MORPHOLOGICAL COMPARISON BETWEEN NEONATAL AND ADULT HUMAN TONGUES

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There are currently no descriptions of neonatal tongue anatomy. Therefore, there have been no reports on the morphological differences between it and the adult tongue that would suggest its suitability for suckling. Serial coronal sections of a neonatal tongue were used to create a 3-dimensional model that was compared to that of the adult tongue. Compared to the adult human tongue, the neonatal tongue was found to contain 1) considerably less fat and soft tissue; 2) a thinner mucosa; 3) relatively enlarged extrinsic musculature; 4) a less-developed superior longitudinal muscle, resulting in a flat dorsal surface; and 5) attachments between the extrinsic muscles and the transverse muscle group that have not been identified in the adult tongue. The particular structure of the neonatal tongue suggests how the neonatal tongue is specialized for suckling.

KEY WORDS — extrinsic muscles, genioglossus muscle, hyoglossus muscle, intrinsic muscles, muscular hydrostat, styloglossus muscle, suckling, tongue, tongue musculature, transverse muscle.

INTRODUCTION

An understanding of the structure and organization of the tongue is essential in understanding many of the functions of the tongue in speech, respiration, control of secretions, deglutition, and suckling. The resources in the literature are rather limited with regard to the gross structure in adults and practically nonexistent for neonates. In humans, from birth to approximately 6 months, an infant's sole natural source of nutrition remains breast milk. As suckling and swallowing are the primary functions of the human neonatal tongue, its morphology would be expected to be specialized for these functions and differ from that of adult humans. In this study, this hypothesis was tested by examining the structure of a human neonatal tongue and comparing it to that of an adult tongue.

The human suckling reflex can be described as the coordinated action of the facial muscles, jaw, palatal structures, and tongue to express milk from the teat.[1,2] By cineradiography, it has been shown that human infants generate positive pressure on the teat by gentle compression between the upper lip and tongue.[3-5] Tamura et al,[6] using a feeding bottle with a specially mounted video camera, noted that once the bolus of milk is expressed from the teat, negative pressure generated by descent of the tongue base transports the bolus to the back of the oropharynx so that it can be swallowed. That study, as well as one performed by Bosma et al[7] using ultrasound, noted that tongue function during the expression and transport of milk consists of a peristaltic wave involving the midline of the tongue but not its lateral edges. Gewolb et al[8] described how this peristaltic motion blends into swallowing-related peristalsis of the pharyngeal muscles that transports the milk bolus to the esophagus.[9]

In the landmark paper on this subject from Abd-el-Malek,[10] the muscles are bilaterally situated in a connective tissue framework divided in half by a median septum. This median septum inserts deep to the dorsal mucosa along the median groove.[11] Within this framework, the tongue muscles are principally divided into the intrinsic and extrinsic muscles. The intrinsic muscles are those whose origins and attachments are entirely within this connective tissue casing, whereas the extrinsic muscles are those that arise external to this framework from a bony attachment before entering the substance of the tongue. The intrinsic muscles are customarily thought to change the shape of the tongue, and the extrinsic muscles are thought to move the entire tongue. From the dorsal mucosal surface to the attachments at the mental spine on the inner surface of the mandibular symphysis, Takemoto[12] organizes the extrinsic and intrinsic muscles into 5 strata in the tongue along the fibers of the genioglossus muscle. These strata are based on the origin and the directionality of muscle fibers. In previous work (unpublished observations), we divided the tongue into 3 parts that are easily recognizable in

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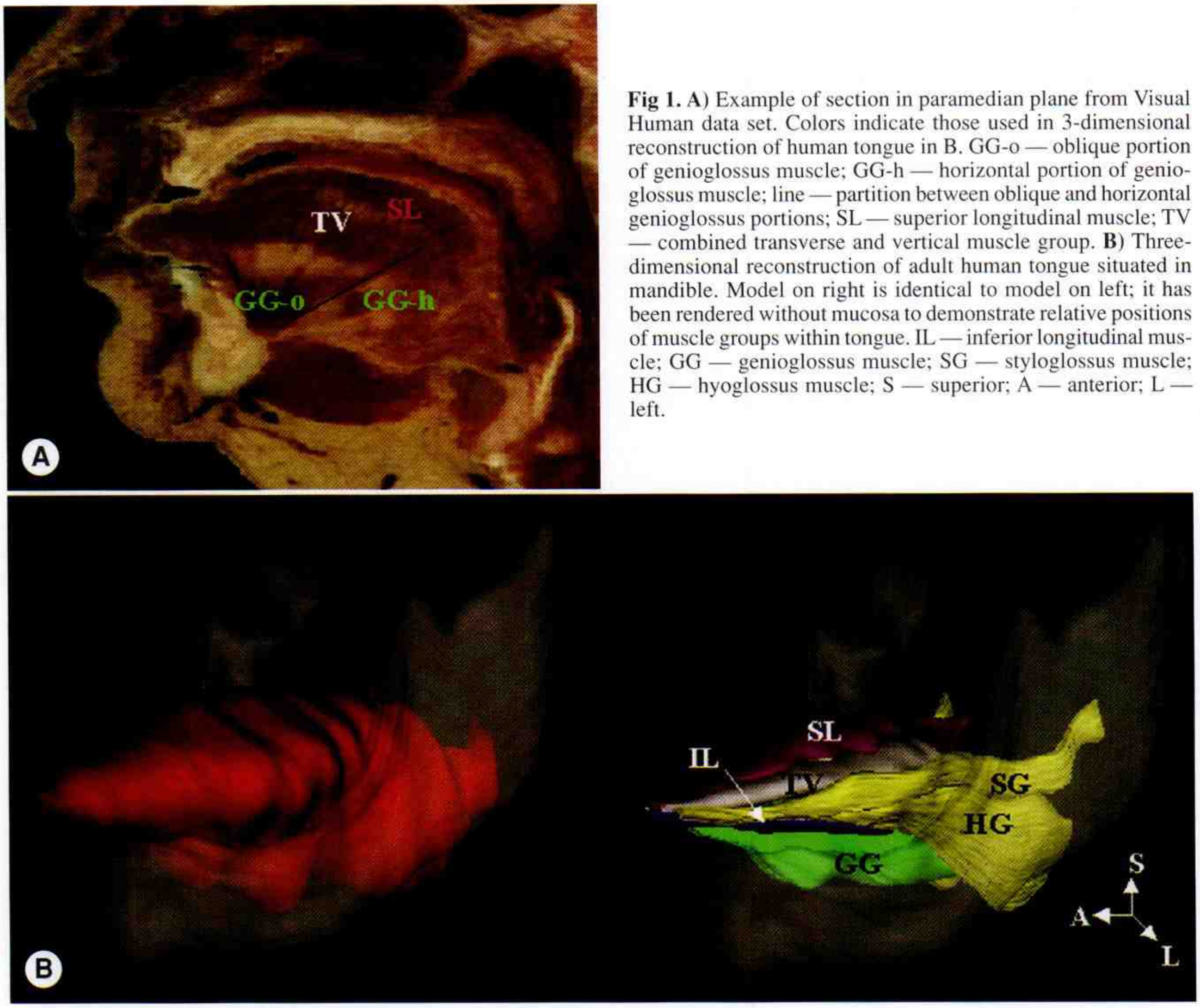


