Skull and Vocal Tract Growth from Fetus to 2 Years

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Abstract

The first two years of life are crucial for the acquisition and development of speech. To accurately follow the growth of the vocal tract and the articulators and to infer their motor control during this period, it is essential to have anatomic and physiologic data throughout ontogenesis from gestation to adulthood. The morphogenesis of the vocal tract, which involves the bony structures, their development, and cranio-facial growth during ontogenesis, is far from linear. The anatomy of the bones, muscles, and cartilages which embody the walls and geometry of the vocal tract is well known for adults, adolescents, and even for children. It is not as well known for the fetus or the baby from birth to two years of age. Our paper concerns the morphogenesis of the mandible, the geometry and the position of the vocal tract relative to skull base and cervical vertebrae, and the differences in growth rate before and after the appearance of breathing, sucking, swallowing, mastication. To predict the consequences of vocal tract growth on speech production we use an articulatory model which can be fitted on midsagittal anatomic images.

1 Introduction

This general frame of this research is the acquisition and development of speech and its motor control in the light of its relationship with craniofacial growth. We focus on the relation between skull growth and the control mechanisms coordinating tongue and mandible from gestation to adulthood. We investigate how the evolution of this bony architecture influences or determines the control of the mandibular, lingual, and labial movements during speech production. These mechanisms are implemented during a specific period of growth, the first two years of life; they are crucial to better understand both speech acquisition and evolution of human speech. In particular, the appearance of babbling at around 7 months can be considered the real start of the emergence of speech; then, between 11 and 14 months, the control of the syllabic structures begins with the acquisition of the first words, presenting coarticulatory gestures between vowels and consonants within syllables. At the level of motor control, studies have shown different stages in the control of the lips, tongue, and mandible [1] and the emergence of motor control representation [2]. The morphogenesis of the vocal tract depends on the bony structures and their development. Moreover, bipedalism modifies the position of the bony and muscular structures of the head and neck and the orientation of the vocal tract. We must keep in mind that to produce speech, mankind has "hijacked" the vocal tract, which evolved, rather, to breath, swallow, and masticate. During fetal growth, the maturation of the respiratory and digestive functions appears gradually. These two functions are associated with two important anatomic and functional units: the airway, constituted by the nasal–ethmoidal–maxillary complex, and the oral region, constituted by the mandible [3]. The functions of breathing, sucking and swallowing have already matured by birth, before the creation and the control of the complex pattern governing mastication. We have investigated whether there are differences in the growth patterns before and after birth.

2 Data

We used two databases. The first [4] used French skulls to determine the average values of anthropometric landmarks for nine growth stages: 5 months and 7.5 months of fetal life; birth; then 1, 2, 4, 8.5, and 14 years of age; plus adulthood. This dataset consists of 3D coordinates of 142 bony landmarks including 13 mandible points. Although this database was not designed to study vocal tract growth, several bony landmarks (anterior and posterior nasal spine, prosthion, infradentale, pogonion, menton, gonion, upper part of the condyle) are usable for determining vocal tract position with regard to the skull and for improving an articulatory model of speech production. The second database is speech oriented: RX measurements (of American subjects) were gathered from medical literature to design a 2D articulatory model of the vocal tracts of women and men from birth to adulthood [5]. All the data (13 anatomical landmarks, 3 reference lines, 3 angles and 16 distances) are fitted by curves (simple and double logistic or exponential) and presented in the form of graphs and tables to represent the expected pattern of growth. In speech science manuals, the laryngeal source and vocal tract are described in terms of soft tissues, typically without relating them to bony architecture other than the upper and lower incisors for mandible position and sometimes the hyoid bone, if it is visible on X-ray images. The cervical vertebrae are only referred to when describing the position of the larynx and the vocal folds. The interest of this second database is the determination of the position of the vocal tract relative to the skull architecture, the hyoid bone, and the cervical vertebrae, all of which are closely related to vocal tract configuration. To these two databases we have added: (i) anatomical landmarks for the fetus between 17 and 37 weeks (12 subjects, 41 anatomical landmarks and 2 reference lines) (Figure 1a); (ii) MRI data [6] for children in early childhood (7 months) (Figure 1b); and (iii) RX data of 4-year-old children (50 subjects, 34 landmarks, 3 reference lines) [7].

