



Longitudinal Kinematic Evaluation of Pharyngeal Swallowing Impairment in Thyroidectomy Patients

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Abstract

The aim of this study was to assess pharyngeal swallowing impairments in thyroidectomy patients and to delineate the contributory kinematic components. Forty consecutive patients (mean age = 47.33 years) and fourteen age- and sex-matched healthy adult volunteers (mean age = 42.64 years) participated in this study. A videofluoroscopic swallowing study (VFSS) was performed 1 day prior to surgery, and at 1 week and 3 months post-surgery. VFSS images were evaluated using the Modified Barium Swallowing Impairment Profile (MBSImp). Kinematic and temporal aspects of swallowing were characterized by measurement of maximum hyoid and laryngeal excursion, pharyngeal transit duration, laryngeal response duration (LRD), and laryngeal closure duration at each three time-points. At 1 week post-surgery, only pharyngeal impairment was significantly deteriorated than pre-surgery ($p = 0.001$). However, at 3 months, a significant improvement was observed to pre-surgery level ($p = 0.01$). Post-surgery, maximum hyoid excursion was significantly reduced in patients compared controls ($p = 0.001$). Although the maximal distance of the hyoid and the laryngeal excursion was shorter than before surgery, laryngeal excursion at all three time-points was similar to that of controls. At all three time-points, LRD was significantly longer in patients than in controls ($p = 0.01$). Following thyroidectomy, pharyngeal aspects of swallowing as measured by the MBSImp and kinematic aspects of swallowing were reduced with incomplete recovery at 3 months. These exploratory data may guide decision regarding management of pharyngeal swallowing impairment with patients undergoing total thyroidectomy.

Keywords Thyroidectomy · The modified barium swallowing impairment · Deglutition · Kinematic hyolaryngeal excursion · Temporal measurement · Deglutition disorders

Introduction

A previous report showed that thyroid cancer accounted for 20% of all carcinoma cases [1]. Specifically, according to the Report of South Korea Statistics, over 30,000

thyroidectomies following thyroid disease had been performed annually over the preceding decade [2]. Although thyroidectomy is the most effective treatment for thyroid cancer, adverse neurological or anatomical changes may occur [3–5]. The post-surgical changes could negatively

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Table 1 Demographic and clinical characteristics of the patient cohort

Characteristic	Total thyroidectomy patients (<i>n</i> = 40)
Mean age, years (SD)	47.33 (11)
Sex, male/female	7/33
Indication for thyroidectomy	
Non-toxic multinodular goiter, <i>n</i> (%)	13 (32.5)
Non-toxic single thyroid nodule	11 (27.5)
Malignant thyroid neoplasm	9 (22.5)
Non-toxic diffuse goiter	4 (10)
Benign thyroid neoplasm	2 (5)
Graves' disease	1 (2.5)

impact swallowing function and any changes might be expected over time. Prior studies reported that post-surgical symptoms occur within 1 week after surgery and a few recoveries after 3 months.

Kinematic measurements such as swallowing duration, hyoid, and laryngeal excursion are used to assess the spatial and temporal aspects of swallowing function. In addition, this measure is widely accepted to identify physiological contribution which may lead swallowing impairment. Prior studies have indicated an increase in swallowing duration and a decrease in maximal range of hyoid and laryngeal excursion during swallowing after thyroidectomy [6]. Despite these results, few studies to date have evaluated physiological change in this population. Furthermore, existing data have been generated via subjective appraisal of swallowing function using interviews or questionnaires [7–9]. A prospective approach with direct measurement of functional and physiologic swallowing change post-thyroidectomy is likely to provide additional, detailed information that may help guide clinical management of these patients. Against this background, the aims of the present prospective study were to compare kinematic measurements in thyroidectomy patients to a cohort of age-matched controls and to evaluate swallowing change over time in thyroidectomy patients.

Materials and Methods

Patients

A total of 40 total thyroidectomy patients (mean age = 47.33 years) were recruited from consecutive admission to a tertiary academic center in the South Korea. Inclusion criteria were as follows: (1) admission for total thyroidectomy with central neck dissection; (2) age 18–59 years. Exclusion criteria were as follows: (1) recurrent local or regional disease/damage; and (2) history of head and neck cancer, or cancer of the nasopharynx. Table 1 describes demographic characteristics for age, sex, and indication for thyroidectomy.

