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Key Words: elderly, maxillary sinus volume, aging, sex difference, number of molars remaining, CT imagery

Summary: In this paper, using full-body CT images of elderly and advanced elderly Japanese cadavers, we measure maxillary and other paranasal sinus volumes in order to examine the effects of age, sex, presence or absence of maxillary molars, and other factors on changes to maxillary sinus volume. The research subjects consisted of 77 of 95 cadavers donated to the Kanagawa Dental University between 2012 and 2014, which average age was 82.6 ± 10 years (33 were male, average age 79.3 ± 8.3 years, and 44 were female, average age 85.1 ± 11.7 years). Sinus volume was measured from full-body CT images on the horizontal plane and computed using the 3D volume rendering software. The average maxillary sinus volume was 31.3 ± 13.2 cm3 (average value ± one standard deviation; hereafter the same), with values of 32.9 ± 13.2 cm3 (6.7 cm^3 ~ 55.7 cm^3) for males and 29.6 ± 12.5 cm^3 (5.5 cm^3 ~ 52.9 cm^3) for females. In this report, we studied the effects of aging, sex, and state of remaining molars on changes to paranasal sinus volume in the maxillary sinus. These results give additional information about maxillary sinus volume of Japanese oldest-old peoples.

Introduction

Japan is currently faced with an aging society, with an increasing number of advanced elderly people aged 85 years and older. In the field of implant therapy involving the maxillary sinus, longer patient lifespans and improved prognoses for implant therapy have meant that implants performed in the prime of life increasingly remain in use for as long as 30 to 40 years. In the future, multifaceted anatomical studies of maxillary sinuses in the elderly will be required in order to determine how long-term use of implants affect and are affected by age-related changes to the anatomical structure of the maxillary sinus.

The maxillary sinus is the first of the paranasal sinuses to develop, at week 10 of fetal development (Shea 1936; Kubo 1959). The pneumatization process of the maxillary sinus is thought to occur as a result of osteoclastic bone loss absorption in the osteoid layer of the inferior wall of the cortical bone in the maxillary sinus's interior (Wehrbein 1992). Volume increases until eruption of the third molar is complete (Tomas 1989; Ritter 1978; Uemura 1974), then decreases with age after 20 years old (Ariji 1994; Ide 1997). It has been reported that maxillary volume is greater in males than in females (Nogi 2002) and that it correlates to tooth loss, height, and weight (Emirzeoglu 2007). This indicates that maxillary sinus volume is influenced by such factors as age, sex, tooth loss, height, and weight, however there is insufficient literature to show how these factors relate to maxillary sinus volume in the elderly. In this paper, using full-body CT images of elderly and advanced elderly Japanese cadavers, we measure maxillary and other paranasal sinus volumes in order to examine the effects of age, sex, presence or absence of maxillary molars, and other factors on changes to maxillary sinus volume.

Materials and methods

The research subjects consisted of 77 of 95 cadavers donated to the Kanagawa Dental University between 2012 and 2014, which displayed no signs of surgical

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Table 1. Average age was 82.6 ± 10 years. Of the subjects, 33 were male, age 79.3 ± 8.3 years, and 44 were female, average age 85.1 ± 11.7 years.

	male	female	total
69 or younger	5	3	8
70s	7	11	18
80s	20	14	34
90s	1	10	11
100 or older	0	6	6
	33	44	77

scarring of the paranasal sinuses or inflammation of the nasal or paranasal sinus membrane and had discernable teeth. Average age was 82.6 ± 10 years. Of the subjects, 33 were male, average age 79.3 ± 8.3 years, and 44 were female, average age 85.1 ± 11.7 years

