



Biting force and tongue muscle strength as useful indicators for eating and swallowing capability assessment among elderly patients

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ABSTRACT

Weakened capability of eating and swallowing is common among elderly population, affecting negatively on their health and well-being. This work measured occlusal force and tongue muscle strength of elderly patients and then assessed whether correlations existed between oral physiological properties and the eating and swallowing capability. A total of 26 elderly patients with potential swallow disorder were recruited in this work. Participants' denture status and daily diet texture were determined by a pre-questionnaire analysis. Their swallowing capability was assessed and rated by water drinking test. Maximum tongue pressure, incisor occlusal force and hand gripping force were measured for each subject. It was observed that participating subjects have on average a significantly lower biting force and maximum tongue pressure than that of normal adults. The swallowing grades assessed by water drinking test showed significant correlations with both the biting force ($r = -0.498$, $P < 0.05$) and the tongue muscle strength ($r = -0.544$, $P < 0.05$). The biting force of dysphagia participants correlates significantly with dental conditions ($P < 0.05$). The observed correlation between tongue pressure and diet texture indicates that tongue muscle strength could be used as a reliable indicator of the eating and swallowing capability for elderly people.

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1. Introduction

Elderly population has been in continuous growth in many developed countries. Fast growth of elderly population is also seen in recent years in some developing countries, such as China. Statistics shows that elderly population in China (those above the retirement age of 60 years old) has reached to over 210 millions at the end of 2015, counting for 15.5% of the total population. How to ensure the well-being and quality of life for elderly people has become a major challenge not only to elderly individuals and their families, but also to societies and governments. One of the main issues which undermine the quality of life for elderly is

the reduced capability of eating and swallowing. Many elderly suffer from difficulties of food ingestion, food oral manipulation, and food transportation from the oral cavity to the stomach, a syndrome clinically called dysphagia [1]. For example, an investigation among 931 elderly subjects living in nursing homes in Shanghai showed that 32.5% of elderly suffered from swallowing disorders [2]. Similar observations were also made by some studies in other regions of the world [3–5]. Immediate consequences of eating and swallowing disorder include reduced food intake, malnutrition, as well as the loss of body mass. Long term psychological effect of eating and swallowing disorder could be very serious, including self-exclusion of social interactions as well as severe depression. Texture modification or special diets are common practices in order to ensure safe food consumption by these people. However, how to achieve this remains technically challenging to carers and food manufacturers [6,7], due to the lack of feasible objective methods for eating and swallowing capability assessment.

Dysphagia is defined by American Speech-Language-Association's (ASHA) Ad Hoc Committee as "a swallowing disorder characterized by difficult in oral preparation for the swallow or in moving material from the mouth to the stomach"

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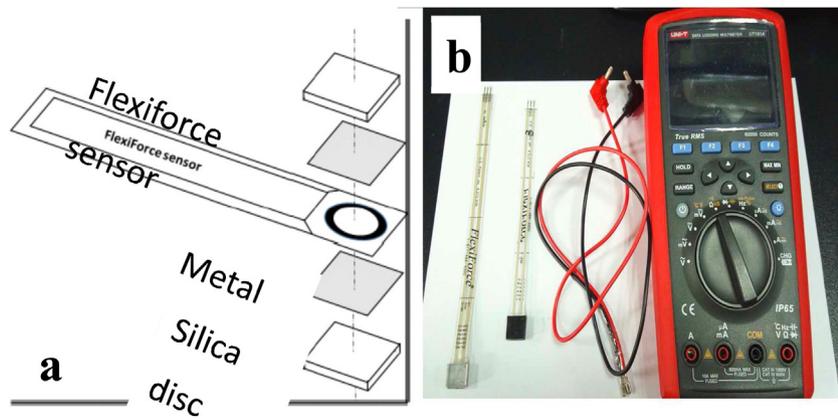


Fig. 1. Illustration of the experimental set up for biting force measurement. (a) the FlexiForce sensor is sandwiched by pieces of metal plate and silica discs; (b) the force sensor is connected to a multimeter for resistance reading.

