Original article

Tooth sizes and configurations within maxillary dentition

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Abstract
Purpose: To explore the relationship between tooth sizes and configurations within a single dentition, the mesiodistal and buccolingual crown diameters were measured using a dentition model, and analyzed using statistical methods.
Methods: A total of 96 maxillary dental casts were used. The mesiodistal crown diameter, buccolingual crown diameter, and crown area from the maxillary central incisor to the maxillary second molar were determined. The mean, standard deviation, median, coefficient of variation, and Spearman's rank correlation coefficients were determined. Hierarchical cluster analysis was performed to form clusters of maxillary dentitions with similar characteristics. Principal component analysis was performed to explore the characteristics of all 96 cases and each cluster. Furthermore, whether there was a difference between the clusters was asked.
Results: Maxillary lateral incisor had a large coefficient of variation and did not show a high correlation coefficient with any of the other teeth. The maxillary dentition was classified into seven groups according to the size of the configuration teeth and the size of the teeth between the tooth types. Furthermore, among the seven groups, there was a group in which the size of the teeth constituting the dentition were in harmony, and a group in which the size of one tooth or tooth type tended to increase while the size of the other tooth or tooth type tended to decrease.
Conclusion: The size of teeth in one maxillary dentition is observed within the same tooth type or between different tooth types, suggesting that they influence each other.

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Keywords: cluster analysis, maxillary dentition, tooth configuration, tooth size

Introduction

Various studies have been conducted on the size and configuration of teeth within a single dentition. In one dentition, the absence of the third molar within one dentition causes other teeth to be smaller [1]. Genes associated with missing second premolars are also involved in the absence of other permanent teeth, including tooth dwarfing [2]. It has been reported that later-developing teeth within the same tooth type show a greater reduction in size than earlier-developing teeth [3]. It is speculated that there is a certain relationship between tooth size and tooth configuration.

In a previous study, Ueno et al. [4] clarified that the width between both incisors and the mesiodistal crown diameter of the central incisors and second premolars affected the length of the maxillary dental arch. There is reported that also a similar report showing a relationship between mesiodistal crown diameter and arch length [5-7].

Dahlberg [8] explains that there are different fields of development and growth for incisors, canines, premolars, and molars and that each field has the strongest effect on the anterior or key teeth of that tooth type. It is inferred that the teeth in one dentition form a dentition while maintaining harmony while influencing each other. However, no consensus has been reached to date.

In this study, to explore the relationship between tooth size and tooth configuration within a single dentition, the mesiodistal crown diameter and buccolingual crown diameter were measured using a dental model. The obtained data were then analyzed statistically for each dentition, and new findings are reported.

Materials and Methods

This study complied with the Declaration of Helsinki (adopted in 1964). The protocol was approved by the Ethic Review Board of Osaka Dental University (No. 111104).

A total of 194 sets of maxillary and mandibular dental casts that were made at Fukai Orthodontic Clinic (Hirakata, Japan) to acquire materials for orthodontic treatment, the specimens were 96 maxillary casts that had erupted from the central incisors to the second molars of no abnormalities affecting the teeth. Dental casts were made using irreversible hydrocolloid impression material (Aroma Fine Mixer Type, GC Corp., Tokyo, Japan) and dental stone (Orthostone, Ransom & Randolph Co., Maumee, OH, USA).

The teeth were measured according to the previous study [9] (Fig. 1), using a 0.01 mm digital caliper (Mitutoyo Corp., Kawasaki, Japan). The mesiodistal crown diameter (MD) and buccolingual crown diameter (BL) from the central incisor to the second molar were measured (Fig. 1). The product MDBL of MD and BL was calculated as the crown area. Measurement was conducted three times, and the means were used for analysis. MD and BL are expressed in mm.

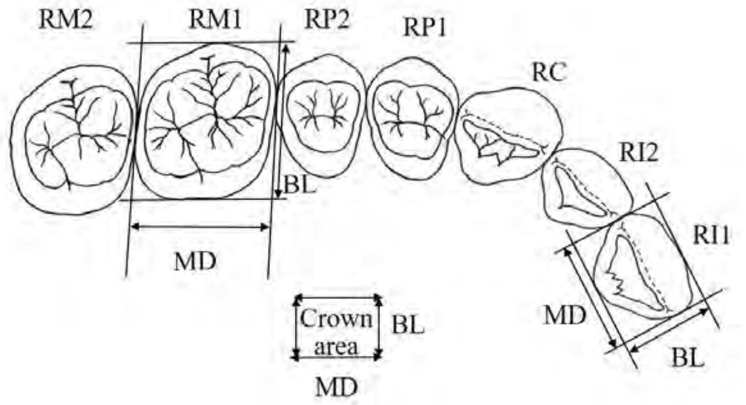

Fig. 1 Measuring items of teeth
R: right,
L: left,
R/LI1: right/left central incisor,
MD: mesiodistal crown diameter,
BL: buccolingual crown diameter,
Crown area*: MD × BL,
*Yamada H, et al. J Kyushu Dent Soc 1983; 37: 1004-11.

The left and right measured values for each item, the means for both sides, the standard deviation (SD), median, the coefficient of variation (CV), and Spearman's rank correlation coefficient (*rs*) were calculated. The difference in the mean values of MD, BL, and crown area between left and right teeth were tested (Paired *t*-test, $\alpha = 0.05$). The strength of the correlation was shown as follows: strong correlation, ±0.7 to ±1; moderate correlation, ±0.4 to ±0.7; weak correlation, ±0.2 to ±0.4; and no apparent correlation, 0 to ±0.2.

