Original

Assessment of Feeding and Swallowing by Cone Beam Computed Tomography

—Changes in Oropharyngeal Airway Shape with Aging—

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Abstract: With super aged society in Japan, the death rate from choking due to blockage of the oropharynx has increased; it is now greater than that from traffic accidents and it is believed that this rate will continue to increase. The shape and function of the oropharyngeal crossing with the respiratory tract are most influential in ensuring that food is carried from the oral cavity to the pharynx and the esophagus. We sought to clarify the changes in the shape and features of the oropharyngeal airway from teenagers to those in their 70 s. A total of 57 patients were grouped by age (teenagers, 20s, 30s, 40s, 50s, 60s and 70s), and all underwent cone beam computed tomography (CBCT) to measure the oropharynx volume, height, cross-sectional area, and length of the superior and inferior extremities. Kruskal-Wallis analysis indicated that the volume and height of the oropharynx did no significant difference among age groups, but there was a different tendency when cross-sectional areas of the superior and inferior extremities were compared between younger and older patients. Further, the shape of the inferior extremity was also different features between younger and older patients. In humans, the oropharyngeal airway plays an important role in carrying food through the esophagus and facilitating phonation. Ideally, it is important for this airway to maintain a constant volume and height. Recently, there has been an increase in the incidence of oropharyngeal airway blockage accidents among the elderly. Declines in feeding and swallowing functions and changes in the form of the oropharynx are major factors in these accidents.

Key words: oropharynx airway, aging change, shape feature, cone beam computed tomography.

With super aged society in Japan, the number of accidents stemming from blockage of the oropharyngeal airway has increased. It is thought that this increase may be related to changes in the oropharynx with aging and hence the rate of such accidents is expected to continue to increase in future.

Accidents caused by blockage of the oropharynx airway are frequent among the very young and the very old. During early childhood, oral morphology and feeding and swallowing functions are still undeveloped and functional changes take place as the child develops.[1,2] In individuals older than 65 years, drooping of the larynx and a dry mouth are common changes associated with aging, and these are also thought to be responsible for most oropharyngeal airway blockage accidents.[3~8] The shape and function of the oropharyngeal crossing with the respiratory tract have a strong influence on the passage of food as it moves from the oral cavity to the pharynx and into the esophagus. The oropharyngeal airway plays an important role in feeding and swallowing. We examined the characteristics and physical changes of the oropharyngeal airway from the teenagers to those in their 70s. Changes to the oropharynx airway volume in children are known to

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increase along with Hellman's Dental Age.[9〜12] Studies of the function of the oropharyngeal airway are important to promote optimal feeding and swallowing, and to preventing choking accidents caused by blockage of the oropharyngeal airway. Our goal was to identify changes to the shape of the oropharynx that are related to aging.

Materials and Methods

This study included all patients who underwent dental and cone beam computed tomography (CBCT) examinations from April 2006 to December 2009 at the Showa University Dental Hospital and Kanomi Dental Clinic. The study was certified by the Showa University Research Ethics Committee (No. 2008-19). Patients with tumors or inflammatory symptoms at the throat were excluded. We included patients whose basis physique was within ±1 standard deviation (SD) in the age range listed by the National Health and Nutritive Investigation of 2006.[13]

We segregated 57 patients (age, 12–76 years) corresponding to basis physique among the 93 patients. The patients were grouped according to age teenagers, 20s, 30s, 40s, 50s, 60s and 70s (Table 1).

All patients underwent CBCT (CB MercuRay, Hitachi Medical, Tokyo, Japan) with a three-dimensional (3D) modeling system[9,10,14〜17] to obtain precise measurements of the feeding and swallowing organs.[18] This system is useful for diagnosis and treatment of disorders of the maxillofacial area.[19] The measurement methods using the CBCT and 3D modeling system are shown in Fig. 1. All measurements were performed according to Yamanaka 2010.[9]

Table 1 Number of participants by age group.

Age Group	Number of Participants Total
Teenagers	6
20s	15
30s	12
40s	5
50s	4
60s [≧65]	8 [5]
70s	7
Totals	57

1. Cone Beam Computed Tomography (CBCT)

The CBCT scanner features a 12-inch image intensifier and a cone beam X-ray source. It has 3 fields of view (FOV); F, P, and I-mode. We used P-mode (FOV=150 mm). It consists of a 512×512×512 isotropic voxel matrix for CT imaging. The slice thickness for the panoramic mode was 0.3 mm, and the resultant isotropic voxel dimension was 0.3×0.3×0.3 mm. The exposure conditions were set as 100 kV, 10 mA, 9.6 s, and 360° rotation.

