学 位 論 文

Effects of viscosity on food transport and breathing-swallow pattern during eating of two-phase food in elderly individuals

(高齢者における年齢、食物輸送時の粘性および二相性食物の咀嚼時の呼吸―嚥下機能の相互関係への影響)

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松本歯科大学大学院歯学独立研究科博士(歯学)学位申請論文

Effects of viscosity on food transport and breathing-swallow pattern during eating of two-phase food in elderly individuals

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《要旨》

固形物と液体を同時に摂取する場合には、口峡部が開いているために、食物は嚥下前に下咽頭まで達し、誤嚥の危険性を増大させる可能性がある。また、食物を咀嚼嚥下している時の呼吸リズムと嚥下とはその間に強固な協調関係があり呼気・嚥下・呼気というパタンがあるということが明らかになっている。

Matsuo(2015)らは若年健常者では，嚥下と呼吸の間に食物の物性によらない強固なパタンがある可能性があると報告した。しかし嚥下ではない咀嚼中や食塊形成時には呼吸との間に典型的な呼吸パタンはない。

そこで本研究では、施設在住高齢者において、 咀嚼嚥下や二相性食物の粘性が、嚥下開始のタイミングを変化させるかどうか、 呼吸リズムと咽頭への食物の侵入との関係を検証した。

対象および方法：

調査対象は摂食・嚥下障害の既往がなく、常食摂取している 80 歳以上の高齢者 19 名であった。

被験食品は、コントロールとして米飯 5g を用い、二相性食物として米飯 5g と水 3ml を同時咀嚼とした。また、二相性食物にはトロミを付与し、0，2，4％の 3 段階とし，それぞれ TP0，TP2，TP4 とした。

咀嚼嚥下中の咽頭への送り込みを嚥下内視鏡で撮影し、DV テープに記録した。それと同時に呼吸状態をプレスチモグラフにて胸郭と腹部の動きをモニタリングした。

結果および考察：

若年健常者において咀嚼時間は TP0 が他の食品に比べ短かった。高齢者においても咀嚼時間は TP0 が他の食品に比べ短かったが、他の食品間で有意差はなく、平均咀嚼時間は若年者に比べ大幅に延長した。

食物先端の位置は若年健常者においては TP0 が他の全ての被検食より深く、下咽頭や梨状窩まで達する割合が高いが、粘性を付与することによりコントロールに近づいてくるという結果であったが、高齢者においては全ての

食品間において嚥下時の食物先端の位置が下咽頭へ達しており、食物先端の位置は全ての食物間で有意差を認めなかった。

また呼吸については若年健常者においては嚥下開始時の呼吸相は食物の粘性によらず、ほとんどの被検食でプラトー相または呼気相であったが、高齢者においては二相性食物の粘性が低下すると、嚥下開始時の呼吸は吸気相で起こる割合が増加し、咽頭への食物の嚥下までの送り込みは二相性食物の粘性によらずに高率に下咽頭にまで達していた。

これらの結果より高齢者では呼吸の予備力低下・咀嚼嚥下と呼吸パタンとの協調性が低下している可能性が示唆された。

この研究により二相食品の粘性は、経口処理や呼吸パタンに大きな影響を与えるので、嚥下前誤嚥などの問題を防止するために、摂食・嚥下障害の既往がなく常食摂取している高齢者であっても呼吸の予備力低下により誤嚥の危険性があり、正しい食品の選択が重要で、定期的なスクリーニング検査の必要性や食形態が適正であるか検討する必要性があると考える。

ABSTRACT

When eating food containing both liquid and solid phases (two-phase food), the liquid component frequently enters the hypopharynx before swallowing, which may increase the risk of aspiration. The aim of this study was to test whether the initial viscosity of two-phase food would alter pre-swallow food transport and breathing-swallowing coordination in elderly persons. Fiberoptic endoscopy was recorded while 18 healthy young and 19 elderly subjects ate 5 g of steamed rice with 3 ml of blue-dye water. Liquid viscosity was set at three levels by adding a thickening agent (0, 2, and 4 wt%, respectively). We measured the timing of swallow initiation and the respiratory phase at swallow initiation. For thin two-phase food, the timing of swallow initiation was not significantly different between young and elderly subjects, but swallows more initiated during inspiration in elderly subjects. For thicker two-phase foods, in contrast, the timing of swallow initiation was delayed in elderly subjects, but swallows usually initiated during expiration in both groups.

