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ORIGINAL RESEARCH

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Growth and development of epiglottis and preepiglottic space of larynx as it acquires vocal tract

Kiminori Sato M.D., Ph.D | Shun-ichi Chitose M.D. | Kiminobu Sato M.D. | Fumihiko Sato M.D. | Takeharu Ono M.D. | Hirohito Umeno M.D.

Department of Otolaryngology-Head and Neck Surgery, Kurume University School of Medicine, Kurume, Japan

Correspondence
Kiminori Sato, Department of Otolaryngology-Head and Neck Surgery, Kurume University School of Medicine, 67 Asahi-machi, Kurume 830-0011, Japan.
Email: kimisato@oct-net.ne.jp

Abstract

Objectives: The growth and development of the epiglottis and preepiglottic space (PES) of the human larynx as it acquires the vocal tract were investigated.

Methods: Three newborns, one infant, four children (2, 7, 8, and 12 years old), and two adult normal larynges were investigated and compared using the whole organ serial section technique.

Results: The newborn PES occupied a small area just anterior to the epiglottis. It was composed of immature adipose tissue and areolar tissue. The epiglottis lay on a somewhat horizontal axis and is partially obscured behind the hyoid bone. The hyoid bone overlapped the thyroid cartilage, partially obscuring the superior thyroid notch. The newborn epiglottic cartilage was immature elastic cartilage, and the elastic fiber component was sparse. In the first 8 years of life, as the PES grew, the PES was located not only anterior to but also posterolateral and inferolateral to the epiglottic cartilage and thyroepiglottic ligament. Meanwhile, the epiglottic cartilage matured.

Conclusions: In order to develop the vocal tract for speech production, it is reported that the human larynx descends as the child grows in the first 9 years of life. This study showed that the PES, occupying a small area just anterior to the epiglottis, grew and existed astride the epiglottis as the larynx descended and the vocal tract developed. Consequently, its distribution allows the epiglottis to more effectively play the role of retroflection during swallowing in order to prevent aspiration. The human speech faculty likely develops in conjunction with swallowing physiology.

KEYWORDS
epiglottic cartilage, epiglottis, growth, larynx, preepiglottic space

1 | INTRODUCTION

In human adults, the larynx has descended to lengthen the pharyngeal space of the supralaryngeal vocal tract, and the vertical pharyngeal space has become equally long as the oral space, forming the two-tube vocal tract that facilitates speech production.[1,2] The distribution of the preepiglottic space (PES) of the adult larynx allows the epiglottis, composed of epiglottic cartilage (elastic cartilage), to more

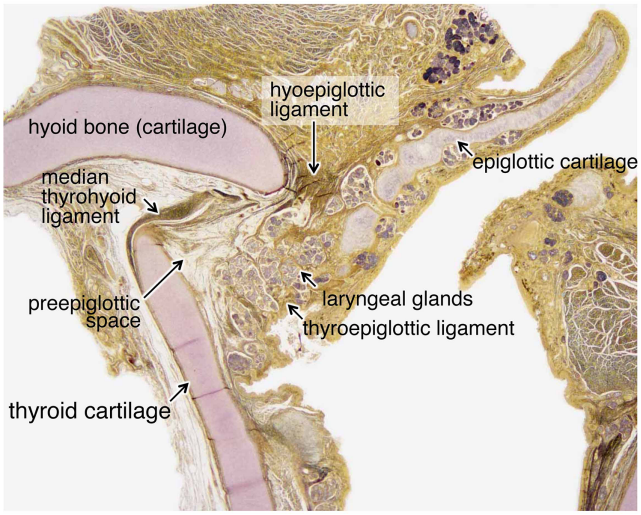

FIGURE 1 Midsagittal section of the human newborn larynx (Elastica-van Gieson stain). The newborn preepiglottic space occupied a small area anterior to the epiglottis. *Source:* Figure adapted from Sato et al.,[7] I am the author of this article and the publisher grants authors the right to reuse their own figures with permission.

effectively play the role of retroflection during swallowing in order to prevent aspiration.[3–6] Therefore, human speech faculty develops in conjunction with swallowing physiology.

On the other hand, in newborns, the larynx has not descended to lengthen the pharyngeal space of the supralaryngeal vocal tract, and the vertical pharyngeal space is not equally long as the oral space. Furthermore, the newborn PES occupies a small area anterior to the epiglottis.[7]

The epiglottis and PES grow and develop as the larynx descends and the pharyngeal space of the supralaryngeal vocal tract grows and develops. However, the growth and development of the epiglottis and PES of the human larynx as it acquires the vocal tract are unknown.

