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Diplôme d'État

par

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SERMENT D'HIPPOCRATE

En présence des Maîtres de cette Faculté,
de mes chers condisciples
et selon la tradition d'Hippocrate,
je promets et je jure d'être fidèle aux lois de l'honneur
et de la probité dans l'exercice de la Médecine.

Je donnerai mes soins gratuits à l'indigent,
et n'exigerai jamais un salaire au-dessus de mon travail.

Admis dans l'intérieur des maisons, mes yeux
ne verront pas ce qui s'y passe, ma langue taira
les secrets qui me seront confiés et mon état ne servira pas
à corrompre les mœurs ni à favoriser le crime.

Respectueux et reconnaissant envers mes Maîtres,
je rendrai à leurs enfants
l'instruction que j'ai reçue de leurs pères.

Que les hommes m'accordent leur estime
si je suis fidèle à mes promesses.
Que je sois couvert d'opprobre
et méprisé de mes confrères
si j'y manque.

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Veuillez recevoir l'expression de mon plus profond respect.

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Veuillez recevoir l'expression de mon plus profond respect.

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Maëlle, je pense qu'il me faudrait écrire une nouvelle thèse pour te dire comme je t'aime et à quel point tu es importante et magnifique. Je te dirai simplement que je ne pourrai plus jamais imaginer ma vie sans toi et que je n'ai jamais été aussi heureux que depuis que je vis avec toi. Je suis le plus chanceux des hommes, je ferai tout pour te mériter. Je t'aime !

ANALYSE AUTOMATISEE DES SONS DE DÉGLUTITION CHEZ LES SUJETS SAINS ET CHEZ LES PATIENTS PRESENTANT UN CANCER DU PHARYNGOLARYNX

Introduction : La dysphagie peut être le premier symptôme d'un cancer ORL. L'exploration de la déglutition est souvent invasive ou irradiante. L'analyse acoustique de la déglutition est une méthode non invasive, mais non utilisée en pratique médicale. Cette étude a évalué une méthode de détection et d'analyse automatique des sons de déglutition chez des sujets sains et chez des patients atteints d'un cancer pharyngolaryngé.

Méthode : Une application pour smartphone, développée pour la détection et l'analyse automatique des sons de déglutition, a été testée sur 10 volontaires sains et chez 26 patients atteints d'un cancer pharyngolaryngé, avant et après traitement. Les sons de déglutition ont été enregistrés avec un laryngophone pendant un repas standardisé (100 ml de purée de pommes de terre, 100 ml d'eau, 100 ml de yaourt). Le nombre et la durée des déglutitions ont été notés; les résultats ont été comparés à ceux d'une analyse standard réalisée sur le logiciel AUDACITY®.

Résultats : Il n'y avait pas de différence significative pour le nombre ou la durée des déglutitions entre les deux méthodes d'analyse chez les sujets sains ni chez les patients traités. Chez les patients non traités, les résultats différaient entre les deux méthodes d'analyse pour la purée de pommes de terre et le yaourt en raison d'artefacts respiratoires.

Conclusion : Chez les sujets sains et chez les patients traités pour un cancer pharyngolaryngé, les résultats de l'algorithme étaient comparables à ceux de l'analyse standard. Une meilleure discrimination des sons de déglutition par l'application est cependant nécessaire chez les patients atteints d'un cancer ORL non traité.

Mots clés : Déglutition, dysphagie, sons de déglutition, analyse automatique, détection automatique, cancer

AUTOMATIC ANALYSIS OF SWALLOWING SOUNDS IN HEALTHY SUBJECTS AND IN PATIENTS WITH PHARYNGOLARYNGEAL CANCER

Introduction: Dysphagia could be the first symptom that occurs in head and neck cancer. Assessment of swallowing function is often invasive or involves irradiation. Acoustic analysis of swallowing is a noninvasive method but is not used in daily medical practice. This study evaluated a method for the automatic detection and analysis of swallowing sounds in healthy subjects and in patients with pharyngolaryngeal cancer.

Method: A smartphone application developed for automatic detection and analysis of swallowing sounds was tested in 10 healthy volunteers and in 26 patients with pharyngolaryngeal cancer, before and after their treatment. Swallowing sounds were recorded with a laryngophone during a standardized meal (100 mL mashed potatoes, 100 mL water, and 100 mL yogurt). Swallowing numbers and durations were noted; the results were compared to a standard swallowing sound analysis using the software AUDACITY®.

Results: There was no significant difference in swallowing numbers or durations between the two analysis methods for the three types of foods in healthy volunteers or in patients after treatment. In patients before treatment, results were different between the two ways of analysis for mashed potatoes and yogurt because of respiratory artefacts.

Conclusion: In healthy volunteers and in patients treated for a pharyngolaryngeal cancer, the results obtained with the application were comparable with standard analysis. A better discrimination of swallowing sounds is necessary for the application to obtain reliable results in patients with head and neck cancer before their treatment.

Key words: Deglutition, deglutition disorders, swallowing sounds, automatic analysis, automatic detection, cancer

ABREVIATIONS

HNC: Head and neck cancer

mL: Milliliter

s: Second

SN: Swallowing number

SSD: Swallowing sound duration

ms: Millisecond

TDP: Total duration for mashed potatoes

TDW: Total duration for water

TDY: Total duration for yogurt

TDM: Total duration for the entire meal

FN: False-negative

FP: False-positive

Se: Sensitivity

PPV: Positive predictive value

DHI: Deglutition handicap index

TNM: Tumoral classification according to tumor (T), nodular (N) or metastasis (M) criteria from the 8th edition of the American Joint Commission of Cancer

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PREAMBULE

Ce travail de thèse est divisé en deux parties. Chacune correspond à un article, tel qu'il a été soumis à la revue Dysphagia, en langue anglaise. Le premier article, « AUTOMATIC DETECTION AND ANALYSIS OF SWALLOWING SOUNDS IN HEALTHY SUBJECTS AND IN PATIENTS WITH PHARYNGOLARYNGEAL CANCER » a été soumis pour publication dans la revue Dysphagia le 21 Novembre 2019. Il est actuellement en cours de relecture, après corrections faites selon les recommandations des relecteurs. Le deuxième article, « AUTOMATIC ANALYSIS OF SWALLOWING SOUNDS IN PATIENTS WITH PHARYNGOLARYNGEAL CANCER BEFORE AND AFTER TREATMENT », a été soumis pour publication dans la revue Dysphagia le 22 Avril 2020. Il est en attente de relecture.

Ces articles exposent les résultats obtenus grâce à une application d'analyse automatisée des bruits de la déglutition dont le développement a fait l'objet d'un Master 2 de science chirurgicale. Cette application a été développée et validée chez des sujets sains, puis testée chez des patients présentant un cancer du pharyngo-larynx avant et après traitement.