Each volunteer sat in the CBCT seat and a small strap was placed around the head in order to prevent motion during the 10-s scanning period. We instructed the participants to bite but not swallow and not to move their head and neck.[20〜22] We included the clearest images and excluded those in which the oropharynx was not clear.

2. Image processing

The selected images were saved in the Digital Imaging and Communication in Medicine (DICOM) format for CT imaging data, which is a global standard for medical imaging and communication. The images were used to create the 3D modeling system using image-processing software (Mimics and Magics, Materialise, Belgium). The 3D rendered images were then used for further measurements (Fig. 1).

3. Three-dimensional image structuring

The 3D modeling system software Mimics was used to estimate the 3D structure of the participants' oropharynx airways and cranial bones. The software was used to establish basic planes for the cranial bones with thresholds in the 3D structure ranging from –1024 to –700 for the oropharynx and from 500 to 3071 for the cranial bone.

4. Specification of the oropharyngeal airway

As noted, we obtained 3D structural models using the Mimics software. The superior and inferior extremity settings differed for each subject, but we used a basic plane for all the oropharynx airway models and it was in the same range. In this situation, we used Magics software.

The basic plane used was the Frankfort horizontal

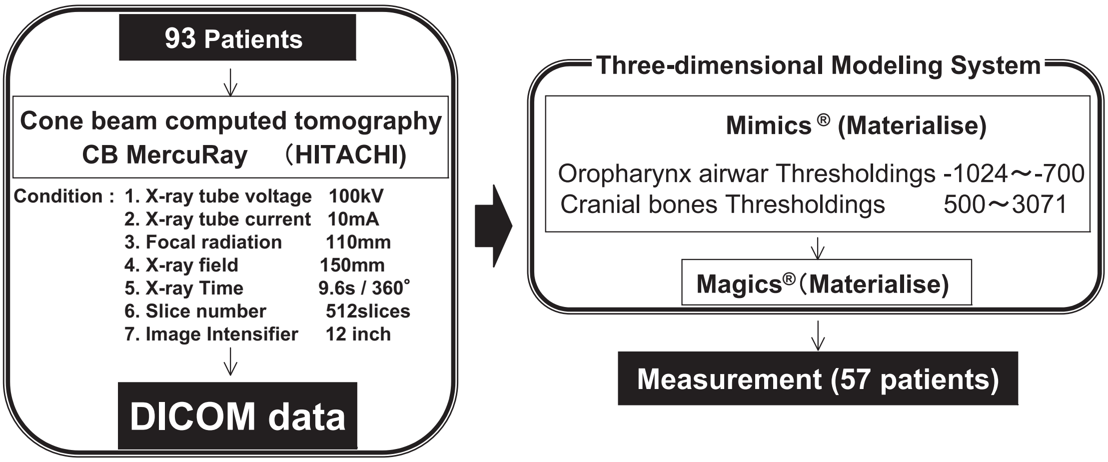

Fig. 1 Measurement method of the oropharynx airway using cone beam computed tomography (CB Mercuray), Computed tomography (CT) and a three-dimensional modeling system.[9]

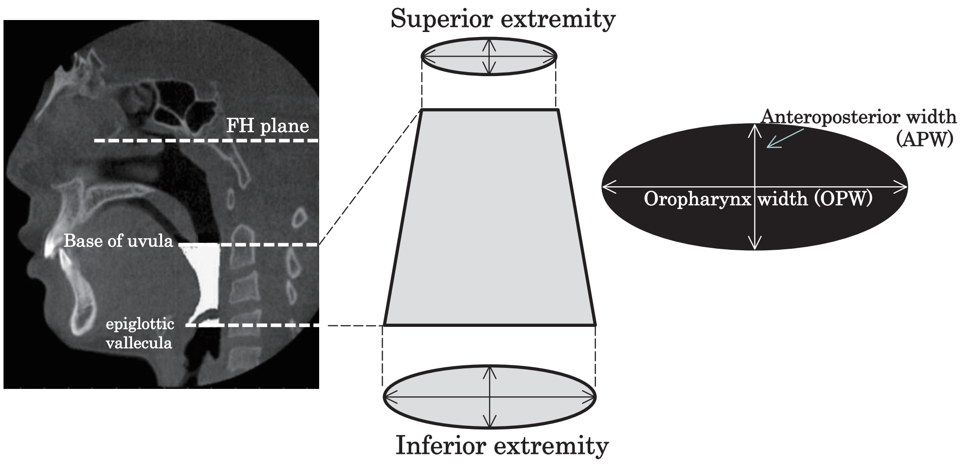

Fig. 2 Schema of three-dimensional reconstruction of the oropharyngeal airway. The upper plane of the oropharyngeal airway is base of the uvula and the lower plane is the deepest area of the epiglottic vallecula.