Fig 1. A) Example of section in paramedian plane from Visual Human data set. Colors indicate those used in 3-dimensional reconstruction of human tongue in B. GG-o — oblique portion of genioglossus muscle; GG-h — horizontal portion of genioglossus muscle; line — partition between oblique and horizontal genioglossus portions; SL — superior longitudinal muscle; TV — combined transverse and vertical muscle group. **B)** Three-dimensional reconstruction of adult human tongue situated in mandible. Model on right is identical to model on left; it has been rendered without mucosa to demonstrate relative positions of muscle groups within tongue. IL — inferior longitudinal muscle; GG — genioglossus muscle; SG — styloglossus muscle; HG — hyoglossus muscle; S — superior; A — anterior; L — left.

histologic sections: blade, body, and base. The blade is the portion of the tongue anterior to the frenulum, the body is the portion from the frenulum to the circumvallate papillae, and the base is that which is posterior to the circumvallate papillae and extends to the bony attachments of the extrinsic muscles. The basis for this distinction is consistent with our previous observation that the morphology of the extrinsic and intrinsic muscles differs extensively among these three levels, although it remains consistent within each level.

In the present study, neonatal and adult human tongues were sectioned and examined. According to our previous knowledge of the anatomy of the adult human tongue and the current specimens,[10,12,13] this article aims to report the anatomy of the neonatal tongue. We also describe a method for creating a 3-dimensional (3-D) computer reconstruction of the neonatal and adult tongues that allows direct morphological comparison of the intrinsic and extrinsic musculature in the specimens.

METHODS

SPECIMENS

A hemisected tongue from a 3-hour-old boy and a hemisected tongue from a 57-year-old woman were obtained from autopsy at the Mount Sinai Hospital. (Hereinafter, we use the term "hemisection" to mean any tongue specimen sectioned along the median plane into approximately equal left and right halves.) These were used for enzyme histochemical staining for the study of the relationship between the extrinsic and intrinsic muscles along the length of the tongue. The neonatal tongue sections were then used to create a schematic 3-D reconstruction. A third adult autopsy specimen was used for thick sectioning, which was to provide 3-D information not possible to obtain from the histochemically studied sections. The fourth specimen used in this study was available through the Visual Human Project of the National Library of Medicine (www.nlm.nih.gov/research.visible/visible_human. html). The images were from a woman's tongue that was cryosectioned, and highresolution images of the tongue in the coronal plane were used for a 3-D reconstruction (Fig 1A).

ENZYME HISTOCHEMISTRY

The hemisected adult and neonatal tongues were used for the study of the anatomic relationship between the extrinsic and intrinsic muscle fibers within the substance of the tongue and for the relative comparison between the adult and neonatal structures. Both specimens were dissected in a similar manner. The hyoid bone was dissected and isolated from its surrounding fascia and the anterior pharyngeal wall. The genioglossus muscle was detached from the mental spine of the mandible. The stylohyoid ligament and styloglossus muscle were severed from the styloid process. The palatoglossus muscle was severed along the palatine aponeurosis of the soft palate.

The method used in the preparation of the histochemical sections is based on that described by Jiang et al.[14] The autopsy specimens were frozen in isopentane cooled by dry ice for sectioning preparation. Serial coronal cross sections 10 μm thick were cut for the length of the tongue with a cryostat at −25°C and mounted. The cross sections were stained for adenosine triphosphatase by the method used by Guth and Samaha.[15]

To study the microscopic relationship between the extrinsic and intrinsic muscles, we then photographed the sections using a digital camera attached to a Zeiss Axiophot light microscope. The captured images were then transferred to a personal computer with image viewing software installed.