(Table 1). Grouped by age, 8 subjects were aged 69 or younger, 18 were in their 70s, 34 in their 80s, 11 in their 90s, and 6 were aged 100 or older, with the majority in their 80s or above. Differentiated by sex, there was a roughly equal distribution of male and female subjects in their 80s and below, but in subjects 90 years and above the male-female distribution changed significantly, with one male subject and 16 female subjects. The imaging device used was a multi-slice x-ray scanner (Asteion Super 4 Toshiba Medical Systems Co., Tochigi, Japan). CT scanning was performed prior to embalming. Scanning was performed in 1mm slices at 120kV, 225mAs, with the head positioned so that the x-ray exposure axis was parallel to the Frankfurt horizontal plane. All measurements were performed by two instructors of anatomy (dentists). All CT image measurements and analyses were performed using a 3D region growing algorithm on Osirix imaging software (v6.0.2 Pixmeo SARL, Geneva, Switzerland). Sinus volume was measured from CT images on the horizontal plane and computed using the 3D volume rendering software of the same imaging software. In all, four regions were measured, consisting of the three sinus regions including the maxillary sinus (bilateral and unilateral), the frontal sinus, and the sphenoidal sinus; and the paranasal, nasal cavity, and nasal pharynx region, which consists of all paranasal sinuses, the nasal cavity, and the nasal pharynx combined (Fig.1). The remaining teeth of the upper and lower jaw were identified and counted using 3D volume rendering on Osirix imaging software (N = 77). Femoral length was measured as the maximum length from the most superior point of the greater trochanter to the lateral joint fissure gap of the knee on the left femur. The femoral length indices were calculated as the ratios of the maxillary sinus volume (M), frontal sinus volume (Fro), sphenoidal sinus volume (Sphe), and paranasal, nasal cavity, and nasal pharynx volume (Para) to the femoral length denominator (F), respectively referred to as the

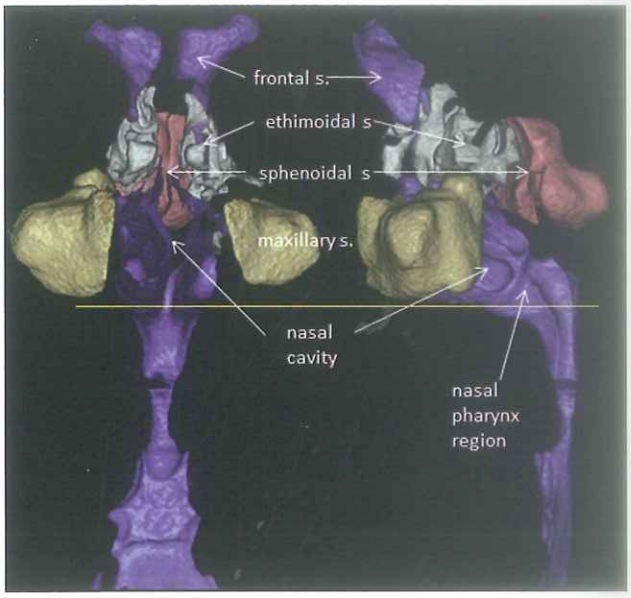

Fig. 1. In all, four regions were measured, consisting of the three sinus regions including the maxillary sinus (bilateral and unilateral), the frontal sinus, and the sphenoidal sinus; and the paranasal, nasal cavity, and nasal pharynx region, which consists of all paranasal sinuses, the nasal cavity, and the nasal pharynx combined.

M/F index, the Fro/F index, the Sphe/F index, and the Para/F index (N = 77). The state of remaining molars in the maxillary molar region was divided into three categories, depending on the number of molars remaining on the relevant side of the maxillary molar region, with no molars remaining classified as "no molars remaining," one or two molars as "minority of molars remaining," and three or more molars as "majority of molars remaining." Comparisons were made between unilateral maxillary sinus volume and M/F index for each respective category. Statistical processing was carried out using SPSS (v22 IBM, New York, USA). Sinus volume changes for each age group were investigated using one-way analysis of variance by age. Validation of differences in average sinus volume values depending on differences in the number of teeth remaining was performed using unpaired t-testing. The correlation between maxillary volume and sphenoidal sinus volume was determined using the Pearson correlation coefficient. Normal distribution of sinus volume vs. femoral length index was confirmed using the Shapiro-Wilk test, and unpaired t-testing was conducted to validate differences in femoral length index depending on differences in age group and number of teeth remaining. All determinations of significant difference were conducted with a significance level of 1% and less than 5%.