3 Articulatory model

We adjusted [8] our articulatory model [9] to midsagittal X-ray and MRI image data from the fetus and from children aged 7 months to 2 years (Figure 1). The parameters available in the model's improved version [10] control the pharyngeal walls, tongue flattening, and inclination angle of the head. The model is controlled by 14 parameters: age and f0, plus three groups: anatomical (palate height, front-back dimension of the oral cavity, and pharyngeal height), positional (inclination of the head relative to the cervical rachis), and articulatory (lip opening and protrusion, tongue body, tongue tip position, degree of tongue flattening, jaw opening, and position of the larynx). In this study, the model was used mainly to calculate vocal tract length and the Larynx Height Index (the ratio between the pharyngeal height and palatal distance), and to simulate [baba] sequences of babbling using dynamic synthesis [11] for a 7 month old child, while taking into account previous research [12].

4 Results

4.1 From birth to adulthood

Growth brings about a complex reshaping of the face and the cranial base, including a sphenoidal flexion which reduces the nasion-sella turcica-basion angle from 125° to 110°. This flexion and the growth of the maxilla and the mandible have important repercussions on the position and the dimension of the vocal tract, and on hyoid and glottis position relative to the cervical vertebrae. Therefore, the pharyngeal cavity presents a very different evolution from that of oral cavity. One important phenomenon: the mandibular angle closes from 135° to 115°, inducing a posterior movement of the tongue root, towards the anterior part of the cervical vertebrae (Figure 2).

4.2 From gestation to 2 years

We find substantial continuity between our measured data for the fetus from 17 to 37 weeks and the previously published data for fetus and newborn [4, 5]. The data we have assembled lead us to these findings about the changes from pre- to post-natal periods (Figures 3-4): the sphenoid angle is reduced (from 140° to 125°); the rate of increase in palate height slows substantially; the infradentale-gnathion-gonion angle decreases rapidly with the appearance of the first deciduous teeth, foreshadowing the appearance of the chin; the hard palate lowers relative to the cervical vertebrae (from above C1 for the fetus); the posterior pharyngeal wall moves distinctly closer to the anterior part of the cervical vertebrae after birth; the hyoid bone and the glottis shift lower (from level with C1 and C3 for the fetus to C3 and C4 at 2 years); and the Larynx Height Index, constant through gestation at approx. 0.55, increases starting at birth (Figure 3). As for growth rates, they differ little before and after birth, except for the increase in the anterior-posterior dimension of the oral cavity which decelerates abruptly after birth (Figure 4), and results in turn in a substantial slowing of vocal tract lengthening. It is important to learn whether this particular slowing of the growth rate is genetically programmed or rather attributable to the functions of respiration and mastication or to the vertical position of the head. In any case, the fetus possesses a vocal tract whose geometry, if it were controlled, would permit vocalic configurations comparable to those of 2-year-old children, adolescents, or adults [13].

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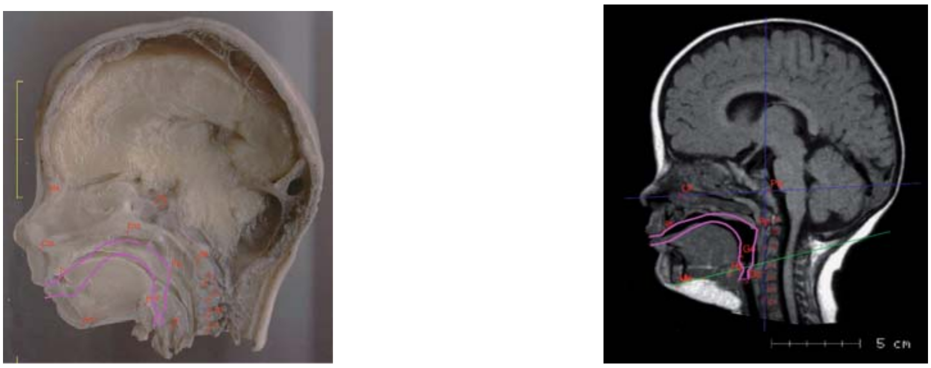

Figure 1a *Figure 1b*

Images for a 17-week-old fetus (1a, anatomic) and a 7-month-old newborn (1b, MRI), showing adjustment of an articulatory model of the vocal tract for simulation of vowels, consonants and syllables.