THICK SECTIONING

The tongue used for thick sectioning aided in determining the 3-D organization of the tongue. The specimen was removed in the manner described above for the neonatal tongue. It was then fixed in formalin and sectioned in the coronal plane at thicknesses from 1 to 3 mm on a rotary microtome along the length of the tongue. The sections were processed as whole mounts and rendered translucent when examined by a transilluminating light source. The sections were then photographed with a Ricoh RDC-7 digital camera and transferred to a personal computer with image viewing software installed. These images did lend themselves to demonstrating the 3-D structure of muscle fibers by providing some depth perception not afforded by the thinner histochemical sections.

THREE-DIMENSIONAL RECONSTRUCTION

The neonatal hemisected specimen and the tongue used in the Visual Human Project were used to render 3-D schematic reconstructions of the tongue to aid in understanding the spatial organization of the tongue. The work of Abd-el-Malek[10] and Miyawaki[13] was limited to the use of photographs and pictures that are themselves 2-dimensional. These do not allow appreciation of the 3-D complexity of the tongue. The neonatal sections were digitized and transferred directly to a personal computer with a Documan 2400S film scanner at 9,600 dpi. With a personal computer, the serial digital images can be used to construct a 3-D schematic of the tongue (Fig 1B).

The schematic is constructed with a program available for the personal computer. The program, Surfdriver (www.surfdriver.com), allows for construction of a 3-D image of any serially sectioned object from digital images of the sections. In this study, 51 of the digitized serial coronal sections were opened in Surfdriver. The fascicle or group of fascicles on each slide that depicted the muscle in question was outlined. The outlines were then aligned to remain consistent with the curvature of the tongue and rendered with a surface into a 3-D object. Each object, therefore, depicts a particular muscle. The characteristics of each surface, including color, texture, and opacity, were then adjusted to clarify their relative orientation and to differentiate them. The mucosal surface was then rendered to encompass all of the muscle groups. The objects were subsequently brought together into a space-filling model of the neonatal tongue.

For the adult 3-D model, the data set provided by the Visual Human Project was used. Fifty-five equally spaced coronal sections along the length of the tongue were taken from the site. Already digitized, the images were used to construct a model of the adult tongue in the manner described above.

In both models, the objects depicted were the muscles being compared. The extrinsic muscles rendered were the styloglossus, hyoglossus, and genioglossus muscles, and the intrinsic muscles included the superior and inferior longitudinal muscles and the transverse and vertical muscles. For the sake of clarity, the palatoglossus muscle was not rendered.

RESULTS AND DISCUSSION

MUCOSA

The mucosa over both the ventral and dorsal aspects of the neonatal tongue is considerably thinner on cross section than that of the adult tongue. The depth of the submucosal connective tissue is also considerably thinner along the entire length of the neonatal tongue.

SOFT TISSUE

The neonatal tongue contains little or no fat and soft tissue. Particularly evident is the lack of palatoglossal soft tissue in the neonate. There is little in-

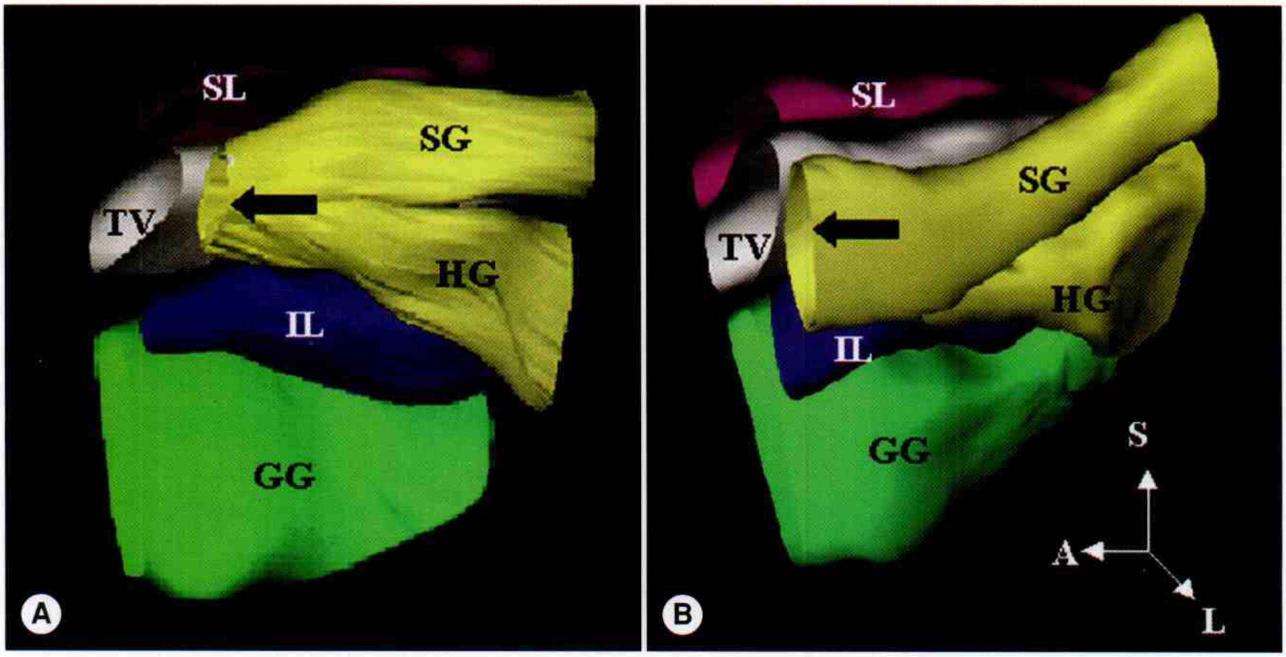


Fig 2. Comparison of 3-dimensional models of left hemisections of adult and neonatal tongues from level of posterior body to anterior base of tongue. Relative cross-sectional area of combined SG and HG (arrow) in adult (**A**) is less than that in neonate (**B**).