Controls

A total of 14 age- and sex-matched healthy adult volunteers (female:male = 11:3, mean age = 42.64 years, SD = 8.64, range 33–57 years) were recruited from the local community. Exclusion criteria included (1) age under 18 years or over 60 years; (2) history of head and neck or nasopharynx cancer; and (3) all swallowing disorders associated with neurological conditions or psychological causes.

VFSS

All patients completed VFSS 1 day prior to surgery, and at 1 week and 3 months post-surgery. Controls also completed VFSS (SONIALVISION VERSA 100I/DAR-8000, SHIMADZU Corp. Kyoto, JPN). Each VFSS followed the same procedure in which the subjects (patients and controls) swallowed a 5 cc thin liquid bolus (viscosity; 3cP, Brookfield Viscometer, Middleboro, MA, USA). The bolus was the 100% w/v mixture of water and barium sulfate powder (Solotop HD; Tea Joon Pharm co. Ltd, Seoul, KOR). Fluoroscopic images included the lips anteriorly, and the soft palate, cervical vertebrae, and esophageal sphincter. A penny coin (diameter of 19 mm) was placed on the image over the area of the fourth cervical vertebrae as a calibration referent. VFSS images were saved on a computer as an AVI file for later analysis. All participants provided written informed consent prior to inclusion. The study was approved by the Institutional Review Board of the Chonbuk National University Hospital.

VFSS Data Analysis

Swallowing impairment severity was quantified using the Modified Barium Swallowing Impairment Profile (MBSImp) score [10]. To assess the changes of airway protective reflex function and efficient movement of bolus through the esophagus after thyroidectomy, the following kinematic characteristics of swallowing were evaluated at each of the three time-points: (1) maximal anterior-superior

displacement of the hyoid bone; (2) maximal anterior-superior displacement of the larynx; (3) pharyngeal transit duration; (3) laryngeal response duration; and (4) laryngeal closure duration.

Swallowing Impairment

MBSImp Score

MBSImp is a standard and valid measurement of quantifying physiologic observations of structural movement related to bolus flow via VFSS with a scoring system of 17 components (oral; six components, pharyngeal; ten components, esophageal; one component) [10]. MBSImp rating for the each component was assigned using a 0–4 point scale, in which 0 indicates normal function and higher ratings indicate a more severe swallowing impairment. To evaluate swallowing impairment, subscores for pharyngeal and esophageal impairment were calculated as the sum of the ten components and one component. In case of oral impairment, the component three related to chewing and mastication ability was excluded due to use of single thin

liquid and then the sum of the five components was collected.

Kinematics Measurements

Spatial: Maximal Hyoid and Laryngeal Excursion

To determine maximal hyoid and laryngeal excursion, the displacement of anterior-superior edge of the hyoid bone and the anterior-inferior edge of the thyroid cartilage was measured. For this purpose, individual frames associated with each swallow were separated using Max TRAQ 2D Standard ver. 2.4 (Innovision Systems Inc., Columbiaville, MI, USA). From the sequence of frames for each swallow, the frame depicting the subject holding the bolus in the oral cavity and the frame depicting maximal excursion of the hyoid bone and thyroid cartilage during swallowing were selected for analysis. Using Image J software, a line was drawn between the anterior-inferior edge of vertebral bodies C_2 and C_4 was used as a reference axis for the measurement of hyoid and laryngeal excursion. The angle of this reference on images was rotated to 90° (Fig. 1a) [11]. On each frame, the anterior-inferior edge of vertebral

