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Data Article

# Data on hydrodynamic flow and aspiration mechanisms in a patient-specific pharyngolaryngeal model with variable epiglottis angles

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A R T I C L E   I N F O

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Dataset link: Hydrodynamics and Aspiration in a Patient-Specific Swallowing Biomechanical Model with Variable Epiglottis Angles (Original data)

*Keywords:*
Epiglottis
Swallowing dynamics
Dysphagia
Laryngeal vestibule
Biomechanical modelling
Etiology-based intervention

A B S T R A C T

This dataset comprises a comprehensive collection of videos and images illustrating the fluid dynamics of swallowing and aspiration in a patient-specific pharyngolaryngeal model with varying epiglottis angles. The data also includes the physical properties of the fluids used, comprising dynamic viscosity, surface tension, and contact angle. Videos under varying swallowing conditions were collected to investigate the mechanisms underlying aspiration. The study utilized a biomechanical swallowing model developed using transparent casts of an anatomically accurate pharyngolaryngeal structure. Fluorescent dye was used to visualize the liquid flow dynamics from both side and back views. The dataset includes videos for two types of liquids, water and a 1% w/v methylcellulose aqueous solution, evaluated under two dispensing speeds (fast and slow) and two dispensing locations (anterior and posterior) across four epiglottis angles (30° up-tilt, 0° horizontal, 45° down-tilt, and 80° down-tilt). Additionally, the dataset includes photos of the pharyngolaryngeal model setup, photos of the epiglottis models used, and STL

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files for both the pharyngolaryngeal model and the epiglottis 3D models.
The videos document the distinct flow patterns and frequent aspiration sites identified during the experiments, including the interarytenoid notch, the cuneiform tubercular recess, and the vallecula. These data are valuable for researchers aiming to understand the etiology of dysphagia and can be reused to validate computational models, guide future experimental designs, and inform clinical diagnostics and treatment strategies. The dataset is organized into folders based on the epiglottis angles, dispensing speeds, and locations, as well as liquid types. This organization facilitates easy access and analysis for researchers in biomedical engineering, clinical research, and computational biology. The data provide a rich resource for further investigation into swallowing mechanics and the development of etiology-based interventions for dysphagia management.



Specifications Table

| | |
|---|---|
| Subject | Biomedical Engineering, otorhinolaryngology, pathology |
| Specific subject area | Study of fluid dynamics and aspiration mechanisms using patient-specific pharyngolaryngeal models for dysphagia research. |
| Type of data | Videos, Images, 3D Models (.stl format), Documents (Word, PowerPoint)<br>Data format: Raw, Processed. |
| Data collection | The dataset contains 46 files comprising 32 videos, 6 images of the epiglottis and pharyngolaryngeal models, 5 STL files of the 3D models used for 3D printing, and 3 documents comprising fluid properties (viscosity, surface tension, and contact angle). The images, STL and fluid property files are placed in a single folder, while the videos are divided into subfolders based on the pharyngolaryngeal model's epiglottis angles, dispensing conditions, and liquid types. Videos were processed in 1080p (HD) resolution and saved in MP4 format for efficient storage. Images were saved in JPG format, and 3D models were saved in STL format. The pharyngolaryngeal and epiglottis models were 3D-printed using SLA and Elastic 50A resins. Water and 1% w/v methylcellulose solutions, dyed with fluorescent dye, were dispensed at fast and slow speeds to simulate swallowing. Liquid flow dynamics were captured using a purple LED light (385 nm) for illumination and recorded from side and back views. Files were named appropriately for easy identification, with videos showing the back view including "back_view" in their file names. |
| Data source location | University of Massachusetts Lowell, Lowell, Massachusetts, USA. |
| Data accessibility | Repository name: Mendeley Data<br>Data identification number: DOI: 10.17632/2d49dpych5.1<br>Direct URL to data: https://data.mendeley.com/datasets/2d49dpych5/1 |
| Related research article | Seifelnasr A, Sun C, Ding P, Si X Xi J. Swallowing hydrodynamics visualization and aspiration quantification in a patient-specific pharyngolaryngeal model with varying epiglottis inversions. Medicine in Novel Technology and Devices 2024,24:100,326. 10.1016/j.medntd.2024.100326. |

## 1. Value of the Data

- These data provide detailed insights into the fluid dynamics of swallowing and aspiration mechanisms in an anatomically accurate pharyngolaryngeal model with varying epiglottis angles. Understanding these dynamics is crucial for developing effective dysphagia management strategies, particularly for patients with head and neck cancers who are prone to aspiration following treatments.

