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The effects of altered maxillary growth on patterns of mandibular rotation in a pig model

Nathan E. Holton [a,b,*], Christina L. Nicholas [b,c], Steve D. Marshall [a], Robert G. Franciscus [b], Thomas E. Southard [a]

[a] Department of Orthodontics, The University of Iowa, Iowa City, IA 52242, USA
[b] Department of Anthropology, The University of Iowa, Iowa City, IA 52242, USA
[c] Dows Research Institute, The University of Iowa, Iowa City, IA 52242, USA

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ABSTRACT

Objectives: A thorough understanding of influence of maxillary growth on patterns of mandibular rotation during development is important with regard to the treatment of skeletal discrepancies. In the present study, we examined whether experimentally altered maxillary position has a significant influence on patterns of mandibular rotation in a pig model.

Design: Maxillary growth was altered in a sample of $n = 10$ domestic pigs via surgical fixation of the circummaxillary sutures. We compared the experimental group to control and surgical sham samples and assessed the effects of altered maxillary growth on mandibular form using geometric morphometric techniques. We tested for significant differences in mandibular shape between our samples and examined axes of morphological variation. Additionally, we examined whether altered mandibular shape resulting from altered maxillary position was predictably associated with morphological changes to the condylar region.

Results: There was a statistically significant difference in mandibular shape between the experimental and control/sham groups. As a result of vertical displacement of the snout, mandibles in the experimental sample resulted in greater anterior rotation when compared to the control/sham pigs. Variation in rotation was correlated with morphological changes in the condyle including the shape of the articular surface and condylar orientation indicative of greater anterior mandibular rotation.

Conclusions: Vertical displacement of the maxilla had a significant effect on mandibular shape by encouraging anterior mandibular rotation. This result has important implications for understanding the effects of altered mandibular posture on condylar remodeling the treatment of skeletal discrepancies such as the correction of hyperdivegent mandibular growth.

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1. Introduction

A significant proportion of variation in human craniomandibular form is arrayed along the vertical dimensions of the facial skeleton.[1–3] As an important contributing factor, the height of the lower facial skeleton is markedly influenced by patterns of mandibular rotation during ontogeny. The morphogenetic influences on mandibular rotation are complex and multifactorial as evidenced by the various rotational patterns documented in classic implant studies.[4] In more general terms however, mandibular rotation can be divided

* *Corresponding author at*: Department of Orthodontics, The University of Iowa, Iowa City, IA 52242, USA. Tel.: +1 319 384 4786.
E-mail address: nathan-holton@uiowa.edu (N.E. Holton).

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into two categories, i.e., forward rotation and backward rotation, which are tied to a larger integrated suite of morphological features of the mandible.[2–4]

Variation in mandibular rotation is influenced by the amount and direction of mandibular condylar growth during development.[5,6] Increased anterior growth at the condyles produces greater forward mandibular rotation whereas greater posterior condylar growth results in a greater degree of backward mandibular rotation.[4]

While numerous factors likely affect the direction of condylar growth, variation in mandibular posture has a significant influence.[7] Changes in mandibular posture and thus condylar position alter the biomechanical environment of the temporomandibular joint thereby affecting the growth of the condylar cartilage.[8] While the precise influence of altered mandibular posture on condylar growth is incompletely understood, experimental studies have demonstrated the effects of postural variation on the condylar growth and resulting gross phenotypic changes in mandibular form.[9,10] For example, posterior relocation of the glenoid fossa relative to the mandibular condyle in a rabbit model results in significant morphological changes in the shape of the condylar surface and an increase in mandibular length.[11,12] Sugiyama et al.[13] found that altering the vertical relationship between the maxilla and mandible using a plate bonded to the maxillary molars in a rat model resulted in altered condylar growth associated with greater posterior mandibular rotation. In a similar fashion, Ferrari and Herring[14] examined the effects of bite blocks on craniomandibular growth using a sample of miniature pigs. In addition to a number of morphological changes in the maxillary region, the mandible exhibited a pattern that suggests increased posterior rotation including a larger gonial angle (see,[14] Fig. 2) as well as significant changes to the condylar surface.