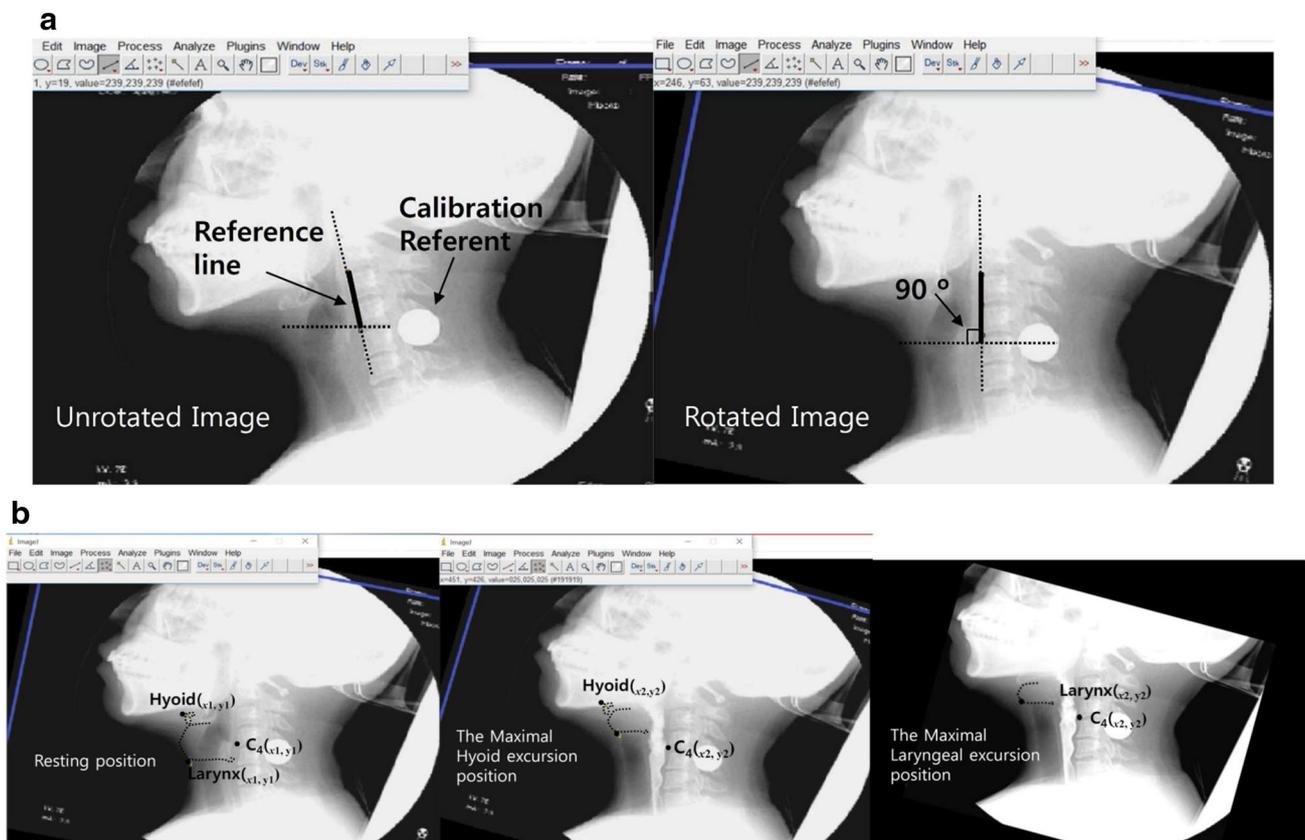


Fig. 1 a Videofluoroscopic image (left) unrotated and rotated image (right) which was adjusted for vertical alignment of the C_2 – C_4 axis of reference; b the image depicted the point in the swallowing reflecting

hyolaryngeal resting position (left) and maximal hyolaryngeal excursion (middle and right)

body C₄ was identified and used as an anchor point [12]. The anterior–superior edge of the hyoid bone and the anterior–inferior edge of the thyroid cartilage were used as reference objects. Maximal distance of hyoid excursion (MDHE) and maximal distance of laryngeal excursion (MDLE) were separately measured (Fig. 1b). These values were calculated as the sum of the total horizontal (*x* coordinates) and the vertical (*y* coordinates) displacement [11].

Temporal: PTD, LRD, and LCD

Measures of swallowing duration comprised PTD, LRD, and LCD. For each measure, duration was calculated as the time in seconds from onset (reference time: 0 s) to offset. For each measure, the onset and offset frames were selected using Max TRAQ. For PTD, the onset frame depicted the arrival of the bolus head at the ramus of the mandible, and the offset frame depicted the tail of the bolus entering the upper esophageal sphincter [13]. For LRD, the onset frame depicted the arrival of the bolus head at the ramus of the mandible, and the offset frame depicted contact between the bolus head and both the arytenoid cartilage and the epiglottis [14]. For LCD, the onset frame depicted the initial contact arytenoid cartilage and the epiglottis, and the offset frame depicted final contact between two structures for returning pre-swallow posture [14, 15].

Statistical Analysis

An independent samples *t* tests was used to compare swallowing outcomes in patients at each time-point with the control values. In patients, change in swallowing outcomes over time was analyzed using repeated measures analysis of variance (RM ANOVA). A *p* value of < 0.05 (2-tailed) was considered statistically significant level. Post hoc analyses (Bonferroni collection) of change in swallowing outcomes over time were then performed. Here, a *p* value of 0.017 was considered significant. In addition, Intraclass correlation (ICC) was used to examine correlation between inter- and intra-observer. All statistical analyses were performed using IBM SPSS ver. 24 (IBM Co., Armonk, NY, USA).