PARTIE I

AUTOMATIC DETECTION AND ANALYSIS OF SWALLOWING SOUNDS IN HEALTHY SUBJECTS AND IN PATIENTS WITH PHARYNGOLARYNGEAL CANCER

INTRODUCTION

Swallowing is a complex but brief action that propels a food bolus from the oral cavity to the esophagus while protecting the respiratory tract. This involves 25 paired muscles of the mouth, pharynx, larynx, and esophagus, which must act in a coordinated manner during voluntary and reflex activation and inhibition sequences [1]. Therefore, any pathology responsible for a change in the anatomy of the aerodigestive tract or in the functions of the central and peripheral nervous system (e.g., Parkinson's disease, stroke, or neuropathies) can be responsible for dysphagia [2–4]. Dysphagia is also a common symptom in patients with head and neck cancer (HNC). Notably, Nguyen *et al*. [5] reported dysphagia in 20% of HNC stages T1-T2 and in 31% of HNC stages T3-T4. This rate increased with the number of lymph node metastases or in oropharyngeal or hypopharyngeal HNC locations. Dysphagia can be complicated by aspiration and pneumonia; complications from pneumonia can be particularly severe, especially in elderly patients [6,7]. Starmer *et al*. [8] reported that aspiration is more frequent in patients with an advanced tumor and a worse initial prognosis, particularly for laryngeal or hypopharyngeal locations. These complications can delay cancer treatment and thus change the initial prognosis. After treatment, long-term dysphagia remains a frequent symptom [9–11]. Swallowing assessment is essential; nasofibroscopy and videofluoroscopy remain the gold standard techniques [12–14] but are invasive and involve irradiation. Since the 1960s, many techniques have been used to record and analyze swallowing sounds [15,16]. Several studies have deepened our knowledge of acoustic swallowing signals [17,18], even in patients with HNC [19,20]. Importantly, the total duration of swallowing sounds is significantly reduced after total laryngectomy and increased after partial laryngectomy. Another study [21] showed that swallowing sound duration increases with the volume and viscosity of the food bolus. We previously established correlations between swallowing sounds recorded and analyzed using a software application and swallowing events confirmed via videofluoroscopy [17-21].

Some authors have reported various techniques for analyzing swallowing sounds [22,23], sometimes automatically [24–26]. Most of these studies have proposed systems for monitoring eating behavior that count swallows without further analysis. In addition, the foods that have been used have varied and the results have not been comparable among participants in different studies. Despite improvements in knowledge regarding the fundamental basis of acoustic signals during swallowing, analysis of this process remains a lengthy procedure, unused in current practice.

Our smartphone application termed SwallowWinSound uses an algorithm that allows the automated detection and analysis of the acoustic signals of swallowing during a standardized meal; the algorithm was written by engineers of our University. We compared the results obtained automatically in healthy volunteers and in patients with pharyngolaryngeal cancer to those of standard manual analysis. Our hypothesis was that the results would not differ significantly.

MATERIALS AND METHODS

1. Volunteers and patients

The study protocol was approved by our hospital's ethics committee before its implementation (Approval No. 2018 040). To test the application, swallowing sounds made by 10 healthy volunteers were recorded. Exclusion criteria were a history of cervical surgery, radiotherapy, or dysphagia. All volunteers provided written informed consent for inclusion in the study.

Then the algorithm was used in 26 patients with pharyngolaryngeal cancer. All adult patients who presented for treatment at our center between November 2, 2018, and June 30, 2019, with primary laryngeal or pharyngeal cancer were prospectively included. All patients provided written informed consent. Exclusion criteria were the presence of recurrent cancer and/or a history of surgery or cervical irradiation. Patients who could not perform strict oral feeding (i.e., those with a nasogastric tube or gastrostomy), with cognitive impairment, and/or with severe laryngeal dyspnea were also excluded.

2. Method

Swallowing sounds were recorded in Windows Media Audio format (WMA) using a Nauzer® laryngophone (model PLX 300K) connected to a Samsung Galaxy tablet. Recording was performed in a stereophonic manner using two microphones placed on each side of the trachea, under the cricoid cartilage. Takahashi *et al*. described this site as optimal for detection of swallowing sounds [27].

SwalloWinSound application was installed on a tablet. This application was able to detect swallowing sounds, measure their duration, and exclude parasitic sounds. The algorithm was developed specifically for our food protocol. The installation protocol is shown in *Figure 1*. *Figure 2* shows the overall results for a complete meal in one healthy subject and *Figure 3* the results obtained for that subject with mashed potatoes.

Figure 1. Installation of SwalloWinSound application

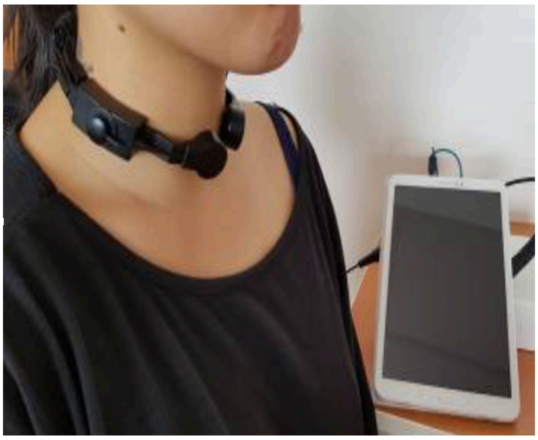

Figure 1. Installation of the laryngophone connected to the tablet containing the SwalloWinSound application on a healthy subject.

Figure 2. Global results given by the SwalloWinSound application for a healthy subject

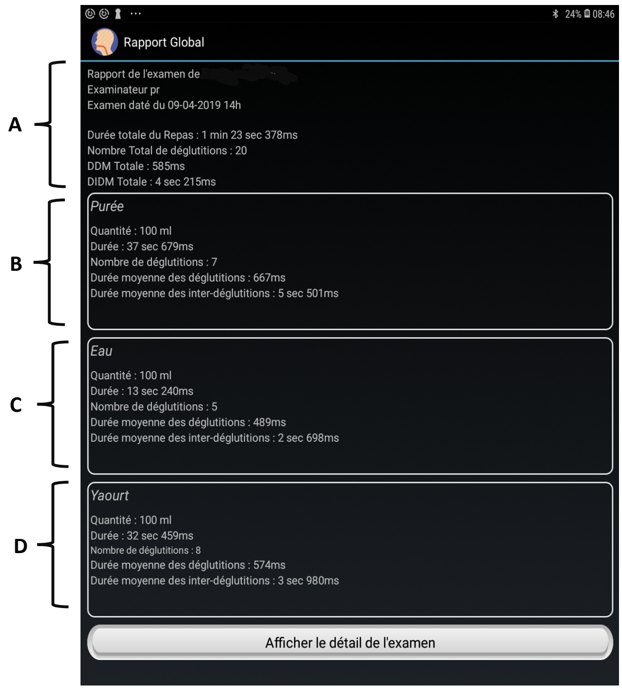

Figure 2. A: Results for the entire meal concerning one healthy subject, B: summarized results concerning mashed potatoes, C: summarized results concerning water, D: summarized results concerning yogurt.