The purpose of this study is to investigate the growth and development of the epiglottis and PES of the human larynx as it acquires the vocal tract using the whole organ serial section technique.[3]

2 | MATERIALS AND METHODS

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guidelines on human experimentation by the Ethics Committee of Kurume University (Permission number, 21129), and informed consent from participants was received.

Three normal human newborns, one normal infant (6-month-old girl), four children (2-year-old girl, 7-year-old girl, 8-year-old boy, and 12-year-old boy), and two adult (17-year-old male and 24-year old male) larynges obtained from autopsy cases were investigated. In order to ensure accurate capture of PES, hyoid bone and tongue base were included when the larynges were harvested. Any diseases that could possibly affect the tissue of the larynges were not observed.

The whole-organ serial section technique[3] was employed. The larynges were fixed with 10% formalin. They were dehydrated in graded concentrations of ethanol and embedded in paraffin. Transverse and sagittal serial sections were made. Transverse serial sections were made parallel to the membranous portion of the vocal folds.

Hematoxylin & Eosin and Elastica-van Gieson stains were employed for each section. Elastica-van Gieson staining facilitates observations of the fibrous tissue (collagen and elastic fibers). Light microscopic observation was performed and compared with human newborn and adult larynges, which were previously reported.[4–10]

3 | RESULTS

3.1 | Epiglottis and PES of the newborn larynx

Some morphological findings have already reported.[7] However, already reported and additional findings were described in this section.

The newborn PES was present as a small space anterior to the epiglottis and epiglottic cartilage (Figure 1).[7]

The hyoid bone (in newborns, not a bone but a cartilage) sat cephalad to the thyroid cartilage and overlapped the thyroid cartilage, partially obscuring the superior thyroid notch, indicating the thyroid cartilage was present close to the hyoid bone (Figure 1). The epiglottis and epiglottic cartilage lay on a somewhat horizontal axis and were partially obscured behind the hyoid bone (Figure 1). Consequently, the newborn hyo-larynx had not yet descended and had not developed the pharyngeal space of supralaryngeal vocal tract as in adults.

The PES was surrounded by the thyroid cartilage anteriorly, by the thyroepiglottic ligament and epiglottic cartilage posteroinferiorly, and by the hyoepiglottic ligament, hyoid bone (cartilage), and thyrohyoid membrane superiorly (Figure 1). However, the newborn PES occupied just a small area anterior to the epiglottis. The newborn PES did not extend posterolateral and inferolateral to the epiglottis (epiglottic cartilage) like in the adult larynx.

The median thyrohyoid ligament and thyrohyoid membrane ran between the superior surface of the lamina of the thyroid cartilage and the posteroinferior surface of the hyoid bone (cartilage) (Figure 1). It did not run between the superior surface of the lamina of the thyroid cartilage and the anteroinferior surface of the hyoid bone, as seen in adults. The thyrohyoid membrane continued into the perichondrium of the hyoid bone (cartilage) and the thyroid cartilage (Figure 1).

The small PES area anterior to the epiglottis of the newborn larynx was a loose connective tissue (areolar tissue) area mainly composed of adipose tissue and loose elastic and collagen fibers (Figure 2A). Adipose tissue was not white but brown adipose tissue (immature adipose tissue) (Figure 2A).