Results

Homogeneity and Reliability

At the 1 week post-surgery evaluation, data on 38 patients were available. The remaining two patients refused to undergo VFSS and were excluded from further analysis. At the 3 month post-surgery evaluation, data on 28 subjects

were available due to loss to follow-up and discharge of patients from clinical care. Homogeneity testing results indicated that the mean age and sex distribution of the control and total thyroidectomy group were comparable (mean age: $t = -1.44$, $p = 0.16$; sex: $\chi^2 = 0.11$, $p = 0.75$).

To assess inter-intra reliability, a second investigator analyzed 20% (eight patients) of all patient measurements. The ICC coefficient for interjudge agreement was excellent (ICC = 0.95, 95% confidence interval, CI 0.95–0.98). The main investigator re-analyzed 20% of the measurements and intrajudge agreement demonstrated excellent as 0.94 of ICC efficient (95% CI 0.94–0.98).

Longitudinal Change in MBSImp Score in Thyroidectomy Patients

Oral Impairment

The mean of oral impairment score did not differ significantly over time [$F(2,54) = 0.71$, $p = 0.50$].

Pharyngeal Impairment

A significant difference was observed for mean of pharyngeal impairment score over time [$F(2,52) = 7.32$, $p = 0.002$]. Prior to surgery, the mean MBSImp score was 1.41 (SD = 1.72). At 1 week, the mean MBSImp score had significantly increased compared with pre-surgery (mean = 2.48, SD = 2.28, $t = -3.89$, $p = 0.001$). At 3 months, the mean MBSImp score was 1.56 (SD = 1.74) and thus significantly lower than at 1 week (mean = 1.56, SD = 1.74, $t = 2.75$, $p = 0.011$). Furthermore, the mean MBSImp score at 3 months did not differ significantly from the mean value obtained prior to surgery (mean = 1.56, SD = 1.74, $t = -0.57$, $p = 0.57$) (Fig. 2).

Esophageal Impairment

The mean score of esophageal impairment did not differ over time [$F(2,50) = 2.08$, $p = 0.16$]. The mean score of each component over time is presented in Table 2.

Longitudinal Change in Kinematic Measurements in Thyroidectomy Patients

Spatial: Maximal Hyoid and Laryngeal Excursion

Mean MDHE differed significantly over time [$F(2,50) = 13.16$, $p = 0.001$, $F(2,50) = 19.02$, $p = 0.001$]. Prior to surgery, mean MDHE was 13.88 (SD = 3.26). At 1 week, mean MDHE (mean = 11.17, SD = 2.60) had decreased significantly compared with pre-surgery ($t = 4.58$, $p = 0.001$). At 3 months, mean MDHE was

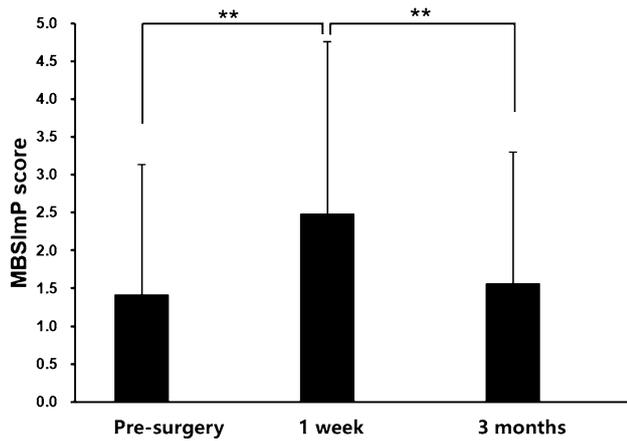


Fig. 2 The Modified Barium Swallowing Impairment Profile (MBSImp) score 1 day prior to thyroidectomy, and 1 week and 3 months post-thyroidectomy. Mean \pm SD, *** $p < 0.01$

11.27 (SD = 2.69), and thus significantly lower than pre-surgery ($t = 4.52$, $p = 0.001$) (Fig. 3a).

Mean MDLE differed significantly over time [$F(2.50) = 13.16$, $p = 0.001$, $F(2.50) = 19.02$, $p = 0.001$]. Prior to surgery, mean MDLE was 23.85 (SD = 4.78). At 1 week, mean MDLE (mean = 19.44, SD = 4.22) had decreased significantly compared with pre-surgery ($t = 4.58$, $p = 0.001$). At 3 months, mean MDLE was 19.57 (SD = 5.37), and thus significantly lower than pre-

surgery ($t = 4.97$, $p = 0.001$) (Fig. 3b). Table 3 presents the mean MDHE and MDLE at three time-points.