- Researchers can use these data to compare with their experimental or computational models of swallowing and aspiration. The dataset includes comprehensive videos of fluid flow patterns under different conditions, which can serve as benchmarks for validating new dysphagia treatment methods or for improving the design of assistive devices aimed at mitigating aspiration risks.
- The detailed visualization of aspiration sites and flow dynamics at various epiglottis angles can guide future studies aiming to explore other physiological or pathological conditions affecting swallowing. Researchers can build upon these findings to investigate the impact of additional variables such as different liquid viscosities or varying anatomical structures across different patient demographics.
- The data provide empirical evidence that can be incorporated into computational models to simulate swallowing and aspiration processes more accurately. By using these real-world flow dynamics, computational biologists and engineers can refine their models to predict the outcomes of surgical interventions or to develop patient-specific therapeutic strategies.
- Clinicians can leverage these data to better understand the underlying causes of aspiration in their patients. The identified aspiration mechanisms can inform diagnostic protocols and help tailor rehabilitation exercises or interventions to the specific needs of individuals, thereby improving patient outcomes and quality of life.
- The dataset can be used as an educational tool in medical and biomedical engineering programs. Students and trainees can analyze the videos to learn about the biomechanics of swallowing, the impact of anatomical variations, and the complexities involved in managing dysphagia, thereby enhancing their practical understanding of these critical physiological processes.

## 2. Background

This data article complements the original research article published in Medicine in Novel Technology and Devices [1] by offering videos, images, and 3D model files. The dataset was compiled to understand the fluid dynamics of swallowing and aspiration, which impact patients with dysphagia. Dysphagia is common, particularly among individuals with head and neck cancers following radiation therapy or surgery, as these treatments impair muscles and nerves involved in swallowing [2–5], increasing the risk of aspiration and complications like pneumonia.

This dataset was developed to investigate aspiration mechanisms by visualizing fluid flow in an anatomically accurate pharyngolaryngeal model with varying epiglottis angles. Data were generated using a biomechanical model created from transparent casts of a patient-specific pharyngolaryngeal structure. Based on CT scans of an 18-year-old male, the model replicates the pharyngolaryngeal anatomy, including the epiglottis and laryngeal vestibule leading to the glottal aperture [6–9]. Fluorescent dye was used to visualize liquid flow from both side and back views, allowing observation of flow patterns and aspiration sites.

These files document experimental conditions and results and provide the geometries used in the study. The dataset serves as a resource for validating computational models, designing experiments, and developing clinical interventions for dysphagia and aspiration.

## 3. Data Description

Compared to the companion paper, the dataset herein offers a more comprehensive presentation by including a collection of videos that provide dynamic visualizations of the fluid behaviours observed in the swallowing hydrodynamics experiments. These videos allow for a clearer understanding of the swallowing mechanics under various conditions, offering insights that static images alone may not fully convey. In addition, the dataset presented here includes supplementary materials that were not part of the published article, such as 5 STL files of the 3D models used in the experiments. These models, provided for those interested in reproducing the experiments, add a valuable resource for researchers. This dataset includes detailed physical properties of the test fluids, specifically the dynamic viscosity, surface tension, and contact angles on various materials. These additional data points enhance the utility of the dataset for those aiming to conduct related studies or validate computational models.

The dataset of the linked repository contains 46 files comprising 32 videos, 6 images of the epiglottis and pharyngolaryngeal models, and 5 STL files of the 3D models used for 3D printing [10]. Moreover, the data consist of 3 separate documents listing the physical properties of the two test fluids (water and 1% w/v methylcellulose aqueous solution), namely dynamic viscosity, surface tension, and contact angles formed by the test fluids on various materials. A detailed description of the dataset structure is illustrated in the form of an organizational chart (Fig. 1). The videos illustrate the fluid dynamics of swallowing and aspiration in a patient-specific pharyngolaryngeal model with varying epiglottis angles. The main folder is named “Dataset,” and it contains several subfolders: “Model Images and 3D Models,” “Up-tilt 30 Deg,” “Horizontal 0 Deg,” “Down-tilt 45 Deg,” and “Down-tilt 80 Deg.” Each of the epiglottis angles subfolders is further divided into subfolders based on the dispensing conditions and liquid types. Videos were processed in 1080p (HD) resolution and saved in MP4 format for efficient storage and compatibility. Images were saved in JPG format, and 3D models were saved in STL format.

