Purpose: The Videofluorographic Swallowing Study (VFSS) has become the routine method for assessing swallowing dysfunction and accordingly, much research has been conducted on this procedure. However, due to a lack of standardization of the method of analysis of VFSS, it is often difficult to compare the results of such studies. Therefore, we conducted a comparative study of VFSS's spatial measurement using different standard planes used in the past study and Camper’s plane and examined which plane was the most preferable.

Method: VFSS was performed on 20 healthy young volunteers (26.9 ± 3 years) and 9 healthy elderly (77.3 ± 3 years). Each subject swallowed 4ml of thin liquid barium. We measured hyoid displacement and opening of the upper esophageal sphincter (UES) by using four different standard planes.

Results: In the young group, the correlation between anterior hyoid displacement and UES opening was significant in all standard planes. In the elderly group, the correlation between anterior hyoid displacement and UES opening was significant only in Camper’s plane. Moreover, this plane is hard to be affected by morphological change as ageing.

Conclusions: Camper’s plane was found to be as the most preferable plane for analyzing swallowing function.

Key words: swallowing, standard plane, videofluorography, Camper’s plane, dysphagia.

Introduction

The Videofluoroscopic Swallowing Study (VFSS) has become the standard method for evaluating swallowing dysfunction as it allows an examination of both oral and pharyngeal function. To date, numerous clinical studies and researches using VFSS to examine swallowing function have been reported. These studies can be divided into two types of analysis of the swallowing process: temporal and spatial. The results of temporal analyses are readily comparable, relying as they do on the same mode of time-based measurement. However, the results of the spatially-based studies are more difficult to compare because the ‘standard’ planes or anatomical reference points used differ among these studies and because some of the planes used are less reliable as standardized anatomical reference points.

In spatial studies, the cervical spine is the most commonly used reference point for the standard plane. Anatomical reference points also used in these studies include the occlusal plane on the upper jaw, Frankfort’s (FH) plane, and SN plane on the neurocranium. The majority of dysphagic patients are elderly and many of them suffer from cerebrovascular and/or other diseases. Approximately 40% of patients who suffer from acute cerebrovascular disease have symptoms of dysphagia. However, in the elderly, diseases of ageing such as a round back, osteo-
phytes\textsuperscript{19} or loss of teeth\textsuperscript{20} mean that the cervical spine or the occlusal plane often cannot provide appropriate reference points. On the other hand, standard planes on neurocranium like FH plane and SN plane are stable anatomical markers that are relatively unchanged by aging\textsuperscript{20}.

If we review the swallowing process, it would seem that a standard plane on the upper jaw is the preferred reference point for a spatial analysis using VFSS. The purpose of swallowing is to send a food bolus from the mouth to the esophagus safely, a process that requires sufficient opening of the upper esophageal sphincter (UES). The UES contracts to stop air from entering the digestive tract during respiration and phonation and to prevent the aspiration of esophageal contents back into the larynx. The sphincter is located on the inlet of the esophagus and normally—except during processes such as swallowing, belching and vomiting—closes the pharyngo-esophageal segment. The cricopharyngeal muscle is attached to the cricoid cartilage and relaxes when swallowing, but does not open automatically\textsuperscript{22}. Instead, successful opening of the UES requires an anterior-superior excursion of the hyoid bone and cricoid cartilage\textsuperscript{23-25}. Especially, forward movement of hyoid bone has been reported to have much relation to opening of UES\textsuperscript{13,26}. And literature reported that 3.5-36.6\% of the patients with dysphagia have UES dysfunction\textsuperscript{27-32} and training of supra-hyoid muscle that pulled hyoid bone improved UES opening of elderly and dysphagic patients\textsuperscript{33-35}. Therefore, we have to have more profound knowledge about the relationship between the displacement of hyoid bone and UES opening. In particular, the relationship between forward displacement of hyoid bone and UES opening is important to know because they highly correlated with each other\textsuperscript{26}. If the standard plane of spatial measurement is to reflect the relationship of these structural movements effectively then a point of reference along the upper jaw would be preferred.