Temporal: PTD, LRD, and LCD

None of the temporal measurements in thyroidectomy patients differed over time.

Case–Control Comparisons of Kinematic Measurements

Pre-surgical Comparisons

The mean MDHE and MDLE did not differ significantly between groups (MDHE: $t = 1.01$, $p = 0.62$, MDLE: $t = -1.12$, $p = 0.27$) (Table 4).

Prior to surgery, a significant inter-group difference was observed for PTD and LRD ($t = -2.10$, $p = 0.041$ and $t = -2.72$, $p = 0.009$). Here, thyroidectomy patients showed longer PTD (mean = 0.74, SD = 0.11) and LRD (mean = 0.27, SD = 0.14) than controls (PTD: mean = 0.67, SD = 0.05; LRD: mean = 0.16, SD = 0.04) (Fig. 4).

Post-surgical Comparisons (1 Week)

Thyroidectomy patients also demonstrated significantly lower MDHE (mean = 11.17, SD = 2.60) than controls

Table 2 Longitudinal comparison of the MBSImp score in thyroidectomy patient

The modified barium swallow impairment profile	1 day prior to thyroidectomy	1 week post-thyroidectomy	3 months post-thyroidectomy
Oral			
Lip closure, mean (SD)	0.04 (0.19)	0.00 (0.00)	0.04 (0.19)
Tongue control	0.26 (0.45)	0.11 (0.32)	0.04 (0.19)
Bolus transport	0.15 (0.36)	0.04 (0.19)	0.00 (0.00)
Oral residue	0.93 (0.27)	0.93 (0.27)	0.89 (0.32)
Initiation of pharyngeal swallow	0.70 (0.91)	0.89 (0.89)	0.93 (0.73)
Pharyngeal			
Soft palate elevation	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Laryngeal elevation	0.42 (0.50)	0.62 (0.50)	0.42 (0.50)
Anterior hyoid excursion	0.38 (0.50)	0.62 (0.50)	0.42 (0.50)
Epiglottis movement	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Laryngeal vestibular closure	0.23 (0.43)	0.31 (0.47)	0.19 (0.40)
Pharyngeal stripping wave	0.04 (0.20)	0.08 (0.27)	0.00 (0.00)
Pharyngeal contraction	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Pharyngoesophageal segment opening	0.04 (0.20)	0.04 (0.20)	0.00 (0.00)
Tongue base retraction	0.16 (0.37)	0.48 (0.71)	0.28 (0.54)
Pharyngeal residue	0.16 (0.37)	0.48 (0.71)	0.28 (0.54)
Esophageal			
Esophageal clearance	0.11 (0.32)	0.19 (0.40)	0.11 (0.32)