[8]. Dysphagia patients have great difficulty in either preparing or transporting food bolus within the oral cavity. Although there are many factors which affect eating and swallowing [9], chewing force and tongue muscle strength are often seen as the two key oral physiological parameters which influence bolus preparation and swallowing, as has been confirmed very recently by a positive correlation between such oral physiological factors and eating and swallowing capabilities [10]. Many studies reported that the biting force varies among different individuals, different ethnic groups, and individuals of different age, gender, body mass index and so on [11,12]. Miura [13] observed that the biting force, contacting area and number of contacting teeth can all influence chewing efficiency and alter the sense of pleasure in elderly people. Various devices have been made available for biting characterizations [14–16]. In this work, an own-designed portable device was used for biting force assessment.

Tongue plays a key role in oral mastication of food and bolus swallowing [17]. The cyclic movements of the tongue are closely associated with jaw opening and closing [18,19]. Steele indicated very recently that tongue strength could have a significant influence on oral viscosity discrimination acuity [20]. The strength of the tongue muscle showed a significant decline among elderly people [21]. An age-related gradual decline of the maximum tongue pressure has also been observed among healthy elderly people [22]. Very recently, Laguna and Chen [23] defined a new concept of the eating capability, in which oral physiological parameters were used for eating capability assessment among dysphagia patients and other disadvantaged individuals. The approach has been tested successfully to elderly subjects from both UK and Spain [24].

This work applied the above concept for the eating and swallowing capability assessment among Chinese elderly populations. We hypothesize that positive correlations exist between measurable oral physiological properties and the eating and swallowing capability among elderly Chinese and the main aim of this study was to collect experimental evidence to approve this hypothesis. The investigation involved some bedside works and even some clinical assessments.

2. Materials and methods

2.1. Participants

Participants involved in this study were the elderly patients recruited at the rehabilitation unit of Huadong Hospital in Shanghai. All patients voluntarily completed a prior survey by their care nurses/doctors, the selection of participants was made based on the following criteria: (1) with potential swallowing disorder; (2) older

than 60 years (with one exception whose age is 50); (3) cognitively fit for understanding and communication. Before the experiment, all clinical doctors and nutritionists involved in this assessment were properly informed about the purpose, the content, as well as precautions of the investigation. Pre-trials and trainings were also given to doctors so that they became familiar with the assessment procedures. Prior to tests, participants were explained about the purposes of the test and what will be examined. They were also informed of the voluntary nature of the test and they were made aware that they can withdraw from the test at any time without giving any explanation. Ethical approval was granted by the Hospital ethic committee. All tests were accompanied by clinical doctors and, throughout the test, clinical doctors can interrupt or stop the test whenever they feel necessary.

2.2. Apparatus

The Iowa Oral Performance Instrument (IOPI[®], Medical LLC, Redmond, Washington, USA) was used to assess tongue muscle strength. The instrument consists of an air-filled bulb (made of polyvinyl chloride and the size is 3.25 cm in length, 1 cm in height and 2 cm in width) and a pressure transducer. The bulb was placed between the tongue and hard palate. The subject was asked to press tongue against the hard palate as firm as possible and a maximum tongue pressure can be read in kiloPascals (kPa) on the LED display of the device. Calibration and validation were performed weekly to make sure its accuracy. Details of measurement procedure have been given in previous studies [22,25].

The apparatus for biting force measurement is a lab-made device. It was based on a very thin and flexible piezoresistive sensor, FlexiForce (Tekscan, Boston, USA), which consists of layers of materials that can produce a measurable change in electric resistance in response to an applied load [26]. Fig. 1 illustrates the setting up of the measuring device (see Fig. 1). For easy and safe biting, two metal plates (length: 12 mm, width: 12 mm, thickness: 0.5 mm) and two silica discs (length: 12 mm, width: 12 mm, thickness: 3 mm) were adhered to the both sides to sandwich the force sensor (silica discs were at the outer layer) (Fig. 1a). A multimeter (UNI-T, UT181A) was connected to the force sensor to register the electric resistance (Fig. 1b). The force accuracy of the sensor was calibrated and affirmed by a compression test using the Texture analyser (TA XT PLUS, Stable micro systems, UK) which can apply a steadily controlled force on the sensor. Reliability and repeatability of the device have been tested by a recent study in which the biting force of elderly was measured at bedside at the same clinical setting [10].

Table 1

Basic information of participating subjects (Mean values are shown for each parameter except the number of participants. Values shown in parentheses are standard deviations.).