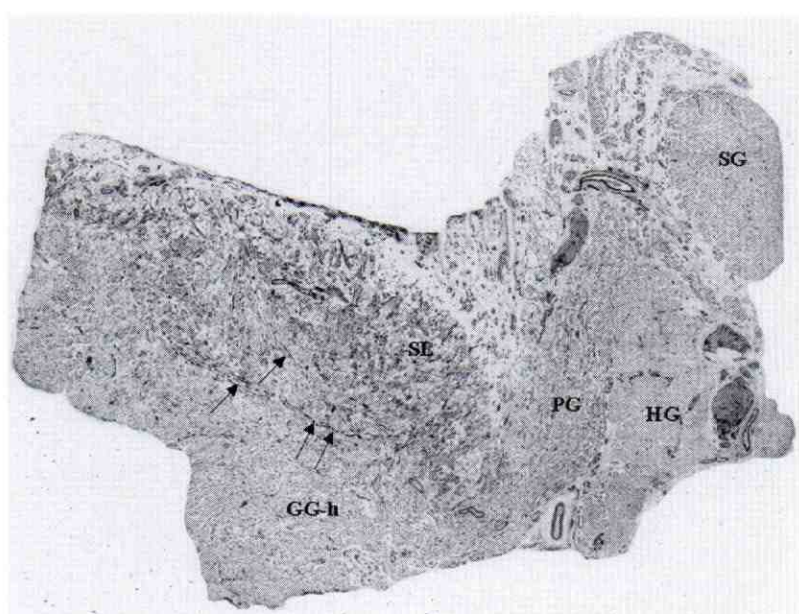
tervening soft tissue between the dorsal mucosa at the level of the tongue base and the underlying styloglossus muscle.

EXTRINSIC NEONATAL MUSCLES

At the level of the tongue base, the styloglossus, hyoglossus, and palatoglossus muscles can be seen originating external to the substance of the tongue. The genioglossus muscle enters at the tongue body. The cross-sectional areas of the styloglossus, hyoglossus, and palatoglossus muscles described below are considerably larger in the neonatal tongue than in that of adults (Fig 2). This difference is observed for the length of the base and body. These muscles are involved in movement of the tongue en bloc, and contribute little to change of its shape.

Genioglossus Muscle. The genioglossus muscle originates from the mental spine of the mandible. In the proximal base, vertical fibers are seen in the most medial aspect of the dorsal mucosa. The most prominent fibers lie closest to the median septum, and lesser fibers fan out slightly laterally along the contour of the dorsal mucosa. These fibers are present in the

Fig 3. Adenosine triphosphatase (ATPase)–stained coronal section of left hemisected neonatal tongue at base. Palatoglossus muscle (PG) is medial to HG and lateral to lateral fascicles of SL. At this level, fibers of horizontal portion of GG are seen. Fibers of transverse muscle group are observed inferior to SL (arrows).



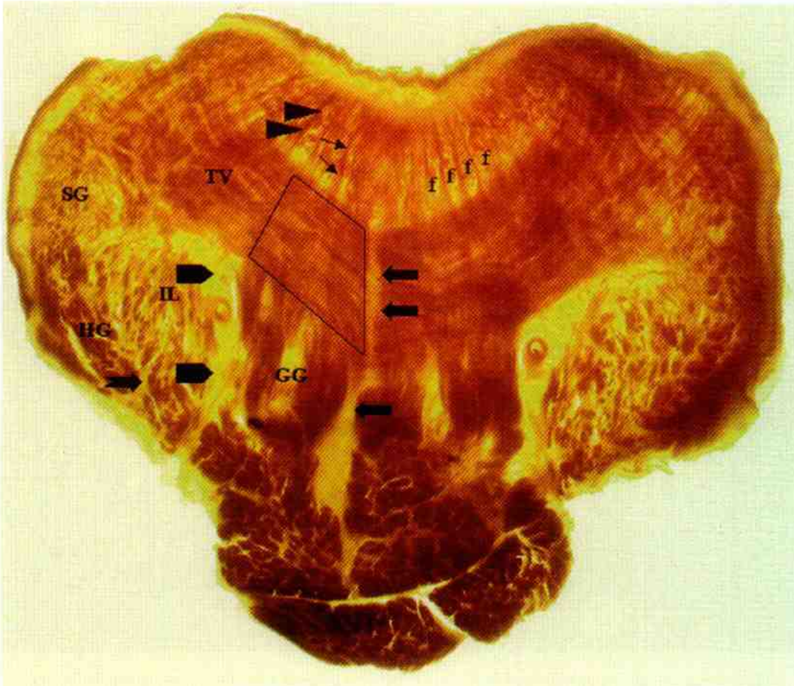


Fig 4. Thick coronal section of adult tongue at body. Region of interdigitation (outline) between vertical GG fibers and transverse muscle fibers is seen. Fibers of vertical muscle group (arrowheads) and GG (thin arrows) can be seen separating fascicles of SL (f) before inserting into dorsal submucosa. Median septum (block arrows) divides substance of tongue in midline. IL is separated from HG laterally by lateral septum (notched arrow) and from GG medially by paramedian septum (pentagons).

base and run from the horizontal portion of the genioglossus muscle (Fig 3). The horizontal portion is one of two components of the genioglossus muscle: horizontal and oblique. In the body, these fibers arise from the horizontal component of the genioglossus muscle, which originates at the mental spine of the mandible and inserts into the hyoid bone and submucosal connective tissue proximal to it (Fig 1A). The horizontal group is believed to act in maintenance of airway patency by pulling the hyoid bone and dorsal mucosa in an anterior direction.