SD standard deviation

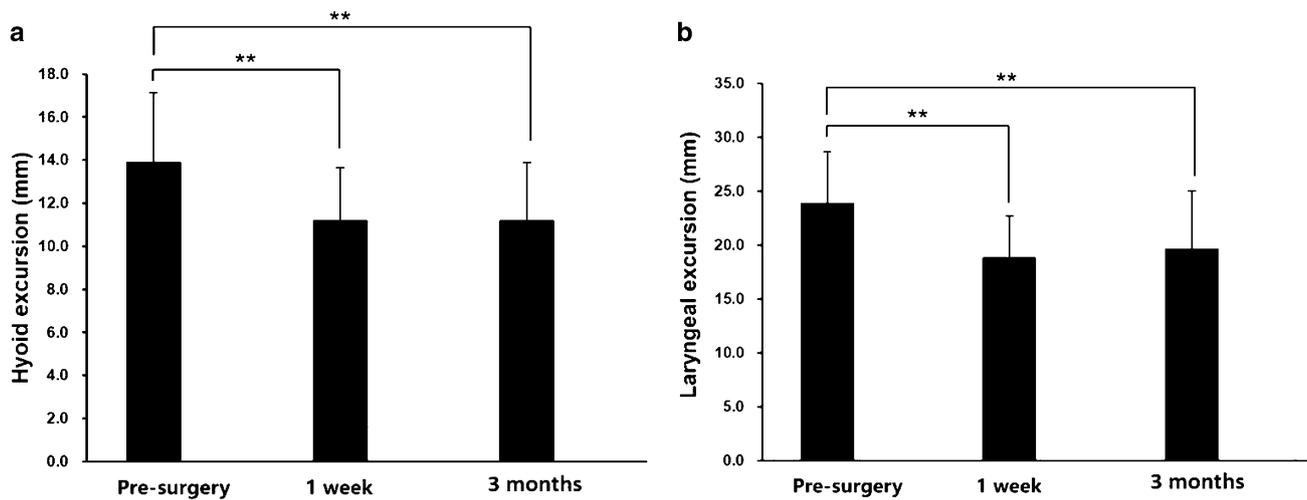


Fig. 3 Comparison of hyoid and laryngeal excursion. **a** Mean maximal hyoid excursion 1 day prior to thyroidectomy, and 1 week and 3 months post-thyroidectomy. **b** Mean maximal laryngeal excursion

1 day prior to thyroidectomy, and 1 week and 3 months post-thyroidectomy. Mean \pm SD, $**p < 0.01$

Table 3 Longitudinal comparison of kinematic measurements in thyroidectomy patients

Measurements	One day prior to thyroidectomy	1 week post-thyroidectomy	3 months post-thyroidectomy	<i>F</i>	<i>p</i>	Post hoc comparisons		
						Comparison	<i>t</i>	<i>p</i>
Maximal hyoid excursion, mm, mean (SD)	13.88 (3.26)	11.17 (2.60)	11.27 (2.69)	13.16	0.00**	1 vs. 2	4.58	0.00 [†]
						2 vs. 3	0.01	0.99
						1 vs. 3	4.52	0.00 [†]
Maximal laryngeal excursion	23.85 (4.78)	19.44 (4.22)	19.57 (5.37)	19.02	0.00**	1 vs. 2	4.75	0.00 [†]
						2 vs. 3	- 0.97	0.34
						1 vs. 3	4.97	0.00 [†]
Pharyngeal transit duration, s, mean (SD)	0.74 (0.11)	0.74 (0.07)	0.70 (0.16)	0.28	0.65			
Laryngeal response duration	0.27 (0.14)	0.25 (0.10)	0.28 (0.11)	1.18	0.31			
Laryngeal closure duration	0.56 (0.27)	0.56 (0.19)	0.47 (0.17)	2.04	0.16			

SD standard deviation

** $p < 0.01$, [†] $p < 0.017$

(mean = 15.00, SD = 4.02, $t = 3.39$, $p = 0.001$) (Fig. 4a). Non-significant inter-group difference was observed for mean MDLE ($t = 1.52$, $p = 0.14$).

At 1 week, thyroidectomy patients demonstrated significantly longer PTD (mean = 0.74, SD = 0.07) and LRD (mean = 0.25, SD = 0.10) than controls ($t = - 3.06$, $p = 0.004$; $t = - 3.20$, $p = 0.002$) (Fig. 4b).

Follow-Up Comparisons (3 Months)

Thyroidectomy patients showed significantly lower MDHE (mean = 11.17, SD = 2.60) than controls (mean = 15.00, SD = 4.02, $t = 3.52$, $p = 0.001$). Non-significant inter-group difference was observed for mean MDLE ($t = 1.22$, $p = 0.23$).

At 3 months, thyroidectomy patients also demonstrated significantly longer LRD (mean = 0.28, SD = 0.11) than controls (LRD: mean = 0.16, SD = 0.04, $t = 3.39$, $p = 0.001$) (Fig. 4c).

Discussion

Results of this study indicate that swallowing impairment occurred only in pharyngeal swallowing and then recovered at 3 months. A significant decrease in maximal range of hyoid excursion was observed after surgery, while all temporal measurements in thyroidectomy patients did not differ over time.

Table 4 Comparison of one day prior to surgery kinematic measurements in patients and controls

Measurements	Group		<i>t</i>	<i>p</i>
	Controls	Thyroidectomy patients		
Maximal hyoid excursion, mm, mean (SD)	15.00 (4.02)	13.88 (3.26)	1.01	0.62
Maximal laryngeal excursion	21.88 (5.52)	23.85 (4.78)	- 1.12	0.27
Pharyngeal transit duration, s, mean (SD)	0.67 (0.05)	0.74 (0.11)	- 2.10	0.04*
Laryngeal response duration	0.16 (0.04)	0.27 (0.14)	- 2.72	0.01**
Laryngeal closure duration	0.53 (0.09)	0.56 (0.27)	- 0.48	0.63