Swallow capability	Grade 1		Grade 2		Grade 3		Grade 4		Mean	Number of participants in each test
	M	F	M	F	M	F	M	F		
Number	5	0	5	2	7	0	5	2		26
Age	82.4(17.8)	–	86 (18.4)	90.5(3.5)	91.6 (6.3)	–	90.2 (6.6)	85.5(2.1)	87.9 (11.6)	26
BMI (kg/m ²)	22.7 (2.4)	–	25.7 (1.4)	20.3	24.2 (2.9)	–	19.1 (3.9)	24.3(2.1)	23.0 (3.2)	18
Hand gripping force (kg)	18.1 (9.7)	–	21.8(13.6)	15	15.8 (2.1)	–	11.8 (6.3)	5.1 (5.1)	15.9 (9.1)	19
Biting force (N)	99.6(50.7)	–	64.5(32.2)	26.1(8.7)	44.8(39.5)	–	37.5 (11)	50.9(5.9)	59.0 (39.9)	21
Tongue pressure (kPa)	43 (15.3)	–	26.4(13.8)	35	13.75(4.6)	–	17.8(11.6)	28	25.6 (15.0)	20

2.3. Data collection

Eating capability is defined as the physical, physiological, and cognitive capabilities of an individual for food handling and consumption [24]. This study focused mainly on the oral physiological and hand muscular capability.

Subjects were asked to complete a questionnaire test, with the help of their carers if necessary. The questionnaire includes basic information (such as name and age, body mass index (BMI) and etc.) and health history as well as dental status. Specifically recommended texture of his/her daily diet was collected for all subjects. Data were then used for further analysis of their eating behaviour.

2.4. Swallow capability

Water drinking test has been commonly used for swallowing disorder assessment because of its good reliability [27]. Participants were asked to drink 30 ml warm water and their swallowing capability was graded into five different levels based on their performance. Grade 1 subjects were those who could drink (swallow) all water in one go with no side effect. Grade 2 was those who could complete drinking all water by two swallows without causing coughing. Grades 3 and 4 meant coughing during drinking, but the former refers to those who swallow in one go and the latter refers to those who need multiple swallows. Grade 5 was those patients who needed multiple swallows and were accompanied with frequently coughing.

2.5. Oral physiological characteristics

2.5.1. Denture status

Participants were checked about their denture status in questionnaire. Six different denture statuses were then identified: natural teeth, few natural teeth, combination (natural teeth and dental prosthesis), up or lower denture, and full denture.

2.5.2. The maximum biting force

Participants were asked to sit on a chair at his/her most natural position. Before the test, the subject was informed about the content and procedure of this test. Then the participant was instructed to bite on the probe with incisors and increase the biting force with the maximum effort. The minimum resistance value (corresponding to the maximum applied load) was recorded and then converted into the biting force in Newton using the calibration curve. The above steps were repeated 3 times with at least 30 s interval between the two biting. The largest force from three tests was used as the participant's maximum biting force.

2.5.3. The maximum tongue pressure

The maximum tongue muscle strength was measured by IOPI. Participants sit comfortably on chairs and keep head upright and eyes on a horizontal target. They were instructed using a graphic illustration to locate the IOPI air-filled bulb onto the anteromedian

position which was defined as the centre of tongue directly behind the front teeth, and press the bulb against the hard palate to their maximum effort. The generated pressure was recorded in kiloPascals (kPa). Each participant was tested 3 times with 30 s interval in between. The obtained maximum value was recorded as patient's tongue muscle strength.

2.6. Hand gripping capability

Hand gripping force represents the capability of food handling (such as gripping food), opening food packages, transporting food from the plate to the mouth, and etc. Hand gripping was measured in this study using an adjustable digital dynamometer (JAMAR Plus Digital Dynamometer, PATTERSON MEDICAL Ltd., Nottinghamshire, UK). Participants were instructed to stand (except for those bedridden) and hold the dynamometer with the habitual hand. They were asked to try their best to squeeze the dynamometer and maintain that for approximately 3 s. The maximum force (in kg) of 3 repeated tests was registered to represent the capability of hand gripping.

2.7. Data analysis

The mean values and the standard deviation (SD) was calculated using Microsoft Office Excel 2013. Pearson's Correlation and one-way analysis of variance (ANOVA) was performed by using IBM SPSS 21.0 (SPSS Inc., Chicago, IL). Least square difference (LSD) was used as the post-hoc analysis.

