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Stabilometric analysis of neck orientations during mealtime by a wearable device for dysphagia patients

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***Abstract*— Postural changes are commonly used treatment to prevent the elderly from the risk of aspiration pneumonia. However, the evidence-based studies regarding effectiveness of this treatment remains unclear since no systematic method exists to measure constantly changing postures without disturbing usual eating behaviors. In this paper, using IMU system attached to a smart-phone based wearable technology, we analyzed data of the neck orientation angles obtained from the dysphagia patients and healthy adults during their mealtime and attempted to see if the obtained data can show differences regarding the dynamics of the angles.**

The result shows the possibilities to use the device to monitor neck orientations while the dysphagia patients eating their meals in daily lives.

I. INTRODUCTION

Dysphagia is a common swallowing disorders for the elderly and it's main symptom is an abnormal entry of bolus into the respiratory tract, called aspiration. Aspiration has been associated with the risk of respiratory complications including aspiration pneumonia, which can be a fatal disease to the elderly. In fact, almost 40,000 people lost their lives due to this disease in Japan[1]. Among many treatments to avoid aspiration, postural changes are widely used methods for the dysphagia patients. These treatment methods usually involve the angle adjustment of the entire body or the head/neck. Some studies suggested that these changes can be effective in reducing aspiration risks[2][3].

Critical problem of this angle adjustment is that each patient's suitable postural positions for safe swallowing are varied depending on their swallow capabilities and health conditions; therefore, no single posture can improve their swallowing functions to every patients[9]. Moreover, even if the body posture is adjusted according to the individual conditions, such postures are easy to be unstable once swallowing activities start, especially for the paralyzed patients or frail elderly (fig. 1). Also, a practical issue is that no systematic method is available to check their positional stabilitiies while their eating meals.

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*PLIMES Inc. is a manufacturer of GOKURI. K. Suzuki, D. Jayatilake and T. Shimokakimoto are shareholders of the company.

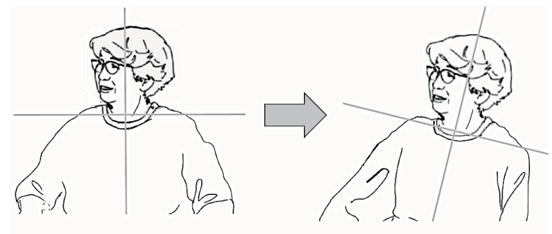

Fig. 1. Trunk collapses are likely to be happened to the patients with paralysis and frail elderly.

Considering the issues above, we attempted to develop a smart-phone based monitoring system of patient's positions which can be used easily anywhere so that patients can keep the safe posture while they are eating meals. Among available body or head/neck positional adjustments, we have been focused on changes of the neck orientations during mealtime and introduced the automatic detection systems based on Inertial Measurement Unit (IMU) in previous study [5]. As a further study, this paper attempts to see how dysphagia patients and healthy adults changed their neck orientation angles while they were eating with the device using stabiometric analysis.

II. NECK ORIENTATION DETECTION

To detect neck orientation angles, we used the IMU-based neck orientation detection system attached to the back of GOKURI, a smart-phone based realtime assessment of the swallowing functions by swallow sounds (PLIMES, Inc, Japan) (fig. 2).

The system utilizes an intelligent 9-axis absolute orientation sensor (BNO055; Bosh, Germany) at the rate of 20 Hz. The device instantly shows the neck angles in realtime on interface and also roll, pitch, yaw angles were produced as an output data. In previous study, we have shown that the measurement offset were less than 15° when comparing IMU detected angles and estimated pharynx and larynx angles captured by X-ray video images[5].

