Generational Differences in Tooth Size in the Japanese Population : Analysis of Cohorts with a Generation Gap of Four to Five Decades

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Original Article

Generational Differences in Tooth Size in the Japanese Population : Analysis of Cohorts with a Generation Gap of Four to Five Decades

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Abstract
Purpose : Since early modern times, tooth size has reportedly been increasing in each successive generation. A detailed analysis of these trends can provide meaningful information for elucidating the origin of various problems caused by larger teeth, such as an abnormal dentition and occlusion. By using data from most recent generations, this study aimed to clarify the time course of changes in tooth size in the Japanese.
Materials and methods : The dentitions of two Japanese cohorts comprising young individuals born in the 1980s and the 1990s were compared with those of another cohort of Japanese individuals born in the 1940s, approximately half a century earlier. The mesiodistal diameter of the tooth crowns was measured on plaster models and subjected to statistical analyses.
Results : A mean difference test revealed that each recent generation showed positive generational differences in the size of more than 50% of the tooth types. In addition, a deviation graph analysis indicated that the degree of change in tooth size varied with the tooth type or sampling site. Principal component analysis clearly showed an increase in tooth size on an individual basis in the more recent generations.
Conclusions : This study revealed positive generational differences in tooth size in the Japanese population. The results may aid in understanding the development of abnormal dentitions and occlusion in recent Japanese populations.

Key words : Tooth size・Generational differences・Japanese

Introduction

The development of teeth is under strong genetic control and less susceptible to environmental factors; therefore, the original morphology of teeth is considered to remain unchanged for centuries[1)]. On the other hand, various studies have reported a rapid increase in tooth size since early modern times, even in population groups within the same geographical region[2)]. However, these results may be ambiguous because of selection bias, such as that caused by the inclusion of data restricted to the anterior teeth[3)] ; excavated archaeological human bone samples[4)], which provide unclear data on era or daily lifestyle; and teeth from patients with orthodontic

Abbreviations : UI1 : Upper central incisor, UI2 : Upper lateral incisor, UC : Upper canine, UP1 : Upper first premolar, UP2 : Upper second premolar, UM1 : Upper first molar, UM2 : Upper second molar, LI1 : Lower central incisor, LI2 : Lower lateral incisor, LC : Lower canine, LP1 : Lower first premolar, LP2 : Lower second premolar, LM1 : Lower first molar, LM2 : Lower second molar

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problems[5)], which are not believed to be of a usual size[6)]. Damaged teeth and/or tooth wears in aged individuals[7)] are also factors responsible for errors. Therefore, generational differences in tooth size are difficult to elucidate and remain unclear.

Many investigators believe that an increase in tooth size is a key reason for the development of abnormal dentitions and occlusion[5)~8)], which are specifically seen in the modern Japanese[9)]. From this perspective, it is important to understand changes in tooth size over time in the general Japanese population. However, few studies have been performed in this regard. Suzuki[10)] reported generational differences in tooth size in the Japanese by analyzing two cohorts of young adults born around 1946 and 1962. In the study, although significant enlargement of each tooth type was suggested, neither the degree of change nor comparisons on an individual basis were investigated. Most importantly, the latest generation included in the study was born approximately 50 years ago. Consequently, it still remains unclear whether generational differences in tooth size exist in the current Japanese population.

This study aimed to upgrade existing knowledge about generational differences in tooth size in the Japanese by using suitable data analyzed with both univariate and multivariate statistical analyses. The results suggested not only an increase in tooth size over time but also variations in the degree of change among tooth types or sampling sites.

Materials and Methods

Plaster models of dentitions obtained from three Japanese female cohorts were subjected to measurements of tooth size. As shown in Table 1, the first group (40s Tokyo) comprised 50 female subjects from Tokyo who were born during 1940–1942 (data stored at the University of Tokyo), 50 from Okinawa prefecture (80s Okinawa) who were born during 1984–1986 (data stored at the University of the Ryukyus), and 54 from Saga prefecture (80–90s Saga) who were born during 1989–1991 (data stored at Saga University). Age at plaster model fabrication ranged from 12 to 15 years in the 40s Tokyo and 80s Okinawa groups and from 18 to 21 years in the 80–90s Saga group. The quality of impression material and plaster used approximately 50 years ago is comparable to that of more recent materials, with negligible dimensional changes or age-related degradation of plaster models stored for a long time[11)].

The mesiodistal diameter of tooth crowns was measured on the plaster models according to the standard method described by Moorrees[12)] and Hillson[13)] using a 1/100-mm digital caliper (Mitutoyo, Kawasaki, Japan) (Fig. 1). A single researcher (K. S.) measured the teeth from the central incisor up to the second molar in the upper and lower arches. Bilateral data of the same tooth type were averaged. In case a tooth was missing or difficult to measure on one side, a value from the other side was corrected.