In elderly individuals, for thin two-phase, swallow initiation is reserved but breathing swallowing coupling was declined. For higher viscosities, swallow initiation is delayed during eating food, but breathing swallowing coordination is not perturbed probably due to slow bolus flow into the hypopharynx.

Coordination between swallowing and breathing pattern during eating of food would decrease with aging, which may expose a risk of pre-swallow aspiration.

Keywords: deglutition/physiology; mastication; viscosity; aging; videoendoscopy; dysphagia; food consistency

INTRODUCTION

Pre-swallow food transport is different during eating food from that during swallowing a liquid bolus. When eating solid food, the food is broken down in size by mastication, and the resulting smaller particles are lubricated and cohered with saliva to form a bolus[1)]. The formed bolus is gradually transported posteriorly before swallowing and accumulates on the oropharyngeal surface of the tongue or the valleculae.

The initial consistency of food alters the pre-swallow food transport and the timing of swallow initiation[2-4)]. When eating solids and liquids simultaneously (two-phase food), the low viscous liquid portion of the food flows easily into the hypopharynx, passing the open fauces during chewing principally by gravity [3]. During this period, the larynx is open to the pharynx for breathing. Mixed food consistencies such as two-phase food can be found in both regular and dysphagic diets alike: mechanically chopped food contains liquid, and liquid soups often contain solid foods. These food consistencies may increase the risk of aspiration for dysphagic individuals with a weak airway protective mechanism[5,6)]. Our previous study with stroke patients showed that, with two-phase food, the leading edge of the food quickly enters the hypopharynx, and retained in the piriform sinus for significantly longer duration before swallowing[6)].

Viscosity is known to alter swallow initiation and bolus location in liquid swallowing[7-10)]. As bolus viscosity increases, oral transit time is extended and the time of initiation of the pharyngeal swallow is correspondingly delayed[7-9)]. Accordingly, modifying the viscosity of liquids is an important compensatory maneuver to manage the risk of aspiration in individuals with dysphagia[11,12)]. Viscosity also alters the flow of liquid transport and the timing of swallow initiation when eating two-phase food. Our preliminary study with healthy young volunteers demonstrated that as viscosity increased, food stayed more in the oral cavity and located higher in the pharynx at swallow onset[13)].

Coordination between swallowing and breathing is thought to be an essential element of airway protection during food passage. Thereby, swallowing has tight phase relationship with breathing. Swallowing usually starts during expiration regardless of the type of food. The predominant respiration-swallowing pattern for a single liquid bolus swallow in adult humans is "exhale – swallow – exhale" (67 – 79% of liquid swallows), followed by "inhale – swallow – exhale" (18 – 21%)[14-16]. When eating solid food, swallowing is predominantly initiated during expiration (87 – 99%)[17-19].

In contrast, mastication and respiration have a loose temporal coupling except for crucial moments surrounding the swallow[20-22][17,18]. Triturated food was accumulated in the pharynx until swallow initiation during eating solid food, but during the period of this time, there is no consistent phase of respiration [18]. Solid food has cohesiveness and adhesiveness to be formed in the valleculae and not to flow into the hypopharynx, which has less risk of pre-swallow aspiration. Our previous study with stroke patients and aged matched elderly individuals showed that when eating corned beef hash, the leading edge of the food were mostly in the valleculae, and few reached to the bottom of the piriform sinus in both subjects[6].