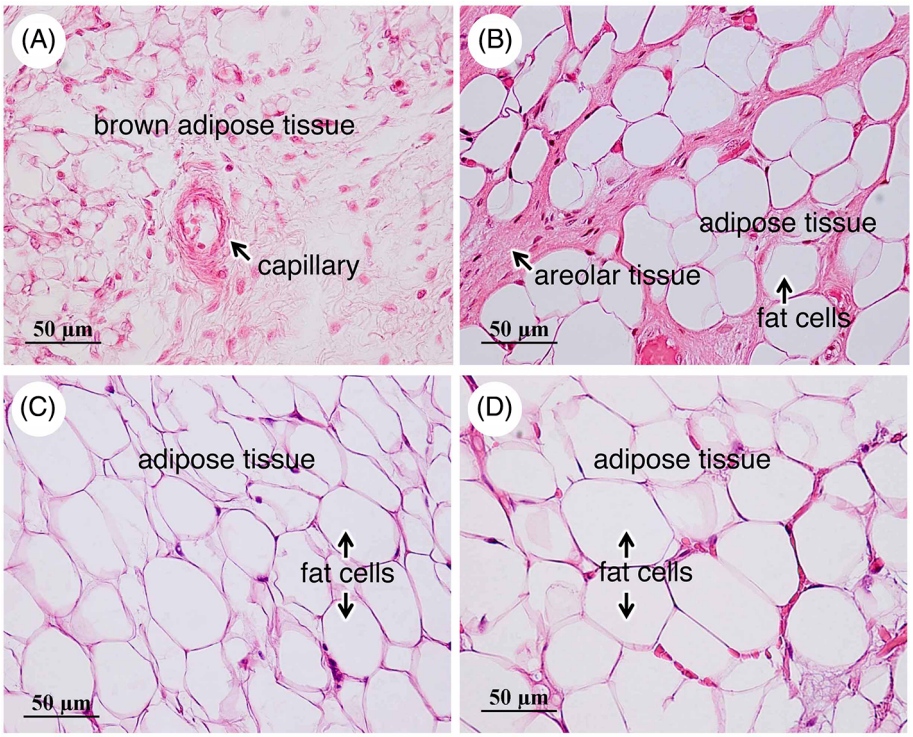

FIGURE 2 Adipose tissue in the preepiglottic space. (A) Newborn, (B) Infant, (C) child (7 years old), and (D) child (8 years old). (A) Adipose tissue was not a white but a brown adipose tissue (immature adipose tissue). (B–D) Adipose tissue was a white adipose tissue (mature adipose tissue).

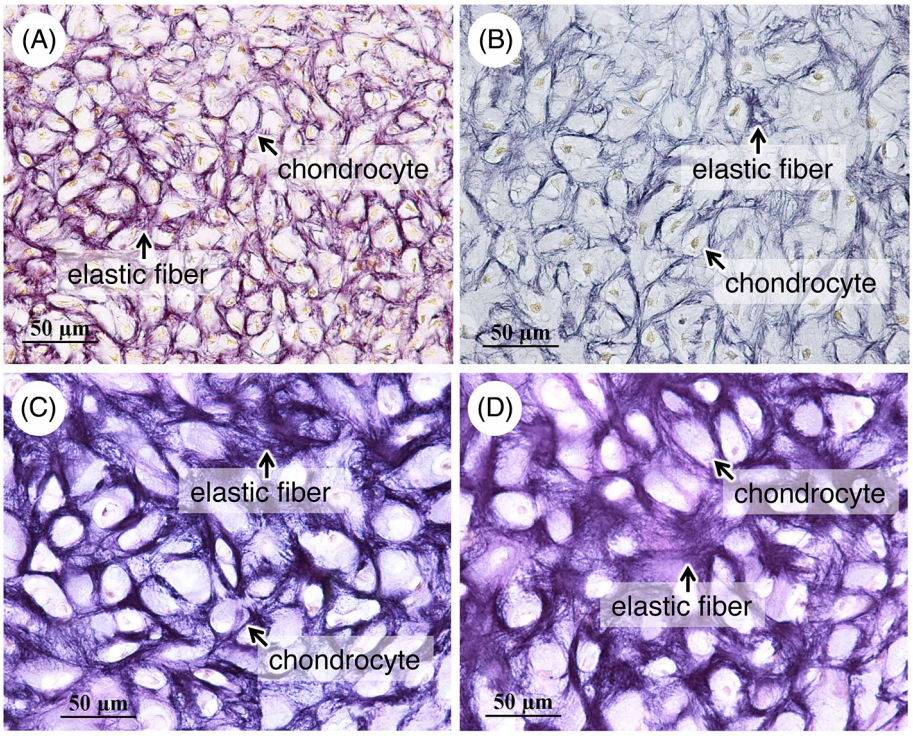

FIGURE 3 Epiglottic cartilage of epiglottis. (A) Newborn, (B) Infant, (C) Child (7 years old), and (D) Child (8 years old). (A, B) Elastic cartilage was immature, and the elastic fiber component was somewhat less abundant. (C, D) Elastic cartilage was mature and the elastic fiber component was somewhat abundant.

The PES contained laryngeal glands, and they opened to the epithelium of the epiglottis (pseudostratified ciliated epithelium) via the pore of the epiglottic cartilage.