On examination of sections from the level of the anterior base and the length of the body and blade, medially positioned vertical fibers of the genioglossus muscle are seen to separate fascicles of the superior longitudinal muscle as they insert into the dorsal mucosa. These fibers can be seen running perpendicular to fibers of the transverse muscle (Fig 4). In the thick sections, vertical fibers can be seen to interdigitate with sheets of the transverse muscle repeatedly along the length of the transverse muscle group. These fibers arise from the oblique compartment of the genioglossus muscle (Fig 5A). They originate from the tendinous insertion into the mandible and radiate in a dorsal direction along the length of tongue to make up the majority of the bulk of the tongue (Figs 1A and 6). These fibers retract the dorsal surface of the tongue away from the palate, particularly along the midline, to form a groove most prominent in the body. The posterior oblique fibers pull the tongue in the anterior direction for protrusion.[16]

In the blade and moving gradually toward the tip, anterior fascicles of the genioglossus muscle gradually become more longitudinal fibers to combine with a group of other longitudinal fibers that originated from the other extrinsic muscles (Fig 7). These fibers, along with fascicles of the superior and inferior longitudinal muscles, together constitute a layer of combined longitudinal muscle fascicles that form a layer of muscle fibers surrounding a core of intrinsic muscle fibers.

Styloglossus Muscle. The styloglossus muscle originates at the styloid process and the stylohyoid ligament. It descends to abut the hyoglossus muscle superolaterally at the level of the base (Fig 3). Heading in an anterior direction in the tongue body, fascicles of the styloglossus muscle insert into the substance of the hyoglossus muscle and separate the hyoglossus muscle into superior and inferior segments. At the level of the tongue body, fibers descend through and intersect the hyoglossus muscle to become contiguous with fascicles of the inferior half of the transverse muscle at the lateral septum (Fig 5B). In the blade of the tongue, longitudinal styloglossus fibers have entirely combined with the above-mentioned longitudinal group of muscle fibers, including those that continue to the blade and tip (Fig 7). The styloglossus muscle is believed to be involved in tongue retraction and curls its sides superiorly when acting with the genioglossus muscle to create a trough along the median groove.[16]

Hyoglossus Muscle. The hyoglossus muscle originates at the body and greater horn of the hyoid bone.