III. EXPERIMENT AND RESULTS

A. Experiments and Participants

To analyze the changes of neck orientations during the mealtime, we evaluated the data of 5 participants including dysphagia patients (3 males; mean age=72.33±9.81) recruited by medical doctors and 2 healthy adults (male and female, age=36 and 43 years old respectively) while

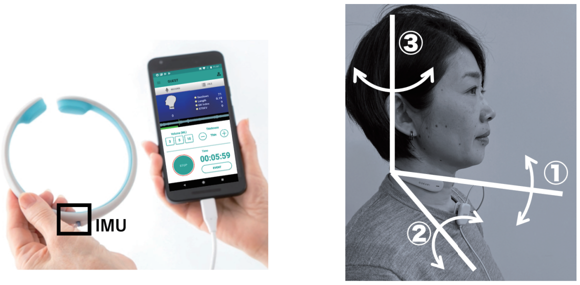

Fig. 2. Left fig.: The neck orientation is shown on the smart-phone's interface in realtime. Right fig.: Measured three neck orientations:①Pitch, ②Roll, and ③Yaw angles.

they were eating and drinking at the usual mealtime settings(table I). All three patients were hospitalized and they were diagnosed as dysphagia by a medical doctor prior to the experiment. Their leading cause of dysphagia symptoms were abnormality of an artery and a vein over the brain or spinal cord (Dural arteriovenous fistulas), oral cancer, and deterioration of the muscle strength due to frailty. In addition to these patients, two healthy adults without any history of swallowing problems were recruited.

TABLE I
BASIC CHARACTERISTICS

Participants	ID	Age	Gender	Health Conditions	Positions
Patients	P1	78	male	Dual arteriovenous fistulas	wheelchair
	P2	61	male	Oral Cancer	bed
	P3	78	male	frailty	wheelchair
Adults	A1	36	male	N/A	chair
	A2	43	female	N/A	chair

Both patients and adults wore GOKURI with IMU on their neck approximately around C4 level while eating their meals and ate their meals by themselves using spoons and chopsticks. While eating, one patient was on the bed and two patients were on the wheelchair but all patients ate their meals in their sitting positions. Their meals were the soft and bite-sized, as prepared by the hospital according to their swallowing levels. Adults ate their usual meals prepared by themselves in the sitting positions. All participants sat comfortably and neck positions were not adjusted to the specific angles. When they were ready to start eating, swallow sounds and neck angles were simultaneously recorded with GOKURI. Considering the safety, all patients ate their meals under the supervision of nurses or other medical professions during the experiment. This study was conducted under the approval of the institutional review board of Kochi Medical School, 31-138.

B. Methods

Even though the device produces three angles (roll, pitch, yaw) as outputs, this study focused on roll and pitch angles. This is because we considered that roll and pitch angles are more likely to represent movements of the pharynx and larynx which implies the direction of bolus flow. Moreover, the neck orientations, which involves the movements of middle and lower cervical spine, is considered to be effective to protect airway for avoiding aspiration[9]. The recorded time spans of neck orientations depended on the participants but we used the first 5 minutes from the time they started eating for the following analysis.

To capture the neck orientation dynamics while eating in details, we focused on following two aspects: 1. average speed of angle changes in neck orientations, and 2. envelope area using convex hull. In these analysis, studies of stabilometry were referred[6] in which the spontaneous body balance and orientation instability for patients (ex. dizziness).

1. Average speed of angle changes
First, to focus on the angle changes of the neck orientations, the standard values, $\bar{x}$ for roll and $\bar{y}$ for pitch, were calculated using averages of one second from the beginning. The following formula shows the calculations for roll angles $\bar{x}$ and $\bar{y}$ was calculated using the same formula. Almost 20 data points were used to calculate $\bar{x}$ and $\bar{y}$ for each participant since the IMU recorded the data every 50 ms (20 Hz). Same calculation was applied to obtain $\bar{y}$ (recorded pitch angles).

$\bar{x} = \sum_{i=1}^{n} x_i/\text{n}$ (n=20; x_i: recorded roll angles)

Second, using $\bar{x}$ and $\bar{y}$ calculated above, we obtained how much angles were changed from the start position while they were eating meals as angle changes (AC).

AC: X_i=x_i-$\bar{x}$ and Y_i=y_i-$\bar{y}$

Then, AC per ms, average changing speed of neck orientations, was calculated. To get the values, the spontaneous changes in roll and pitch angles (C) in every 50 ms was produced by:

C_i=$\sqrt{X_i^2 + Y_i^2}$ (i=data for 5 minutes)

Next, the total changes of neck orientation (T) was calculated and angle change (AC) per ms was obtained where T was divided by time (5 minutes).