This research was conducted with the approval of the Kanagawa Dental College ethics committee (approval number 140).

Table 2. Volumes and sex differences for each sinus (average value ± one standard deviation;cm^3 hereafter the same) Concerning volume differences between male and female subjects, a significant difference ($P < 0.05$) was found for the frontal sinus, but there were no significant differences for the maxillary or sphenoidal sinuses or the paranasal, nasal cavity, and nasal pharynx volume.

	Male (N = 33)	Female (N = 44)	Total (N = 77)
maxillary sinus	32.9 ± 13.2	29.6 ± 12.5	31.3 ± 12.9
sphenoidal sinus	10.2 ± 4.4	8.7 ± 5.9	9.6 ± 5.6
frontal sinus	8.9 ± 6.3	5.2 ± 3.1	7.1 ± 5.7
paranasal, nasal cavity, and nasal pharynx	124.5 ± 29.0	101.6 ± 21.0	113.3 ± 30.4

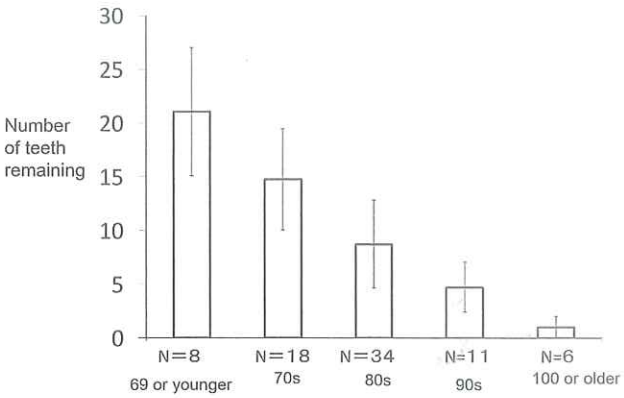

Fig. 2. Number of teeth remaining in upper and lower jaws by age group. The number of teeth remaining for each age group ranged between 20.1 ± 6 for 69 or younger (N=8) and 2.4 ± 1.2 for subjects 100 years or older (N=6), with number of remaining teeth decreasing with age.

Results

1. Volumes and sex differences for each sinus

The average maxillary sinus volume was 31.3 ± 13.2 cm^3 (average value ± one standard deviation; hereafter the same), with values of 32.9 ± 13.2 cm^3 (6.7 cm^3 ~ 55.7 cm^3) for males and 29.6 ± 12.5 cm^3 (5.5 cm^3 ~ 52.9 cm^3) for females. The average sphenoidal sinus volume was 9.6 ± 5.6 cm^3, with values of 10.2 ± 4.4 cm^3 (1.1 cm^3 ~ 22.1 cm^3) for males and 8.7 ± 5.9 cm^3 (1.0 cm^3 ~ 22.4 cm^3) for females. The average frontal sinus volume was 7.1 ± 5.7 cm^3, with values of 8.9 ± 6.3 cm^3 (1.3 cm^3 ~ 30.1 cm^3) for males and 5.2 ± 3.1 cm^3 (0.4 cm^3 ~ 13.5 cm^3) for females. The average paranasal, nasal cavity, and nasal pharynx volume was 113.3 ± 30.4 cm^3, with values of 124.5 ± 29.0 cm^3 (69.4 cm^3 ~ 183.7 cm^3) for males and 101.6 ± 21.0 cm^3 (59.9 cm^3 ~ 147.0 cm^3) for females. Concerning volume differences between male and female subjects, a significant difference ($P < 0.05$) was found for the frontal sinus, but there were no significant differences for the maxillary or sphenoidal sinuses or the paranasal, nasal cavity, and nasal pharynx volume (Table 2).