Table 2 Oropharyngeal airway measurement parameters.

Volume (mm^3)
Height (mm) From superior extremity to inferior extremity
Cross-sectional area (mm^2) i) Superior extremity ii) Inferior extremity
Superior extremity length (mm) i) Oropharynx width (OPW) ii) Anteroposterior width (APW)
Inferior extremity length (mm) i) Oropharynx width (OPW) ii) Anteroposterior width (APW)
Ratio of the Oropharynx width to the Anteroposterior width (OPW/APW) i) Superior extremity ii) Inferior extremity

plane (FH plane). This plane is used in orthodontics and is created by connecting 3 points.[23～25] The upper plane of the oropharyngeal airway is base of the uvula. The lower plane of the oropharyngeal airway is the deepest area of the epiglottic vallecula. We constructed a 3D figure of the oropharynx airway, which is shown in Fig. 2.

5. Measurement and statistical analysis

The measurement parameters for the Magics 3D modeling system software are shown in Table 2.

The Kruskal-Wallis test was applied with significance set at $p<0.01$, and we used SPSS 19.0 software (SPSS Inc.) for statistical processing.

Results

1. Volume measurement

The volume of the oropharyngeal airway of all patients was measured. The results are shown in Table 3 and Fig. 3. Kruskal-Wallis analysis indicated that the volume was no significant difference among the different age groups.

2. Height measurement

The height of the oropharyngeal airway was measured from the superior extremity to the inferior extremity. The results are shown in Table 3 and Fig. 4. Kruskal-Wallis analysis confirmed that the height was no significant difference among the different age groups. The mean height was 33.1± 4.9 mm.

3. Cross-sectional area

The measurements of the cross-sectional area of the oropharyngeal airway are shown in Table 3 and are compared in Fig. 5. Kruskal-Wallis analysis indicated that the cross-sectional area was no significant difference among the different age groups.

1) Superior extremity

Subjects in the teenagers group had the smallest cross-sectional area of the superior extremity (182.89±71.92 mm²), and the size of this area gradually increased with

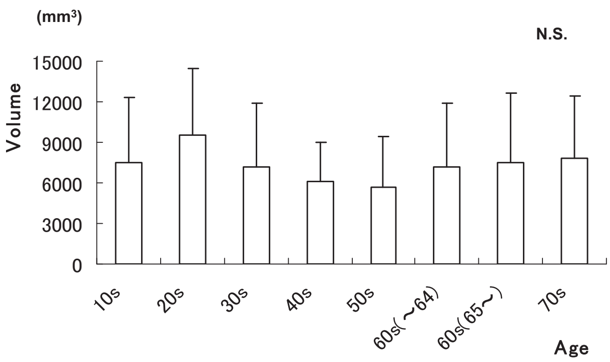

Fig. 3 Averaged volume of the oropharyngeal airway. N.S. : Not significant.

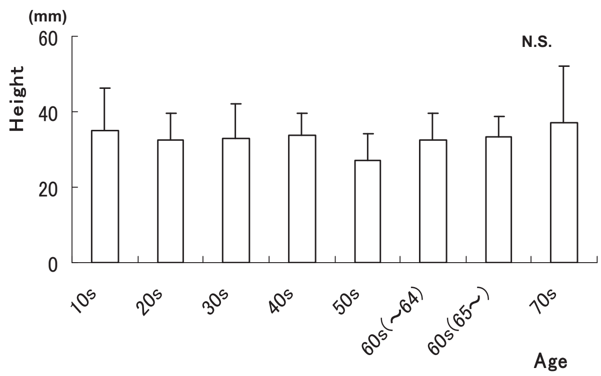

Fig. 4 Height of the oropharyngeal airway. N.S. : Not significant.

Table 3 Oropharyngeal airway dimensions by age group.