However, with two-phase food, the low viscous liquid component reaches easily the bottom of the piriform sinus. It is little known how the respiratory pattern is affected at the moment when liquid flows in the hypopharynx. The hypopharyngeal area is regarded as the region triggering protective swallows that is more independent from the oral phase of swallowing[20-22]. When liquid enters the hypopharyngeal area, a reflexive swallow occurs to protect the airway from aspiration[22]. A similar airway protective mechanism may occur to prevent aspiration for thin two-phase food. Breathing pattern is usually stable when eating solid food, but when the protective swallow occurs, the breathing pattern may be perturbed because the reflexive swallow ceases breathing. We hypothesized that more protective swallowing reflex occurs when the liquid enters the hypopharynx, and swallowing would occur more during inspiration, and that initial viscosities of the food alter breathing-swallowing coordination. The aim of this study was to test whether the initial viscosity of two-phase food would alter food transport before swallowing and breathing-swallowing coordination in elderly persons.

METHODS

Subjects and materials

The study protocol was approved by the Institutional Review Board of Matsumoto Dental University (approved No. 0170). The data in the young group has been previously used in the other published study [13]. because the experimental design was mostly same for young and old subjects, we used the data set of young subjects for the control. Eighteen healthy, asymptomatic young adults (9 males, 9 females, mean age 26.7 ± 3.9 years) and twenty-one elderly subjects living in a nursing home (4 males, 17 females, mean age 86.6 ± 4.0 years) participated after giving informed consent. All the subjects had regular diet, and had no history of aspiration pneumonia or dysphagia. For elderly subjects, the mean Mini Mental State Examination (MMSE) score was 23.2 ± 3.5, and mean Barthel Index was 78.6 ± 11.3.

Each subject was seated comfortably upright in a chair and asked to eat 4 kinds of test foods: five grams of steamed rice was adopted as the control (CTRL), and 5 g of steamed rice with 3 ml of blue-dye water (two-phase food, TP) adjusted to 3 levels of viscosity (0, 2, and 4 wt%; TP0, TP2, and TP4, respectively) using a thickening agent (Through-King *i*, Kissei Pharmaceutical Co., Japan). The characteristics of the water thicknesses are shown in Table 1. Liquid viscosity was measured with a rotational viscometer (TV10, Toki Sangyo, Tokyo, Japan). Hardness, cohesiveness, and adherence were measured with a creepmeter (RE-3305S, Yamaden, Tokyo, Japan). Each characteristic was measured 30 minutes after dissolving the thickening agent in 100ml of 20℃ distilled water

Procedures

Rice was first placed in the mouth, and then water was injected into the mouth with a syringe. Participants were instructed to eat the rice and water simultaneously and swallow in their usual manner for each food consistency. Young subjects completed 2 trials for each of the 4 test foods. Old subjects completed only 1 trial for each food. Two trials from one subject in young group were accidentally not recorded on a digital video (DV) tape. One subject in old group was excluded because masticatory duration was extremely prolonged due to no dental occlusion in the molar regions. Another subject in the old group was excluded because the subject did not chew the test foods and swallowed them in the most trials. After these exclusions, 220 recordings (144 recordings of young subjects and 76 recordings of old subjects) were included in the analysis.

To investigate the entry of the food from the oral cavity into the pharynx before swallowing, video endoscopic swallowing study (VESS) was performed (Matsuo et al., 2012). A fiberoptic endoscope (3.6 mm in diameter, Olympus, Japan) was passed transnasally without topical anesthesia with its optical head positioned behind the soft palate, just above the uvula. From this position, the uvula, base of the tongue, valleculae, valleculae, piriform sinuses, and the larynx were all observable. Endoscopic images were recorded on a DV tape recorder at 30 frames/s.

Respiration was monitored with a respiratory plethysmograph bands placed around the chest and abdomen. All the physiological signals were collected on a laptop computer using a data recorder (PowerLab System, ADInstruments Japan, Nagoya, Japan) at 1.0 KHz acquisition rate.

A trigger switch box was connected to the digital data and DV tape recorders. Depressing the trigger button generated a square-wave spike signal that was recorded on the digital data recorder and simultaneously created a distinctive sound recording on the DV recorder that appeared as wave forms in our video editing software (Adobe Premiere, Adobe systems, CA). The subjects were instructed to start chewing when the trigger switch was beeped. The timing of the sound signal was extracted using this program. The physiological data and VESS images were then synchronized by matching the timing of the spike signal from the data recorder with the time of the sound in the VESS recording.