Files were named appropriately for easy identification. For example, a video named “MC_fast_posterior_horizontal.mp4” indicates that the video is associated with the MC aqueous solution dispensed in a fast manner to the posterior wall of the pharyngolaryngeal model lumen using the horizontally positioned straight epiglottis model. In the “Model Images and 3D Models” subfolder, there are 4 photos, each showing the pharyngolaryngeal model with each of the epiglottis models installed. The files are named to reflect this accurately; for example, “PL_model_with_down-tilt_45_deg_epiglottis.jpg” is a photo of the pharyngolaryngeal model with the down-tilted 45° epiglottis model installed. This subfolder also contains a photo (“epiglottis_models.jpg”) of the three 3D-printed epiglottis models laid side-by-side. Additionally, there is a photo (“epiglottis_top_and_bottom_views.jpg”) showing the top and bottom views of the straight epiglottis model. The folder also contains 5 STL files with the segmented 3D models used to 3D-print the epiglottis and pharyngolaryngeal models used in the study [1]. There are 3 STL files for the 3 epiglottis models, and 2 STL files for the pharyngolaryngeal model (one for the upper part and one for the lower part, named “pharynx_upper.stl” and “pharynx_lower.stl,” respectively).

The videos are located in the terminal subfolders at the very end of the dataset’s organizational folder structure. These terminal subfolders are named based on the specific liquid used (MC or Water) and house the video files. For example, the path to a video file might be: Dataset > Horizontal 0 Deg > Fast-Posterior > MC. Each terminal subfolder contains two videos, one showing the liquid dispensing action and fluid behavior from the side view and the other from the back view. Videos showing the back view have the words “back_view” added to their file name. Videos without “back_view” in the file name show the action from the side view of the pharyngolaryngeal model. Fig. 2a shows snapshots taken at various timesteps from the side and back views in two different test scenarios, demonstrating the progression of fluid within the pharyngolaryngeal model’s lumen from when it is dispensed until it exits the lumen via the esophagus, with fractional leakage via the trachea (i.e., aspiration). The viscosity as a function of MC concentration along with the contact angle of a drop of 1% w/v MC aqueous solution dispensed on a flat sample of elastic 50A SLA resin, is depicted in Fig. 2c.