Figure 3. Detailed results given for mashed potatoes by the SwalloWinSound application.

Figure 3. Detailed results for mashed potatoes. A: different swallowing events seen on the swallowing recording, B: detailed durations and positions of each swallowing event detected by the application.

The algorithm was first tested in 10 healthy volunteers. The food intake protocol featured ingestion of 100 milliliter (mL) of mashed potatoes, a 30 s break, ingestion of 100 mL of water, a 30 s break and ingestion of 100 mL of yogurt. We first used AUDACITY® software to analyze the swallowing records (standard analysis), as in our previous study. These data served as reference. For each food, we recorded the swallowing numbers (SNs) and swallowing sound durations (SSDs) in ms. Each SSD was measured from the time when noise began to when noise ended for each swallow. Durations of the meal for each texture were measured from the time when the first swallowing sound began to when the last sound ended: the total duration for mashed potatoes (TDP), total duration for water (TDW), total duration for yogurt (TDY), and total duration for the entire meal (TDM) were recorded. The TDM was: TDM = TDP + TDW + TDY. The application automatically analyzed all data and yielded outputs within a few seconds. In order to compare the algorithm predictions to a human judgement, the accuracy of the algorithm was calculated. We noted if application-detected swallowings were also detected via standard analysis. The numbers of false-negatives (FN) and false-positives (FP) were recorded and the sensitivity (Se) and the positive predictive value (PPV) were calculated. Results without significant difference between either analysis and a high Se and PPV were expected. The times required for standard analysis and the application were compared.

The algorithm was next tested on patients with pharyngeal-laryngeal cancer using the same dietary protocol. The SN, SSD, TDP, TDW, TDY and TDM were recorded for each patient and compared between automatic and standard analyses; the durations of standard and automatic analyses were noted.

3. Statistical analysis

We used the paired Student *t*-test to compare the mean SN, SSD, TDP, TDW, TDY, and TDM values of the two analysis techniques (by subject, patients and food; an average SSD was calculated to facilitate paired Student *t*-test comparisons). Each participant served as their own control. We assumed that the mean difference between the two methods was zero (i.e., assumption H0). Unpaired Student's *t*-tests were used to compare the results of healthy volunteers and patients, as well as the results obtained for two different foods. This test was performed bilaterally, also assuming that the mean values did not differ between the standard and automatic analyses (assumption H0). For all comparisons, $p < 0.05$ was considered to indicate statistically significant differences.

RESULTS

1. Automatic analysis of healthy volunteers

Ten healthy volunteers were included: four women and six men (mean age, 25.4 ± 4.4 years). SNs were recorded as follows: 93 for mashed potatoes, 58 for water, and 88 for yogurt. For all records, automatic analysis had a sensitivity of 0.97 and a PPV of 0.91 for mashed potatoes (10 false positives and 3 false negatives), a sensitivity of 0.97 and a PPV of 0.97 for water (2 false positives and 2 false negatives), and a sensitivity of 0.93 and a PPV of 0.88 for yogurt (12 false positives and 7 false negatives). Results with mean SN per volunteer are shown in Table 1. There were no statistically significant differences in SN between the two analyses methods.

For mashed potatoes, the mean SSD was 598.2 ms according to standard analysis and 597 ms according to automatic analysis. The values were 485.7 ms and 494.2 ms for water and 569.8 ms and 563.9 ms for yogurt. There were no significant differences for any of the three foods in terms of SSD between the two analyses methods; these results are shown in *Table 1*. The standard analysis required a mean duration of 136 ± 29 min per volunteer. The automatic analysis required a mean duration of 3.6 ± 1.4 s per volunteer.

Table 1. Comparison in 10 healthy subjects for SN (swallowing number) and SSD (swallowing sound duration), in milliseconds, for each type of food between standard and automatic analysis.

		Standard	**Automatic**	**p**
Mean SN	**Mashed potatoes**	9.3 ± 2	10 ± 3	0.09*
	Water	5.8 ± 2	5.8 ± 2	1*
	Yogurt	8.8 ± 2	9.3 ± 3	0.2*
Mean SSD (ms)	**Mashed potatoes**	598.2 ± 30	597 ± 36	0.8*
	Water	485.7 ± 76	494.2 ± 105	0.5*
	Yogurt	569.8 ± 31	563.9 ± 36	0.3*

*Legend: SN = Swallowing number, SSD = swallowing sound duration, ms = milliseconds, * = results without statistically significant difference.*

2. Automatic analysis of patients with HNC

Among the 31 patients, two had substantial dysphagia and could not complete the protocol, one had substantial aspiration and the recording was stopped, one was excluded because final histologic analysis concluded the tumor was an *in situ* epidermoid carcinoma, and one patient was excluded because of cognitive troubles. Thus, swallowing sounds from 26 patients were included. The demographic and clinical data of the included patients are shown in *Table 2*.

Table 2. Demographic data for patients.

Age	64 ± 8 years		
Sex	24 M and 2 W		
HNC localization and TNM	**Laryngeal**	n = 9	Stage I: n = 2 Stage IVa: n = 4 Stage IVb: n = 3
	Oropharyngeal	n = 13 (*P16+ = 2*)	Stage II: n = 6 Stage III: n = 4 Stage IVa: n = 2 Stage IVb: n = 1
	Hypopharyngeal	n = 4	Stage IVa: n = 3 Stage IVc: n = 1

Legend: M = men, W = women, P16+ = positive result for P16 protein in immunohistochemical test, HNC = head and neck cancer. TNM refers to the 8th classification of malignant tumors.

SNs were recorded as follows: 216 for mashed potatoes, 193 for water, and 235 for yogurt. Our application detected 404 SNs for mashed potatoes, 175 for water, and 336 for yogurt. The mean SNs for mashed potatoes and yogurt significantly differed between the two analysis methods. There were no statistically significant differences in SN for water.

The mean SSD was 619.7 ± 69 ms according to standard analysis and 587.7 ± 53 ms according to automatic analysis for mashed potatoes, 493.6 ± 115 ms and 496.6 ± 109 ms for water, and 614.7 ± 97 and 573.4 ± 62 ms for yogurt (*Table 3*); the differences were statistically significant for yogurt and potatoes but not for water.

Table 3. Comparison in patients for SNs (swallowing numbers) and SSDs (swallowing sound durations) in milliseconds for each food between standard and automatic analysis.

		Standard	Automatic	p
Mean SN	**Mashed potatoes**	8.3 ± 3	15.5 ± 7	< 0.001
	Water	7.4 ± 3	6.7 ± 4	0.3*
	Yogurt	9 ± 2	12.9 ± 8	0.01
Mean SSD (ms)	**Mashed potatoes**	619.7 ± 69	587.7 ± 53	0.03
	Water	493.6 ± 115	496.6 ± 109	0.9*
	Yogurt	614.7 ± 97	573.4 ± 62	0.04

*Legend: SN = Swallowing number, SSD = swallowing sound duration, ms = milliseconds, * = results without statistically significant difference.*

Comparing the different foods, in standard analysis, the mean SSDs were significantly longer for mashed potatoes ($p < 0.001$) and yogurt ($p < 0.001$) than for water but did not significantly differ between mashed potatoes and yogurt ($p = 0.8$). They tended to be longer for patients than for healthy volunteers, but this difference was only significant for yogurt ($p = 0.04$). There were no statistically significant differences between healthy volunteers and patients regarding SN ($p = 0.2$ for mashed potatoes, $p = 0.09$ for water, and $p = 0.77$ for yogurt). The standard analysis required a mean duration of 195.8 ± 26 min per patient and the automatic analysis required a mean duration of 4 ± 1.4 s.