Data analysis

Feeding

We measured the timing of both the start of mastication and swallow initiation. Swallow initiation was defined as the timing of "white-out" for swallowing in VESS images. Swallow occurred several times in one eating sequence. For this study, we only used first swallow of the sequence. Masticatory time was defined as the interval from the start of mastication to the first swallow.

The time when the leading edge of the food reached the base of the epiglottis was identified in VESS images. We then divided masticatory time to the first swallow into oral processing time (OPT) and pharyngeal aggregation time (PAT); oral processing time was defined as the time from the start of mastication to the time of the leading edge reaching the base of the epiglottis, and pharyngeal aggregation time was defined as the time from the leading edge reaching the base of the epiglottis to the first swallow. If the leading edge did not reach the base of the epiglottis before swallowing, oral processing time was regarded to be the same as masticatory time and pharyngeal aggregation time to be zero seconds.

The location of the leading edge of the food at swallow initiation was classified into five areas: 1) oral cavity, the area where the food was not observed in VESS images; 2) orophaynx, the area where the leading edge was observed in VESS images but had not reached the base of the epiglottis; 3) valleculae, the area where the leading edge reached the base of the epiglottis but had not entered the hypopharynx; 4) hypopharynx, the area where the leading edge entered the hypopharynx but had not reached the bottom of the piriform sinus; and 5) piriform sinus, the area where the leading edge had reached the bottom of the piriform sinus.

Respiration

The sum of chest and abdominal respiratory signals was processed with digital signal analysis software (LabChart 7, ADInstruments Japan, Nagoya, Japan). Each respiratory cycle had inspiratory and expiratory phases, usually with a pause after active expiration. On the respiratory signals, we noted the phase of respiration during which the swallow initiated.

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Statistical analysis

Differences in the mean durations of masticatory time, OPT, and PAT among the food types were tested using repeated measure ANOVA, and between young and old subjects using t-test. Paired t-test with Holm's correction was employed for multiple comparisons. Differences in the location of the leading edge of the food at swallow initiation among the food types was assessed using Friedman test, and between young and old subjects using Mann-Whitney's u-test. We employed the Wilcoxon signed-rank test with the Bonferroni correction for multiple comparisons if the Friedman test was significant. Differences in the respiratory phase between young and old subjects were tested with chi-square test.

The critical value for rejecting the null hypothesis was $p < 0.05$. Statistical analyses were performed using SPSS 20.0 software (IBM Corp., Armonk, NY, USA).

RESULTS

Food transport

In young group, mean (± SD) masticatory time to the first swallow was significantly shorter for TP0 (6.62 ± 4.37 s) than for the other foods ($p < 0.01$, Fig. 1-A), and it was shorter for TP2 (9.54± 4.67 s) than for CTRL or for TP4 ($p < 0.02$). In old group, mean masticatory time was also significantly shorter for TP0 (6.05 ± 4.08 s) than for the others ($p < 0.002$) but it did not vary significantly among the other food types (Fig. 1-A). Mean masticatory time was significantly longer in old group than in young group ($p < 0.01$), except for TP0 ($p = 0.64$).

In young group, OPT was shortest for TP0 (4.59± 2.99 s), and was the next for TP2 (8.09± 3.75 s) ($p < 0.01$, Fig. 1-B). In old group, OPT was shorter for TP0 than the others ($p < 0.01$), and was shorter for TP2 than for CTRL. OPT was not significantly different between for CTRL and TP4 in both groups. For CTRL, OPT was significantly shorter in young than in old group ($p =0.046$), but no differences were seen for the remaining foods.

For PAT, there were no significant differences among food types in young group (Fig. 1-C). In old group, PAT was shorter for TP0 than TP2 or TP4 ($p < 0.02$), but no other differences were not seen for the others. For only TP0, PAT was not significantly different between in young and old groups ($p = 0.18$), but, for the others, PAT was significantly longer in old than in young group ($p < 0.02$, Fig. 1-C).