For univariate comparison, the Bonferroni multiple comparison test was performed to independently calculate the mean differences among the 14 tooth types. Each group was compared with the other as follows : 40s Tokyo vs. 80s Okinawa, 40s Tokyo vs. 80–90s Saga, and 80s Okinawa vs. 80–90s Saga.

To compare the degree of change for each tooth type, mean values for each group were standardized and converted into a Morrison's deviation graph. For normalization, the means and standard deviations (SDs) for the older generation group (40s Tokyo) were used. Subsequently, standardized mean values were calculated for each tooth in the younger generation groups (80s Okinawa and 80–90s Saga) using the following equation :

$$z = (xi - m)/SD$$

where z is the standardized mean, xi is the mean for the 80s Okinawa or 80–90s Saga group, m is the mean for the 40s Tokyo group, and SD is the standard deviation for the 40s Tokyo group.

If one tooth is enlarged, another tooth in the

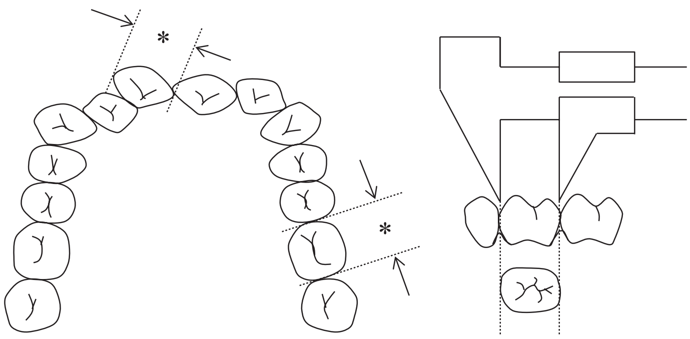

Fig. 1 Schematic illustrations of tooth crown measurements
The mesiodistal crown diameters (asterisks) of teeth from the central incisor up to the second molar were measured on plaster models of the upper and lower arches using a digital caliper.

Table 1 Nomenclature and characteristics for the groups

Sample name	No. of individuals	Recruitment Site	Year of birth	Age	Stored at
40s Tokyo	50 (43)	Myoujyou-Gakuen Junior High School	1940–1942	12–15 y.o.	the University of Tokyo
80s Okinawa	50 (38)	Kadena Junior High School	1984–1986	12–15 y.o.	University of the Ryukyus
80–90s Saga	54 (45)	Saga Dental Hygienist School	1989–1991	18–21 y.o.	Saga University

Numbers in parentheses indicate number of individuals with a complete dentition.

same individual may not be enlarged. Therefore, the mean difference test and the deviation graph do not always reveal tooth enlargement on an individual basis because they are simply based on size differences in each tooth. To clarify this issue, we used principal component analysis (PCA). Hanihara and Hanihara[14] reported that PCA using permanent tooth crown size revealed size relationships among individuals regardless of tooth size variations within the same individual, such as variations between anterior teeth and molars. For PCA, samples including all tooth types were used. The number of samples is shown in parentheses in Table 1. The three groups were analyzed together to extract the principal components that did not correlate with each other. Then, the mean principal component score in each group was compared using the Bonferroni multiple comparison test.

Results

Table 2 shows statistical data for each tooth size in the three groups and results of the Bonferroni multiple comparison tests. When compared with the 40s Tokyo group, the 80s Okinawa group was found to have significantly larger upper central incisor (UI1), upper lateral incisor (UI2), upper canine (UC), upper first premolar (UP1), upper second premolar (UP2), upper second molar (UM2), lower first premolar (LP1), and lower second premolar (LP2), while the 80–90s Saga group had significantly larger UI2, UC, UP1, UP2, UM2, lower lateral incisor (LI2), lower canine (LC), LP1, LP2, lower first molar (LM1), and lower second molar (LM2). Therefore, the 80s Okinawa and 80–90s Saga groups shared five tooth types (UI2, UC, UP1, UP2, and UM2) in the upper arch and two (LP1 and LP2) in the lower arch that were larger than their counterparts in the 40s Tokyo group. Meanwhile, LM1 and LM2 were significantly larger in the 80–90s Saga group than in the 80s Okinawa group. Upper first molar (UM1) and lower central incisor (LI1) were not significantly different among the three groups.

