2021 43rd Annual International Conference of the
IEEE Engineering in Medicine & Biology Society (EMBC)
Oct 31 - Nov 4, 2021. Virtual Conference

Design of an Artificial Tongue Driven by Shape Memory Alloy Fibers

Yasuyuki Shiraishi, Akihiro Yamada, Genta Sahara, Tomoyuki Yambe, *Member, IEEE*
Kengo Kato, Jun Ohta, Yukio Katori, Dai Homma

Abstract— **Dysphasia is one of the complications which may cause functional disability after the surgical treatment of oral cancer. The loss of the function derived by tongue and other oral tissues impairs the retention and delivery of liquids and food masses as well as the swallowing motion into pharynx. As accumulation of liquids or food masses in the larynx can lead to pneumonia, therefore swallowing support to improve each coordination of the tongue, the epiglottis and the esophagus in the process of swallowing is highly desirable. In this study, we designed a new artificial tongue which was capable of contracting to deliver the bolus masses in the swallowing propulsion phase in the oral cavity. We designed a two-layered artificial tongue simulating the anatomical identical muscle structures with the longitudinal muscle, and the transverse muscle-genioglossus layer. A silicone rubber material was used for the surface layer, and the covalent shape memory alloy fibers (diameter: 150µm) were implemented in the secondary structure beneath of the silicone rubber material of the artificial tongue. Its contraction was driven by with shape memory alloy fibers shortage inside of the artificial tongue unit. The actuation was accurately controlled by the originally designed electrical current input with pulse width modulation. Firstly, we examined a prototype structure of the artificial tongue as well as the changes in unit thickness as it constricted by electric power supply switching. Secondly, we performed a feasibility study of the prototype into the head-neck medical training model with larynx-tracheal structure with esophagus. The results were as follows: a) the artificial tongue model showed a large contraction with a motion to increase upward pressure, b) the tongue unit expressed the capability of reducing shallow space between dorsal tongue surface and palate in the oral cavity model. Therefore, the first artificial tongue design with active contractile motion will be useful orally installable device for improving delivery function of bolus masses through swallowing procedure in dysphasia.**

***Clinical Relevance*— The active artificial tongue system designed for the first time exhibited an effective contractile motion to support bolus food masses propulsion in swallowing process in the oral cavity in the patients with dysphasia.**

I. INTRODUCTION

Dysphasia is one of the complications with may cause functional disability after the surgical treatment of oral and neck cancer [1]. The loss of the function derived by tongue and other oral tissues impairs the retention and delivery of liquids and food masses as well as the swallowing motion into pharynx. As accumulation of liquids or bolus masses in the larynx may lead to pneumonia, therefore, swallowing support device to improve each coordination of the tongue muscle, the epiglottis and the esophagus in the process of swallowing propulsion is highly desirable. Despite of these biomechanical needs to reconstruct tongue function, the properties of artificial tongue design are still unknown other than the characteristics of biosensing for taste detection [2].

The purpose of this study was to design a new active contractile implantable artificial tongue by using anisotropic shape memory alloy fibered actuators as shown in Fig. 1. We invented a new mechanism of dynamic artificial tongue which was capable of contracting for food bolus delivery propulsion in the patients' oral cavity. Primary concerns on the structure and function of artificial tongue were dynamic motion to deliver food masses in oral cavity between the tongue and the palate to larynx in order to provide coordination of propulsion with epiglottis and esophagus in the process of swallowing. Then we developed a prototype model which was to be installed in oral cavity and examined its function in vitro.

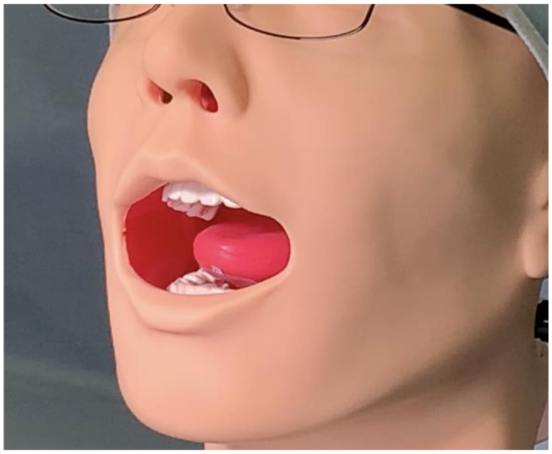

Figure 1. The artificial tongue developed in this study shown in the head and neck model. The contraction was achieved by the anisotropic shape memory alloy fibered actuator implemented into the artificial tongue unit layer with the electric DC supply.