Bolus location at swallow onset

In young group, with TP0, the leading edge reached the bottom of piriform sinus before swallowing in 28% (10/36) of sequences, but never reached there with the other food type. Thus, the leading edge of the food at swallow onset was significantly deeper in the pharynx for TP0 than for TP2 or TP 4($p < 0.01$, Fig. 2). In old group, there was no significant difference in the location of the leading edge at swallow onset among food types. With TP0, the leading edge was at the bottom of piriform sinus in 53% (10/19) of sequences, but also was seen there with the other consistencies: 26% of sequences for CTRL, 37% for TP2, and 32% for TP4, respectively (Fig. 2). Thereby, withTP2 and TP4, the leading edge of the barium was significantly deeper in the pharynx at swallow onset in old than in young subjects ($p < 0.01$).

Respiratory phase at swallow initiation

In young group, with all the food types, the swallows mostly initiated during active expiration or the following pause (Fig 3), and there was no statistical difference among food types. In old group, the swallows sometimes initiated during inspiration. For TP0, in 32% (6/19) sequences of old subjects, the swallow initiated during inspiration, and its fraction was significantly greater than in young group ($p < 0.01$, Fig. 3).

Penetration and aspiration were not seen in young subjects. Aspiration was not seen in all the old subjects, but penetration was observed in 6subjects (2 trials for CTRL, 2 trials for TP0, 3 trials for TP2, and 3 trials for TP4, respectively).

DISCUSSION

Effects of viscosities and age on food transport and swallow initiation

Our previous study revealed that increased viscosity has significant influence on pre-swallow bolus transport and swallow initiation in healthy young adults. The present study with elderly individuals living in nursing homes demonstrated similar tendency with TP0, but with the other foods, the duration of food movement and the food location at swallow initiation was significantly different from that of young adults. For TP0, mastication time, OPT, and PAT were not significantly different between young and old adults. As viscosity increased, OPT did not differ but PAT extended significantly in older group. These findings suggest that, in very old individuals, when eating thin two-phase food, swallow initiation was not altered, but as initial viscosities in the two-phase food increase, swallow initiation was significantly delayed.

When eating two-phase food, bolus movement and swallow initiation was not altered in elderly subjects compared to young subjects. The fauces is closed by tongue-palate contact when a liquid bolus is held in the mouth before swallowing, but is opened during mastication because the tongue and soft palate incessantly moves associated with masticatory jaw movements[23,24)]. Because the fauces is not sealed during mastication, low viscous liquid quickly passes the fauces, reaching the valleculae. The liquid further flows to the piriform sinus while chewing continues. The hypopharyngeal area is regarded as the region triggering protective swallows that is more independent from the oral phase of swallowing [20,22,25,26)]. When liquid enters the hypopharyngeal area, a reflexive swallow occurs to protect the airway from aspiration. Dua et al., examined direct water perfusion to the hypopharynx with thin catheter in rapid and slow speed to elicit reflexive pharyngeal swallow[26)], and reported that with rapid water injection the threshold volume to trigger the swallow does not differ between the young and elderly subjects. Our findings suggest that for TP0, due to thin viscosity, swallowing maybe evoked reflexively for airway protection and its airway protective mechanism may be preserved in very old individuals.

When eating steamed rice (CTRL), the mean duration of OPT in the elderly was as about twice as in the young subjects. Aging itself has little influence on masticatory performance when eliminating the confounding effects of missing teeth or the other illness[27-29)], but various factors in the elderly people reduce masticatory performance[4,29)]. Subjects with decreased occlusal contact areas or use of removal denture(s) need more chewing strokes compared to subjects with natural dentition [29-31)]. Recent studies reported that decline of general muscle strength or physical performance, or sarcopenia has significant correlations with lower chewing ability[32-33)]. Various local and general factors may influence on prolongation of OPT in the elderly participants. When eating solid food, chewed food is propelled by the tongue squeeze motion against the palate. Declined masticatory performance may delay the onset of oropharyngeal food transport, resulting in the OPT prolongation for rice without liquid. On the other hand, OPT was not prolonged in elderly subjects for TP2 and TP4. When the food contains liquid, the leading edge of the liquid component, regardless of its viscosity, passes the opened fauces and reached the pharynx by the gravity. Thus, the duration of OPT was not extended in the elderly subjects in contrast to eating rice.