Whereas many experimental studies have examined the influence of functional appliances that encourage posterior condylar growth and thus backward mandibular rotation, less is understood about the morphological effects of developmental modifications that encourage anterior rotation of the mandible. This is particularly important from an orthodontic perspective given that treatment of hyperdivergent patients with retrognathic mandibles via functional appliances achieves dental correction but is unable to correct associated vertical and sagittal skeletal discrepancies.[15] Moreover, maxillary impaction surgery producing autorotation of the mandible in growing patients does not appear to inhibit mandibular growth or affect the long-term rotational pattern of the mandible.[16] A limited number of studies, however, have documented that anterior mandibular rotation induced by molar intrusion results in favorable skeletal changes in hypodivergent patients such as increased chin projection, reduced facial height and a decreased gonial angle.[15,17,18]

In the present study, we examined whether experimentally altered maxillary position has a significant influence on patterns of mandibular rotation in a pig model. This is a continuation of our research examining the influence of rigid plate fixation of the circummaxillary sutures on facial growth and development.[17–19] Previously we found that sutural fixation affects maxillary morphology such that pigs with restricted sutural growth exhibited shorter and more dorsally rotated (i.e., superiorly displaced) snouts. Using geometric morphometric techniques, we report how altered vertical maxillary position affects the growth of the mandible by addressing the following research questions. First, to what degree does variation in vertical maxillary position affect the pattern of mandibular rotation in our experimentally modified pigs when compared to normal, non-experimentally modified sample of control pigs? Second, if the pattern of rotation is altered as a result of the vertical displacement of the maxilla, how is this pattern reflected in the morphology of the condylar region?

2. Materials and methods

Ten female *Sus scrofa* sibship cohorts, each consisting of three individuals, were allocated to one of three trial groups (i.e., experimental, sham and control). Surgical procedures are described in detail in Holton et al.[18] Briefly, in the experimental group ($n = 10$), rigid miniplates were bilaterally affixed across the zygomaxillary, frontonasal and nasomaxillary sutures at two months of age. The sham group ($n = 10$) underwent an identical surgical procedure but received only microscrew implantation. The control group ($n = 10$) underwent no surgical procedure. All animals were euthanized following four months of post-surgical growth (i.e., six months of age). One control pig did not survive to age 6 months, and one sham pig was damaged during post-mortem processing resulting in a total of $n = 28$ pigs available for analysis (i.e., $n = 10$ control, $n = 9$ sham and $n = 9$ control). Since there were no significant differences between our control and sham pigs, these were combined into a single control group for all analyses. The University of Iowa Institutional Animal Care and Use Committee approved all procedures. For comparison, CT images illustrating the gross morphological differences between an experimental pig and a control pig are found in Fig. 1.

To assess variation in mandibular form, we collected a series of $k = 25$ two-dimensional traditional and semilandmarks from CT images that were imported into tpsDIG 2.12 software.[20] We selected landmarks that adequately represented the mandibular corpus, mandibular ramus and condylar process including the articular surface of the condyle (Fig. 2). All landmarks were superimposed and scaled using generalized Procrustes analysis (GPA). This method translates objects to a common centroid origin, scales for size, and rotates objects using a least-squares criterion. In the case of our semilandmarks, a sliding semilandmark analysis was also conducted (as a component of the GPA). Sliding semilandmark analysis superimposes the semilandmarks by sliding them along the curve to a consensus position that minimizes the summed squared deviations for each given landmark across the sample. This renders the semilandmarks homologous, allowing semilandmarks henceforth to be treated the same as standard landmarks in further analyses.[21]

With regard to our first research question, (i.e., effect of maxillary variation on mandibular rotation), we first tested for significant differences in overall mandibular shape between our experimental and control trial groups using Procrustes ANOVA. Next, we used principal components analysis (PCA) of Procrustes scaled shape variables to examine axes of variation

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