Y. Shiraishi, A. Yamada, G. Sahara, T. Yambe are with Pre-Clinical Research Center, Institute of Development, Aging and Cancer, Tohoku University, Sendai 980-8575, Japan (corresponding author to provide phone: +81 22 717 8517; fax: +81 22 717 8518; e-mail: shiraishi@tohoku.ac.jp).

K. Kato, J. Ohta, Y. Katori are with the Department of Otolaryngology and Head and Neck Surgery, Tohoku University Graduate School of Medicine, Sendai 980-8574, Japan.

D. Homma is with Biometal Division, Toki Corporation, Tokyo, Japan.

978-1-7281-1178-0/21/$31.00 ©2021 IEEE

II. MATERIALS AND METHODS

A. Structural Design of an Artificial Tongue

We designed the active artificial tongue by two-layered structure as shown in Fig. 2; a) the surface layer by silicone rubber representing the liquid and food masses contacting membrane, b) the actuation layer to implementation of shape memory alloy actuators. The size of the surface length and the width of silicone membrane were set to be 80 and 45 mm, respectively [3, 4]. The leading edge of the tongue layer was internally anchored and connected to the root of tongue model by the shape memory alloy fibers (Biometal, Toki Corporation, Tokyo, Japan) [5]. Four-fibered string actuator was used in the model for the contraction. Each fiber was covered by silicone sleeves providing heat preservation during contraction.

B. Contraction Mechanisms

Special feature of the anisotropic shape memory alloy fiber used in this study was its large deformation up to around 4-10 % of contraction ratio with high cyclic durability more than 100 million times provided under the optimized counter stress conditions. Unique and effective displacement changes applied as artificial muscles has been presented previously [6, 7]. By triggering signal input to MOS-FET controller, the electric was applied to the fibers connected to a 36VDC battery. Programmable pulse width modulation was implemented into the controller (Due, Arduino, MA, USA) to arrange contractile velocity and fiber displacement. Upward pressurizing motion by the upper surface of the first layer of tongue prototype was derived by bending structure along with the contraction of shape memory alloy fibers at the triangular base distances. The tip of the tongue was covered with 0.5mm-thickness ePTFE (expanded polytetrafluoroethylene) sheet to eliminate friction during sliding motion on the base.

C. Examination of Motion of Artificial Tongue Unit

Dynamic property of the artificial tongue unit was measured without oral outer rigid structures. Video captured analysis was performed by feature tracking calculation (Mathematica 12, Wolfram, IL, USA) as shown in Fig. 3 to examine the changes in the height of dorsal tongue surfaces against the contraction of actuation fibers in the secondary internal layer of the tongue unit. The changes in height and length of the tongue unit were obtained during phases from dilatation to contraction by 2-seconds duration of applying electric power to the shape memory alloy fibered actuator by the pulse width modulation ratio at 100%.

D. Feasibility and Propulsion in the Oral Cavity

We performed the feasibility test of the artificial tongue in the medical training model with anatomically identical oral-neck speculations: larynx, tracheal tubing, epiglottis and esophagus (MW13, Kyoto Kagaku, Kyoto, Japan). The prototype model was installed into the oral cavity without tongue body space including genioglossus muscle rooms. The silicone-made artificial tongue relocated in proper resting position in the model, and we obtained sagittal X-ray images to examine the dynamic changes during the device contraction. We also tested the delivery propulsion by using a 3mL-baloon food bolus analogue filled with contrast agent (Oypalomin, Fuji Pharma, Tokyo, Japan) in a C-arm X-ray system (BV Vectra, Philips Japan, Tokyo, Japan).