SD standard deviation
 p* < 0.05, *p* < 0.01

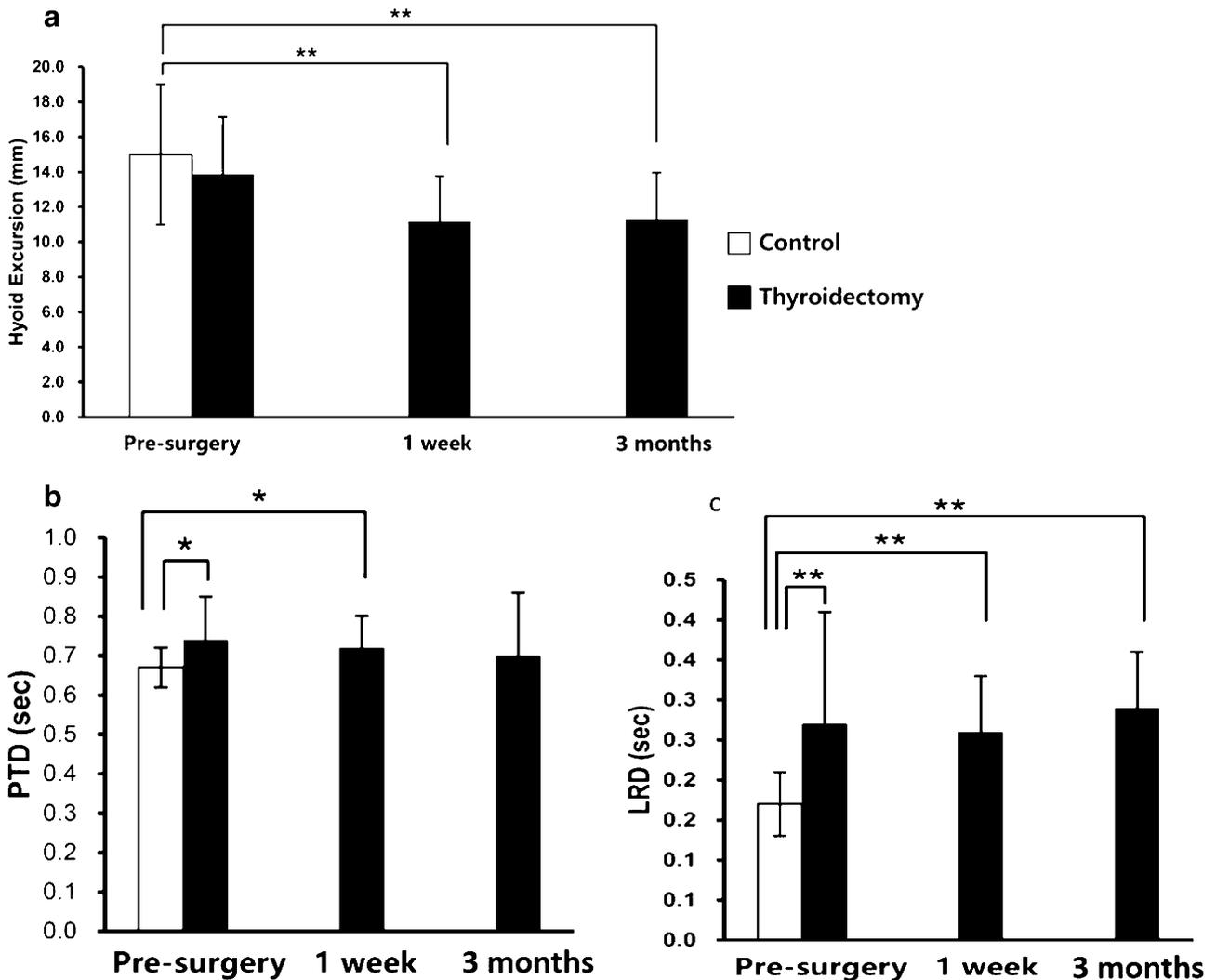


Fig. 4 Comparison of kinematic measurements in controls and patients. **a** Mean maximal hyoid excursion 1 day prior to thyroidectomy, and 1 week and 3 months post-thyroidectomy. **b** Mean PTD 1 day prior to thyroidectomy, and 1 week and 3 months post-

thyroidectomy. **c** Mean LRD duration 1 day prior to thyroidectomy, and 1 week and 3 months post-thyroidectomy. Mean ± SD, **p*<0.05, ***p* < 0.01