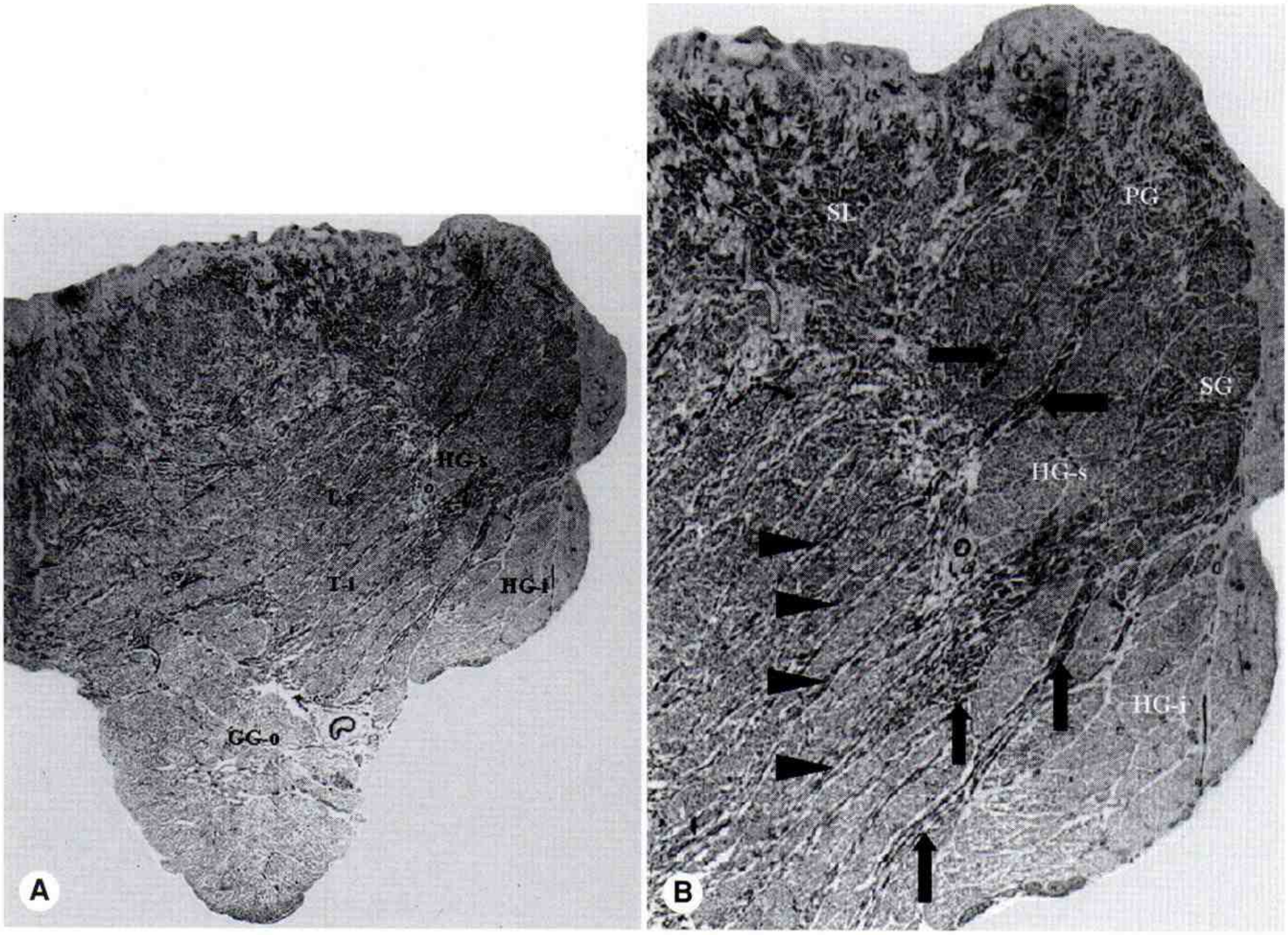


Fig 5. ATPase-stained coronal section of left hemisected neonatal tongue at posterior body. **A)** GG fibers are from oblique portion (GG-o). Relative to their attachments to fibers of PG and SG along lateral septum, transverse fibers are grouped into superior (T-s) and inferior (T-i) strata, respectively. **B)** Enlargement of area in A. HG-s — superior portion of HG separated from inferior portion (HG-i), by descending fibers of SG. These fibers (vertical arrows) are seen coursing beyond lateral septum to become congruent with fibers of transverse muscle group (arrowheads). Fibers of PG are seen descending (horizontal arrows) to attach to fibers of transverse muscle group.

It ascends to insert into the lateral aspect of the distal tongue base posteroinferior to the styloglossus muscle (Fig 3). The most posterior fibers course and insert superiorly with fibers of the superior longitudinal muscle. As the muscle runs distally through the body, fascicles of the hyoglossus muscle decrease in cross-sectional area and increase in number and are separated by intervening fibers of the styloglossus muscle inferiorly and fibers of the palatoglossus muscle superiorly (Fig 5A). At the level of the tongue blade, horizontally coursing fibers of the hyoglossus muscle combine with the above-mentioned longitudinal group of muscles that continue to the blade tip (Fig 7). The hyoglossus muscle is involved in retraction and depression of the entire tongue.[16]

Palatoglossus Muscle. The palatoglossus muscle arises from the aponeurosis of the soft palate. It inserts into the lateral aspect of the tongue base and inserts into the tongue substance anteroinferior to the styloglossus muscle. Its fibers initially course from the superolateral mucosa situated between the lateral fascicles of the superior longitudinal muscle and the medial fascicles of the styloglossus and hyoglossus muscles (Fig 3). In the proximal tongue body, medial and inferior fibers of the palatoglossus muscle can be seen to intersect between fascicles of the hyoglossus muscle to attach to fascicles of the superior half of the transverse muscle along the lateral septum (Fig 5B). Superior fibers of the palatoglossus muscle course longitudinally at the transition from base to body to terminate in the submucosa at the lateral edge of the overlying dorsal mucosa. The palatoglossus muscle is thought to elevate the posterior part of the tongue.[7]

INTRINSIC NEONATAL MUSCLES

The cross-sectional area of the intrinsic muscles, particularly that of the transverse and vertical muscles, is considerably less in neonates than in adults.

Superior Longitudinal Muscle. The fibers of the

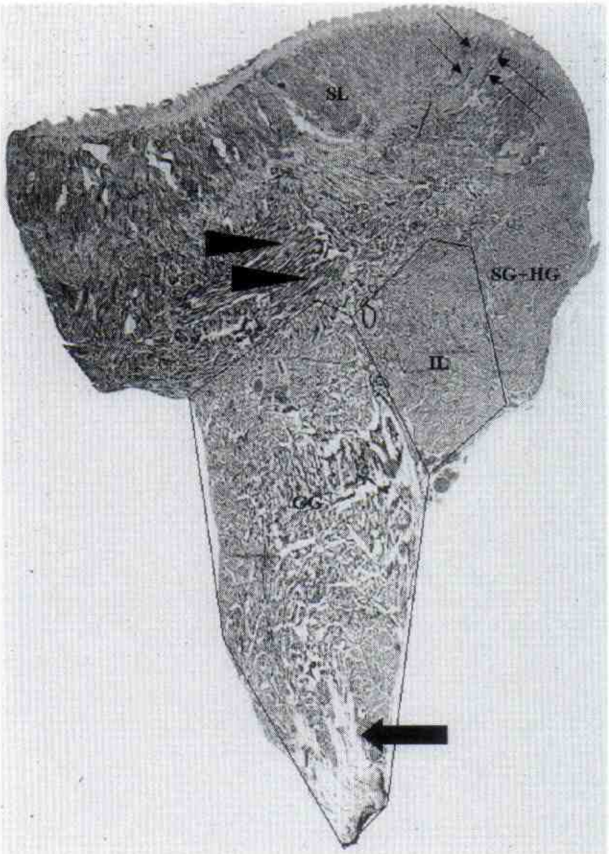


Fig 6. ATPase-stained coronal section of left hemisected neonatal tongue at anterior body. Extent of GG is outlined to show relatively large contribution of GG to cross-sectional area of tongue at this level. Tendinous origin of GG (thick arrow) is seen at this level. Fibers of SG and HG have combined (SG+HG). IL is outlined along its borders with SG and HG lateral, GG medial, and transverse muscle group superior. In dorsolateral mucosa, thin fibers of transverse muscle originate lateral to SL (thin arrows). Compared to those seen in Fig 5, strata of transverse muscle at this level have begun to consolidate into fewer, thicker fascicles (arrowheads).