2. Femoral length index for each paranasal sinus

Average M/F index was 0.41, with values of 0.42 (0.09 ~ 0.72) for males and 0.4 (0.07 ~ 0.75) for females; no significant difference was observed between males and females. Average Sphe/F index was 0.25, with values of 0.26 (0.03 ~ 0.54) for males and 0.25 (0.04 ~ 0.64) for females; no significant difference was observed between males and females. Average Fro/F index was 0.18, with values of 0.23 (0.03 ~ 0.73) for males and 0.15 (0.02 ~ 0.39) for females; a significant difference ($P < 0.05$) was observed between males and females. Average Para/F index was 2.97, with values of 3.1 (1.82 ~ 4.47) for males and 2.8 (1.5 ~ 4.02) for females; a significant difference ($P < 0.05$) was observed between males and females.

3. Number of teeth remaining in upper and lower jaws by age group

The average number of teeth remaining in the upper and lower jaws was 9.7 ± 9.5 (0 ~ 29 teeth). The number of teeth remaining for each age group ranged between 20.1 ± 6 for 69 or younger (N = 8) and 2.4 ± 1.2 for subjects 100 years or older (N = 6), with number of remaining teeth decreasing with age (Fig. 2).

4. Femoral length by age group

Average femoral length ranged between 39.3 ± 1.9 cm in subjects 69 years or younger and 34.4 ± 1.7 cm in subjects 100 years or older, gradually decreasing with age. Results of one-way analysis of variance of average femoral length indicated a significant difference of $P<0.05$ between subjects 100 years or older and subjects in their 70s or 80s, and of $P<0.01$ between subjects 100 years or older and subjects 69 years or younger (Fig. 3).

5. Unilateral maxillary sinus volume and M/F index by age group

Average unilateral maxillary sinus volume was 15.5 ± 6.7 cm^3, with values of 16.5 ± 6.9 cm^3 (2.7 cm^3 ~ 26.4 cm^3) for men and 14.5 ± 6.6 cm^3 (3.3 cm^3 ~ 27.8 cm^3) for women. Whereas unilateral maxillary sinus volume was fairly consistent between 15.9 ± 5 cm^3 and 16.6 ± 7.0 cm^3 for each age range until subjects reached their 80s, a significant difference ($P < 0.05$) was observed between the unilateral maxillary sinus volumes of subjects 100 years and older and the groups in their 80s and below, with a trend commencing in the 90s toward smaller volume accompanying age. One-way analysis of variance showed a significant difference ($P < 0.05$) between unilateral maxillary sinus volume and M/F indices for each age group (Fig. 4).

6. Age-related volumes and sex differences for unilateral maxillary sinus

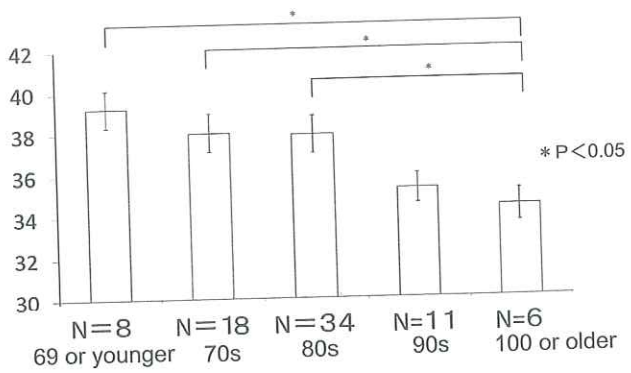

Fig. 3. Femoral length by age group(cm). Results of one-way analysis of variance of average femoral length indicated a significant difference of $P < 0.05$ between subjects 100 years or older and subjects in their 70s or 80s, and of $P < 0.01$ between subjects 100 years or older and subjects 69 years or younger.

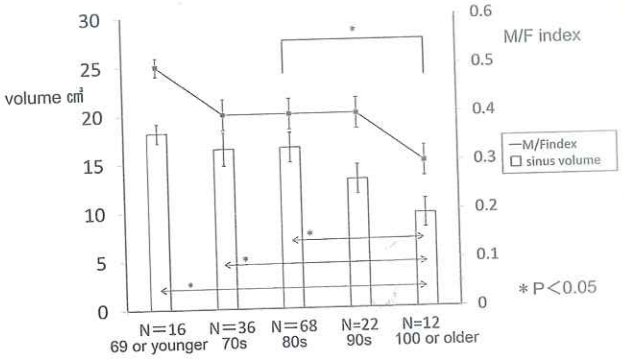

Fig. 4. Unilateral maxillary sinus volume and M/F index by age group One-way analysis of variance showed a significant difference ($P < 0.05$) between unilateral maxillary sinus volume and M/F indices for each age group.