The epiglottic cartilage of newborns was immature elastic cartilage and was mainly composed of elastic fibers and chondrocytes (Figure 3A). Elastic fibers were somewhat less abundant (Figure 3A). The structure of the epiglottic cartilage indicated that the newborn epiglottis had less flexibility.

3.2 | Epiglottis and PES of the infant larynx

The infant PES was immature and occupied a small area anterior and lateral to the epiglottis (Figure 4).

The PES was surrounded by the thyroid cartilage anteriorly, by the thyroepiglottic ligament and epiglottic cartilage posteroinferiorly, and by the hyoepiglottic ligament, hyoid bone, and thyrohyoid membrane superiorly. However, the infant PES occupied a small area

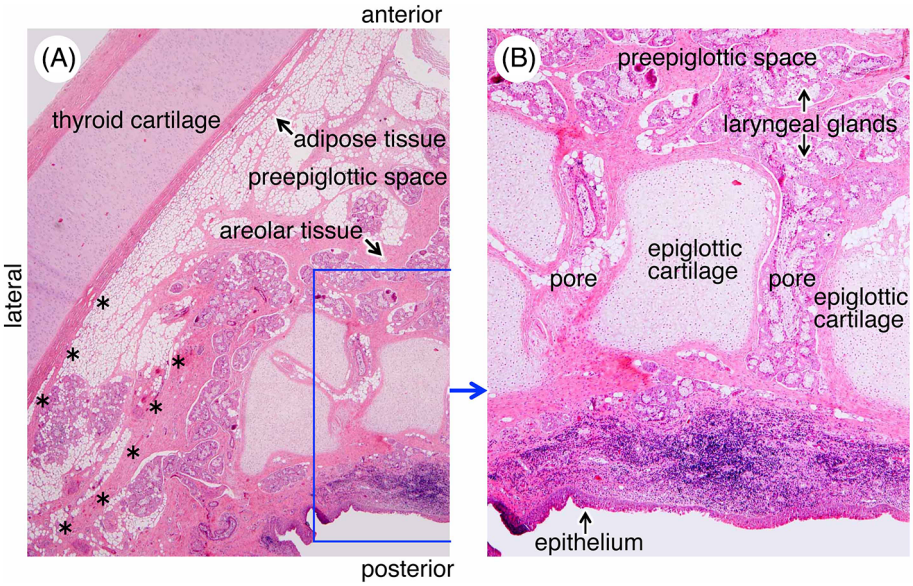

FIGURE 4 Transverse section of the human infant hemilarynx near the upper portion of the thyroid notch ([B]: square region in [A], Hematoxylin and Eosin stain). The preepiglottic space occupied a small area anterior and lateral to the epiglottis.* shows the lateral portion of the preepiglottic space

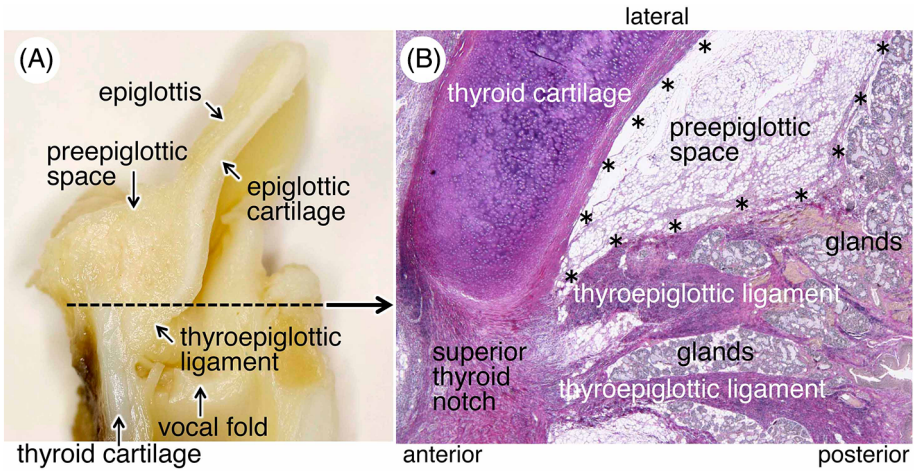

FIGURE 5 Midsagittal and transverse sections (near the upper portion of the thyroid notch) of the human child (7 year old girl) hemilarynx ([B]: transverse section at the dotted line level in [A], Elastica-van Gieson stain). The preepiglottic space of the child larynx became mature and occupied an area not only anterior to but also posterolateral and inferolateral to the thyroepiglottic ligament and epiglottic cartilage (asterisks show the posterolateral and inferolateral portions of the preepiglottic space).

anterior and lateral to the epiglottis. The infant PES did not extend posterolateral and inferolateral to the epiglottis (epiglottic cartilage) like in the adult larynx.