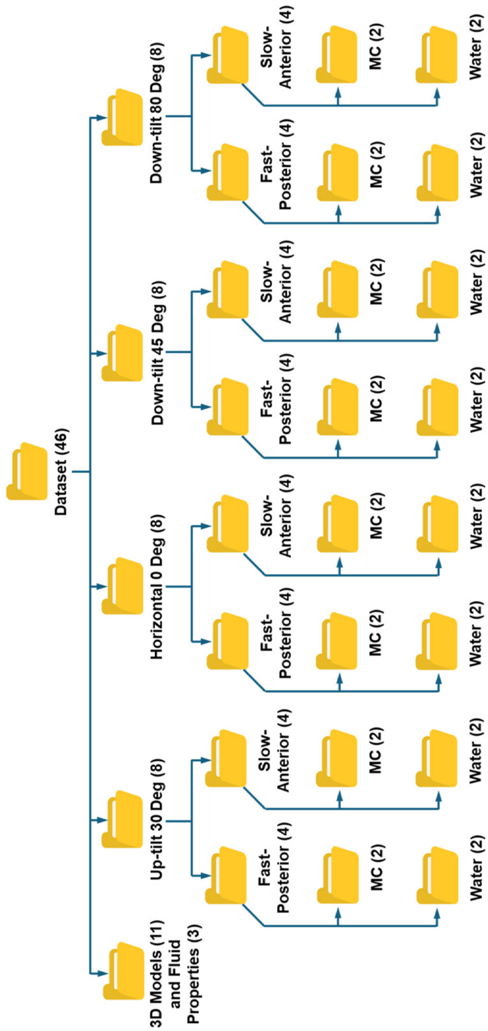


**Fig. 1.** Organizational structure of the dataset.

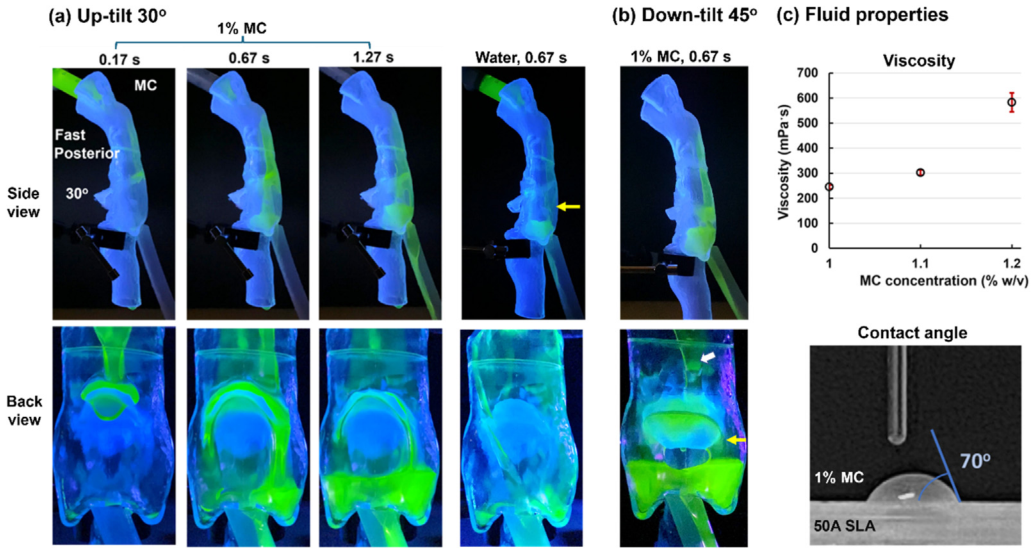


**Fig. 2.** Data examples: (a) Time series snapshots of hydrodynamics within the pharyngolaryngeal model with an up-tilt 30° epiglottis, (b) snapshot of 1 % MC aqueous solution hydrodynamics within the pharyngolaryngeal model with a down-tilt 45° epiglottis, and (c) viscosity as a function of MC concentration (upper) as well as contact angle of a drop of 1% w/v MC aqueous solution dispensed on a flat sample of elastic 50A SLA resin (lower).

**Table 1**
Cases involving four different epiglottis angles for both 1% w/v MC aqueous solution and water, evaluated at two dispensing speeds.

| | Up-tilt 30° | 0° | Down-tilt 45° | Down-tilt 80° |
|---|---|---|---|---|
| Fast-Posterior | MC | MC | MC | MC |
| | Water | Water | Water | Water |
| Slow-Anterior | MC | MC | MC | MC |
| | Water | Water | Water | Water |

## 4. Experimental Design, Materials and Methods

### *4.1. Pharyngolaryngeal model development*

The pharyngolaryngeal model used in this study (Fig. 3a) was derived from CT scans of an 18-year-old male, providing an anatomically accurate representation essential for both respiratory and swallowing functions. The CT scans had an isotropic resolution of 623 μm, capturing key anatomical features such as the hyoid, larynx, pharynx, epiglottis, true vocal fold, false vocal fold, and laryngeal sinuses [6–9]. The model was printed using a Formlabs 3D printer (Form 3B+, Somerville, Massachusetts, USA) and transparent stereolithography (SLA) resin (Formlabs Clear Resin, Somerville, MA). The epiglottis models were separately 3D-printed using Elastic 50A Resin (Formlabs, Somerville, MA), which is a flexible material (Fig. 3b&c). For each experimental setup, an epiglottis model was inserted to assume various fixed angles: 30° up-tilt, 0° (horizontal), 45° down-tilt, and 80° down-tilt (Fig. 3b). A transparent adhesive (Shoe Goo, Eugene, Oregon) was used to ensure a leak-proof interface between the epiglottis and the anterior pharynx.