Concerning age- and sex-related volume differences for the unilateral maxillary sinus, there were no significant differences for any age group up to and including subjects in their 80s. No sex difference comparison was conducted in the 90 years and older age group due to the large difference in male-female composition for this group.

7. Frontal sinus volume and Fro/F index by age group

Average frontal sinus volumes for each age group did not show a consistent trend, ranging from a minimum of 3.4 ± 2 cm^3 for subjects 100 years and older ($N = 6$) to 7.9 ± 5.8 cm^3 for subjects in their 80s ($N = 34$). Volume and femoral length index was analyzed for each age group using one-way analysis of variance, and showed no significant difference.

8. Sphenoidal sinus volume and Sph/F index by age group

Consistent results for average sphenoidal sinus volumes for each age group could not be obtained, ranging from a minimum of 5.4 ± 5.5 cm^3 for subjects in their 70s ($N = 18$) to a maximum of 10.5 ± 5.5 cm^3 for subjects in their 80s ($N = 34$). Sphenoidal sinus volume and femoral length index was analyzed by age group using one-way analysis of variance, and showed no significant difference.

9. Comparison between unilateral maxillary sinus volume and M/F index and the number of maxillary molars remaining

Volume for the majority-of-molars-remaining group ($N=41$) was 18.4 ± 5.5 cm^3 while volume for the no-molars-remaining group was 14.4 ± 6.8 cm^3, indicating a significant difference of $P < 0.05$ between the two groups. In addition, the M/F index was 0.5 for the majority-of-molars-remaining group and 0.4 for the no-molars-remaining group, indicating a significant difference ($P < 0.05$) between the two groups. This indicates a trend for the maxillary sinus to be smaller the greater the number of molars that are missing (Fig. 5).

Discussion

Because the maxillary sinus is the closest of all the paranasal sinuses to the oral cavity, the focus of research into lesions such as tumors and inflammation relating to the maxillary sinus has been mainly on dental surgery (Sahoda 1941; Okajima 1960; Tanaka 1983; Gray 2000; Mitukawa 2011). However, in recent years implant therapy involving the maxillary sinus in areas where maxillary molars are absent is becoming more widespread, making the maxillary sinus a familiar anatomical structure that cannot be avoided by general dental clinicians. Anatomical study of the maxillary sinus is commonly conducted on subjects ranging between youth and the prime of life (in their 50s and 60s)(Oyama 1988; Okamatsu 2004; Uchida 2011). In this particular study approximately half of the cadavers used as test subjects are referred to as advanced elderly, 85 years or older. However, with regard to male-female composition, a major gap occurs in the male-female component distribution ratio among advanced elderly subjects 90 and older. This made it difficult to conduct a male-female comparison of anatomical structure for this age group.

Femoral length index

In this study it would have been difficult to measure body height using CT imaging according to uniform standards due to malpositioning caused by secondary changes, long-term hospitalization, long-term disabilities, and so on. Methods for estimating living stature based on

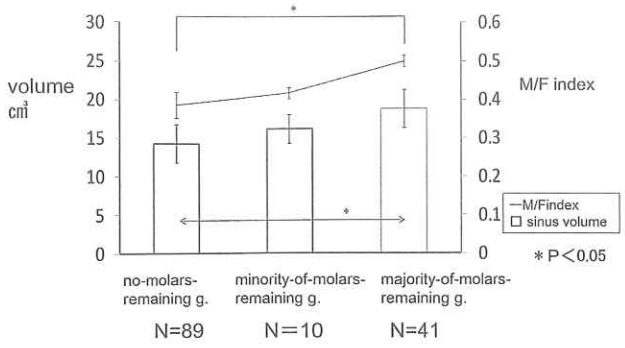

Fig. 5. Comparison between unilateral maxillary sinus volume and M/F index and the number of maxillary molars remaining. The M/F index was 0.5 for the majority-of-molars-remaining group and 0.4 for the no-molars-remaining group, indicating a significant difference ($P < 0.05$) between the two groups. This indicates a trend for the maxillary sinus to be smaller the greater the number of molars that are missing.