3. Results

3.1. Assessment of the swallowing capability

Altogether 26 elderly patients (4 female, 22 male) were selected to participate this study. Subjects were aged from 53 to 105 years old (mean = 87.9 yrs, SD = 11.6 yrs) (see Table 1). According to water drinking test, participants were categorized into different grade groups. Among 26 subjects, 5 were assessed as Grade 1 (normal), and 7 subjects were on Grades 2 to 4 each. There was no subject on Grade 5 according to the criteria set in Section 2.4.

3.2. Assessment of oral physiology and hand gripping capability

3.2.1. Oral physiological properties

The maximum biting force and the maximum tongue muscle strength were measured 3 times for every participant. Average values and standard deviations for subjects of four different grades as assessed by water drinking tests and for both genders are summarized in Table 1, in which subjects' basic information and oral physiological functions are listed according to different grades of swallowing capability. Pearson's correlation analysis was performed to see whether a relationship exists between these parameters and results are shown in Table 2. One can see

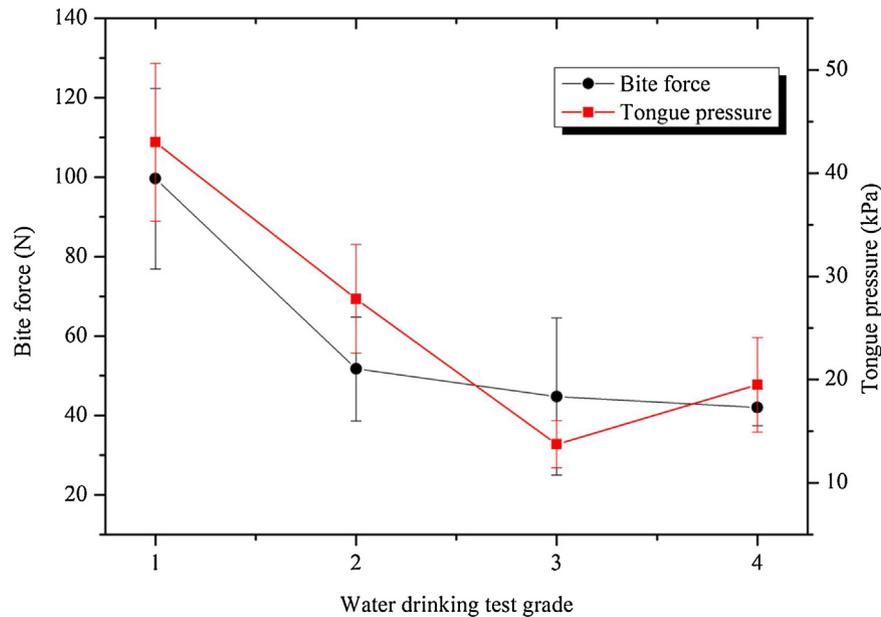


Fig. 2. The maximum biting force and the maximum tongue pressure in relation to the swallowing capability grade obtained from water drinking test.

Table 2

Correlation matrix (Person) with the measured eating and swallowing capabilities and oral physiological properties.

	Water drinking test	Age	Biting force	Tongue pressure	Hand gripping force
Water drinking test	1	-.224	-.498*	-.544*	-.411
Age	-.224	1	-.622**	-.206	-.774**
Biting force	-.498*	-.622**	1	.203	.573*
Tongue pressure	-.544*	-.206	.203	1	.214
Hand gripping force	-.411	-.774**	.573*	.214	1

that age seems to have a low correlation with water swallowing grades ($r = -0.224$), but has a high correlation with the biting force ($r = -0.622, P < 0.01$) and hand gripping force ($r = -0.774, P < 0.01$), suggesting that aged individuals have an overall reduced muscle strength both for biting and for hand gripping. However, it was surprising to see that tongue muscle strength also has a low correlation with age ($r = -0.206$). This is somewhat contradictory to a previous study in which tongue muscle strength was found to decrease with increased age [22]. Despite the fact that the previous study was conducted on European population and the current one was on Chinese, one wouldn't think different ethnic background is the cause of the contradictory finding. A highly possible explanation could be because of all healthy elderly participants in the previous study but hospitalized patients in this study. For the latter case, age becomes less important but health status is the main determining factor of individual's physiological functions.