### *4.2. Fluid characterization*

Water and a 1% w/v methylcellulose (MC) aqueous solution were chosen to simulate drink and saliva, respectively. The physical properties of the liquids, including contact angle, viscosity, and consistency, were measured. The contact angle was measured using a Hamilton 81,242 500 μL threaded plunger syringe, and viscosities were determined with a rotational viscometer (Cgoldenwall NDJ-5S) [11]. The consistency classification followed the International Dysphagia Diet Standardization Initiative (IDDSI) flow test, categorizing liquids based on the volume remaining in a syringe after 10 s.

### *4.3. Experimental setup and procedures*

The experiments were designed to evaluate the impact of epiglottis inversion angles and dispensing conditions on aspiration risk. The liquids were dispensed at two speeds: fast (5 ml within 1 s to the posterior oropharynx) and slow (5 ml within 3 s to the anterior oropharynx) [12–14]. The dispensing conditions and epiglottis angles formed a matrix of experimental conditions detailed in Table 1.

To visualize liquid flow dynamics, 0.2771 g of fluorescent dye (GLO Effex, Murrieta, CA, USA) was added per 100 ml of each liquid. A purple LED light with a wavelength of 385 nm illuminated the liquid in a dark room, and videos were recorded from both side and back views to capture the fluid dynamics. The setup allowed detailed observation of liquid movement and aspiration sites within the pharyngolaryngeal model. By comparing liquid hydrodynamics under different conditions (Table 1), the scenarios predisposed to aspiration can be identified. Moreover, by identifying the site of liquid entering the laryngeal vestibule, the correlation between the swallowing condition and aspiration likelihood can be established.

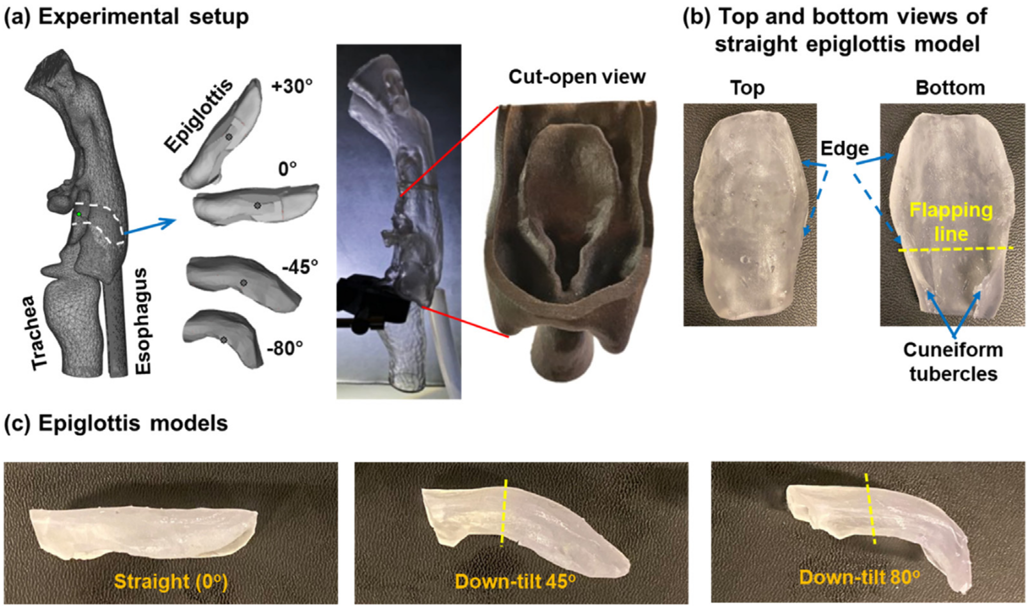


**Fig. 3.** Experimental setup and epiglottis models: (a) Hollow 3D-printed pharyngolaryngeal model, (b) top and bottom views of the straight epiglottis model, and (c) epiglottis models featuring different angular profiles: 0°, −45°, −80°.

### 4.4. Equipment and software

The pharyngolaryngeal and epiglottis models were designed using Autodesk Maya (Autodesk, San Francisco, CA) and printed with Formlabs SLA and Elastic 50A resins. Video recordings, originally captured in .MOV format, were converted to HD .mp4 format using ClipChamp (Microsoft), a freely available video editing software. This conversion was performed to reduce the file size without losing resolution or detail, ensuring clarity and maintaining video quality.