Swallowing impairment after thyroidectomy was only observed in pharyngeal swallowing. In addition, this pharyngeal impairment recovered at 3 months. This finding is

consistent with the results of a study by Jung et al. [6] which reported an improvement in surgery-related swallowing impairment over time. In total, fourteen (35%) of

the present thyroidectomy patients showed an increased swallowing impairment at 1 week after surgery. At 3 months, most of these patients (89.3%) showed an improvement but three patients continued to have pharyngeal residue-related impairment. More specifically, MBSImp scores secondary to pharyngeal residue (components 15 and 16) did not reduced over time. Prior study reported a change in pharyngoesophageal motility after thyroidectomy and occurrence of residues in the vallecular and pyriform sinuses after thyroidectomy [4]. Hence, though preliminary, these results might indicate that thyroidectomy could affect pharyngeal residue-related impairment. However, pharyngeal residue is likely to involve multiple aspects of oral and pharyngeal swallowing. Although post-surgery physiological changes, such as an abnormal retraction of the tongue and pharyngeal wall, can cause pharyngeal swallowing deficits, at present VFSS-based MBSImp cannot be used to assess physiological changes that provoke pharyngeal residue-related impairments [10, 16]. Therefore, a more thorough investigation would be required to fully understand pharyngeal residue as a clinical symptom.

Deterioration of hyoid and laryngeal excursion after surgery was anticipated. Prior to the analyses, we hypothesized that the maximal anterior-superior ranges of hyoid and laryngeal excursion would decrease at 1 week, and that this decrease would continue until the 3-month time-point, as in a previous investigation of patients with oropharyngeal cancer by Pauloski et al. [17]. In their previous study, hyoid and laryngeal excursion in oropharyngeal cancer patients were also observed to have more deterioration of movement than those of normal subject at each time-point. However, at 3 months, deteriorated hyoid and laryngeal excursion in the present thyroidectomy patients still remain similar to at 1 week after surgery. Given that physiological change and surgical procedure are dependent on tumor location [8, 18, 19], minor discrepancies between previous reports and the present study are understandable. Under normal circumstances, the usual trajectory of the hyoid and laryngeal excursion in swallowing involves stylohyoidal and stylopharyngeal muscle contraction. Thus, thyroidectomy might influence post-surgical skin adhesion or skin scarring which may result in dysfunction of the thyroid and hyoid muscle system [20–23].

The difference of temporal measurement in the two groups is that thyroidectomy patients showed longer PTD than controls at prior to surgery and 1 week post-surgery. However, at 3 months PTD in the two groups was comparable. Additionally, thyroidectomy patients showed longer LRD than control at all three time-points. At pre-surgery, a significant inter-group difference for PTD and LRD might be related to thyroid disease. In the present subset of patients with thyroid cancer, a plausible

hypothesis is that the relatively late pharyngeal response could be attributed to negative modulation such as the presence of tumor tissue [6]. At 3 months post-surgery, at least one of the factors related to the movement of the bolus into esophagus had improved, since PTD was then comparable to that of controls. For LRD, among controls laryngeal closure was completed within 0.17 s of the bolus entering the pharynx, whereas in thyroidectomy patients, the larynx closed within 0.27 s at all three time-points, i.e., irrespective of surgery status. As these results show, the glottis closure function may be more impacted by thyroid disease and/or thyroidectomy.

The present study has several limitations. First, the analyses did not take into account the impact of demographic factors, such as age and sex, on post-surgical recovery because the incidence of thyroid cancer in women is significantly higher than that in men epidemiologically. Second, the small patient cohort, an issue that was further compounded by study drop-out, renders generalization of the results to thyroidectomy population problematic. Finally, these data are restricted to single thin liquid bolus. Bolus viscosity (and/or volume) may have influenced results. Prior study reported viscosity effect with thick liquids in terms of reducing swallowing impairment. The bolus effect also contributes to it a risk of post-swallow residue in the pharynx with thicker consistencies [24]. Considering the impact of liquid consistency on swallowing physiology, future studies with various bolus types will be required to fully explore post-surgical changes in thyroidectomy patients.

Conclusion

The present analyses indicate that thyroidectomy patients only had pharyngeal swallowing impairment at 1 week post-surgery, but recovered by 3 months. A significant decrease in maximal range of hyoid excursion was observed after surgery, and none of the temporal measurements in thyroidectomy patients differed over time. These exploratory data regarding functional and physiologic swallowing change post-thyroidectomy is likely to provide additional and detailed information that may help guide clinical management of total thyroidectomy patients.

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Compliance with Ethical Standards

Conflict of interest The authors have no conflict of interest to disclose.

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