It has been suggested that Camper’s plane\textsuperscript{36}, a line running from the superior border of the tragus to the inferior border of the ala of the nose, might be a preferable standard plane for swallowing analysis. Its anatomical reference points are relatively stable even in the elderly. Given these potential benefits, this study sought to investigate the hypothesis that Camper’s plane is valid when used as a spatial marker in VFSS. We thus designed a comparative study that uses Camper’s plane as well as several standard planes used in previous studies\textsuperscript{10-12}.  

**Material and Methods:**

**Subjects**

Subjects were 20 young and 9 elderly healthy volunteers without any history or symptoms of swallowing difficulty. Young group consisted of 10 females and 10 males, and the average age was 26.9±3.0 (mean±SD) with a range from 23 to 34 years. Elderly group consisted of 3 females and 6 males. And the average age was 77.3±3.4 (mean±SD) with a range from 72 to 81 years. This study was approved by the Ethics Committee of the Tokyo Medical and Dental University Hospital. Informed consent was obtained from each subject before examination.

**Procedure**

Subjects were seated comfortably in a chair as if they were eating at a table. VFSS (Medix-900DR, Hitachi Medical Corp) was performed from a lateral projection to assess the swallowing movement. A radiopaque ball marker made of lead (12.8mm diameter) was attached to the chin of each subject to calibrate the image. Radiopaque disk markers (Gold-Silver-Palladium alloy, 5mm diameter, 1mm thickness) were also attached at the base of the nose and at the inferior margin of the tragus as a reference point for Camper’s plane (Fig 1). A liquid barium was delivered with a 10ml disposable plastic syringe by a single operator and each subject was instructed to hold the bolus in their mouths until given a cue to swallow.  

![Fig. 1. Example of Camper’s plane and the displacement of hyoid bone on the Camper’s plane. A: base of nose, B: inferior margin of tragus

•: The reference point of hyoid bone (the most anterior-superior point on hyoid bone).

△: The position of hyoid bone at rest.

▲: The position of hyoid bone during swallowing reflex.

□: horizontal displacement. □: vertical displacement.](image)
4ml of thin liquid barium sulfate (barium/water 50/50% weight/volume; Barytgen sol, Fushimi Pharmaceutical Co.,Ltd., Kagawa, Japan.) was swallowed by each subject.

Data analysis

The VFSS image was recorded on a digital video recorder (GV-D1000, NTSC, Sony, Japan, 30 frames/s). Immediately after each recording, the VFSS images were captured on a personal computer as AVI format movie files and manipulated for quantitative analysis (Adobe Premiere, Adobe Photoshop, and Adobe Systems. Inc., CA, USA). Spatial measurement was performed to analyze hyoid (Fig 1) and UES opening (Fig 2). Hyoid displacement during swallowing was measured by using four kinds of standard planes, Camper’s plane, C2C4 plane, C2C5 plane, and C3C5 plane (Fig 3). FH plane and occlusal plane were not used in this study because these were approximately parallel to Camper’s plane. And SN plane was not studied also because this plane is generally not included in radiation area when looking at swallowing function. The reference point of hyoid bone was the most anterior-superior point of hyoid bone.

Due to the lack of an obvious anatomical structure, UES opening size was measured via a lateral VFSS view aimed at the narrowest point of opening between C3 and C6 during the moment of maximal distention for the passage of the liquid barium bolus (Fig. 2).

Fig. 3 shows the four kinds of standard planes used in this study. Fig. 3-a shows Camper’s plane. The X axis represents Camper’s plane (the line passing through the marker on the base of the nose and the inferior margin of the tragus), while the Y axis is defined by the line perpendicular to the X axis that intersects it at the marker on the inferior margin of the tragus. Fig. 3-b shows C2C4 plane. The Y axis is defined as the line passing through the inferior margins of C2 and C4 and the X axis represents the line perpendicular to the Y axis that intersects it at the marker on the inferior margin of the tragus. Fig. 3-c shows C2C5 plane. The Y axis here is the line passing through the inferior margins of C2 and C5 while the X axis is defined by the line perpendicular to the Y axis that intersects it at the marker on the inferior margin of the tragus. Fig. 3-d shows C3C5 plane. The Y axis represents the line passing through the inferior margins of C3 and C5 and the X axis is the line perpendicular to the Y axis that intersects it at the marker on the inferior margin of the tragus.