While the movement of the food during mastication is similar in the young and elderly subjects for TP0, with higher viscosity of two-phase food, the movement of the food in the pharynx was altered in the elderly subjects: PAT was significantly extended and the location of the food was significantly deeper in the pharynx. For TP2 and TP4, after the leading edge of the food reached the base of the epiglottis, the liquid component must flow into the hypopharynx more slowly compared to thin two-phase food, and took more time to reach the area surrounding the arytenoid folds. The findings indicate that slow penetration to the hypopharynx would not trigger the reflexive swallow immediately. Dua et al. reported that during slow water infusion, reflexive pharyngeal swallow was elicited significantly less in the elderly subjects than in the young subjects, while during fast infusion, reflexive pharyngeal swallow was elicited in 100% of both young and elderly groups. Their results support our results that longer PAT with higher viscous food in the elderly. Increasing viscosity slowed food transport to the high sensitive area surrounding the arytenoid folds, viscous liquid pooled in the bottom of the piriform sinus, while chewing continued in the oral cavity until the chewed food in the mouth was ready to be swallowed. Prolonged PAT means that the swallow is not elicited immediately when the food reached the pharynx. The evoking factors of swallow initiation remain unclear, but these results suggest there are multiple trigger points of swallow initiation during eating food. This would be the reason for significant extension of masticatory duration and PAT with higher viscous two-phase foods.

Effects of viscosities and age on respiratory phase at swallow initiation

We hypothesized that swallowing would occur more during inspiration when eating TP0 because reflexive pharyngeal swallows more occur to protect the airway for TP0. Our hypothesis was rejected that swallows mostly initiated during expiration or the following pauses regardless of the food types in young subjects. Previous studies reported that swallowing has tight temporal relationships with breathing that swallows usually initiate during expiration when drinking a liquid bolus or eating solid foods[14-19]. Our findings are consistent with the previous studies. When eating solid food, chewed food is transported to the valleculae and collected there until swallow initiation. The respiratory phase pattern has loose temporal couplings with mastication during pre-swallow bolus aggregation: The respiratory airflow could be inspiration, expiration or paused, and frequently multiple respiratory phases during bolus aggregation[18]. However, as oral processing progresses, the respiratory phase correspondingly becomes expiration by the time when swallowing initiates. The expiratory phase duration is significantly prolonged when swallow occurs compared to that without swallowing. Via these conditions, most swallows is prone to initiate during expiration or the following pause in young volunteers regardless of food type or viscosity of two-phase food.

In elderly subjects, with TP0, the swallows significantly more initiated during inspiration than in young subjects, while with the other food types, swallows mostly initiated during expiration in elderly subjects. Eating of food significantly perturbed respiratory rhythm. The respiratory rhythm becomes irregular and increasing respiratory rate[18]. Gross[34] reported that patients with chronic obstructive pulmonary disease (COPD), who had less functional reserve of respiration showed disordered coordination between breathing and swallowing during eating food. Swallowing initiated more during inspiration when the COPD patients ate cookie. Of our elderly subjects, whose average age were over 80 years old, swallowing breathing coordination may decline. The timing of switching the respiratory phases from inspiration to expiration for swallowing would be delayed, and it results in increases swallow initiation during inspiration when thin liquid flows to the piriform sinus. In contrast, when eating thicker two-phase food, because the flow of liquid component to the bottom of piriform sinus was slower than that for TP0, the swallows could be initiated more during expiration. Respiratory phase couplings with swallowing are not the direct airway protective mechanism. Our findings suggest that the switching of the respiratory phase would become dull in very old individuals.