superior longitudinal muscle originate in the median septum and lamina propria of the dorsal aspect of the tongue base. They course longitudinally in the anteroposterior direction to attach gradually to the submucosa along its length. The muscle forms a layer that spans the entire length of the tongue. In the tongue base, it is bordered laterally by the descending fibers of the palatoglossus muscle and the fascicles of the hyoglossus muscle (Fig 3). Medially, most prominently in the tongue body, fascicles of superior longitudinal muscle are separated by vertical fibers of the genioglossus muscle that have traversed the transverse and vertical muscles and insert into the dorsal submucosa (Fig 4). Laterally evident are fascicles separated by fibers of the vertical muscle inserting into the dorsal submucosa. In the tongue blade and tip, the fibers of the superior longitudinal muscle have become combined with the combined longitudinal fibers that originated from the extrinsic muscles already discussed (Fig 7). The superior longitudinal muscle of the neonatal tongue appears less substantial than that of the adult tongue. Its cross-sectional area also is much smaller than that in the adult tongue. In the neonatal tongue, it does not appear to have as deeply contoured a medial depression, especially in the base and proximal body. The superior longitudinal muscle is involved in curling the tip and sides of the tongue in the superior direction.

Inferior Longitudinal Muscle. The inferior longitudinal muscle is composed of fibers that originate in the base of the tongue lateral to the genioglossus muscle. Consistent with observations of Barnwell et al,[17] there is no evidence of fibers originating from the hyoid bone. Its fibers course longitudinally along the entire length of the tongue. In the tongue body, it remains as a single fascicle and is separated from the genioglossus muscle medially by the paramedian septum and the hyoglossus muscle laterally by the medial lamellae of the lateral septum as described by Abd-el-Malek[10] (Fig 4). In the blade, fibers of the inferior longitudinal muscle have combined with the other longitudinally coursing muscle fibers of the extrinsic muscles (Fig 7). Together, with the superior longitudinal muscle, they form the aforementioned layer of longitudinal muscles that surround the core of intrinsic muscle fibers. The inferior longitudinal muscle is responsible for curling the tip and sides of the tongue in the inferior direction and, along with the superior longitudinal muscle, shortens the tongue.

Transverse Muscle. The fibers of the transverse muscle are arranged in horizontally oriented strata that lie in the substance of the tongue, inferior to the superior longitudinal muscle. In the base, the most superior strata can be seen originating in the submucosal fibrous membrane in the dorsal surface. These fibers can be seen inferior to the lateral fascicles of the superior longitudinal muscle (Fig 3). In the proximal body of the tongue, these strata are seen inserting into the median septum. The lower strata originate from a line along the medial lamellae of the lateral septum to contact the palatoglossus and styloglossus muscles as described above (Fig 5). Klueber et al[18] observed the attachments to the palatoglossus muscle by transverse fibers in the 15-week fetus, but they made no mention of those to the styloglossus muscle. These fibers also insert into the median septum. In adults, transverse muscle fibers are not noted to attach to the palatoglossus and styloglossus muscles.

More distal in the anterior body and blade, the strata are consolidating into fewer but larger strata (Fig 6).

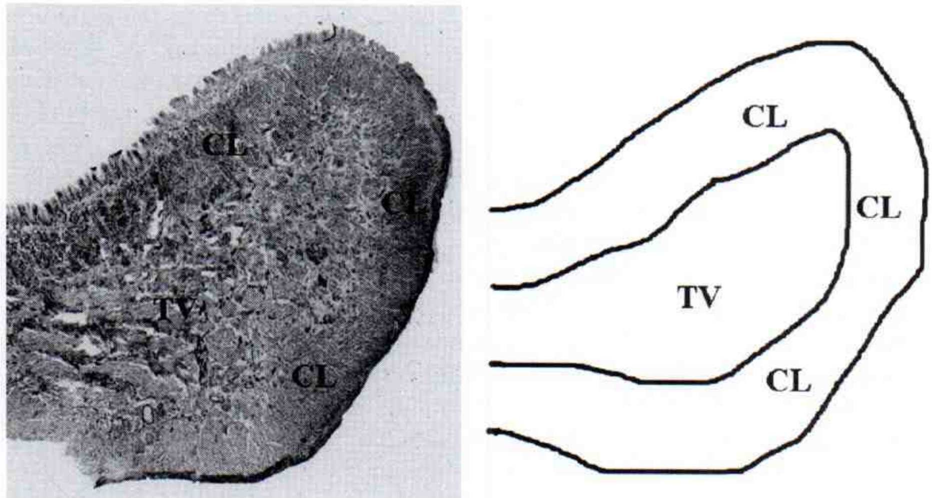


Fig 7. ATPase-stained coronal section and diagram of left hemisected neonatal tongue at blade. CL — combined longitudinal fibers of GG, IL, HG, SG, and SL muscles surrounding core of TV.