In order to compare measurements from each standard plane, we focused on the relationship between hyoid displacement and UES opening since hyoid excursion is involved with the opening of the UES. The correlation between the anterior-superior displacement of the hyoid as measured against each standard plane and the UES opening size was calculated. Pearson’s correlation coefficients were calculated by using SPSS (SPSS 11.0J, SPSS Japan Inc., Tokyo,
Results

UES opening and hyoid displacement

In the young group, the mean UES opening size was 0.30 ± 0.09 cm when subjects swallowed (Table 1). The anterior displacement of the hyoid was 0.64 ± 0.26 cm on the Camper’s plane, 0.65 ± 0.31 cm on the C2C4 plane, 0.65 ± 0.32 cm on the C2C5 plane, and 0.63 ± 0.32 cm on the C3C5 plane. And all of the correlation between UES opening and anterior hyoid displacement were significant. The superior displacement of the hyoid was 0.18 ± 0.37 cm on the Camper’s plane, 0.45 ± 0.47 cm on C2C4 the plane, 0.38 ± 0.37 cm on C2C5 the plane, and 0.35 ± 0.39 cm on C3C5 the plane. UES opening and superior hyoid displacement correlated negatively, and significantly only in Camper’s plane.

In the elderly group, the mean UES opening size was 0.72 ± 0.17 cm (Table 1). The anterior displacement of the hyoid was 0.97 ± 0.37 cm on the Camper’s plane,
Table 1. The relationship between UES opening size and displacement of hyoid at swallowing on four standard planes.

<table>
<thead>
<tr>
<th>Standard plane</th>
<th>Anterior hyoid displacement (cm)</th>
<th>Superior hyoid displacement (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camper</td>
<td>0.64±0.26**</td>
<td>0.18±0.37*</td>
</tr>
<tr>
<td>C2C4</td>
<td>0.65±0.31**</td>
<td>0.45±0.47</td>
</tr>
<tr>
<td>C2C5</td>
<td>0.65±0.32**</td>
<td>0.38±0.37</td>
</tr>
<tr>
<td>C3C5</td>
<td>0.63±0.32**</td>
<td>0.35±0.39</td>
</tr>
</tbody>
</table>

UES opening (cm) 0.30±0.09

Statistics were based on 20 swallows, 4ml for 20 subjects.

Each structural movement and the relationship between them in the elderly.

<table>
<thead>
<tr>
<th>Standard plane</th>
<th>Anterior hyoid displacement (cm)</th>
<th>Superior hyoid displacement (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camper</td>
<td>0.97±0.37*</td>
<td>0.03±0.66</td>
</tr>
<tr>
<td>C2C4</td>
<td>1.06±0.51</td>
<td>0.25±0.52</td>
</tr>
<tr>
<td>C2C5</td>
<td>1.10±0.52</td>
<td>0.42±0.59</td>
</tr>
<tr>
<td>C3C5</td>
<td>1.06±0.49</td>
<td>0.06±1.00</td>
</tr>
</tbody>
</table>

UES opening (cm) 0.72±0.17

Statistics were based on 9 swallows, 4ml for 9 subjects.

1.06±0.51cm on the C2C4 plane, 1.10±0.52cm on the C2C5 plane, and 1.06±0.49cm on the C3C5 plane. And the correlation between UES opening and anterior hyoid displacement was significant only in Camper’s plane. The superior displacement of the hyoid was 0.03±0.66cm on the Camper’s plane, 0.25±0.52cm on C2C4 the plane, 0.42±0.59cm on C2C5 the plane, and 0.06±1.00cm on C3C5 the plane. UES opening and superior hyoid displacement correlated negatively.