The water drinking test grades showed significant correlations with both oral physiology parameters, the maximum biting force ($r = -0.498, P < 0.05$) and the maximum tongue muscle strength ($r = -0.544, P < 0.05$). Results confirmed initial hypothesis that reduced swallowing capability is closely related to weakened oral physiological properties. Above results also indicate the feasibility of using oral physiology assessment as a low-risk and less invasive tool for swallowing capability tests. Table 2 also shows that a low hand gripping force ($r = -0.411$) could also be seen as an indication of the reduced eating and swallowing capability of elderly subjects.

Fig. 2 shows the relationship between water drinking grades and the biting force as well as the tongue muscle strength. Differences of both oral physiological parameters between Grade 1 and Grade 2 are obvious and statistically significant (Table 3). However, no statistical difference was observed for the two oral physiological

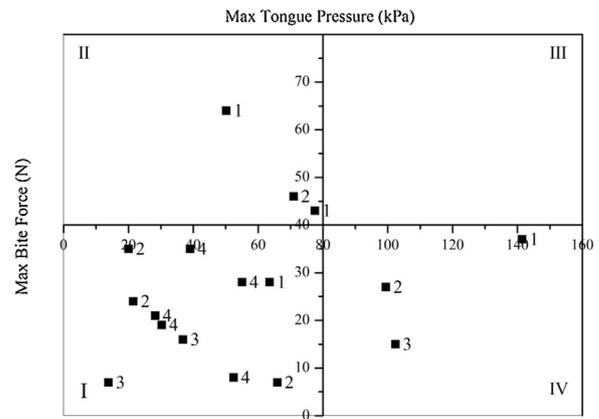


Fig. 3. Scatter plot of the maximum biting force and the maximum tongue muscle strength (the number labeled next to each symbol represents the swallowing capability grade assessed by water drinking test).

parameters between Grades 3 and 4 dysphagia patients (Table 3). As males always showed higher biting force than females [28], gender influence was excluded but conclusion remained the same as above (Table 1).

It was a surprise to see a low correlation ($r = 0.203$, Table 2) between the maximum biting force and the maximum tongue pressure among the 17 participated subjects. However, when plotting the two parameters against each other (Fig. 3), something interesting emerges. Subjects with swallowing disorders are largely clustered in the lower left corner (Region I), with biting force below 80 N and tongue muscle strength mostly below 40 kPa. This result is very similar to that previously reported results by Alsanei et al.

Table 3

Eating capability of each grade classified by water drinking test (Values in parentheses are standard deviations. Means in the same row with the same letter do not differ significantly ($P > 0.05$) according to LSD test).

Water drinking test	Grade 1	Grade 2	Grade 3	Grade 4
Age	82.40 ^a (17.77)	87.29 ^a (15.24)	93.40 ^a (3.65)	88.86 ^a (5.96)
Max hand gripping force (kg)	18.10 ^a (9.68)	20.46 ^a (12.13)	15.77 ^a (2.08)	9.12 ^a (6.30)
Max biting force (N)	99.62 ^a (50.78)	51.68 ^b (32.10)	44.76 ^b (39.54)	41.97 ^b (11.29)
Max tongue pressure (kPa)	43.00 ^a (15.30)	27.83 ^{ab} (12.89)	13.75 ^b (4.57)	19.50 ^b (11.22)

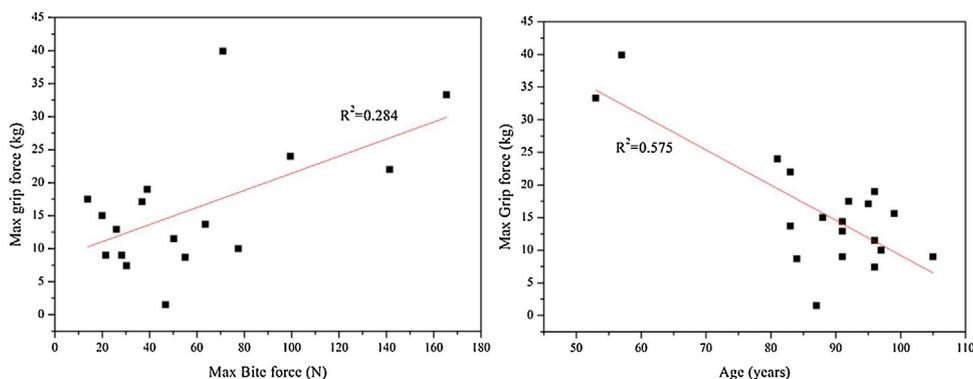


Fig. 4. The hand gripping force is plotted against (A) the maximum biting force, (B) the age of the subjects.