The transverse muscle in adults does not appear to consolidate into fewer, thicker strata as seen in neonates. These thickened strata are bordered below by the inferior longitudinal and genioglossus muscles, on the sides by the hyoglossus and styloglossus muscles, and above by the superior longitudinal muscle. At this level, transverse muscle fibers originate at a point in the superolateral aspect of the dorsal submucosa just lateral to the superior longitudinal muscle. They continue to insert into the median septum. In the anterior blade to the tip, the transverse muscle can be seen to interdigitate with fibers of the vertical muscle group in the thick sections. When they contract, the fibers of the transverse muscle are responsible for narrowing and lengthening the tongue.

Vertical Muscle. Over the length of the body and blade, the vertical muscle is a group of fibers the majority of which course vertically, lateral to the vertical fibers of the genioglossus muscle. The fibers originate in the submucosa of the ventral mucosa and insert into the dorsal submucosa between fascicles of the superior longitudinal muscle lateral to those of the genioglossus muscle (Fig 4). From the blade to the tip, the vertical muscle is seen interdigitating with fibers of the transverse muscle in the thick sections. The transverse and vertical muscles constitute the core of intrinsic muscle fibers seen deep to the combined longitudinal fibers described above (Fig 7). The vertical muscle is responsible for the flattening and, along with the transverse muscle, lengthening of the tongue.

It should be noted that the change of shape of the tongue is the rationale behind describing the mammalian tongue, including that of humans, as a muscular hydrostat[19,20] (also our unpublished observations). As such, the tongue can be thought of as composed of repeating structural units responsible for elongating or changing the shape of the tongue in the direction perpendicular to the dorsum (ie, bending) or along the longitudinal axis (ie, elongation) of the tongue — motions fundamental to speech.[21] These repeating units, as described by Takemoto,[12] are the interdigitating layers of transverse and vertical muscles. This pattern is consistent with the notion that changing the shape of the tongue is primarily the work of intrinsic muscles. Napadow et al[20] examined tongue deformation, using magnetic resonance imaging during specific tongue postures. They concluded that the bending and elongation motions of the tongue characteristic of speech must be the result of regional activation of the mutually orthogonal intrinsic musculature of the transverse and vertical muscle fibers. Therefore, the relatively increased contribution to tongue cross-sectional area by the intrinsic muscles observed in adults suggests a possible functional adaptation of the tongue to the eventual development of speech.

NEONATAL TONGUE ANATOMY AND SUCKLING

In the work by Tamura et al,[6] the suckling cycle is defined as the time period from the elevation of the tongue tip to the migration of the peristaltic wave to the base of the tongue. The peristalsis begins again at the tip. Within each cycle, there is a biphasic pressure gradient: 1) the positive pressure phase in which the masseter muscle, orbicularis oris, jaw, upper alveolar surface, lips, and tongue all contribute to initiate the expression of milk from the teat and 2) the much longer negative pressure phase in which the activity of what they call the suprahyoid muscles, including the styloglossus muscle, and the peristaltic motion of the medial portion of the tongue act to move the milk to the pharynx. This movement occurs in the context of a "cylindrical milk pathway in the medial part of the tongue."[6(p507)] Therefore, the activity of the styloglossus muscle, an extrinsic muscle, during the negative pressure phase of suckling in which there is a change of shape (namely, the peristaltic wave), suggests that it is at least partially involved in an activity thought to be entirely the work of intrinsic muscles.

A similar description of a medial channel was made by Bosma et al.[7] In that study, the peristaltic motion of the tongue during suckling was seen progressing in an anteroposterior direction within the channel. The repeated displacement occurred relative to the elevation of the lateral portions of the tongue against the palate. Given the known anatomy of the tongue, they suggested a mechanism for the shape and motion of the tongue during suckling. The peristaltic movement of the dorsum of the tongue toward the palate was the result of the wavelike contraction and relaxation along the length of the transverse muscle. The wave of motion toward the palate was offset by a complementary wave of motion away from the palate, created by the peristaltic contraction along the length of the genioglossus muscle, which increased the amplitude of peristalsis of the tongue. The lateral portions of the tongue, including the styloglossus muscle, then acted as a framework within which the wave of peristalsis took place against the palate.

Thus, the difference in morphology between the adult and neonatal tongues points to the suitability of the neonatal tongue for suckling. The elevation of the lateral aspects of the tongue during suckling underlies the need for relatively larger extrinsic muscles — the palatoglossus, styloglossus, and hyoglossus muscles — in neonates. The larger extrinsic muscles, particularly the styloglossus muscles responsible for curling the lateral edges of the tongue, suggest a morphological adaptation to suckling by acting as a buttress enabling the peristaltic wave from the medial portion to drive milk out of the nipple. The increased activity of the styloglossus muscle during the negative phase of suckling, the time when the peristaltic wave is active, may also suggest an active role of the styloglossus muscle in the progression of the wave. The continuation of fibers from the styloglossus muscle to the transverse muscle observed here makes it possible for the peristaltic activity in the transverse muscle to be complemented by a similar wave of activity in the fibers of the styloglossus muscle. Countered by the wave of activity along the length of the genioglossus muscle, this wave would create a functional sling acting along the length of the tongue to draw milk from the nipple.

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