A deviation graph of the standardized means for the 80s Okinawa and 80–90s Saga groups is demonstrated in Fig. 2. The values for the 40s Tokyo group were used as the standard. All teeth

Table 2 Means of mesiodistal diameters (mm) and univariate comparison among groups

	40s Tokyo			80s Okinawa			80–90s Saga		
Tooth type	n	Mean	SD	n	Mean	SD	n	Mean	SD
UI1	50	8.40	0.49	50	8.68**	0.50	54	8.58	0.52
UI2	50	6.84	0.65	50	7.16*	0.67	54	7.19**	0.59
UC	49	7.72	0.39	49	7.92*	0.41	54	7.95**	0.38
UP1	50	7.32	0.47	50	7.52*	0.40	54	7.66**	0.37
UP2	47	6.78	0.42	48	7.02*	0.46	54	7.06**	0.42
UM1	50	10.48	0.50	50	10.58	0.48	53	10.67	0.54
UM2	48	9.71	0.51	43	10.16**	0.45	52	10.18**	0.49
LI1	49	5.47	0.38	50	5.56	0.35	54	5.55	0.36
LI2	49	6.01	0.37	50	6.09	0.37	54	6.21*	0.40
LC	50	6.71	0.41	50	6.85	0.38	54	6.86*	0.34
LP1	50	7.18	0.46	50	7.43**	0.42	54	7.50**	0.40
LP2	49	7.15	0.49	49	7.36*	0.39	54	7.49**	0.40
LM1	50	11.27	0.48	50	11.35	0.51	53	11.60**#	0.54
LM2	48	10.49	0.65	47	10.54	0.55	49	10.92**##	0.58

Significant levels as revealed by the Bonferroni multiple comparison test were denoted by asterisks (comparison between each recent group and 40s Tokyo), and hash symbols (comparison between recent groups). *and # : $P < 0.05$, ** and ## : $P < 0.01$. All the symbols were attached to larger values.

from the more recent generations, i.e., the 80s and 80–90s, showed a tendency for increased size compared with those from the older generation, i.e., the 40s. In both the younger groups, UM2 showed a marked degree of change, whereas the degree of change in UM1 and LI1 was less remarkable. Notably, the degree of change in LM1 and LM2 was clearly different between the 80s Okinawa and 80–90s Saga groups, although the other teeth showed a similar pattern.

Table 3 shows the eigenvectors, eigenvalues, and cumulative proportions of total variances (abbreviated as Cum. prop. in Table 3) for the initial three principal components. Because a total variance of approximately 70% was obtained when we considered the first two principal components, and because the third principal component (PC3) had an eigenvalue of less than 1.0, PC1 and PC2 were further analyzed.

Fig. 3 shows the two-dimensional expression of the mean principal component scores calculated for each group. Both the 80s Okinawa and 80–90s Saga groups exhibited higher scores for PC1 compared with the 40s Tokyo group ($P < 0.05$ and $P < 0.01$, respectively). The PC2 scores, on the other hand, were significantly different between the 80s Okinawa and 80–90s Saga groups ($P < 0.05$).

Table 3 Eigenvectors, eigenvalues, and proportions of the pooled correlation matrix by principal component analysis

Tooth	PC1	PC2	PC3
UI1	0.269	−0.330	0.135
UI2	0.243	−0.319	−0.018
UC	0.259	−0.297	−0.340
UP1	0.287	0.102	−0.315
UP2	0.279	0.205	−0.274
UM1	0.269	0.177	0.322
UM2	0.251	0.331	0.046
LI1	0.257	−0.299	0.409
LI2	0.272	−0.321	0.132
LC	0.285	−0.236	−0.144
LP1	0.283	0.175	−0.271
LP2	0.278	0.231	−0.261
LM1	0.263	0.222	0.388
LM2	0.241	0.355	0.297
Eigenvalue	8.226	1.273	0.879
Proportion	58.75%	9.09%	6.28%
Cum. prop.	58.75%	67.84%	74.12%