3. Total meal durations

Results obtained for TDP, TDW, TDY, and TDM were not statistically different between the two analyses methods, regardless of texture, in either group (*Table 4*). Standard analysis showed that all durations were longer for patients, but the differences were not statistically significant ($p = 0.55$ for TDP, 0.8 for TDW, 0.27 for TDY, and 0.44 for TDM).

Table 4. Comparison of healthy subjects and patients for mean total durations in seconds with mashed potatoes (TDP), water (TDW), yogurt (TDY) and the entire meal (TDM).

		Standard	**Automatic**	**p**
Healthy volunteers	**TDP (s)**	54.8	53.5	0.2*
	TDW (s)	19.6	19.8	0.16*
	TDY (s)	42.4	44	0.06*
	TDM (s)	116	117	0,7*
Patients	**TDP (s)**	59.2	59.2	0.96*
	TDW (s)	20.8	20.9	0.88*
	TDY (s)	50.6	51.2	0.67*
	TDM (s)	130.7	131.4	0.78*

*Legend: s = seconds, * = results without statistically significant difference.*

DISCUSSION

Our application allowed the automatic detection and analysis of swallowing sounds using a smartphone or a tablet and a laryngophone. The results between automatic analysis and standard analysis were comparable for healthy volunteers but not for HNC patients for potatoes and yogurt. However, the application had good accuracy for water and could precisely measure various time parameters (TDP, TDW, TDY, and TDM).

1. Automatic analysis of healthy volunteers

This application detected swallowing sounds and defined the SN and SSD during a standardized meal composed of three different textures. This application was first used in 10 healthy volunteers before it was tested on patients. We obtained a minimum sensitivity of 0.93 and a minimum PPV of 0.88 with no statistically significant difference compared to standard analysis. Thus, our application was reliable for detecting swallowing sounds and accurately measuring their mean durations in healthy volunteers.

With this algorithm, we measured mean SSDs of 593.5 ± 84.2 ms for mashed potatoes, 480.3 ± 157.4 ms for water, and 570.2 ± 94.1 ms for yogurt. Hammoudi *et al*. [21] described a mean SSD between 411 ms and 515 ms depending on the volume and texture of the bolus (between 5 and 10 mL puree, water, or yogurt). The slight difference compared to our results is potentially because, in our protocol, volunteers could eat at their own rhythm and the boluses were often greater than 10 mL. This could have increased SSDs in our study. Many studies have conducted analyses of swallowing sounds with liquids (water or barium) in healthy volunteers. We found results similar to those of Cichero *et al*. [28]; however, other authors have described longer total durations [22,29]. Furthermore, SSDs have been reported to increase with bolus viscosity [30,31]. In our study, SSDs were significantly longer for mashed potatoes and yogurt than for water, with no statistically significant differences between mashed potatoes and yogurt. These results are likely because of the higher viscosity of mashed potatoes and yogurt, relative to water.

The meta-analysis of Dudik *et al.* [32], emphasized that other methods have been used to automatically analyze swallowing sounds using fast Fourier and/or wavelets transform analysis. These techniques allow sound description and classification according to their time and frequency domains but are more complex and require the use of a support vector machine [24,33,34]. These authors developed their algorithms based on non-dysphagic volunteers, as we did, and our results are largely in line with those previous results. Makeyev *et al*. [34] obtained a sensitivity of 71.3% and a specificity of 87%. Sazonov *et al*. [24] described a detection of swallowing events with an overall swallowing detection performance of 84.7%. However, their results were obtained under daily living conditions with patients allowed to speak and walk; swallowing detection performance was thus reduced to 6% in situations featuring high levels of parasitic sounds.

Jayatilake *et al*. [35] used an algorithm developed for use on a smartphone. The cited authors defined a sound threshold for detection of swallowing sounds and used continuous wavelet transformation analysis to filter out speech or cough noises. Their system was efficient because it detected swallowing events with a sensitivity of 93.9% and a PPV of 83.7%. Although they stated that they could measure SSD, they did not compare these durations to the results of a standard analysis method.

The sample of healthy volunteers used to test the algorithm was small, but data of 239 swallows from a complete food protocol were analyzed and compared.

2. Automatic analysis of patients with HNC

In patients, there were no statistically significant differences between the two methods regarding the SN and SSD for water. However, the values were significantly different for mashed potatoes and yogurt. We presume that the results were better with water because several swallows were often performed during the same apnea phase. This element limited the presence of respiratory artifacts on the recording. The SN was also lower for water, which limited the total duration of the recording, and the resulting probability of parasitic noise. In addition, swallowing sounds had a higher intensity for water than for other textures, which increased the probability that the algorithm could detect them. Following Dudik *et al.* [36], we suggest that swallowing sounds differ between healthy subjects and patients with dysphagia. The most common false positives were due to microphone rubbing, coughing, or breathing noises. These parasitic noises had not been observed during the development of our algorithm in healthy volunteers. Some of these dysphagic patients had begun speech therapy and learned compensatory techniques to protect the airways. Others were already performing these techniques spontaneously. These cervical bending maneuvers increase microphone rubbing against the skin, and thus the number of false positives. In addition, some patients were severely malnourished, and others had large cervical adenopathies at the time of diagnosis. These anatomical changes were responsible for increased microphone friction noises, because contact with the skin was no longer optimal. The presence of a locally advanced laryngeal tumor was presumably responsible for turbulent air flow and generation of parasitic sounds. This situation could be exacerbated by aspirations, regardless of volume. Indeed, this change in respiratory flow had sufficient acoustic impact that it could be detected by an algorithm, as shown by Sarraf-Shirazi *et al*. [37]. Our goal for a future algorithm is to discriminate the acoustic signatures of swallowing and silent aspiration.

Yamashita *et al*. [38] demonstrated that in 78% of videofluoroscopies performed in patients who underwent surgery for ear, nose, and throat cancer, aspirations were noticed regardless of the presence of an associated cough. This highlights the importance of developing tools for analysis of the swallowing acoustic signal in this population.

Our SSD results on the standard analysis are consistent with those reported by Morinière *et al*. [20] for patients with laryngeal cancers. In that study, the SSDs were between 562 and 602 ms with barium boluses that exhibited viscosity approximately between that of water and yogurt. As reported by Paulosky *et al*. [39], SSDs in our study tended to be longer in patients with pharyngeal-laryngeal cancer than in healthy volunteers; however, this difference was only statistically significant for yogurt in our study.