long bone length include formulae developed by Andou (1923), Fujii (1960), and Yoshino (1986) (Hasegawa 2010). Femoral length exhibits no significant male-female or left-right differences and correlates closely with height, with a correlation coefficient of 0.8 or greater (Sharan 2008). Consequently, reports have suggested that a standard be adopted for living body height comparison based on femoral length (Gaussian distribution) (Inoue 2002; Hanawa 2006; Kuroki 1985; Hoshi 1988). Here, femoral length could be consistently measured and decreased with age. This was thought to indicate that both height and physique deteriorated with age in the subjects measured. Based on these factors, in this study we attempted to use femoral length as a basis for comparison of the volumes of each paranasal sinus using femoral length index with Gaussian distribution. As a result, measurements made in this study showed a trend toward reduction in unilateral maxillary sinus volume accompanying age, and even the M/F indices showed a trend toward reduction among successive age groups. This would indicate that the cause of differences in maxillary sinus volume among different age groups was not due to differences in physique between those age groups.

Relationship between unilateral maxillary sinus volume and age

Ariji et al found that maxillary sinus volume increased with age, but the subjects for their research had an average age of 46.8 years and many were from age groups in which the effect of tooth loss was minimal. Emirzeoglu (2007) measured the volumes of each sinus cavity in clinical cases and correlated them with age, finding that there was a weak negative correlation of maxillary sinus volume with age. Iwai (1995) et al reported a trend toward reduction of sinus volume with age and tooth loss, based on research using panoramic x-rays and CT images from clinical cases. Currently there is no established consensus on age-related changes to sinus volume. In this report, results of one-way analysis of unilateral maxillary sinus volume were not statistically significant, but the same trend toward decrease in volume was observed as in Emirzeoglu's findings. A factor in the difference between the findings of this report and those of Ariji may have been that this research included many cadavers of advanced elderly subjects in their 80s, who had significantly fewer remaining teeth. It is likely that, while there is a high correlation between maxillary sinus volume and age in the prime of life, the number of teeth remaining affects sinus volume in the elderly.

Unilateral maxillary sinus volume and sex differences

Kanda (1992) found that maxillary sinus volume was 17.77 cm^3 in males and 15.73 cm^3 in females, based on measurements taken using CT imagery. Volume was significantly larger in males than in females. Moriguchi (1989) observed a significant difference, with male maxillary sinus volume measuring 17.8 cm^3 and females measuring 15.0 cm^3, based on CT exams taken for diagnosis of head injuries in 72 cases averaging 42 years old. Kim (2010) et al found that male sinus volume was significantly larger than female sinus volume, based on measurements of maxillary sinus volume using three-dimensional construction processing of CT imagery. Ariji (1994) performed CT image measurements on 115 subjects with an average age of 46.8 years and found that, while males measured 15.40 cm^3 and females measured 13.98 cm^3, indicating a sex difference, that difference was not statistically significant. The majority of previous research reports a significant difference in maxillary sinus volume between males and females in ages from around the time of growth period to prime of life. In this report, a significant sex difference in unilateral maxillary sinus volume was not observed, either in all elderly subjects including advanced elderly subjects or in subjects in their 80s and younger in which the male-female component ratio was equal. This may indicate that, while males have a larger maxillary sinus than females until prime of life, when the male-female difference is distinct, in the elderly sex differences become less clear as maxillary sinus volume reduces with age.