## Limitations

The dataset has several limitations. Firstly, it is based on a pharyngolaryngeal model of a single subject, an 18-year-old male, limiting the generalizability of the findings. Patients with dysphagia and aspiration exhibit various anatomical differences due to age, sex, and medical conditions, necessitating further research with a diverse population to validate these results [6,15,16].

The pharyngolaryngeal model was 3D-printed using SLA resin, which may not accurately replicate the interfacial behaviors of in vivo tissues. The contact angle measurements indicate differences in hydrophilicity and wettability between the SLA resin and biological tissues, potentially affecting the fluid dynamics observed [17–19]. This suggests that in vivo tissues may exhibit higher flow stability and lower aspiration rates than those observed with the SLA resin model.

Additionally, the study did not consider the motions of the tongue, pharynx, and larynx, focusing solely on varying epiglottis angles. This simplification excludes many factors involved in natural swallowing processes [8,20]. The use of fluorescent dye and LED lighting for visualization, while effective, may introduce artifacts, impacting the data's accuracy. Finally, the dataset lacks quantitative measurements of fluid velocity or pressure, which could provide a more comprehensive understanding of dysphagia and aspiration mechanisms.

## Ethics Statement

The authors have read and follow the ethical requirements for publication in Data in Brief and confirm that the current work does not involve human subjects, animal experiments, or any data collected from social media platforms.

## CRediT Author Statement

**Amr Seifelnasr:** Conceptualization, Methodology, Investigation, Writing- Original draft preparation. **Chen Sun:** Data curation, Visualization, Writing- Reviewing and Editing. **Peng Ding:** Conceptualization, Methodology, Writing- Reviewing and Editing. **Xiuhua A. Si:** Conceptualization, Methodology, Writing- Reviewing and Editing. **Jinxiang Xi:** Conceptualization, Data curation, Methodology, Supervision, Writing- Reviewing and Editing.

## Data Availability

Hydrodynamics and Aspiration in a Patient-Specific Swallowing Biomechanical Model with Variable Epiglottis Angles (Original data) (Mendeley Data).

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Yuchen Gong at University of Virginia and Mohamed Talaat at UMass Lowell were gratefully acknowledged for technical assistance in Autodesk MAYA.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## References

[1] A. Seifelnasr, C. Sun, P. Ding, X. Si, J. Xi, Swallowing hydrodynamics visualization and aspiration quantification in a patient-specific pharyngolaryngeal model with varying epiglottis inversions, Med. Novel Technol. Devices 24 (2024) 100326, doi:10.1016/j.medntd.2024.100326.

[2] L.W.J. Baijens, M. Walshe, L-M Aaltonen, C. Arens, R. Cordier, P. Cras, et al., European white paper: oropharyngeal dysphagia in head and neck cancer, Eur. Arch. Oto-Rhino-Laryngol. 278 (2021) 577–616, doi:10.1007/s00405-020-06507-5.

[3] T. Hopkins-Rossabi, K.E. Armeson, S.G. Zecker, B. Martin-Harris, Respiratory-swallow coordination and swallowing impairment in head and neck cancer, Head Neck 43 (2021) 1398–1408, doi:10.1002/hed.26609.

[4] M.B. Kristensen, E. Isenring, B. Brown, Nutrition and swallowing therapy strategies for patients with head and neck cancer, Nutrition 69 (2020) 110548, doi:10.1016/j.nut.2019.06.028.

[5] K.F. Skarbinski, E. Glennon, Dysphagia: a review, Nurse Pract. 45 (2020) 9–16, doi:10.1097/01.NPR.0000669120.41930.5e.

[6] R.A. Corley, S. Kabilan, A.P. Kuprat, J.P. Carson, K.R. Minard, R.E. Jacob, et al., Comparative computational modeling of airflows and vapor dosimetry in the respiratory tracts of rat, monkey, and human, Toxicol. Sci. 128 (2012) 500–516, doi:10.1093/toxsci/kfs168.

[7] A. Seifelnasr, P. Ding, X. Si, A. Biondi, J. Xi, Oropharyngeal swallowing hydrodynamics of thin and mildly thick liquids in an anatomically accurate throat-epiglottis model, Sci. Rep. 14 (2024) 11945, doi:10.1038/s41598-024-60422-x.