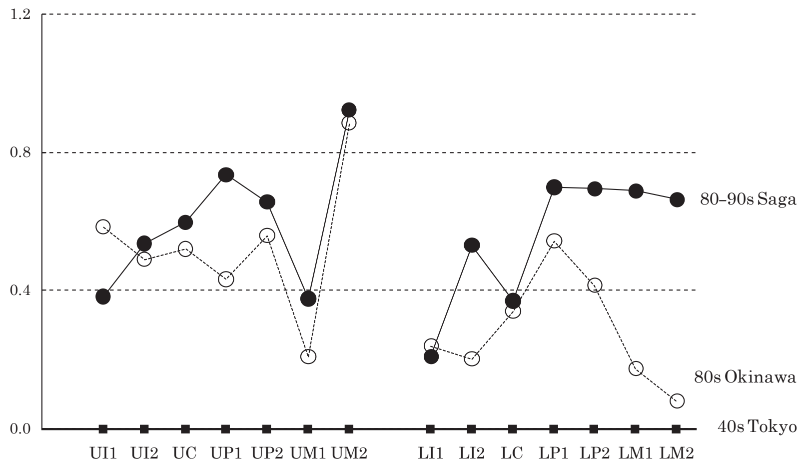

Fig. 2 Comparison of the degree of change in individual tooth size using a deviation graph
Using data for the 40s Tokyo group as the standard, standardized mean values for the 80s Okinawa and 80–90s Saga groups were calculated and indicated as white and black dots, respectively.

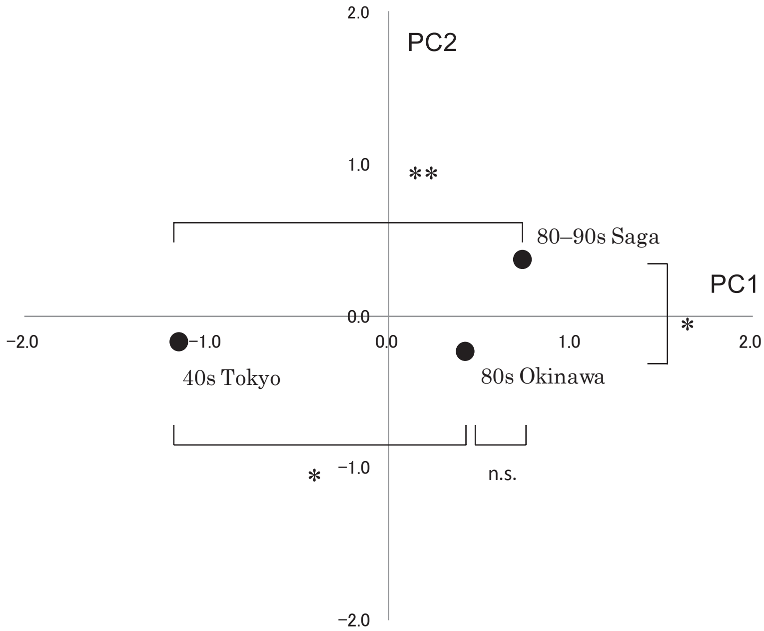

Fig. 3 Two-dimensional expression based on principal component analysis (PCA) scores and the Bonferroni comparison test
$^{*}P < 0.05$, $^{**}P < 0.01$

Discussion

Study materials

It is difficult to obtain adequate samples to study generational differences in teeth. The following three factors should be taken into consideration. First, a sufficient time interval should be present between target groups. Second, the samples should be retrieved from a general population. Third, the samples should preferably comprise young individuals to avoid size differences caused by tooth wear or dental treatment[15]. In this study, young individuals aged 12–21 years were selected from the general population, and a gap of approximately 40–50 years was ensured between the older and younger groups. Furthermore, the number of individuals (approximately 50) in each group was adequate for statistical analyses. Therefore, our samples seem to fulfill the above mentioned requirements. However, another problem should be considered with regard to young subjects. In Japan, studies in this field have often included individuals with many unquantifiable teeth because they belonged to an era when caries was spreading[16]. The 40s Tokyo group had only a few teeth that could not be quantified because of tooth crown destruction or restoration because they were born during the era of World War II (1939–1945), when sugar intake and caries incidence were significantly low in the Japanese population[17]. The 80s Okinawa and 80–90s Saga groups also had fewer unquantifiable teeth because they belonged to an era when caries was fairly preventable. These factors seemed to improve the reliability of our study.

Validity of PCA in dental anthropology

Multivariate statistical analyses are effective techniques for dental anthropology and widely used in this field. In particular, PCA enables direct comparisons between dentitions on an individual basis. As shown in Table 3, all eigenvectors of PC1 were pointed in the positive direction, indicating that PC1 represented a size component interpreted as the total size of the teeth in each individual[14]. With regard to PC2, the eigenvectors of the anterior teeth (including incisors and canines) and those of the posterior teeth (premolars and molars) were pointed in the opposite direction (Table 3), clearly indicating a contrast in size and functional differences between the anterior and posterior teeth. Therefore, PC2 represented a shape component interpreted as the proportion of tooth size in a dentition[14].

Study results

Our results showed an overall trend of tooth enlargement over time in the Japanese population, while they also suggested different degrees of change according to the tooth type or sampling site.