Table 4

Biting force and tongue strength for subjects in different dental status (Values in parentheses are standard deviations. Means in the same column with the same letter do not differ significantly ($P > 0.05$) according to LSD test).

	Age	Biting force (N)	Tongue Pressure (kPa)
Natural teeth	79.7 ^a (12.3)	101.79 ^a (42.50)	26.7 ^a (7.82)
Combination	76.5 ^{ab} (19.5)	68.46 ^{ab} (2.51)	26.5 ^a (19.50)
Few natural teeth	91.0 ^{ab} (7.8)	53.40 ^b (19.30)	23.3 ^a (14.61)
Up or down denture	90.7 ^{ab} (5.5)	43.19 ^b (15.95)	35.8 ^a (13.87)
full denture	94 ^b (4.7)	26.44 ^b (7.40)	19.2 ^a (7.25)

[22,29], in which a tongue pressure of 35 kPa was noted as an indication marker of the capability impairment of swallowing. No single participant in this study possessed both high tongue muscle strength and high occlusal capacity (Region III). Although most of the subjects were concentrated in Region I, it was observed that several subjects had high tongue muscular strength but low occlusal force (Region II) or high occlusal force but low tongue muscular strength (Region IV). These are mostly Grades 1 or 2 subjects based on water drinking test.

3.2.2. Grouping of different dental status

Participants in different dental conditions were classified and the average value of the maximum biting force and the maximum tongue pressure were calculated. Results are shown in Table 4. It is very clear that subjects with natural teeth have the highest biting force (101.79 N). This was followed by those with combination teeth (68.46 N), few natural teeth (43.19 N) and full denture (26.44 N). Full denture wearers have a significantly lower biting force of all groups ($P < 0.05$). However, dental status seems to have no direct influence on the tongue muscle strength. No significant difference was observed among groups of different dental status.

3.2.3. Hand gripping capability

Hand gripping force has been proposed as a possible alternative non-invasive method to replace oral physiology tests for eating capability assessment [23]. However, results from this work show a low correlation with the swallow capability ($P > 0.05$, Table 2), despite that subjects of Grades 1 and 2 (good swallowing capability) have relatively higher hand gripping strength, while those of

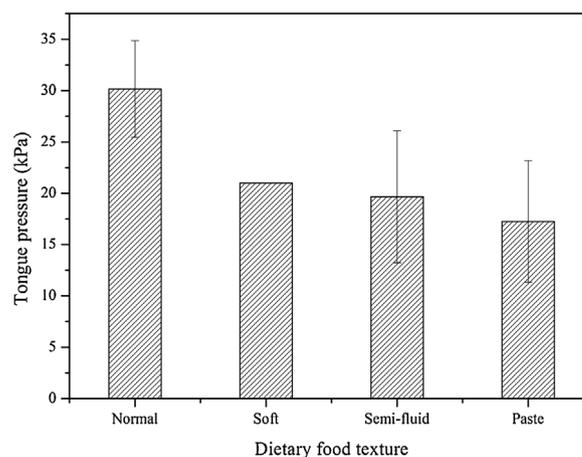


Fig. 5. The maximum tongue strength for subjects on diets of different recommended texture.

Grades 3 and 4 (poor swallowing capability) have relatively a lower hand gripping strength.

Pearson's correlation analysis showed correlations of the hand gripping capability with the biting force and age. Fig. 4 shows that hand gripping force is moderately correlated with the biting force ($R^2 = 0.284$, $P < 0.05$), but significantly correlated with the age ($R^2 = 0.575$, $P < 0.01$). These results suggest that a moderate confidence can be given in using hand gripping strength tests for eating and swallowing capability assessment, may be as a supportive assessment method.

3.3. Correlation between oral capability and the texture of dietary food

Dietary food texture of participated subjects was recorded based on the questionnaire test and results were analysed against their oral physiological capability. According to questionnaire analysis, 14 subjects were on normal food, 1 subject was on soft food, 5 subjects were on semi-fluid food, and 4 subjects were on paste food; Fig. 5 plots the average maximum tongue pressure for groups on

different recommended diets. One can observe that subjects who are on normal diets have on average the highest maximum tongue pressure (30.2 kPa), compared to only 21 kPa for those on soft texture, 19.7 kPa for those on semi-fluid texture, and 19.2 kPa for those on paste texture on average. This observation agrees well with a previous finding on the correlation between tongue pressure and capability of food oral handling [29]. However, despite the correlation between diet texture and the maximum tongue muscle strength, no direct correlation was observed between dietary food texture and the maximum occlusal biting force.