T=$\sum_{i=1}^{n} C_i$
AC per ms = T/time (time: 5 minutes in ms)

2. Envelope area (Convex Hull)
Additionally, envelope area of neck orientations is calculated to see its stability using convex hull method. This method is commonly utilized to analyze the body stabilities and dynamics referring stabilometric analysis[6]. In this method, the scatter plots of maximal distance from the center are connected each other and the surrounded polygon area is calculated. A critical issue of calculating the convex hull is that the area is likely to be larger when the data contains outliers since the calculation uses the most distant points. Therefore, we used mean+2SD for the edge points of the

TABLE II
RESULTS: ANGLE CHANGES AND ESTIMATED AREAS

ID	Angle Changes(AC) P^1(min)	P(max)	R^2(min)	R(max)	AC /ms	Area (Convex Hull)	Area 10 min. later
P1	0.42	-9.58	0.42	6.42	0.053	63.50	39.00
P2	0.00	-24.00	0	±15.00	0.089	202.00	-
P3	0.21	-26.79	-0.32	-11.32	0.166	461.00	370.50
A1	-0.10	-27.10	±0.50	-13.50	0.116	306.00	-
A2	-0.20	14.80	0	-12.00	0.144	145.50	-

(Angle Changes (AC): 1. P=Pitch Angles, 2. R=Roll Angles)

boundary in every 36° and calculated the each polygon area based on the points so that we can minimize the influences of outliers for this area calculation.

As an additional analysis, we included the frequencies into the plots with a MATLAB command function of 'heatscatter' to show frequencies of spotting roll and pitch angles while participants were eating their meals. Each dot represents pitch and roll angles of one measurement and the yellow color get brighter if the certain angles were measured frequently. All analyses were conducted with MATLAB (MathWorks, Inc.) .

IV. RESULTS

A. *movements of neck orientations*

TableII shows the overall results. The maximum and minimum angle changes (AC) shows the largest and smallest angle changes of participant's neck orientation angles from their starting position. For pitch angles, positive number shows the patients moves their neck upwards and the negative number shows they moved their neck downwards. For roll angles, the patient's neck inclined toward left if the number is negative and their neck inclined toward right if the number is positive.

In first 5 minutes, P2, P3 and A1 showed larger range of neck orientation movements than other two participants and they seemed moved downward largely while they were eating meals. Most of the participants moved their heads to left and right, but these movements were not as dynamic as pitch angle changes.

P3 and A1's neck moved almost 24∼27° down and inclined toward left in about 11∼14° while they were eating meals. P2 also shows relatively large changes in angles both for pitch (-24°) and roll (±15.00). However, combined with the scatter plots for P2 (Fig.3), dynamic changes of neck angles was occurred temporarily and not constantly repeated.

Regarding AC per ms, participants' necks were orientated by between 0.05∼0.17° per ms. on average while eating. Change speed of neck orientations were similar among two adults (A1 and A2), and the speed of P3 was the fastest among all. Larger differences in speed were found between P1 and P3 about 0.1° per ms.

Consequently, for the estimated areas by convex hull, P3 and A1 had larger estimated areas than other participants since they moved their necks in wider angles as shown in the figure (fig. 3). However, compared to A1 in details, P3's neck seemed to move in more various directions. Moreover,