Only two teeth, UM1 and LI1, did not show apparent generational differences among the three groups (Table 2 and Fig. 2). Because UM1 and LI1 develop early[18], this result may suggest a relationship between the stage of tooth development and susceptibility to a change in size. However, the degree of change in the other teeth was variable. For example, premolars, which develop at a relatively later stage[18], did not always present the maximum enlargement. Further analysis is required to clarify this issue because little data or discussions are available in published research.

The results of this study also suggested regional differences in tooth size, particularly for teeth in the lower arch. All teeth types except LI1 in the lower arch showed a significant increase in size in the 80–90s Saga group, while only two premolars, LP1 and LP2, were significantly enlarged in the 80s Okinawa group. Differences between the two younger groups were also remarkable for LM1 and LM2 (Table 2 and Fig. 2). Furthermore, PC2 scores were significantly different between the 80s Okinawa and 80–90s Saga groups (Fig. 3). While little information about dental diversity in the Japanese is available today, these results may indicate that the two groups are different populations from the perspective of the shape factor, although we used them as representatives of recent generations. In fact, Oh-uchi et al.[19] reported that the craniofacial skeleton of infants in Okinawa prefecture showed a remarkable tendency of brachycephaly compared with the national average. Such factors in the growing phase may have influenced the differences between the 80s Okinawa and 80–90s Saga groups.

Causes of tooth enlargement over time in the Japanese population

Historically, the Jomon people, indigenous inhabitants of the Japanese archipelago, had smaller teeth than the modern Japanese. After gradual mixing with immigrants with larger teeth from continental East Asia around the 3^{rd} century B. C., the tooth characteristics of the Japanese became eclectic[20)21)]. This phenomenon is designated as the dual structure theory[21)]. However, because a huge gene flow is not likely in current times, environmental factors should have a more significant impact on tooth size compared with genetic factors.

Many researchers considered nutritional status to have the most significant influence among other environmental factors[5)7)10)15)]. Santo[22)] reported that the degree of increase in the height of Japanese children significantly decreased immediately after World War II, because of a food crisis. For the 40s Tokyo group, the period corresponding to their tooth crown formation coincided with that when food was scarce. Taken together, the growth potential of their teeth may have been restricted. In contrast, the younger generations, represented by the 80s Okinawa and 80–90s Saga groups, grew up during a period when food availability and sanitation were rapidly improving. Therefore, they could achieve their growth potential and consequently developed larger teeth.

Relationship between malalignment of teeth and tooth size

Hayashi et al.[23)24)] and Kasai et al.[25)] suggested that the young Japanese tend to have insufficient masticatory function because of the habit of eating soft food. In such cases, the tooth axes are not straight and the width of the dental arch becomes narrow, resulting in an abnormal dentition. However, there is another hypothesis, which regards the developmental imbalance between teeth and jaws to be pathogenetically important. In general, to avoid misalignment, both the jaws and teeth need to grow synchronously[26)]. Patients who required orthodontic treatment usually have large tooth crowns[6)8)]. Therefore, unnecessarily enlarged teeth are likely to form an abnormal dentition. According to our data (Table 2), the simple aggregate of size increments in all teeth was approximately 2–4 mm per individual over half a century. However, it remains unclear whether the jaws also enlarged to accommodate the change in tooth size. Further morphological investigation of the masticatory system is important to reveal the mechanisms underlying the development of abnormal dentitions and occlusion in today's Japanese adolescents.

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（和文抄録）

この40～50年における日本人の歯の大きさの変化について

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目的：近代以降，ヒトの歯のサイズが世代とともに大きくなっていると報告されてきた．歯の大型化は，不正歯列や咬合異常など様々な問題を引き起こす要因となっている可能性があり，この変化に関する詳細な分析は病態解明の観点からも重要である．本研究の目的は，最も新しい世代のデータを用いて日本人の歯の時代変化を検証することである．
材料と方法：1980–1990年代生まれの若年者集団と，誕生年に50年余りの差がある1940年代生まれの若年者集団の歯列石膏模型につき，歯冠近遠心幅径を計測し統計解析を行った．
結果：歯種別に平均値の差を検定した結果，半数以上の歯種において若い世代群の歯のサイズが大きくなっていることが明らかになった．偏差折線による分析では，増加の程度には歯種間の，あるいは資料が収集された地域間のばらつきがあることが示唆された．主成分分析では，若い世代における個体レベルの歯のサイズ増大が明らかになった．
結論：本研究によって，日本人の歯のサイズは世代間で異なり，大型化しつつあることが明らかになった．この結果は，近年の日本人にしばしば発生する歯列異常や咬合異常の原因を理解する上で，有益な基礎データと考えられる．