[8] A. Seifelnasr, X. Si, P. Ding, J. Xi, Liquid dynamics in the upper respiratory–digestive system with contracting pharynx motions and varying epiglottis angles, Liquids 4 (2024) 415–431, doi:10.3390/liquids4020022.

[9] Wikiwand. Epiglottic vallecula, From Wikipedia, the free encyclopedia. https://www.wikiwand.com/en/Epiglottic_vallecula, 2012.

[10] A. Seifelnasr, J. Xi, C. Sun, P. Ding, X. Si, Hydrodynamics and aspiration in a patient-specific swallowing biomechanical model with variable epiglottis angles, Mendeley Data V1 (2024), doi:10.17632/2d49dpych5.1.

[11] M. Bolivar-Prados, Y. Hayakawa, N. Tomsen, V. Arreola, W. Nascimento, S. Riera, et al., Shear-viscosity-dependent effect of a gum-based thickening product on the safety of swallowing in older patients with severe oropharyngeal dysphagia, Nutrients 15 (2023) 3279, doi:10.3390/nu15143279.

[12] E.R. Murphy, R. Thompson, K.L. Osman, C. Haxton, M. Brothers, L. Lee, et al., A strength endurance exercise paradigm mitigates deficits in hypoglossal-tongue axis function, strength, and structure in a rodent model of hypoglossal motor neuron degeneration, Front. Neurosci. 16 (2022) 869592, doi:10.3389/fnins.2022.869592.

[13] A. Printza, M. Boziki, S. Triaridis, V. Kiousi, M. Arnaoutoglou, J. Constantinidis, et al., Tongue strength, dysphagia questionnaire, pharyngeal secretions and FEES findings in dysphagia management in amyotrophic lateral sclerosis, Auris Nasus Larynx 48 (2021) 672–682, doi:10.1016/j.anl.2020.10.007.

[14] V. Rutili, M. Nieri, D. Franceschi, F. Pierleoni, V. Giuntini, L. Franchi, Comparison of rapid versus slow maxillary expansion on patient-reported outcome measures in growing patients: a systematic review and meta-analysis, Prog. Orthod. 23 (2022) 47, doi:10.1186/s40510-022-00440-5.

[15] N. Hashida, H. Tamiya, M. Korematsu, T. Fujii, Does oral intake of thin fluids increase aspiration pneumonia for dysphagia after head and neck cancer surgery? A retrospective study for a total of 654 cases, Auris Nasus Larynx 50 (2023) 757–764, doi:10.1016/j.anl.2023.01.007.

[16] H. Shirasu, T. Yokota, S. Hamauchi, Y. Onozawa, H. Ogawa, T. Onoe, et al., Risk factors for aspiration pneumonia during concurrent chemoradiotherapy or bio-radiotherapy for head and neck cancer, BMC Cancer 20 (2020) 182, doi:10.1186/s12885-020-6682-1.

[17] T.W. Bacha, D.C. Manuguerra, R.A. Marano, J.F. Stanzione, Hydrophilic modification of SLA 3D printed droplet generators by photochemical grafting, RSC Adv. 11 (2021) 21745–21753, doi:10.1039/d1ra03057d.

[18] H. He, W. Zhou, J. Gao, F. Wang, S. Wang, Y. Fang, et al., Efficient, biosafe and tissue adhesive hemostatic cotton gauze with controlled balance of hydrophilicity and hydrophobicity, Nat. Commun. 13 (2022) 552, doi:10.1038/s41467-022-28209-8.

[19] C.-M. Lehr, J.A. Bouwstra, H.E. Boddé, H.E. Junginger, A surface energy analysis of mucoadhesion: contact angle measurements on polycarbophil and pig intestinal mucosa in physiologically relevant fluids, Pharm. Res. 9 (1992) 70–75, doi:10.1023/a:1018931811189.

[20] Y. Inamoto, M. González-Fernández, E. Saitoh, 3D-CT Evaluation of Swallowing: metrics of the Swallowing Response Using Swallowing CT, Dysphagia 37 (2022) 237–249, doi:10.1007/s00455-021-10288-2.