3. Total meal durations

Our application was able to measure TDP, TDW, TDY, and TDM for both healthy volunteers and patients. It provided results that did not significantly differ from those of the standard analysis. All durations tended to be longer for patients with HNC than for healthy volunteers, but the differences were not statistically significant. To the best of our knowledge, no other study has described these durations for an entire standardized meal. This food protocol permitted us to establish references for these durations in healthy volunteers and patients with HNC and the data will serve as reference data in future studies.

4. Perspectives

Some authors have suggested other novel methods for automatically analyzing swallowing sounds. In 2016, Dong and Biswas [40] developed an automatic swallowing detection system based on analysis of respiratory cycles, which exhibited a PPV of 0.75 and a sensitivity of 0.86. Fukuike *et al*. [25] obtained a sensitivity of 97.2% and a specificity of 95.2% using a system for detecting swallowing sounds during apnea phases alone. Apneas were detected using a nasal microphone, and no sound during breathing was analyzed. This strategy reduced the number of false-positives; it would be appealing to test it on patients with dyspnea or laryngeal tumors. The inclusion of a respiratory cycle detection system in our application, using a third microphone (e.g., located in front of the trachea), could allow us to improve the results obtained for patients.

We found no significant difference between the SNs of healthy subjects and pharyngo-laryngeal cancer patients. We expected that the SNs would be lower in non-dysphagic subjects. Further analyses of larger samples may reveal such a difference. Dysphagia associated with geriatric and neurodegenerative pathologies requires attention. SSD is an important parameter. It increases in many pathologies, such as Parkinson's disease [3] and stroke [4], as well as after partial laryngectomy [20] and in elderly patients [28,30]. In a recent meta-analysis, Furkim *et al*. [6] showed that a longer pharyngeal response time was a risk factor for aspirations, and that a longer opening time of the upper sphincter of the esophagus was associated with more aspirations. Thus, our application may be useful as a screening test: an increased SSD could indicate that further assessment is needed to prevent potentially dangerous complications of dysphagia. Water yielded reliable results and could be used with this application in a screening test. However, for use with a complete and standardized food protocol in patients, the algorithm must be improved. Further analyses are necessary involving a larger sample of patients, or in separate samples according to tumor location and stage.

CONCLUSION

We tested an application with algorithm adapted to a standardized food protocol, which was able to detect swallowing sounds in healthy volunteers during a standardized meal with excellent Se and PPV, and reliably and automatically analyzed SSDs. The application was also able to precisely measure the total durations for different food textures and for the whole meal in both healthy volunteers and patients. In patients with pharyngolaryngeal cancer, the results obtained for water were reliable, but the algorithm must be improved for the detection of the other foods. Further analyses are needed to increase its discrimination ability and to allow its use during a complete meal in patients with pharyngolaryngeal cancer or other swallowing dysfunctions.

PARTIE II

AUTOMATIC ANALYSIS OF SWALLOWING SOUNDS IN PATIENTS WITH PHARYNGOLARYNGEAL CANCER BEFORE AND AFTER TREATMENT

INTRODUCTION

Dysphagia is a common complaint of patients with head and neck cancer (HNC). Nguyen *et al*. [5], reported that dysphagia is present in 20% of non-treated T1-T2 HNC and in 31% of T3-T4 HNC. This rate increases with the number of lymph node metastases or with cancer in oropharyngeal or hypopharyngeal locations. Dysphagia is a severe symptom that increases with a late stage and the age of the patients.

The main complications of dysphagia are aspiration and pneumonia with severe consequences, particularly in elderly patients [6,7]. Starmer *et al*. [8] reported that aspiration is more frequent in patients with advanced tumors and a worse initial prognosis, particularly for laryngeal or hypopharyngeal locations. These complications can delay cancer treatment and thus change the initial prognosis. Long-term dysphagia remain a common symptom for patients with HNC, even after treatment, with potentially lethal morbidity [9–11].

Gold standard techniques to assess swallowing, such as nasofibroscopy and videofluoroscopy, are effective but are invasive or involve irradiation [12–14]. Acoustic analysis of swallowing sounds was initiated in the 1960s [15,16]. In our center, studies have been conducted to describe the acoustic signals of swallowing sounds and the variations among age, sex and type of food in healthy subjects [17,18,21]. Other studies have provided a further understanding of acoustic swallowing signals and their variations following different surgical treatments [19,20]. These studies established correlations between acoustic and physiological events during deglutition. However, acoustic analysis remains a lengthy procedure to analyze sound signals and is still not used in practice.

To overcome this difficulty, some authors have described faster techniques with automatic analyses of swallowing sounds [24–26,34]. They reported good results, but the studies involved healthy subjects or various foods and the results were not comparable between subjects and studies. A smartphone application has been developed using healthy subjects with an algorithm that allows automated analysis of swallowing sounds to obtain the swallowing number (SN) and the swallowing sound duration (SSD) during a standardized meal. It contained an algorithm that allowed the automated detection and analysis of the acoustic signal of swallowing during a standardized meal in healthy subjects. This study aimed to test this application, with the same food protocol, in patients with HNC before and after treatment. An improvement of swallowing function was expected following treatment for patients that were free of the disease.

MATERIALS AND METHODS

1. Subjects

Patients with primitive laryngeal or pharyngeal cancer between November 2, 2018, and June 30, 2019 were prospectively included. Patients received surgical and/or medical treatment (radiation and/or chemoradiation) according to a multidisciplinary staff decision. Patients were informed and provided written informed consent for inclusion in the study. Exclusion criteria were patients with recurring cancer, history of cervical surgery, or irradiation. Feeding with a nasogastric tube or gastrostomy, cognitive impairment, and/or severe laryngeal dyspnea were also exclusion criteria. This study protocol was approved by the ethics committee before its implementation (Approval No. 2018 040).

2. Methods

Swallowing was recorded before the beginning of treatment and at least 1 month after the end of treatment. A laryngophone Nauzer® (ref. PLX 300K) was placed on each side of the trachea under the cricoid cartilage. Takahashi *et al*. described this site as optimal for detecting swallowing sounds [27]. The installation is shown in Figure 1.

The laryngophone was connected to a Samsung Galaxy® tablet running the smartphone application "SwallowinSound". The food intake protocol was as follows: ingestion of 100 mL of mashed potatoes, a 30 s break, ingestion of 100 mL of water, a 30 s break, ingestion of 100 mL of yogurt. A standard analysis, was first done manually by one expert in our department (first author), using AUDACITY® software. The studied parameters were: SN and SSD for each food, total duration for mashed potatoes (TDP), total duration for water (TDW), total duration for yogurt (TDY), and total duration for the entire meal (TDM). SSD was measured from the beginning of noise increment to the end of the noise decrement for each swallowing event. Durations for each texture were measured between the beginning of the first swallowing sound and the end of the last sound recorded, and TDM was defined as follows: TDM = TDP + TDW + TDY. This analysis served as a reference. Then, the algorithm automatically analyzed the recordings and provided a result in a few seconds concerning the same parameters (SN, SSD, TDP, TSW, and TDM). These parameters were compared to obtain the false-positives (FPs) and false-negatives (FNs) during automatic detection of SNs. Sensitivity (Se) and positive predictive value (PPV) of the application were calculated for each food. Thus, the accuracy of the application for detecting swallowing sounds was evaluated and compared with the standard analysis in patients with HNC before and after treatment. The parameters obtained from the standard analysis before and after treatment were also compared to evaluate the modifications after treatment.