3.4. Discussion

This study aimed to establish feasibility of using oral physiological parameters to assess eating and swallowing capability of elderly dysphagia patients. We speculated that reduced eating and swallowing capability among elderly people could be closely related to their weakened oral physiological functions and want to explore the possibility of optimal matching between swallowing capability and food texture modification. Laguna et al. [24,25] have already conducted a quantitative assessment of the eating capability among elderly European individuals. This work applied the same approach and methodologies to elderly Chinese subjects, by measuring their oral physiological functions (incisor biting force, tongue muscle strength and dental status) and hand gripping force, with the aim of establishing correlations between oral physiology and eating and swallowing capability among Chinese elderly.

The analysis of oral physiological parameters against swallow capability reveals different influences of tongue pressure and biting force. Most participants of this study were found to have a biting force of less than 80 N and a tongue pressure of less than 40 kPa, with few exceptions who have either a high biting force or a high tongue pressure, but not both. The average of the maximum biting force was significantly different between groups: 99.62 ± 50.78 N for Grade 1 subjects but only 51.68 ± 32.70 N for Grade 2 subjects. This is consistent with the previous findings that there is a significant difference in the maximum occlusal force between elderly with or without swallow disorder [30]. It was reported that the average maximum biting force of healthy elderly was 346 N for males and only 188 N for females [31]. However, biting force for hospitalized participants in this work was much lower, only 64 N for males and only 39 N for females.

Denture status will also strongly influence the occlusal force [32]. It was reported that, for healthy subjects, the total denture wearers usually have their biting force approximately 20% lower than that of natural teeth group [33]. But, in this study, the average maximum biting force for the full denture group was 26.44 ± 7.40 N, only about a quarter of that for corresponding natural teeth group. This again shows the very different scenarios between healthy elderly and hospitalized elderly.

Tongue pressure was measured as an indication of tongue's capability for food oral manipulation and swallowing. It was reported that tongue disorders might result in difficulties in swallowing and can be related to dysphagia. In this study, 20 participants were examined for their maximum tongue pressure. The values are scattered between 7 kPa and 64 kPa, with an average at 27 ± 14 kPa. This number is much lower than that of healthy elderly individuals (35 ± 11 kPa) and of course much lower than that of younger adults group (48 ± 10 kPa) [22,29]. Differences of the average maximum tongue pressure were also significant among subject groups within this study. The Grade 2 subjects have an average of 27.83 ± 12.89 kPa, but those of Grade 3 have only 13.75 ± 4.57 kPa. The reason for the observed difference between the results obtained from this work for Chinese elderly and those for European elderly is not yet clearly. Apart from ethnic and cultural differences, the average age of the participating subjects were much

higher in this study than that in the European studies. More importantly, all subjects in the current study were hospitalized ones while subjects in previous European studies were not.

This study confirms that elderly people do suffer from reduced eating and swallowing capability. Therefore, texture modification and proper texture grading will be mostly helpful for such populations [34,35]. However, further research involving clinical studies is still need on the proper matching between the texture properties and one's capability of eating and swallowing.

4. Conclusions

Measurements of the oral physiological functions (biting force and tongue muscle strength) as well as hand gripping force of Chinese elderly patients in a quantitative manner were conducted in this work. These measured parameters were then analyzed against the swallowing capabilities assessed based on water drinking test. Statistical analysis of results showed that age has a low correlation with the swallowing capability among the subjects of this study, even though it has a high correlation with both the biting force and the hand gripping force. Biting force showed a significant correlation with the dental status, with those of natural teeth having the highest biting force and those of full dentures having the lowest biting force. Subjects in low biting force (< 80 N) and in low tongue pressure (< 40 kPa) are mostly categorized as Grades 3 or 4 from the water drinking test, showing impaired eating and swallowing capability. Results clearly demonstrated inter-correlation between the swallowing capability and one's oral physiological functions. It was concluded that the maximum tongue pressure and the maximum biting force could be used as feasible indicators for swallowing capability assessment for elderly dysphagia patients.

Conflict of interests

Authors declare that they do not have any conflict of interests involved in this project.

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