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Changes in mandibular dimensions during the mediaeval to post-mediaeval transition in London: A possible response to decreased masticatory load

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ABSTRACT

Objectives: Biomechanical forces, such as those produced during mastication, are considered a primary agent in stimulating craniofacial growth and development. There appears to be a strong connection between the strength of the masticatory muscles and the dimensions of the craniofacial complex, with changes in biomechanical force and muscular strength influencing and altering the underlying bony tissues. This is markedly apparent in the mandible and it is possible to infer that changes to mandibular form are due in part to dietary changes. This study aims to investigate this idea by using an archaeological sample from a period that experienced important dietary changes as a result of the Industrial Revolution.

Design: 279 skeletons from the mediaeval and post-mediaeval periods in London were selected for analysis, and a detailed metric examination of each mandible was carried out.

Results: Males and females were analysed separately and statistically significant reductions were observed in nearly all post-mediaeval measurements. This effect was most pronounced in the areas of the mandible associated with masticatory muscles attachment, including the gonial angle, ramus height and width, bi-gonial breadth and bi-condylar breadth.

Conclusions: These recorded changes in mandibular morphology of mediaeval and post-mediaeval Londoners are most likely the result of a shift in diet (and associated decrease in masticatory function) observed in the period surrounding the Industrial Revolution.

1. Introduction

The masticatory muscles are the strongest in the human skull and play the primary role in placing mechanical strain (compression, tension and shear) on the growing bones, with all growth zones (chondral, sutural and periosteal) responsive to biomechanical forces.[1] Changes in masticatory muscle activity can alter the strain applied to the bones of the skull, affecting the growth of the craniofacial complex.[2] According to Frost[3,p. 5], during embryonic development, the 'biologic machinery that can adapt bones after birth to mechanical and other challenges' is created, and this machinery includes the thresholds that control bone resorption and formation.

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When the strain on a bone exceeds the upper thresholds, depositional mechanisms are switched-on which stimulate bone production and increase the overall strength of the bone; conversely, when strain falls below the lower thresholds, bone is resorbed, reducing bone strength.[3] Grunheid et al.[4] note that bone mineral density is related to bone loading (strain), such that more heavily loaded bones tend to be less mineralised and stiff, while weakly loaded bones tend to be stiffer and more mineralised. The regions of bone most likely to be affected by changes to strain/loads are those directly involved in mechanical loading – such as muscle attachment sites – with membranous bones, including the mandible and the bones of the face, more susceptible to external factors.[5]

The complex relationship between underlying masticatory muscle structure, bite force (strength), and craniofacial dimensions has been well established in the literature. Raadsheer et al.[6] note four important connections when considering the dynamics between these variables: (1) bite force magnitude is related to jaw muscle cross-section; (2) bite force magnitude is related to craniofacial dimensions; (3) craniofacial dimensions and jaw muscle cross-sections are related; and (4) a relationship between muscle size and craniofacial dimensions exists. Each of these will be briefly addressed considering both human and animal models.

Using human models, multiple studies have observed that changes in bite force strength are correlated with corresponding changes in craniofacial dimensions. Ingervall and Helkimo[7] observed that individuals with stronger bite force tended to have broader faces, a straighter cranial base, and a more uniform facial shape, while Ingervall and Minder[8] noted that larger bite force in children was correlated with smaller mandibular inclination, smaller gonial angles and larger posterior facial height. Tuxen et al.[9] also noted that stronger molar bite force was associated with smaller gonial angles, as did Sondang et al.[10]. In one of the few studies on this subject experimenting on human subjects, Ingervall and Bitsanis[11] initiated a muscle training programme in children (between 7 and 13 years old) to observe the direct connection between increasing bite force and craniofacial measurements. Throughout the course of training, bite force in the children increased more than would be expected as a result of the normal ageing process and the children with increased bite force experienced an increase in mandibular rotation and resorption along the gonial angle.

Jaw muscle thickness has been found to be connected to craniofacial dimensions, in that thicker muscles (more specifically, the masseter) tend to be negatively correlated with anterior facial height and mandibular length, but positively correlated with intergonial width and bizygomatic width.[12] Weijs and Hillen[1] observed a correlation between the cross-sectional size of the jaw muscles and craniofacial dimensions, suggesting that each of the different muscles of mastication plays a different role in the growth of the face; the cross sections of the masseter and temporalis are positively correlated with facial width, while the masseter and medial pterygoid are associated with mandibular length. Kubota et al.[5] observed that the thickness of the masseter was significantly correlated with the mandibular plane angle and the thickness of the alveolar process, the mandibular symphysis, and the mandibular ramus.

Studies on animals have shown that reduced masticatory muscle function results in reduced size and altered proportions of the craniofacial complex, especially in the mandible.[5] This suggests that large masticatory muscles and strong chewing forces are needed to attain ‘normal’ facial growth. Research examining rats[13–22] and rock hyrax[23] has shown that animals fed a soft diet (compared against animals fed a hard diet) exhibit differences not only in facial dimensions, but also in the rate of bone growth. Hard diet fed animals tend to have larger dimensions overall, especially in the maxillary breadth[13,17] and posterior facial measurements,[23] compared with the soft-diet groups. In their study, Maki et al.[19] noted that it was rats fed a powdered diet, rather than those with just a soft diet, that experienced the most profound alterations to jaw bone morphology. The rate of bone growth appears lower in the soft-diet animals,[15–18] thought to be a result of reduced muscle function and reduced demands on the masticatory system. Alterations to bone density have also been observed in rabbits fed a soft diet, with heavily loaded bone being less mineralised or stiff and weakly loaded bone has a decreased rate of remodelling and is stiffer/more mineralised.[4] Grunheid et al.[4] further noted that this is most pronounced in areas of mechanical loading – such as those at muscle attachment sites.

Through examination of muscle thickness and the shape/size of the maxillofacial skeleton, multiple studies[5,24,25] have noted that changes in human diet have reduced the forces generated by the masticatory complex. This reduction has had an impact on craniofacial dimensions, furthering the idea that changes in masticatory function have been a predominating factor in the alteration of the human face since the emergence of agriculture and the adoption of less chewing intensive foods. Furthering this notion, clinical studies focused on dental attrition, bite force and cranial dimensions[26–29] have noted that patients with ‘advanced’ dental wear present with reductions in the height of the lower face, smaller gonial angles, increased bite force and somewhat more prognathic faces. It is worth noting here that the tooth wear observed in these cases may be considered pathological – the result of bruxing – and may not be useful when considering changes to dietary composition.

The post-industrialized human diet is notably softer and more refined than traditional agricultural diets, and as such contributes very little to tooth wear.[30–32] This is primarily the result of the advancement of food processing technologies which have effectively stripped food of any abrasive particles and fibrous content, and due to our ‘reliance on [these] factory processed foods’[33,p. 861] as the main (and nearly only) means of food procurement. With the Industrial Revolution and increasing urbanisation, the majority of people no longer made or grew their own foods and had to rely solely on what was available for purchase. Naturally the most readily and convenient foods tended to be the most processed, softest, and sweetest ones, which caused a marked increase in oral pathology but created little in the way of tooth wear.

The evidence from the clinical literature supports the notion that bone responds to external mechanical stresses and that changes to diet, as observed in animal studies, can alter both the growth and form of the skull, particularly the jaws and the face. This study aims to investigate whether, in