UES opening and anterior hyoid displacement in both groups significantly correlated only in Camper’s plane. However, superior hyoid displacement didn’t represent UES opening. In short, anterior hyoid displacement on Camper’s plane should be measured when the relationship between hyoid displacement and UES opening needs to be investigated.

None of young subject had cervical osteophytes and round back. Two elderly had cervical osteophytes at C4 and C5 region, and four elderly had mild round back.

The angle between each standard plane

In the young group, the angle between X axis on Camper’s plane and Y axis was 100.65°±4.24° on C2C4 plane, 102.40°±7.99° on C2C5 plane, and 102.05°±10.86° on C3C5 plane.

In the elderly group, the angle between X axis on Camper’s plane and Y axis was 106.89°±9.24° on C2C4 plane, 109.67°±11.25° on C2C5 plane, and 110.33°±13.89° on C3C5 plane. In addition, the angle with round back between X axis on Camper’s plane and Y axis was 113.00°±7.7° on C2C4 plane, 117.75°±10.05° on C2C5 plane, and 120.25°±11.87° on C3C5 plane. The angle between X axis on Camper’s plane and Y axis with normal elderly was 107.33°±3.21° on C2C4 plane, 108.33°±3.79° on C2C5 plane, and 109.67°±2.52° on C3C5 plane (Table 2).

Discussion

Past reports using several standard planes

In this study we sought to compare the efficacy and validity of a range of standard planes commonly used for spatial analysis in VFSS. The standard planes used in our study included C2C4 plane, C2C5 plane,
C3C5 plane and Camper’s plane. Our findings showed Camper’s plane was the most reasonable standard plane. However, it is hard to compare our findings to past reports directly as there is a lack of standardization of anatomical reference points used in the spatial analysis of VFSS. While some preference has been shown for using the cervical spine as a standard reference, studies to date have used a variety of measures.

For instance, Hattori\textsuperscript{10} conducted a study examining the influence of wearing complete dentures on swallowing function using the cervical spine (C2, C4) as a standard plane. VFSS was performed on nine healthy edentulous elderly volunteers. This study showed that, during swallowing, the hyoid and larynx moved more in subjects without dentures than in those with dentures. Haishima et al.\textsuperscript{11} compared three types of coordinate planes in order to investigate the growth direction pattern of organs related to swallowing using cephalograms. They resulted C2C5 plane was the best coordinate plane when looking at the growth direction of organs related to swallowing. Furukawa\textsuperscript{12} conducted a study on the laryngeal displacement during deglutition. Forty-eight males ranging in age from 30 to 70 years were analyzed by means of cineradiography. The standardized line passed through the anterosuperior margin of C3 and the anteroinferior margin of C5; the laryngeal displacement was measured both horizontally and vertically. This study indicated that the superior displacement of the larynx during the slow ascending phase (the voluntary stage of deglutition) increased with age.

Ishida et al.\textsuperscript{13} studied hyoid displacement during the swallowing of both chewed solid food and liquid. VFSS was performed on 12 healthy volunteers ranging in age from 20 to 28 years. The standard plane used in this study was the occlusal plane, that is, an anteroposterior (X) axis which passed through the metal markers on the upper canine and posterior molar teeth. The vertical axis was defined by a line perpendicular to the X axis that intersected at the marker on the upper canine. This study found that a superior displacement of the hyoid bone when swallowing was related primarily to events in the oral cavity and secondarily to motions of the jaw and tongue. Yet anterior displacement of the hyoid was also related to pharyngeal processes, especially the opening of the upper esophageal sphincter.

Finally, Mays et al.\textsuperscript{14} investigated the relationship between the Frankfort Mandibular Plane Angle (FMA) and hyoid bone displacement in swallowing. The FMA is the angle between Frankfort’s plane and the mandibular plane. VFSS was performed on 12 healthy subjects in order to examine forward and upward displacement of the hyoid bone. Their results indicated that the greater the FMA, the smaller the horizontal displacement of the hyoid.