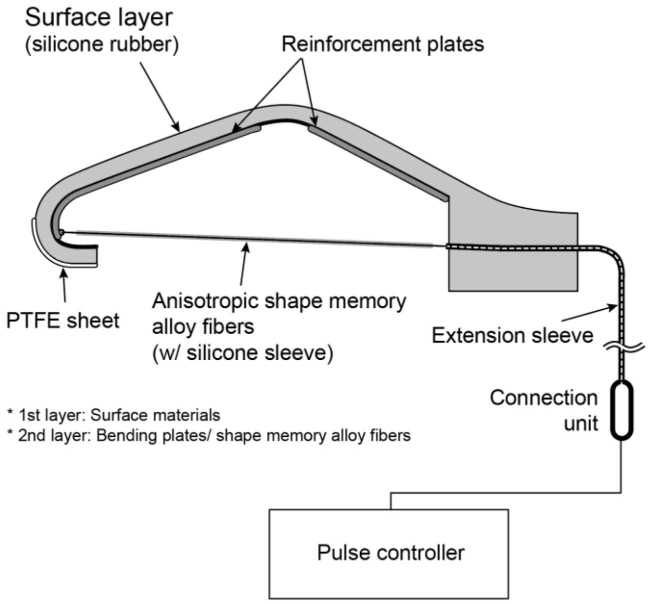

Figure 2. Schematic illustration of the structural components of the artificial tongue. It consisted of a surface layer to cover the actuator unit moving towards upward to palate in the oral cavity. PTFE sheet was attached onto the bottom of the leading edge of tongue to decrease the friction during the motion along the triangular base in the sagittal plane.

Figure 3. Test image of motion analysis of the artificial tongue deformation of artificial tongue unit using shape memory alloy fibers.

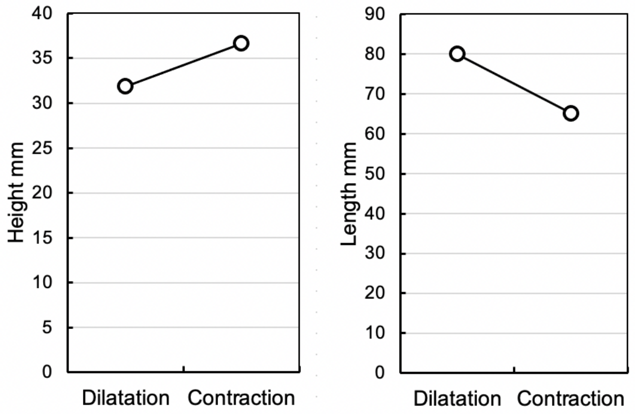

Figure 4. An example of the changes in height of artificial tongue deformation obtained by the internal fiber contraction.

III. RESULTS

A. *Motion of Contraction Obtained by Layered Structure*

Fig. 4 shows the changes in the height and the length of the tongue unit at the dilatation or the contraction phases. The height increased by 15% by the contraction of shape memory alloy actuator. The artificial tongue calculated to reduce the oral cavity volume up to around 5mL between the upper surface region of the tongue and the palate by its upward pressurizing motion.

Fig. 5 shows sequential images during the retraction of the tongue unit. The propulsion contraction was derived in 2-second period arranged by the controller.

B. *Feasibility of the Artificial Tongue in the Mock Head*

Installation feasibility was tested as shown in Fig. 6 in the head-neck model. The retraction was investigated in the oral cavity as performed by the single unit (Fig. 5). The leading edge of the tongue provided the sliding support on the lower jaw model, and the elimination of oral cavity was obtained against the deformation by the shape memory alloy fibers as shown in Fig. 6.

