Wilks lambda = 0.00; $F = 1.69$; $df_{1,\ 2} = 138, 6{,}47$; $P = 0.2$), indicating that the measurement errors were smaller than the sample variations.

2.2. Geometric morphometrics and statistical analyses

The degree of covariation patterns were quantified with a two-block partial least squares (PLS) analysis,[27] by assessing correlations between the first PLS vector scores[25] and the RV coefficient.[28] The integration pattern was quantified by using Procrustes registered configurations along the PLS vectors of the corresponding blocks.[29] Blocks 1 was the cranium (cranial base and face), and block 2 was the mandible.

Integration vectors for the full sample after correction for sexual dimorphism were calculated. Sex correction was performed by multivariate regression of shape on sex (dummy) and avoided assessment of integration patterns driven by male and female mean shape differences. Then, mesofacial (FMA between 20° and 28°, $n = 97$), dolichofacial (FMA > 28°; $n = 49$), and brachyfacial (FMA < 20°; $n = 41$) patterns, and skeletal Class I (ANB angle between 0° and 3°, $n = 88$), Class II (ANB angle > 3°; $n = 54$), and Class III (ANB angle < 0°; $n = 45$) malocclusions were distinguished, following standard orthodontic criteria (ANB angle and FMA angle-mandibular plane to the Frankfurt horizontal angle).[30,31]

To assess the overall similarity of integration patterns in different groups of facial patterns and skeletal classes, craniofacial and mandibular PLS1 scores were analyzed by a Generalized Linear Model (GLM).[32] We considered the overall correlation between the craniofacial and the mandibular PLS scores as principal factor as well as a group factor with three levels (doli-, meso- and brachyfacial groups, skeletal Class I, II,