The Deglutition Handicap Index (DHI) was completed before and after treatment to follow the evolution of dysphagia.

3. Statistical analysis

A paired Student's *t*-test was used to compare results obtained with the two analytical techniques or patients before and after treatment. Each participant served as their own control (average SSD was calculated to use the paired Student's *t*-test with these data). A standard Student's *t*-test was used to compare the results obtained from different patients. A p-value < 0.05 was considered significant.

RESULTS

1. Patients before treatment

Thirty-one patients were included in this study. Among them, five were excluded: two could not complete the food protocol because of substantial dysphagia, one aspirated water and the recording had to be stopped, one was excluded because the final histologic analysis detected only *in situ* epidermoid carcinoma, and one patient had cognitive troubles. Thus, 26 patients with HNC were included in this study and their demographic and clinical data are shown in Table 2.

a. *Deglutition Handicap Index*

The mean DHI before treatment was 17.3/120 for the 26 patients. The mean DHI for patients with stage I and II HNC was 6.7. The mean DHI for patients with stage III and IV was 20.5 ($p = 0.03$).

b. *Application accuracy*

A total of 216 SNs were recorded for mashed potatoes, and the application detected 404 SNs (52 FN and 240 FP). The Se of the application was 0.76 and the PPV was 0.41 for mashed potatoes before treatment.

A total of 193 SNs were recorded for water, and the application detected 175 SNs (50 FN and 32 FP). Thus, the Se of the application was 0.74 and the PPV was 0.82 for water before treatment.

A total of 235 SNs were recorded for yogurt, and the application detected 336 SNs (109 FN and 210 FP). The Se of the application was 0.54 and the PPV was 0.38 for yogurt before treatment.

c. *SNs and SSDs*

The mean SNs for mashed potatoes and yogurt were significantly different between the two analytical methods. No significant difference was observed in SN for water.

The mean SSD was 619.7 ± 69 ms according to the standard analysis and 587.7 ± 53 ms according to the automatic analysis for mashed potatoes, 493.6 ± 115 ms and 496.6 ± 109 ms for water, and 614.7 ± 97 and 573.4 ± 62 ms for yogurt (Table 3), respectively; the differences were statistically significant for yogurt and potatoes but not for water.

The mean SSDs in the standard analysis were significantly longer for mashed potatoes ($p < 0.001$) and yogurt ($p < 0.001$) than for water but did not significantly differ between mashed potatoes and yogurt ($p = 0.8$).

d. Total meal durations

The results obtained for TDP, TDW, TDY, and TDM were not different between the two analytical methods (Table 4). All durations tended to be longer for patients with stage III or IV HNC than for other patients ($p > 0.05$). The TDM was 117.7s for stages I or II and 135.2s for stages III or IV ($p = 0.47$).

2. Patients after treatment

Among the 26 patients included, 19 were analyzed following treatment. The mean total follow-up was 181.5 ± 82 days, and the second acoustic analysis was conducted after a mean follow-up of 102.5 ± 54 days after the end of their treatment. Seven patients did not undergo the second acoustic analysis: two patients died before the end of treatment, one patient was treated in another center, and four patients were feeding by nasogastric tube or gastrostomy at least 6 months after the end of treatment.

a. Deglutition Handicap Index

The mean DHI for the 19 patients who had completed follow-up decreased from 15.1 before treatment to 13.1 after treatment ($p = 0.68$).

Patients with stage III and IV had more severe dysphagia before treatment than other patients (DHI = 19.6 vs 2.2, $p = 0.004$). Following treatment, DHI was not different between patients with initial stage III and IV and the other patients (12.3 vs 15.2, p = 0.96). We noticed that the DHI for patients with stage I or II HNC tended to increase after treatment (from 2.2 to 15.2) (p = 0.29).

b. Application accuracy

A total of 173 SNs were recorded for mashed potatoes, and the application detected 226 SNs (61 FN and 114 FP). The Se of the application was 0.65 and the PPV was 0.5 for mashed potatoes after treatment.

A total of 122 SNs were recorded for water, and the application detected 119 SNs (18 FN and 15 FP). The Se of the application was 0.85 and the PPV was 0.87 for water after treatment.

A total of 171 SNs were recorded for yogurt, and the application detected 175 SNs (53 FN and 57 FP). The Se of the application was 0.69 and the PPV was 0.67 for yogurt after treatment.

c. SNs and SSDs

No significant difference in SNs was observed for the entire food protocol.

The mean SSD for mashed potatoes was 542.5 ± 113 ms according to the standard analysis and 548.2.7 ± 112 ms according to the automatic analysis, 452 ± 103 ms and 457.5 ± 92 ms for water, and 527.7 ± 120 and 523.4 ± 94 ms for yogurt (Table 5); the results obtained from the analytical methods were no statistically different.

Table 5. Comparison of SNs and mean SSDs for each food between standard and automatic analysis for 19 patients after treatment.

		Standard	Automatic	p
Mean SN	**Mashed potatoes**	9.1 ± 3	11.9 ± 8	0.18*
	Water	6.4 ± 2	6.3 ± 3	0.78*
	Yogurt	9 ± 3	9.2 ± 5	0.86*
Mean SSD (ms)	**Mashed potatoes**	542.5 ± 113	548.2 ± 112	0.53*
	Water	452 ± 103	457.5 ± 92	0.59*
	Yogurt	527.7 ± 120	523.4 ± 94	0.79*

Legend: SNs = swallowing numbers, SSDs = swallowing sound durations, ms = milliseconds.

No significant variations in SNs were observed for the 19 patients analyzed after treatment, according to the standard analysis: SNs for mashed potatoes went from 8.2 ± 3 to 9.1 ± 3 ($p = 0.25$), the SNs for water decreased from 7.3 ± 3 to 6.4 ± 2 ($p = 0.24$) and the SNs for yogurt changed from 9.1 ± 2 to 9 ± 3 ($p = 0.9$).