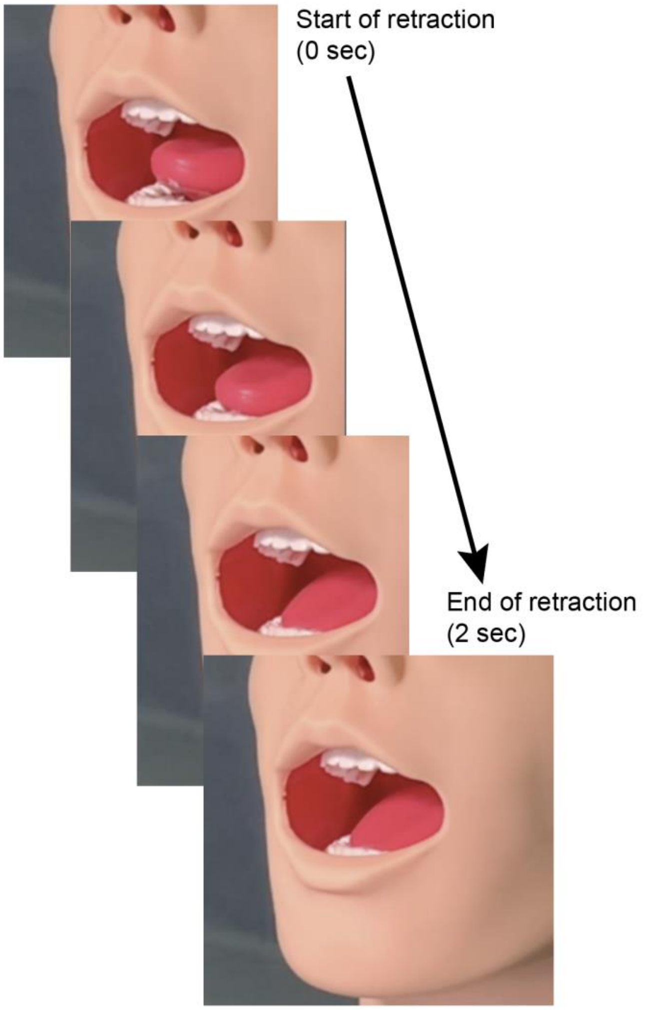

Figure 6. Images of sequential changes of the prototype tongue obtained in the head mock model with the static opening mastication position.

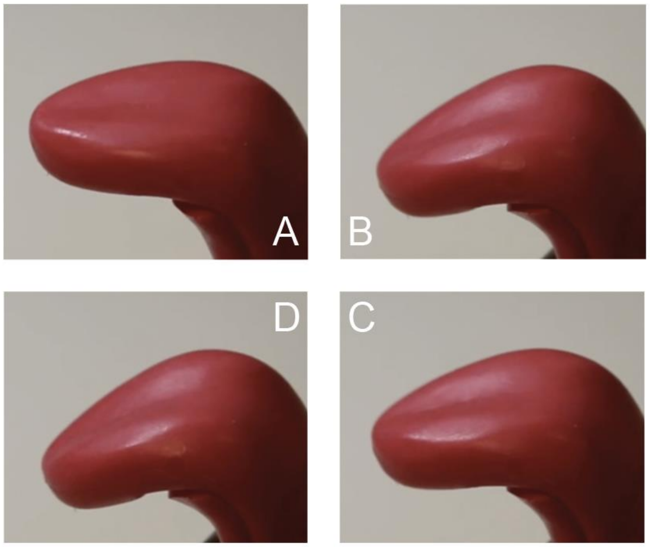

Figure 5. Sequential changes in the shape by the contraction driven by shape memory alloy fibers installed into the artificial tongue unit: from the start (A) to the propulsive retraction end (D) in 2 seconds.

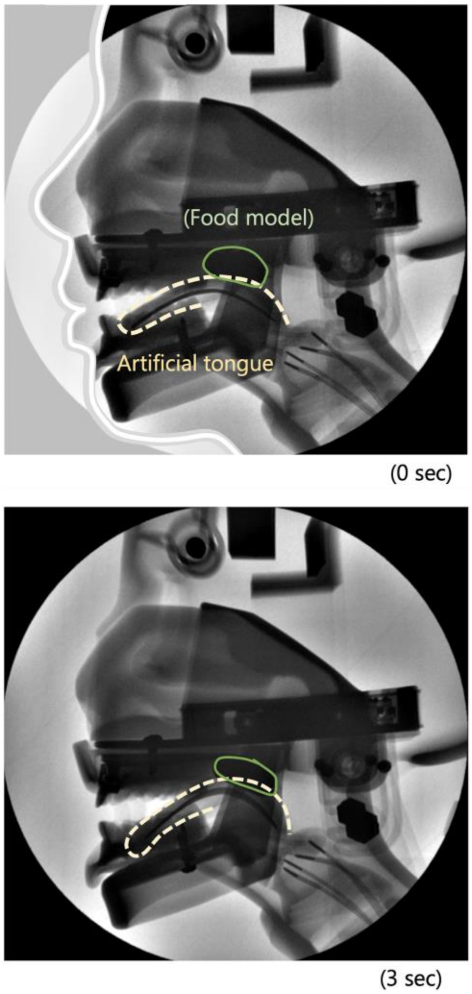

Figure 7. Demographic changes in the food analogue masses during the tongue motion derived by the X-ray investigation (top, dilatation phase at 0 sec; bottom, contraction phase at 3 sec): dashed line indicated the surface layer of the artificial tongue unit.