Relationship between maxillary sinus volume and number of teeth remaining

Concerning the effect of tooth loss on sinus volume, Uemura (1974) conducted direct measurements on desiccated human skulls, comparing dentulous and edentulous jaws, and reported a trend toward smaller sinus volume of the maxillary sinuses in the edentulous jaw group due to elevation of the sinus floor in the infrazygomatic crest region. Iwai (1995) et al used panoramic x-ray and CT images of clinical cases to report reduction in sinus

volume due to aging and tooth loss. Ide (1985) reported a trend toward reduced sinus volume in edentulous cases due to the appearance of cancellous bone trabeculae in the basal part of the maxillary sinus and morphological changes to the anterior sinus wall. As this indicates, past research reports a reduction in sinus volume due to tooth loss (Kanda 1992; Moriguchi 1989; Kim 2010). On the other hand, Nogi (2002) reports that, in research conducted on desiccated skulls using CT imagery in which subjects were divided into three groups, with either no maxillary teeth, one or more teeth missing, or all teeth present, sinus volume was greater in the edentulous group than in the dentulous group. Sharan (2008) confirmed inferior expansion of sinus volume after molar extractions, based on measurements using fixed reference lines directly over panoramic x-ray photographs. Thus, there also exist opposing reports showing an increase in maxillary sinus volume due to tooth loss (Ikeda 1996; Ikeda 1997). Additionally, Uchida (2011) et al preformed measurements of mold samples obtained by injecting impression material into the maxillary sinuses of cadavers and reported a high positive correlation between sinus volume and the vertical dimension component of the maxillary sinus, but found no statistically significant difference between the edentulous maxillary group and the group with partial molar loss. Ohba et al (2001) used panoramic x-ray photographs to measure the depth of the right and left maxillary sinus floors in edentulous and dentulous jaws, reporting that, in edentulous jaws, the maxillary sinus floor was significantly lower than in dentulous jaws on the left side, but there was no correlation between the state of remaining teeth and ipsilateral maxillary sinus floor depth for either side. Factors affecting the different results for the left and right sides may include the length of time since molar loss and differences in dominant chewing side. From this it is apparent that, in past reports, there has been no consensus on the relationship between the number of teeth remaining and maxillary sinus volume. Factors explaining this lack of consensus may include that the sex and age of research subjects was unclear or that consideration was not given for age differences between the groups compared. Ikeda (1996, 1997) studied 102 cases with no signs of nasal cavity or paranasal sinus inflammation, measuring maxillary, frontal, and sphenoidal sinus volumes with a slice thickness of 5 mm, and found a moderate positive correlation between maxillary and sphenoidal sinus volume (R = 0.44). Kurabayashi (2008) et al Conducted measurements on desiccated human skulls using CT imaging with a slice thickness of 2 mm, and reported a moderate positive correlation between the maxillary and sphenoidal sinuses (R = 0.53). Our research also obtained similar results, with a moderate positive correlation between the maxillary and sphenoidal sinuses (R = 0.45). When subjects were divided into edentulous (no remaining teeth in upper or lower jaws) and dentulous (one or more remaining teeth in upper or lower jaws) groups and the correlation between maxillary and sphenoidal sinus volumes compared, the edentulous group showed low correlation in maxillary and sphenoidal sinus volumes (R = 0.20), while the dentulous group showed a correlation (R = 0.50). No relationship was observed between volume and number of teeth remaining when comparing the maxillary and frontal sinuses or the frontal and sphenoidal sinuses. From this, we surmise that the influence of number of teeth remaining on sinus volume is a distinctive characteristic of the maxillary sinus, and that tooth loss influences the form of the maxillary sinus in particular. Also, there was a significant difference in maxillary sinus volume and M/F index between the molars-remaining and no-molars-remaining groups, with a smaller maxillary sinus volume the greater the number of missing molars. This suggests that, in the elderly, loss of molars influences reduction in maxillary sinus volume. The long-term reduction in maxillary sinus volume as the number of maxillary molars remaining decreases also exerts an influence on the development of characteristic facial features of elderly people who have experienced reductions in mastication muscle and bone volume due to the effects of tooth loss. It is predicted that the number of cases involving implants in seniors will increase in the future. We would like to consider the benefits of maintaining proper dental articulation and mastication through implants in the elderly from a cosmetic perspective as well.

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