The small PES area of the infant larynx was a loose connective tissue (areolar tissue) area mainly composed of adipose tissue and loose elastic and collagen fibers (Figure 4). Loose connective tissue (areolar tissue) was relatively abundant. Adipose tissue was white adipose tissue (mature adipose tissue) (Figure 2B).

The PES contained laryngeal glands, and they opened to the epithelium of the epiglottis (pseudostratified ciliated epithelium) via the pore of epiglottic cartilage (Figure 4B).

The epiglottic cartilage of the infant was immature elastic cartilage and was mainly composed of elastic fibers and chondrocytes (Figure 3B). The elastic fibers were somewhat less abundant (Figure 3B). The structure of epiglottic cartilage indicated that the infant epiglottis had less flexibility.

3.3 | Epiglottis and PES of the child larynx

The PES of children around 8 years old was mature and occupied an area not only anterior to but also posterolateral and inferolateral to the thyroepiglottic ligament and epiglottic cartilage; that is, the PES existed astride the epiglottis, similar to that of adults (Figures 5 and 6).

The PES was surrounded by the thyroid cartilage and thyrohyoid membrane anteriorly, by the thyroepiglottic ligament and epiglottic cartilage posteroinferiorly, by the hyoepiglottic ligament superiorly, and by the hyoid bone (already ossified) anterosuperiorly (Figures 5 and 6).

The median thyrohyoid ligament and thyrohyoid membrane ran between the superior surface of the lamina of the thyroid cartilage and the posteroinferior surface of the hyoid bone (Figure 6). It did not run between the superior surface of the lamina of the thyroid cartilage and the anteroinferior surface of the hyoid bone, as seen in adults.

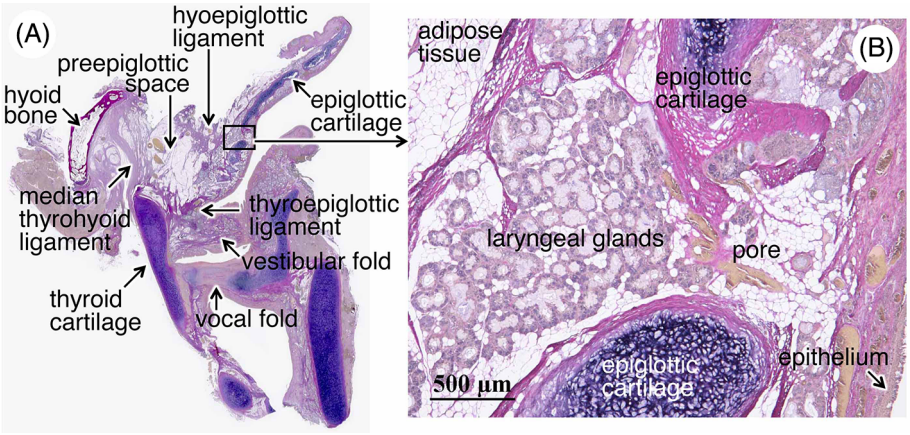

FIGURE 6 Midsagittal section of the human child (8 year old boy) hemilarynx ([B]: square region in [A], Elastica-van Gieson stain). The preepiglottic space of the child larynx had become mature. The preepiglottic space contained laryngeal glands, and they opened to the epithelium of the epiglottis via the pore of epiglottic cartilage.

The thyrohyoid membrane continued into the perichondrium of the hyoid bone and the thyroid cartilage (Figure 6).

The PES of the child larynx was a loose connective tissue (areolar tissue) area mainly composed of adipose tissue and loose elastic and collagen fibers (Figures 5B and 6B). Adipose tissue was white adipose tissue (mature adipose tissue) (Figure 2C,D).

The PES contained laryngeal glands, and they opened to the epithelium of the epiglottis (pseudostratified ciliated epithelium) via the pore of epiglottic cartilage (Figure 6B).

The epiglottic cartilage of children was mature elastic cartilage and mainly composed of elastic fibers and chondrocytes (Figure 3C,D). The matrix consisted mostly of frequently branching elastic fibers (Figure 3C,D). The structure of the epiglottic cartilage indicated that the epiglottis had greater flexibility.