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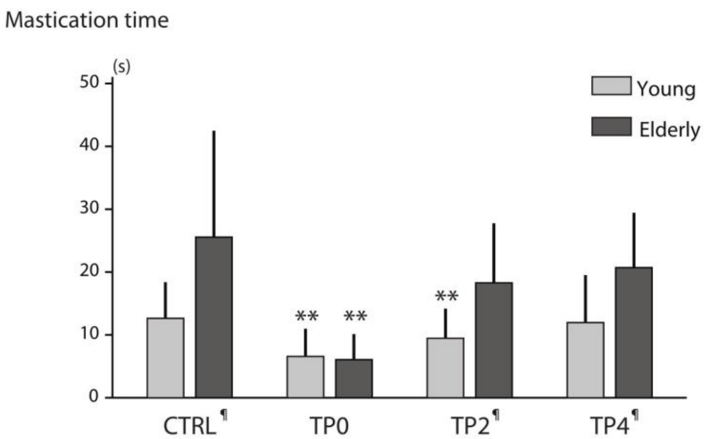

Fig.1-A. Mastication time

Mean masticatory time was significantly longer in the elderly group than in the young group for all foods ($p < 0.01$, respectively) apart from TP0 ($p = 0.64$) .

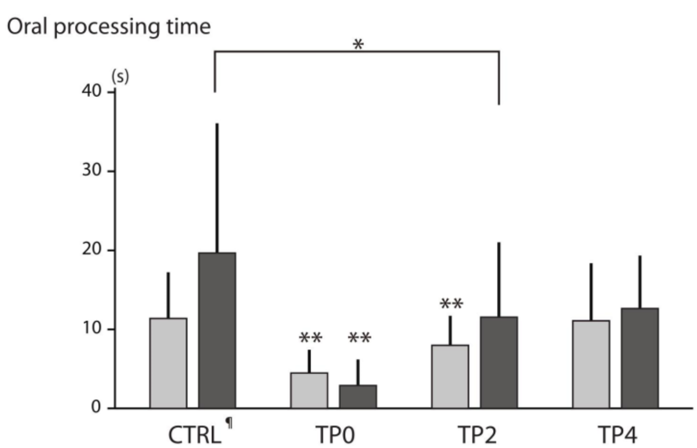

Fig.1-**B**. Oral processing time

In the elderly group, OPT was significantly shorter for TP0 than for the other foods ($p < 0.01$) and was significantly shorter for TP2 than for CTRL ($p < 0.05$).

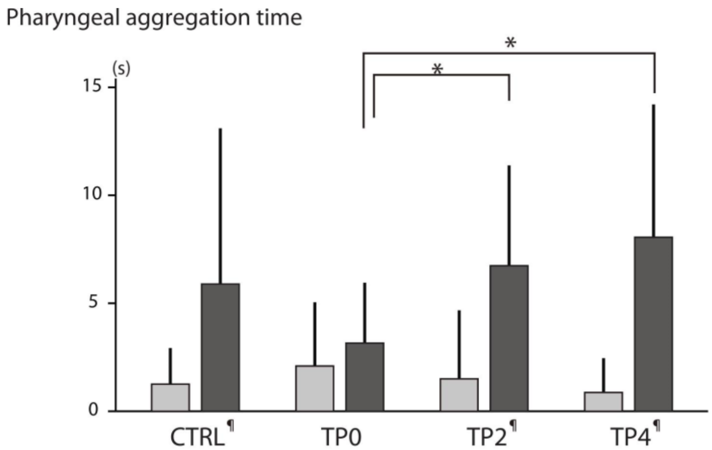

Fig.1-C. Pharyngeal aggregation time

In the elderly group, PAT was shorter for TP0 than for TP2 or TP4 ($p < 0.05$, respectively). Apart from TP0 ($p = 0.18$), PAT was significantly longer in the elderly group than in young group for all samples ($p < 0.05$, respectively) .

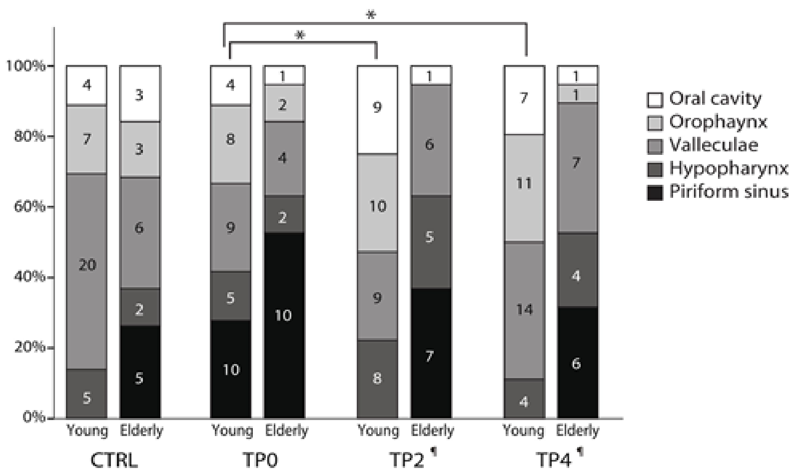

Figure2. The location of the leading edge of the food at swallow initiation.