IV. DISCUSSION

Although the impairment of swallowing function depends the rest of native function after the surgical treatment of cancer, the loss of functional reserve of the tongue may lead dysphasia during swallowing motion. At present, to minimize the loss of tongue propulsion function, rehabilitation as well as reconstructive surgery will be performed to reshape the tongue, which involves grafting skin, fat, muscle and other tissues extracted from the patients' own thighs, abdomen, chest or arms. We invented an active contractile artificial tongue functioning in the patient's oral cavity reproducing food bolus masses propulsion in the swallowing process. Our approach with the implantable artificial tongue presented in this study exhibited dynamic deformation of the tongue prototype in the oral cavity. Therefore, the dynamic motion of the artificial tongue can provide active food delivery in patients with considerable loss of tongue function. The implanted artificial tongue may reproduce physiological tongue function in patients' mouths for alternative tongue restoration surgery as an artificial active flap.

Recent studies on pharyngoesophageal swallow process in dysphasia showed the tongue base motion and pressure defined vallecular clearance [8,9]. This study reveals that the significant motion at the artificial tongue surface layer eliminated the room between the tongue and the palate by contraction. The bending motion of the tongue was constructed by triangular support against the tongue base between the leading edge and the root of the tongue from the sagittal view. Our new mechanism for the support of propulsive bolus delivery may offer the similar characteristics to generate pressure by the motion of the tongue. The longitudinal deformation of the natural tongue may produce sufficient pressure to deliver food bolus to pharyngo-esophageal portion, which is not included in the present prototype of artificial tongue.

We demonstrated the active propulsive motion to support food bolus masses in the static head model. However, the threshold force and acceleration ratio to deliver food by the tongue pressures are yet unknown. Therefore, the optimum pressure and propulsive velocity of the artificial tongue mechanisms could be analyzed with the combination of mastication in the future works.

V. CONCLUSION

The first implantable artificial tongue was designed by the actuation of fine shape memory alloy fibers. We examined basic dynamic characteristics and also tested the feasibility in the anatomically identical oral-neck model. As a proof of concept, we have achieved its useful food bolus delivery propulsion using a large deformation shape memory alloy fibers.

REFERENCES

[1] A. Ohkoshi, K. Kato, T. Ogawa, A. Nakanome, R. Ishii, and Y. Katori, "Improvement of a delayed swallowing reflex following treatment for advanced head and neck cancer," *Cancers Head Neck,* vol. 5, p. 8, 2020, doi: 10.1186/s41199-020-00055-5.

[2] M. Pein *et al.*, "Independent comparison study of six different electronic tongues applied for pharmaceutical analysis," *J Pharm Biomed Anal,* vol. 114, pp. 321-9, Oct 10 2015, doi: 10.1016/j.jpba.2015.05.026.

[3] G. B. Hopkin, "Neonatal and adult tongue dimensions," *Angle Orthod.,* vol. 37(2), pp. 132-133, 1967.

[4] I. Sanders and L. Mu, "A three-dimensional atlas of human tongue muscles," *Anat Rec (Hoboken),* vol. 296, no. 7, pp. 1102-14, Jul 2013, doi: 10.1002/ar.22711.

[5] D. Homma, S. Uemura, and F. Nakazawa, "Functional anisotropic shape memory alloy fiber and differential servo actuator," *Proceedings of the International Conference on Shape Memory and Superelastic Technologies* vol. SMST-2007, pp. 463-472, 2008.

[6] Y. Shiraishi *et al.*, "Development of an Artificial Myocardium using a Covalent Shape-memory Alloy Fiber and its Cardiovascular Diagnostic Response," *Conf Proc IEEE Eng Med Biol Soc,* vol. 2006, pp. 406-8, 2005, doi: 10.1109/IEMBS.2005.1616431.

[7] A. Yamada *et al.*, "Peristaltic hemodynamics of a new pediatric circulatory assist system for Fontan circulation using shape memory alloy fibers," *Annu Int Conf IEEE Eng Med Biol Soc,* vol. 2013, pp. 683-6, 2013, doi: 10.1109/EMBC.2013.6609592.

[8] C. P. Orsbon, N. J. Gidmark, T. Gao, and C. F. Ross, "XROMM and diceCT reveal a hydraulic mechanism of tongue base retraction in swallowing," *Sci Rep,* vol. 10, no. 1, p. 8215, May 19 2020, doi: 10.1038/s41598-020-64935-z.

[9] M. A. Knigge and S. Thibeault, "Relationship Between Tongue Base Region Pressures and Vallecular Clearance," *Dysphagia,* vol. 31, no. 3, pp. 391-397, Jun 2016, doi: 10.1007/s00455-015-9688-0.