3.4 | Growth and development of epiglottis and PES of the human larynx

This study indicated that in the first 8 years of life, as the PES grew, it became located not only anterior to but also posterolateral and inferolateral to the thyroepiglottic ligament and epiglottic cartilage; that is, the PES grew to be situated astride the epiglottis (thyroepiglottic ligament and epiglottic cartilage), similar to that of adults (Table 1). Meanwhile, the epiglottic cartilage matured and was composed of chondrocytes and abundant elastic fibers (Table 1).

4 | DISCUSSION

A space is defined as a demarcated portion of the body, either an area of the surface, a segment of tissue, or a cavity.[11] Therefore, the laryngeal space is defined as a demarcated portion and a segment of tissue in the larynx.

The chief laryngeal spaces of the human larynx are the PES, the paraglottic space, and the cricoid area.[6] These laryngeal spaces are very important physiologically and clinically, especially oncologically.[6] However, they are commonly used terms[12] and not included among the international standard on human anatomic terminology (Terminologia Anatomica[13]).

4.1 | Pharyngeal space of supralaryngeal vocal tract

The vocal tract is a complicated-shaped tube that acts as a resonator, and its shape is varied by the movement of the vocal organs.[14] In human adults, the vertical pharyngeal space and the horizontal oral space are almost equally long to form the two-tube configuration of the supralaryngeal vocal tract that facilitates speech production.[14] The hyo-larynx descends along the neck to lengthen the pharyngeal space of the supralaryngeal vocal tract. The resulting changes in its resonant frequencies play an important part in speech production.[14] On the other hand, the hyo-laryngeal descent increases the potential risk of aspiration during swallowing and obstructive sleep apnea in human adults.

Human newborns have not acquired the pharyngeal space of the supralaryngeal vocal tract and show a supralaryngeal vocal tract configuration and tongue posture that resemble those seen in adult nonhuman primates.[15] In order to develop the human adult pharyngeal space of the supralaryngeal vocal tract, the human larynx descends as the child grows.[1] The hyoid bone and the thyroid cartilage, at birth overlapping, become separate[1] and the hyoid bone and larynx descend along the cervical curvature in the first 9 years of human life.[2,16]

Our investigations are consistent with the hypothesis that, in the process of evolution, the histoanatomical structures of the epiglottis and PES change and allow the larynx to descend and lengthen the pharyngeal space of the vocal tract, which facilitates speech production in humans.[17,18] Moreover, the distribution of the human PES likely allows the epiglottis to more effectively play the role of retroflection during swallowing in order to prevent aspiration.[17,18]

4.2 | Distribution of the PES in the larynx

Boyer first described the PES as a "prelaryngeal bursa."[19,20] Boyer reported that the "prelaryngeal bursa" is present anterior to the thyrohyoid membrane.[19,20] However, the PES exists posterior to the thyrohyoid membrane. Some authors have investigated the distribution of the PES.[4,21,22]

TABLE 1 Growth and development of the epiglottis and preepiglottic space of the human larynx as it acquires the pharyngeal space of the supralaryngeal vocal tract.

Newborns	Infants	Children (7–8 years old)	Adults
Epiglottis • Immature elastic cartilage (elastic fiber component was sparse)	Epiglottis • Immature elastic cartilage (elastic fiber component was sparse)	Epiglottis • Mature elastic cartilage (elastic fiber component was rich)	Epiglottis • Mature elastic cartilage (elastic fiber component was rich)
Preepiglottic space • Immature and occupied a small area anterior to epiglottis • Composed of brown adipose tissue (immature adipose tissue) and loose connective tissue • Contain laryngeal glands	Preepiglottic space • Existed anterior to and lateral to epiglottis • Composed of white adipose tissue (mature adipose tissue) and abundant loose connective tissue • Contain laryngeal	Preepiglottic space • Existed not only anterior to but also posterolateral and inferolateral to epiglottis • Composed of white adipose tissue (mature adipose tissue) and sparse loose connective tissue • Contain laryngeal glands	Preepiglottic space • Existed not only anterior to but alsoposterolateral and inferolateral to epiglottis • Composed of white adipose tissue (mature adipose tissue) and sparse loose connective tissue • Contain laryngeal glands
Larynx • Not descended Vocal tract (vertical pharyngeal space) • Not acquired	Larynx • Not descended Vocal tract (vertical pharyngeal space) • Not acquired	Larynx • Descended Vocal tract (vertical pharyngeal space) • Acquired	Larynx • Descended Vocal tract (vertical pharyngeal space) • Acquired