Age		Teenagers	20s	30s	40s	50s	60s (<65)	60s (≧65)	70s
Volume (mm³)		7503.92± 1360.47	9532.27± 2440.20	7208.68± 1281.11	6088.98± 833.00	5685.34± 940.58	7200.67± 1380.10	7527.76± 1369.41	7868.36± 1516.19
Height (mm)	From superior extremity to inferior extremity	34.89±4.98	32.39±3.21	32.96±4.06	33.85±6.25	26.93±3.41	32.50±4.50	33.47±6.36	37.10±6.65
Cross-sectional area (mm²)	i) Superior extremity	182.89± 71.92	187.06± 44.59	180.96± 56.02	190.28± 40.28	211.48± 46.90	219.84± 49.60	223.85± 76.42	227.91± 32.96
	ii) Inferior extremity	253.54± 81.56	263.11± 68.69	252.30± 70.96	251.35± 64.35	225.00± 79.32	180.00± 54.96	156.82± 46.78	144.40± 33.45
Superior extremity length (mm)	i) OPW	24.63±3.88	32.71±3.01	25.05±2.70	25.73±3.30	24.10±4.83	24.2±6.2	24.23±3.16	24.80±2.11
	ii) APW	10.88±3.76	14.80±1.73	10.78±2.55	10.50±2.78	9.27±4.53	9.1±5.7	9.10±1.89	9.12±2.58
Inferior extremity length (mm)	i) OPW	23.01±5.60	28.21±3.48	24.39±3.34	23.14±3.28	27.33±5.99	24.7±2.5	25.70±4.13	25.00±5.51
	ii) APW	7.91±2.01	9.00±3.66	8.31±2.32	7.92±1.77	9.47±1.99	8.6±1.4	10.49±3.72	10.78±2.13
Ratio of OPW/APW	i) Superior extremity	2.26	2.21	2.32	2.45	2.60	2.65	2.66	2.72
	ii) Inferior extremity	2.91	3.13	2.94	2.92	2.89	2.88	2.45	2.32

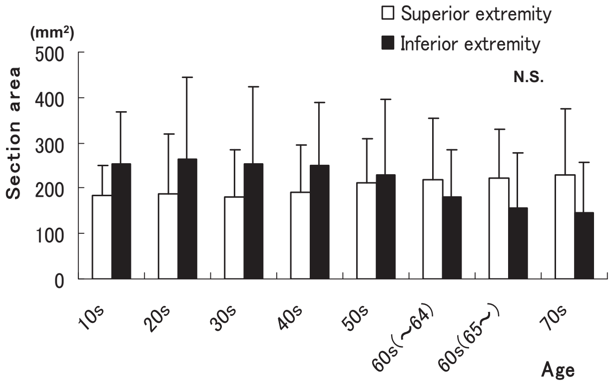

Fig. 5 Cross-sectional area of the oropharyngeal airway. N.S. : Not significant.

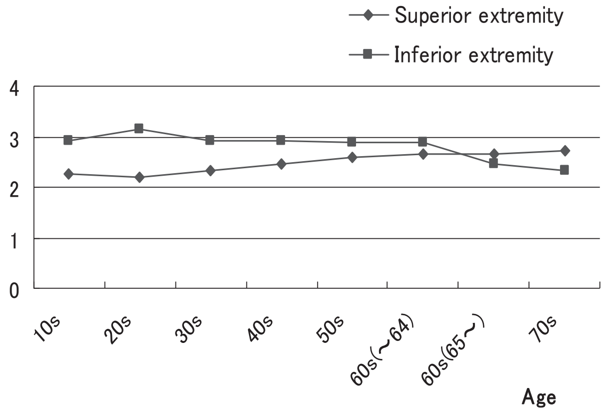

Fig. 6 Ratio of the oropharynx width to the Anteroposterior width (OPW/APW).

age. It was largest among subjects in their 70 s (227.91± 32.96 mm^2).

2) Inferior extremity

The teenage group also had the largest cross-sectional area of the inferior extremity (253.54±81.56 mm^2). This gradually decreased in size with advancing age; it was smallest among subjects in their 70s (144.40±33.45 mm^2).

4. Ratio of the oropharynx width to the anteroposterior width of the superior and inferior extremities (OPW/APW)

The ratio of the superior and inferior extremities is shown in Table 3 and compared in Fig. 6. Differences in the shape of the inferior extremity were observed between younger individuals and those over age 65.