To date research using VFSS has tended to adopt a variety of different standard planes when adopting a spatial approach to the analysis of swallowing. This lack of consistency means that it is hard to compare the results of these studies. Furthermore, the majority of subjects involved in these studies are healthy adults. Accordingly, an area that remains unexamined in VFSS studies is whether the standard planes commonly adopted are useful for measuring swallowing function in elderly patients.

**Hyoid displacement and UES opening**

There have been several reports about the relationship between hyoid displacement and UES opening. And they looked into the anterior hyoid displacement, but not into superior hyoid displacement\textsuperscript{13,26,39}. In our study, anterior hyoid displacement had relation to UES opening, however, superior hyoid displacement didn’t contribute to UES opening. This is because of the direction and the order of the displacement of each structure when swallowing. During swallowing reflex, at first hyoid bone moves superiorly, and immediately after that, larynx moves superiorly. And then, hyoid bone moves anteriorly, and immediately after that, UES opens\textsuperscript{13,24}. Therefore, anterior hyoid displacement had relation to UES opening, and superior hyoid displacement had relation to laryngeal movement\textsuperscript{3}. In brief, anterior component of hyoid displacement on valid

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**Table 2.** The angle between X axis on Camper’s plane and Y axis on the other planes.

<table>
<thead>
<tr>
<th></th>
<th>Y axis on C2C4 plane (degree)</th>
<th>Y axis on C2C5 plane (degree)</th>
<th>Y axis on C3C5 plane (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young group (n=20)</td>
<td>100.65±8.44</td>
<td>102.40±7.99</td>
<td>102.05±10.86</td>
</tr>
<tr>
<td>Elderly group (n=9)</td>
<td>106.89±9.24</td>
<td>109.67±11.25</td>
<td>110.33±13.89</td>
</tr>
<tr>
<td>normal (n=3)</td>
<td>107.33±3.21</td>
<td>108.33±3.79</td>
<td>109.67±2.52</td>
</tr>
<tr>
<td>with round back (n=4)</td>
<td>113.00±7.70</td>
<td>117.75±10.05</td>
<td>120.25±11.87</td>
</tr>
<tr>
<td>with cervical osteophytes (n=2)</td>
<td>94.00±1.41</td>
<td>95.50±3.54</td>
<td>91.50±2.12</td>
</tr>
</tbody>
</table>
standard plane should be looked at when the relationship between hyoid displacement and UES opening needs to be studied.

A possible standard plane for the elderly

For instance, cervical osteophytes and other hypertrophic changes of the cervical spine are found in approximately 20-30% of the elderly population\(^\text{19}\). Furthermore, a number of studies have found that patients with swallowing difficulties are more likely to have cervical osteophytes. Granville et al.\(^\text{40}\) studied the prevalence of cervical osteophytes and the relationship between osteophytes and swallowing function. Results showed that cervical osteophytes were prevalent in about 11% of dysphagic patients over 60 years-of-age with the most common region for osteophytes being the C5-C6 (40%), C4-C5 (23%), and C2-C3 (14%) sections of the spine.

Koyama et al.\(^\text{41}\) reported the influence of osteophytes on swallowing and found that large osteophytes interfered with the downward tilt of the epiglottis and the opening of the cricopharyngeal sphincter. In contrast to Granville’s study, the area most commonly affected by osteophytes in the Japanese subjects in Koyama’s study was C3-C4-C5 and C4-C5. These findings reflect racial differences in the range of neck movement. In Asian adults the range of neck movement is larger at the C4-C5 region than in Westerners, therefore, in Asian subjects, this region is more prone to developing osteophytes\(^\text{42}\). Strasser et al.\(^\text{43}\) reported the relationship between the size of cervical osteophytes and the frequency of aspiration. This study showed that cervical osteophytes larger than 10mm can be a cause of aspiration. Another report\(^\text{44}\) found that dysphagic patients who had cervical osteophytes larger than 19mm were more likely to be aspirators. In our study, two elderly out of 9 had cervical osteophytes at C4 and C5. Their osteophytes were not too large to interfere the epiglottis downward movement during swallowing, but rotated the coordinates that had reference point on cervical spine toward dorsum (Table 2). Therefore, anterior hyoid displacement and UES opening might not be correlated well in the elderly group when using cervical spine as reference point. Anterior hyoid displacement might be underestimated in the subject with cervical osteophytes because of the rotation of the coordinates.