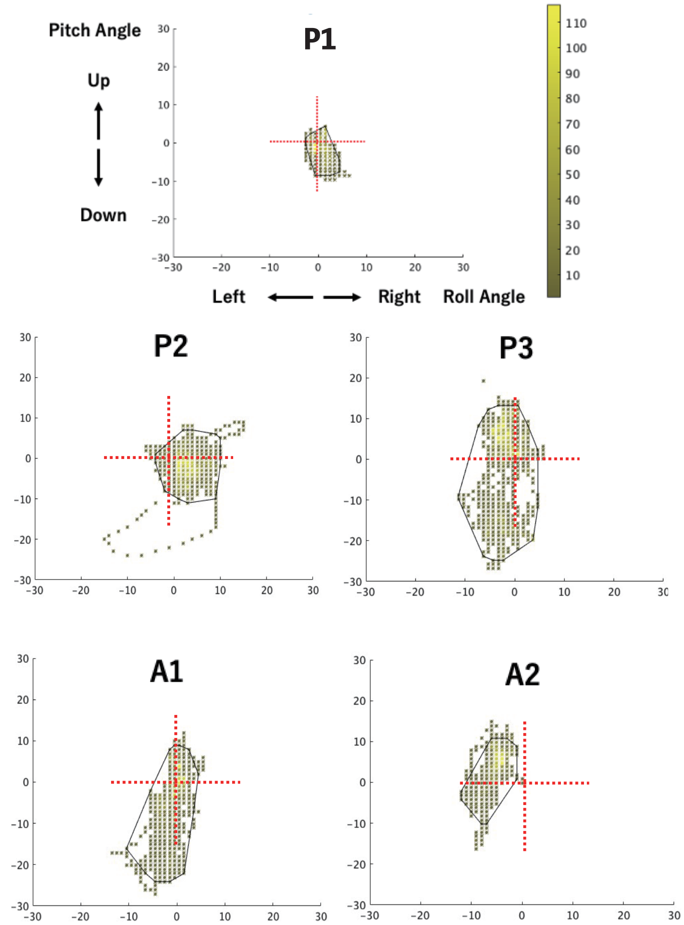

Fig. 3. Scatter Plots with Frequencies of neck orientation changes

even though the high frequent spots were gathered around the center (0° for pitch and roll) for A1, such spots were appeared in a few places to P3, especially the upper left positions from the original posture.

P1 showed the smallest plotted area overall. They are frequently gathered around the center and intensively spotted between -10° to 10° in both angles. Neck movement for P2 were almost equally distributed with some temporal outliers. For A2, her neck position kept stable on upper-left than the original position and her move was mostly up-downs within 20° ranges and left-right movements within 10° ranges.

B. *additional analysis for convex hull*

As mentioned previously, many elderly have difficulties in keeping balances and their posture becomes unstable while they were sitting due to paralysis or muscle weakness because of frailty. Considering the physical conditions above, we conducted an additional analysis to see how their neck moved 10 minutes after they started eating their meals.

Since we did not control the time lengths for participants to finish eating meals on this experiment, 3 participants finished up their meals within 10 minutes. Therefore, data of 2 participants, P1 and P3, were used for this additional analysis. Estimated areas by convex hull were shown on table

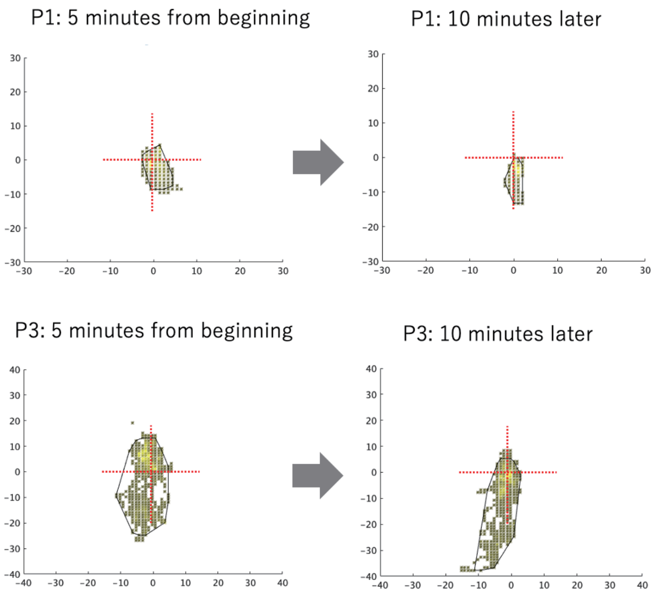

Fig. 4. Scatter Plots 10 minutes later.

II. Also, Fig.4 shows scatter plots of first 5 minutes and 10 minutes after participants started eating.

Regarding P1, the plotted area became much smaller and the neck angle were likely to move down from the original position. For P3, estimated convex hull area was large still but the movement toward left and right seemed to become relatively smaller. Also, it is apparent that the neck angles moved to the direction toward left and down.