Discussion

The oropharynx plays an important role in feeding and swallowing. We evaluated the characteristics, aging changes and functional changes to the oropharyngeal airway from teenagers to those in their 70s.

Volume and height of the oropharynx

Comparison of the volume of the oropharyngeal airway among the age groups by Kruskal-Wallis analysis was no significant difference. We also measured the height of the oropharyngeal airway from the superior extremity to the inferior extremity. These measurements showed that the height of the oropharyngeal airway was similar among teenagers and adults in their 20s and 30s. In early childhood, the oral morphology and feeding and swallowing functions are still maturing and functional changes also take place. Teenagers also undergo changes in oral morphology along with physical growth during the development of secondary sex characteristics and physical changes such as alterations i.e., voice changes and tooth eruption.[9~12] We therefore speculated that there could be a relationship between increasing height, changes to oral morphology, and the development of secondary sex characteristics. On the other hand, drooping of the larynx is thought to be common changes associated with aging in individuals older than 65 years.[3~8] Thus, we anticipated that the shape of the oropharynx would change with age.

Cross-sectional area of the oropharynx

The cross-sectional area of the oropharynx was measured across all age groups. The cross-sectional area of the superior extremity was smaller among younger (those in their teens and 20s) compared with elderly (in their 60s and 70s) subjects. In contrast, the inferior extremity was larger in younger compared with older subjects. Thus, the cross-sectional area increases from the superior to the inferior extremity in younger individuals, but decreases in older individuals. It shows the morphorogic changes when comparing the superior and inferior extremities.

In elderly individuals, a food bolus may easily pass through the larger cross-sectional area of the superior extremity of the oropharynx, but it could then become trapped by the narrower cross-sectional area of the inferior extremity. Thus, the narrowing of the inferior extremity form with age may increase the likelihood of suffocation by choking among the elderly.

The ratio of the oropharynx width to the antero-posterior width (OPW/APW)

The lengths of the superior and inferior extremities of the oropharyngeal airways were measured and the ratio of the OPW and APW compared. Among younger subjects, the superior extremity was smaller than the inferior extremity. On the other hand, among those older than 65 years, the superior extremity was larger than the inferior extremity. These findings indicate that the shape of the inferior extremity differs between younger individuals and those older than 65. Aging has also previously been associated with drooping of the larynx.[8] Thus, changes in the shape of the entire oropharynx might increase the risk of choking and suffocation among the elderly.

In addition to drooping of the larynx, it has also been suggested that aging increases the volume of the oropharynx, but that this does not increase the rate of chocking or suffocation.[3~8] In the present study, we did not find significant changes to the height of the oropharyngeal airway with age.

Taylor indicated that in general, two periods of accelerated change (6 to 9 years and 12 to 15 years) and two periods of quiescence (9 to 12 years and 15 to 18 years) were identified for the oropharynx soft tissues.[2] Yamanaka indicated that it is clear that the oropharynx airway increases significantly, and the patterns of increase vary until completion of second molar eruption suggesting a relationship with the stage of tooth eruption from periods IIC to IVA.[9] These studies show that the oropharynx was formed at the middle of teenage. And the oropharynx plays an important role in the transport of food to the esophagus and in phonation. The middle of teenage corresponded approximately to the development of secondary sexual characteristics. And these periods was recognized as an individual (ex; face, voice, and so on), too. Thus we thought that the height of the oropharynx is important for the maintenance of a constant in these functions. In future studies we hope to examine the shape and function of the upper pharynx and lower pharynx in more detail.

We also speculated that if the ratio reverses after the age of 65, then the shape of the oropharyngeal airway would appear to be thinning in a reverse conical form, which would also be a factor in choking and suffocation. The changes in form from the oropharynx to below the pharynx with increasing age seem to depend mainly on narrowing of the cross-sectional area. Therefore, we believe that the loss of swallowing function and the increase in choking and suffocation risk with age arises in the zone from the oropharynx to below the pharynx.

Conclusions and Limitations

In recent years the number of oropharynx airway blockage accidents has increased among the elderly. The major factors responsible for these accidents include declines in feeding and swallowing functions as well as changes to the form of the middle pharynx.

In the present study we analyzed the data without considering the effects of individual height and weight, but these factors will need to be considered in future studies.

Our aim is to use the technique of measuring the oropharynx to ensure safe food consumption among individuals requiring rehabilitation.

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