In old group, there was no significant difference in the location of the leading edge at swallow onset among food types.

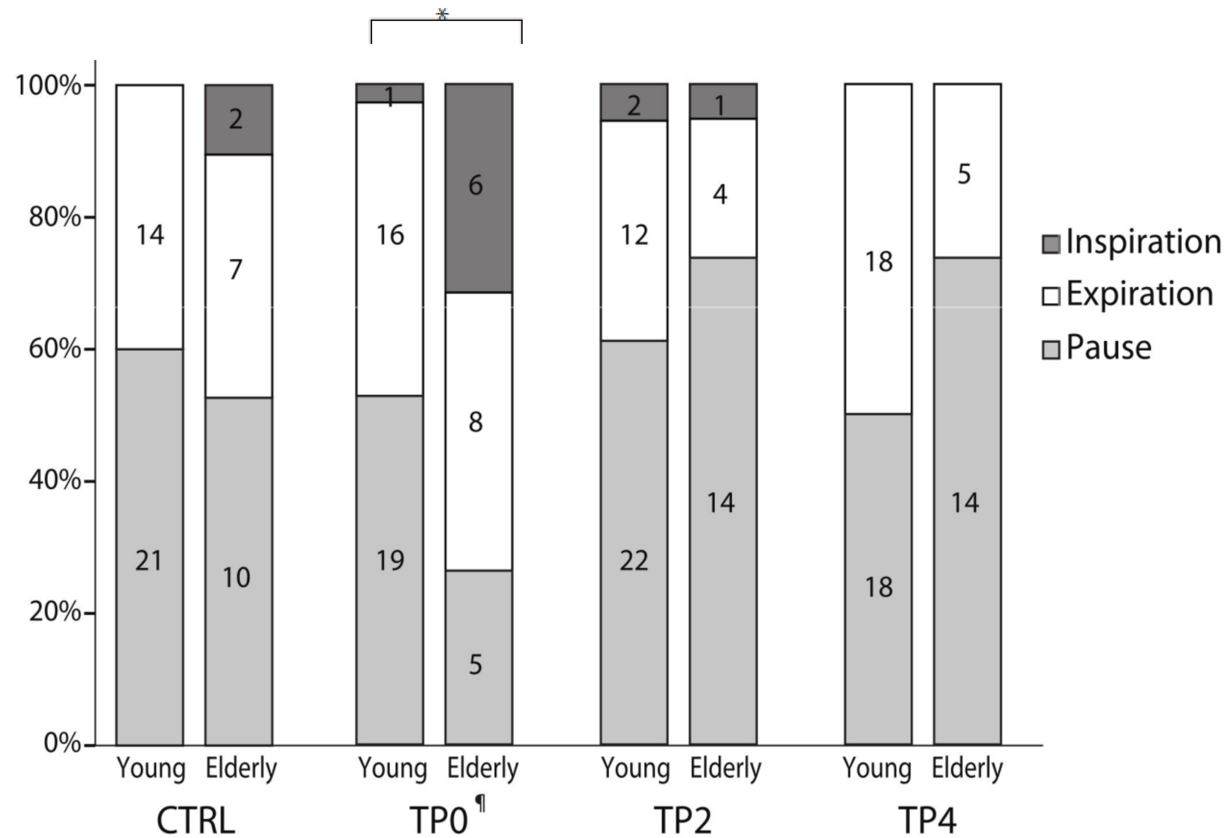

Figure3. The phase of respiration in which the swallow was initiated.

In the elderly group, swallowing was occasionally initiated during inspiration; this was observed in 32% (6/19) of TP0 sequences, which was significantly more frequent than in the young group ($p < 0.01$) .