V. DISCUSSION & CONCLUSIONS

In this paper, we present that the automatic angle measurements to observe the dynamics of the neck orientation movements quantitatively. Regarding the speed, a difference between fastest and slowest speed on average was about 0.1° per ms. It is difficult to argue what this differences mean since we could not find any studies looking into the speed of neck orientations while eating. However, the results reveal critical implications. For instance, regarding P1, he did not only move his neck very slowly, but his estimated areas was also much smaller than others. A possible reason for the feature would be a side effect of medications due to his history of suffering from Schizophrenia. It is well known that some types of psychiatric medications often causes motor impairments, not only to the entire body but also to the swallowing mechanisms[8]. Moreover, patients of Parkinson's disease are also likely to have same issues in swallow reflex while they were swallowing and suffer from risks of aspiration pneumonia[7].

On the other hand, careful attention would be needed if participants show larger and unilateral leaning movements as well. Unintentional trunk collapses can be happened to the patients with paralysis and frail elderly since muscles of their neck are not strong enough to support their heads. In this experiment, scatter plots of P3 showed that his neck angles moved down as the time passed and this result may imply that P3, whose cause of dysphagia is frailty, could not support his neck against gravity. Similar issues are common to the patients with paralysis and their body were likely to go down toward paralyzed or unpralyzed side unintentionally.

Also, we carefully need to see the patterns of the neck orientations. Even though P3 and A1 have similar overall patterns in scatter plots, the differences of densely plotted areas show different features. For A1, spots were more densely clustered to the center than P3. It probably means that A1 moved his neck for certain purpose, such as looking at dishes, but was more likely to go back to the original position than P3.

It is well known that instability of eating positions and tiredness while eating tends to lead to aspiration[9]; however, eating positions can naturally change when picking up foods. The critical question can be what is the allowable ranges of angle changes while drinking and eating meals, especially for the dysphagia patients to prevent aspiration. For the purpose, further detailed research is required to quantitatively assess the movements of neck orientations.

As a future study, we are planning to analyze the data of persons without eating and see how much angle changes happen even we are still. Also, as a limitation of this paper, we could not obtain data which last more than 10 minutes in healthy adults, the next analysis will be performed using the data to compare the angle changes after a certain time is passed. Moreover, we need to compare data of dysphagia patients with different diagnoses including patients with paralysis and see if any similar or different features can be found by their physical conditions.

REFERENCES

[1] Ministry of Health, Labour and Welfare Tech. Rep., "Vital Statistics," 2019.

[2] R. Terré and F. Mearin, "Effectiveness of chin-down posture to prevent tracheal aspiration in dysphagia secondary to acquired brain injury. A videofluoroscopy study," *Neurogastroenterology & Motility*, vol. 24, no.5, pp414-419, 2012.

[3] J. Ashford, D. McCabe, K. Wheeler-Hegland, T. Frymark, R. Mullen, N. Musson, T. Schooling, CS. Hammond. "Evidence-based systematic review: Oropharyngeal dysphagia behavioral treatments. Part III– impact of dysphagia treatments on populations with neurological disorders," *J Rehabil Res Dev*. vol.46, no.2, pp195-204, 2009.

[4] H. Kagaya, Y. Inamoto, S. Okada and E. Saito, "Body positions and functional training to reduce aspiration in patients with dysphagia, " *Japan Medical Association Journal*, vol.54, no.1, pp35-38, 2011.

[5] N. Kuramoto, K. Ichimura, D. Jayatilake, K. Hidaka and K. Suzuki. "Automatic measurements of neck angles toward the bedside treatment for the dysphagia patients at the community-based health care, " in Proc. of *2019 41st Annual International Conference of the IEEE Engineering in Medicine and biology Society*, pp595-598, 2019.

[6] K. Imaoka, H. Murase and M. Fukuhara, " Collection of data for healthy subjects in Stabilometry," *Equilibrium Res Suppl.*, vol.12, pp1-84, 1997.

[7] M.E. Groher and M. A. Crary, "Adult Neurologic Disorders," In *Dysphagia: Clinical Management in Adults and Children, 2nd Edition*. St. Louis, MO: Elsevier, 2016, pp271-304.

[8] D.P. Kulkarni, V.D. Kamath and J.T. Stewart, "Swallowing Disorders in Schizophrenia," *Dysphagia*. vol32, pp467-471, 2017.

[9] H. Kagaya, Y. Inamoto, S. Okada and E. Saito, "Body positions and functional training to reduce aspiration in patients with Dysphagia, " *Japan Medical Association Journal*, vol.54. No.1, pp35-38, 2011.