All SSDs decreased after treatment: from 620.6 ± 74 to 542.5 ± 113 ms for mashed potatoes, from 503.6 ± 131 to 452 ± 103 ms for water, and from 618 ± 108 to 527.7 ± 120 ms for yogurt. This decreases in SSDs were significant for mashed potatoes ($p = 0.009$) and for yogurt ($p = 0.01$) but not for water ($p = 0.12$). This significant variation concerns patients with stage III or IV HNC: SSD decreased significantly from 621.9 ± 84 ms to 514.5 ± 119 ms for mashed potatoes ($p = 0.006$) and from 626 ± 123 ms to 489.2 ± 104 ms for yogurt ($p = 0.001$). The decrease in SSDs was not significant in patients with stage I or II HNC.

d. Total meal durations

The results obtained for TDP, TDW, TDY, and TDM were not statistically different between standard and automatic analyses after treatment (Table 6). The entire meal was 14 seconds longer after treatment, according to the standard analysis because TDP and TDY tended to increase ($p > 0.05$). TDM went from 130.6 ± 67 s to 144.5 ± 67 s ($p = 0.43$). TDP went from 58.5 ± 24 s to 71 ± 35 s (p = 0.2). TDW went from 22.1 ± 18 s to 19.1 ± 11 s (p = 0.39). TDY went from 50 ± 19 s to 54.4 ± 28 s (p = 0.51).

After treatment, the TDM was longer for patients with stage III or IV than for other patients (151.1s vs 126 s) without statistical difference (p = 0.33). For both groups, the TDM increased after treatment, without statistical difference: from 117.7s to 126s for stage I or II (p = 0.63) and from 135.2s to 151.1s for stage III or IV (p = 0.47).

Table 6. Comparison in 19 patients after treatment of total durations in seconds for mashed potatoes, water, yogurt and for the entire meal between standard and automatic analysis.

	Standard	**Automatic**	**p**
TDP (s)	71 ± 35	64 ± 31	0.12*
TDW (s)	19.1 ± 11	19.1 ± 12	0.85*
TDY (s)	54.4 ± 28	51.5 ± 23	0.13*
TDM (s)	144.5 ± 67	134.8 ± 56	0.13*

*Legend: s = seconds, * = results without statistically significant difference, TDP = total duration for mashed potatoes, TDW = total duration for water, TDY = total duration for yogurt, TDM = total duration for the entire meal.*

DISCUSSION

This application automatically detected and analyzed swallowing sounds of water with good accuracy in patients with pahryngolaryngeal cancer before and after treatment. No significant differences were observed in terms of SNs and SSDs compared with the standard analysis for this food. Following treatment, SSDs were significantly shorter for thicker food (mashed potatoes and yogurt) than before treatment.

1. Patients before treatment

Twenty-six patients were analyzed before treatment. As described previously, patients with an advanced tumoral stage were significantly more dysphagic [5,39]. The application detected swallowing sounds with a Se of 0.74 and a PPV of 0.82 for water; there was no significant difference between the standard and automatic analyses concerning SNs and SSDs. The accuracy of the application was lower for mashed potatoes and yogurt. The results were better for water because several swallows were often performed during the same apnea phase. The number of FP due to respiratory artifacts was limited. The number of FP was 32 for water but 240 for mashed potatoes and 210 for yogurt which explains the lower accuracy of the application with mashed potatoes and yogurt.

Sarraf Shirazi *et al*. [37,41] demonstrated that aspirations can change the respiratory flow from laminar to turbulent and that this has a sufficient enough acoustic impact to be detected by the algorithm. Our microphones placed on each side of the trachea recorded these changes which increased the rate of FP. The algorithm was unable to distinguish the sound generated by aspirations from other swallowing sounds. Thus, the accuracy of this application must be improved to obtain a more reliable analysis of swallowing anomalies.

Few studies have precisely measured the SSDs in patients with HNC but our results of the standard analysis are consistent with those reported by Morinière *et al*. for patients with laryngeal cancers [20]. In that study, SSDs were 562-602 ms with barium boluses that exhibited viscosity approximately between that of water and yogurt.

The application remained reliable to measure meal durations. No differences were observed between the standard and automatic analyses concerning TDP, TDW, TDY, or TDM. The highest DHI score for patients with stage III or IV HNC was related to a TDM 17.5 s longer than patients with less advanced cancer. To the best of our knowledge, no other study has described these durations for an entire standardized meal. This food protocol permitted us to establish references for these durations in patients with HNC, which will be used in future studies and will allow further comparison between different pathologies. These durations could be used as a reference to inform the user of the application if the patient results are pathological.

2. Patients after treatment

Nineteen patients were analyzed, after a mean duration of 102.5 ± 82 days after treatment. Our results show that dysphagia remained a frequent symptom following medical and/or surgical treatment of HNC.

Following treatment, the application detected swallowing sounds with better accuracy (Se of 0.85 and a PPV of 0.87) for water and there was no difference between the standard and automatic analyses concerning SNs and SSDs. The number of FP decreased after treatment: from 240 to 114 for mashed potatoes, from 32 to 15 for water and from 210 to 57 for yogurt. This finding was associated with better results. However, the accuracy of the application for mashed potatoes and yogurt remained low.

Most studies have shown that dysphagia is often more severe following treatment in patients with a more severe initial tumoral grade [42–45]. This finding is inconsistent with our results. The DHI was not different following treatment regardless of the presence of advanced HNC. The DHI decreased from 19.6 to 12.3 following treatment for patients with stage III and IV HNC but increased from 2.2 to 15.2 for patients with stage I and II HNC. However, the TDM increased more in patients with stage III and IV HNC. The DHI is a quality of life questionnaire validated for all kinds of swallowing disorders [46]. We assumed that TDM and DHI would be correlated, but this result shows the limits of a subjective tool that is not always correlated with an objective assessment. Patients with stage I or II did not have initial dysphagia (DHI = 2.2) and so, even a small change in their swallowing function (increase of 8 seconds for TDM) could significantly modify the DHI score after treatment.

No significant difference was observed between the standard and automatic analyses concerning SNs and SSDs following treatment. These results allow use in routine medical practice. No significant variation was observed in terms of SNs in patients with pharyngolaryngeal cancer following treatment according to the standard analysis. The measurement of SSD is also an important parameter, as it increases in many pathologies, such as Parkinson's disease [3] and stroke [4], as well as after partial laryngectomy [20] and in elderly patients [28,30]. In a recent meta-analysis, Furkim *et al*. [6] showed that longer pharyngeal response time is a risk factor for aspiration, and that a longer opening time of the upper esophageal sphincter is associated with increased aspiration. In this study, all SSDs decreased after treatment (statistically for mashed potatoes and yogurt) because the swallowing function improved following treatment of upper aerodigestive tract cancer, particularly in stage III or IV tumors.

The application remained reliable to measure meal durations. No difference was observed between standard and automatic analyses concerning TDP, TDW, TDY, or TDM. The mean TDM according to standard analysis was 14 s longer than prior to treatment due to increases in TDP and TDY. This variation in TDM was not correlated with variations in SSD or SN. Evaluation of dysphagia cannot be reduced to measure SSDs which decreased following treatment in our study. Further analyses, with a larger sample, may show a correlation between these three parameters. This application, associated with our food protocol, is a useful tool that offers various and reliable results for a global swallowing evaluation.