Another disease of ageing which may interfere with the validity of commonly used standard planes such as the cervical plane is increasing curvature of the thoracic spine, or what is commonly referred to as ‘round back’\(^\text{18}\). Tsuritani et al.\(^\text{45}\), for instance, have reported that round back is associated with fractures of the cervical spine caused by osteoporosis. In this study, 4 elderly out of 9 had mild round back. Standard plane of the subject with round back was bent forward (Table 2). This might be another reason of poor correlation between anterior hyoid displacement and UES opening in elderly group when using cervical spine as reference point. This forward-bend coordinates might underestimate anterior hyoid displacement.

On the other hand, when using Camper’s plane as a standard, anterior hyoid displacement and UES opening correlated well in both of young group and elderly group (Table 1). Hyoid bone is hanging down from neurocranium and mandible. Furthermore, jaw closes when swallowing\(^\text{46}\). According to them, coordinates didn’t rotate for hyoid bone when using Camper’s plane as a standard. This is the advantage when looking at the hyoid bone displacement of elderly. Moreover, losing teeth is very common in elderly\(^\text{20}\).

In summary, the fact that many of the standard anatomical reference points used in swallowing studies may be affected by disease in elderly patients. Therefore, the need for a standard plane which is relatively unaffected by ageing processes is strongly suggested.

The usefulness of Camper’s plane

This study used Camper’s plane, a line that runs along the upper jaw approximating the occlusal plane and passing through the inferior margin of the tragus and the base of the nose, as one of the anatomical markers for spatial analysis. This plane is always used as a reference plane when making upper full denture clinically, but we were motivated to use it as standard plane because Sakaguchi et al.\(^\text{47}\) reported that Camper’s plane coordinates as the organic standard plane to enable easy evaluation of the movements of perioral soft tissue. Because the component of movements that is specific to perioral soft tissue during mastication is equal repetition spatially and stable movement temporally and useful for evaluation of the smoothness of masticatory movement.

We have noted a number of reasons why Camper’s plane is preferable to other standard planes.

Firstly and most importantly, the results of our study suggest that Camper’s plane is a highly reliable reference point for measuring swallowing function compared with the other standard planes used in our study. Indeed, anterior displacement of the hyoid bone and UES opening correlated significantly in both of the
young and the elderly group when using Camper’s plane as a standard (Table 1).

Secondly, Camper’s plane is a reliable standard plane in both of the young and the elderly as all its reference points lie on the upper jaw, and are therefore unaffected by the shape of the cervical spine, cervical osteophytes or loss of teeth.

Lastly, we like to add another advantage. Camper’s plane enables clinicians and researchers to minimize unnecessary radiation exposure during VFSS. While FH plane and SN plane also have reference points on the upper jaw, these planes require wider radiation exposure than Camper’s plane because their reference points include Po (Porion) and Or (Orbitale), and S (Sella turcica) and N (Nasion) respectively.

In light of this, we surmised that Camper’s plane is the preferable standard plane for swallowing studies, not only in the elderly but in the patient population more generally. Standardization of the standard plane would allow comparison among studies and enable researchers to examine the impact of factors such as age and cervical deformation on swallowing. Furthermore, regulation and standardization of the irradiation area would not only lessen exposure but would also contribute to a greater ability to make generalizations across studies.

Conclusion

This study sought to compare the validity of several standard planes in assessing the spatial measurement of swallowing using VFSS. The results indicate that Camper’s plane is preferable as an anatomical reference point as the correlation between UES opening and anterior hyoid displacement was strongest when using this plane as a standard. Furthermore, unlike other standard planes, Camper’s plane is largely unaffected by specific morphological changes caused by aging, and is also safer due to its narrower irradiation area. As a standard, the Camper’s plane is preferable for the videofluoroscopic kinesiologic analysis of swallowing function.

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