In the adult larynx, the PES exists not only anterior to but also posterolateral and inferolateral to the epiglottis (thyroepiglottic ligament and epiglottic cartilage); that is, the PES exists astride the epiglottis.[3–6] And the PES is a loose connective tissue (areolar tissue) area composed of white adipose tissue and loose elastic and collagen fibers.[4,6] The epiglottic cartilage of the adult larynx is elastic cartilage and mainly composed of chondrocytes and abundant elastic fibers, indicating the epiglottis has greater flexibility.

The distribution of the human newborn PES differed considerably from that of adults.[7] The newborn PES was present as a small space anterior to the epiglottis and epiglottic cartilage.[7] However, the growth and development of the epiglottis and PES of the human larynx are unknown.

The present study showed that the PES, occupying a small area just anterior to the epiglottis, grew to exist astride the epiglottis as the larynx descended as the children grew in the first 8 years of life. Meanwhile, the epiglottic cartilage became mature and gained flexibility.

4.3 | Physiological significance of the PES in the larynx

Physiologically, the PES bends the epiglottis posteriorly during swallowing. Regarding laryngeal closure, the preepiglottic body (Fink used the term "preepiglottic body" instead of PES) and tubercle are applied to the top of the adducted ventricular folds and are pressed against them by approximation of the hyoid bone and thyroid cartilage.[23]

Sato[3,6] reported that the adult PES exists astride the epiglottis (thyroepiglottic ligament and epiglottic cartilage), and its distribution allows the epiglottis to more effectively play the role of retroflection during swallowing. Sato[3,6] also reported that the PES appears to act as a cushion whose purpose is to protect the epiglottic cartilage from mechanical damage that might otherwise be caused during swallowing.

4.4 | Growth and development of the epiglottis and PES of the human larynx as it acquires the vocal tract

In order to develop the vocal tract for speech production, it is reported that the human larynx descends as the child grows in the first 9 years of life.[2,16]

The present study showed that the PES of the newborn, occupying a small area just anterior to the epiglottis, grew and developed. And the PES was located not only anterior to but also posterolateral and inferolateral to the epiglottic cartilage and thyroepiglottic ligament after the first 8 years of life. Meanwhile, the epiglottic cartilage became mature, and its structure indicated that the epiglottis had greater flexibility.

The present study suggested, in the same years of life that the human larynx descends and develops the pharyngeal space of the supralaryngeal vocal tract for speech production, the PES grows to exist astride the epiglottis. Meanwhile, the epiglottic cartilage becomes mature elastic cartilage, and the epiglottis gains greater flexibility. Consequently, the distribution of the PES and the maturation of the epiglottic elastic cartilage allow the epiglottis to more effectively play the role of retroflection during swallowing in order to prevent aspiration. The human speech faculty likely develops in conjunction with swallowing physiology.

This study has some limitations. This study is based on a small number of samples because it was extremely difficult to correct newborn, infant, and child larynges obtained from autopsy cases. This study was a functional histoanatomy of the growth and development of the epiglottis and PES of the human larynx as it acquires the vocal

tract. Physiological investigations using methods such as swallowing videofluorography are necessary.

5 | CONCLUSIONS

The PES of the newborn larynx, occupying a small area just anterior to the epiglottis, grew in the first 8 years of life to exist astride the epiglottis (epiglottic cartilage and thyroepiglottic ligament). Meanwhile, the epiglottic cartilage became mature elastic cartilage, indicating the epiglottis gained great flexibility. The PES and epiglottic cartilage grow as the larynx descends and develops the pharyngeal space of the supralaryngeal vocal tract. As a result, the distribution of PES allows the epiglottis to more effectively play the role of retroflection during swallowing in order to prevent aspiration. The human speech faculty likely develops in conjunction with swallowing physiology.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Kiminori Sato https://orcid.org/0000-0001-5415-0176
Shun-ichi Chitose https://orcid.org/0000-0002-9307-2331
Kiminobu Sato https://orcid.org/0000-0001-6537-4490
Fumihiko Sato https://orcid.org/0000-0002-7990-7590
Takeharu Ono https://orcid.org/0000-0003-2414-7034
Hirohito Umeno https://orcid.org/0000-0002-2347-495X

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