3. Perspectives

As suggested by Dudik *et al.* in their meta-analysis [32], other methods can automatically analyze swallowing sounds using fast Fourier and/or wavelet transform analyses. These techniques provide sound descriptions and classification according to their time and frequency domains but are complex and require the use of a support vector machine [24,33,34]. Several authors have developed algorithms based on non-dysphagic volunteers and obtained good results. Makeyev *et al*. [34] obtained a sensitivity of 71.3% and a specificity of 87% while Sazonov *et al*. [24] described detecting swallowing events with an overall swallowing detection performance of 84.7%. As in our study, Jayatilake *et al*. [35] used an algorithm developed for a smartphone. Their system efficiently detected swallowing events with sensitivity of 93.9% and PPV of 83.7%. Although they stated that they could measure SSD, they did not compare durations to the results of a standard analytical method.

Some authors have suggested other novel methods to automatically analyze swallowing sounds. In 2016, Dong and Biswas [40] developed an automatic swallowing detection system based on an analysis of respiratory cycles, which exhibited a PPV of 0.75 and a sensitivity of 0.86. Fukuike *et al*. [25] obtained sensitivity of 97.2% and specificity of 95.2% using a system for detecting swallowing sounds during apnea phases only. Apnea was detected using a nasal microphone, and no sound was analyzed during breathing. This strategy reduced the number of false-positives; it would be appealing to test this method on patients with dyspnea or laryngeal tumors. Including a respiratory cycle detection system in our application, using a third microphone (e.g., located in front of the trachea), would improve the accuracy of the application.

This application could be used as a screening test for detecting swallowing disorders: an increased SSD would indicate that further assessment is needed to prevent potentially dangerous complications of dysphagia. Water yielded reliable results and could be used with this application in a screening test. However, the accuracy of the application must be improved to obtain a reliable analysis of a complete and standardized food protocol in patients. Further analyses are necessary, involving a larger sample of patients with stratification according to tumor location and stage.

CONCLUSION

The smartphone application tested automatically analyzed swallowing recordings during a standardized food protocol in patients with pharyngolaryngeal cancer. The application precisely measured SNs and SSDs for water before treatment, but the accuracy of the algorithm must be improved for mashed potatoes and yogurt. Following treatment, the application produced reliable results for all of the studied parameters and detected a difference in swallowing function prior to treatment with a significant decrease in SSD for mashed potatoes and yogurt. The results obtained with this standardized meal could serve as a reference and this application could be used to automatically screen for swallowing dysfunction. Further analyses are needed to increase the discrimination ability of this application in patients at risk for dysphagia.

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ANNEXE

French version of the DHI

The Deglutition Handicap Index (D.H.I)

	Merci de bien répondre à toutes les questions :	J	PJ	P	PT	T
	Je sens une gêne quand j'avale					
D	Les aliments restent collés ou bloqués dans ma gorge					
O	J'ai des difficultés à déglutir les liquides					
M	Je tousse ou je racle ma gorge pendant ou après les repas					
A	Je m'étouffe en mangeant ou en buvant					
I	Je sens des remontées de liquides ou d'aliments après les repas					
N	J'ai du mal à mâcher					
E	Des aliments passent dans mon nez quand je bois ou quand je mange					
	Je bave quand je mange					
S	J'ai mal à la gorge quand j'avale					

	Mes difficultés pour avaler me rendent incapable de manger certains aliments					
D	J'ai besoin de modifier la consistance des aliments pour pouvoir les avaler					
O	La durée des repas est allongée à cause de mes difficultés à avaler					
M	Je mange moins à cause de mes problèmes de déglutition					
A	J'ai faim ou j'ai soif après le repas					
I	Je suis fatiguée à cause de mes difficultés pour avaler					
N	Je perds du poids à cause des mes difficultés pour avaler					
E	J'ai peur de manger					
	Je fais plus souvent des bronchites ou des infections pulmonaires depuis mes problèmes de déglutition					
F	Je suis plus gêné(e) pour respirer depuis mes problèmes de déglutition					

	J'évite de manger avec les autres à cause de mes difficultés pour avaler					
D	Mes problèmes de déglutition limitent ma vie personnelle et sociale					
O	Je suis ennuyé(e) par la manière dont je mange au moment des repas					
M	Manger devient un moment désagréable à cause de mes difficultés pour avaler					
A	Mes difficultés pour avaler me contrarient					
I	Je trouve que les autres ne comprennent pas mes problèmes de déglutition					
N	Les gens semblent irrités par mon problème de déglutition					
E	Je suis tendu(e) quand je mange avec d'autres à cause de ma déglutition					
	Je suis honteux(se) de mon problème de déglutition					
E	Je me sens handicapé(e) à cause de mes difficultés pour avaler					

J : jamais (0) ; **PJ** : presque jamais (1) ; **P** : parfois (2) ; **PT** : presque toujours (3) ; **T** : toujours (4)

Domaine S :...../40 Domaine F :...../40 Domaine E :...../40

Total :......./120

Vu, le Directeur de Thèse

Vu, le Doyen
De la Faculté de Médecine de Tours
Tours, le

RAYNEAU Pierre

58 pages – 6 tableaux – 3 figures

ANALYSE AUTOMATISEE DES SONS DE DÉGLUTITION CHEZ LES SUJETS SAINS ET CHEZ LES PATIENTS PRESENTANT UN CANCER DU PHARYNGOLARYNX

Résumé :

Introduction : La dysphagie peut être le premier symptôme d'un cancer ORL. L'exploration de la déglutition est souvent invasive ou irradiante. L'analyse acoustique de la déglutition est une méthode non invasive, mais non utilisée en pratique médicale. Cette étude a évalué une méthode de détection et d'analyse automatique des sons de déglutition chez des sujets sains et chez des patients atteints d'un cancer pharyngolaryngé.

Méthode : Une application pour smartphone, développée pour la détection et l'analyse automatique des sons de déglutition, a été testée sur 10 volontaires sains et chez 26 patients atteints d'un cancer pharyngolaryngé, avant et après traitement. Les sons de déglutition ont été enregistrés avec un laryngophone pendant un repas standardisé (100 ml de purée de pommes de terre, 100 ml d'eau, 100 ml de yaourt). Le nombre et la durée des déglutitions ont été notés ; les résultats ont été comparés à ceux d'une analyse standard réalisée sur le logiciel AUDACITY®.

Résultats : Il n'y avait pas de différence significative pour le nombre ou la durée des déglutitions entre les deux méthodes d'analyse chez les sujets sains ni chez les patients traités. Chez les patients non traités, les résultats différaient entre les deux méthodes d'analyse pour la purée de pommes de terre et le yaourt en raison d'artefacts respiratoires.

Conclusion : Chez les sujets sains et chez les patients traités pour un cancer pharyngolaryngé, les résultats de l'algorithme étaient comparables à ceux de l'analyse standard. Une meilleure discrimination des sons de déglutition par l'application est cependant nécessaire chez les patients atteints d'un cancer ORL non traité.

Mots clés : Déglutition, dysphagie, sons de déglutition, analyse automatique, détection automatique, cancer

Jury :

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