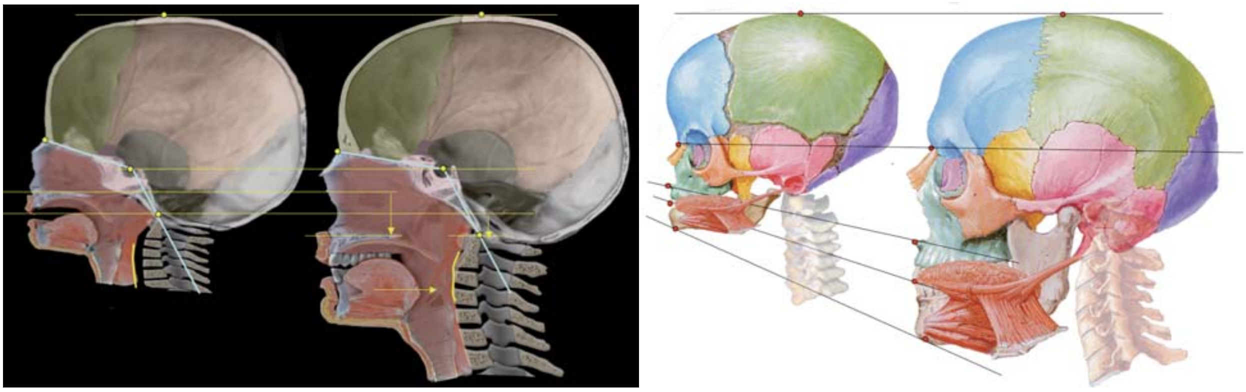

Figure 2a *Figure 2b*

Bony architecture and tongue growth from newborn to adult. Note the differences for: the sphenoid angle; the relative positions of hard palate, pharyngeal wall, and cervical vertebrae; and the angle of the styloglossus muscle.

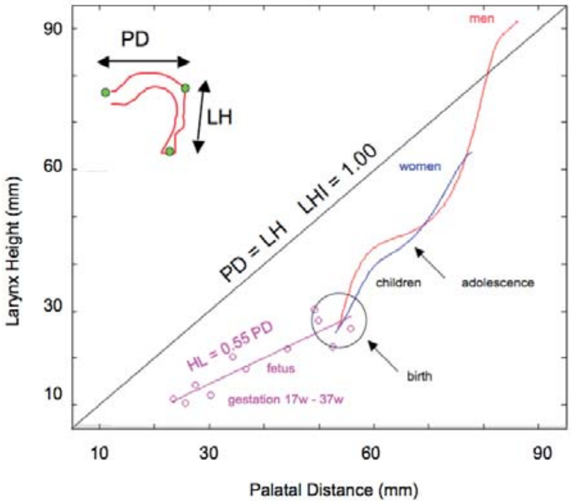

Figure 3: Variations of palate and larynx height during growth.

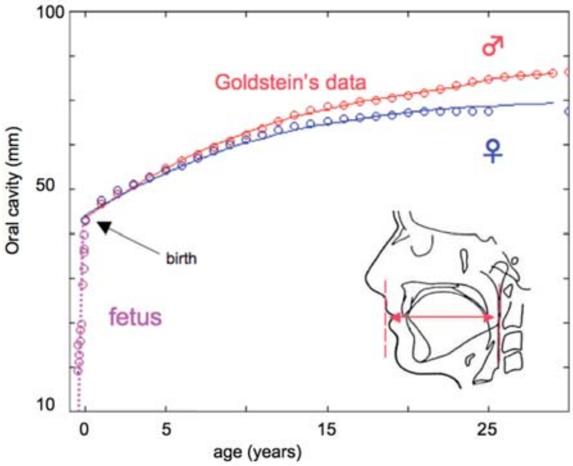

Figure 4: Variation in the oral cavity's anterior-posterior dimension. Note the change in growth rate before and after birth.