Furthermore, regarding the MD, BL, and crown areas, a difference test (Student *t*-test / Mann-Whitney *U* test) was performed of the tooth on the mesial side and the tooth on the distal side of the same type ($\alpha = 0.05$).

The obtained data were standardized and a hierarchical cluster analysis (standardized Euclidean distance, Ward's method) was performed using those standardized data [4]. Next, primary component analysis (PCA) was performed to explore the characteristics of all 96 cases and each cluster. Scree plots were used to determine the number of primary components, and linearly combined variables were excluded from the analysis. In addition, differences between clusters were examined by means of one-way analysis of variance (ANOVA) / Kruskal-Wallis test. For each cluster of data for each item, the Shapiro-Wilk test was used to examine whether the data were normally distributed or not. If all the data followed a normal distribution, a Bartlett's test was conducted to test for equal variances, and if they were equally distributed, a one-way ANOVA was conducted. When the data for each cluster of items did not follow a normal distribution, or when the Bartlett's test could not be assumed to be equally distributed even if the data followed a normal distribution, the Kruskal-Wallis test was conducted. Statistical processing was performed using BellCurve for Excel (Social Survey Research Information Co., Ltd., Tokyo, Japan).

Results

Values for measurement item, comparison between teeth of the same type, and correlation coefficients

The maximum MD (M1MD) was 10.3 mm, and the minimum (P2MD) was 7.0 mm (Table 1). The maximum BL (M1BL) was 11.3 mm, and the minimum (I2BL) was 6.2 mm. The maximum crown area (M1) was 117.3, and the minimum (I2) was 44.4. Significant differences were observed between left and right homonymous teeth for I1BL ($P < 0.05$), I1MDBL ($P < 0.05$), CMDBL ($P < 0.05$), P1MD ($P < 0.05$), P1BL ($P < 0.05$), M1MD ($P < 0.05$), M1BL ($P < 0.01$), M2MD ($P < 0.01$), M2BL ($P < 0.01$). The values of MD, BL, and the crown area of teeth located distally within the same tooth type all showed smaller values than the same measurement items of teeth located on the mesial side, and a significant difference was observed ($P < 0.01$, Table 1). The maximum CV (I2MDBL) was 0.15, the minimum (I1MD and M1BL) was 0.05. Almost values of *rs* between teeth of the same type were 0.50 or higher (Table 2).

Hierarchical cluster analysis

The maxillary dentition was classified into seven groups based on tooth size by using cluster analysis (Fig. 2). In addition, the tooth size of each cluster was shown using a graphic drawing (Fig. 3). Clusters were divided between clusters 1-4 and clusters 5-7 (Fig. 2). Clusters 1-4 were further divided into clusters 1 and 4, and clusters 2 and 3. Clusters 5-7 were further divided into clusters 5 and 6-7. The left and right graphic drawing showed almost similar morphologies in all clusters (Fig. 3).

The z scores of cluster 1 showed 0.5 or more in all teeth. The z scores of cluster 2, I values were around 0.5, but C, P, and M values were close to 0. The z scores of clusters 3 and 5 showed similar trends on anterior teeth, but in the molars, cluster 3 showed values close to cluster 2, while cluster 5 showed values close to cluster 6. The z scores of cluster 4 showed similar trends to cluster 1 on both sides except for I2. The z scores of cluster 6 were small, but distal from P1 had values close to cluster 5. The z scores of cluster 7 were lowest values throughout the dentition.

Table 1 Mean values, standard deviations (SD), median, and coefficients of variation (CV)

Items	I1MD[b] (mm)	I1BL[ac] (mm)	I1MDBL[ad]	I2MD[b] (mm)	I2BL[c] (mm)	I2MDBL[d]	CMD (mm)	CBL (mm)	CMDBL[a]
n	96	96	96	96	96	96	96	96	96
Mean	8.6	6.9	58.9	7.2	*6.2*	*44.4*	8.0	7.9	62.9
SD	*0.4*	0.5	6.4	0.6	0.6	6.8	0.5	0.7	8.2
Median	8.6	6.9	59.0	7.2	*6.3*	45.2	8.0	7.9	63.4
CV	*0.05*	0.08	0.11	0.08	0.10	**0.15**	0.06	0.09	0.13

Items	P1MD[ae] (mm)	P1BL[af] (mm)	P1MDBL[g]	P2MD[e] (mm)	P2BL[f] (mm)	P2MDBL[g]
n	96	96	96	96	96	96
Mean	7.5	9.6	72.6	*7.0*	9.3	65.4
SD	0.5	0.6	8.3	0.5	0.6	7.7
Median	7.5	9.7	73.7	*7.0*	9.4	64.9
CV	0.06	0.07	0.12	0.07	0.06	0.12

Items	M1MD[ah] (mm)	M1BL[ai] (mm)	M1MDBL[j]	M2MD[ah] (mm)	M2BL[ai] (mm)	M2MDBL[j]
n	96	96	96	96	96	96
Mean	**10.3**	**11.3**	**117.3**	10.0	11.1	111.2
SD	0.6	0.6	11.6	0.6	0.6	**12.1**
Median	10.3	11.4	**116.9**	10.0	11.1	110.3
CV	0.06	*0.05*	0.10	0.06	0.06	0.11

Rounded to the first decimal place (excluding CV). Maximum values are shown in bold, and minimum values are shown in italics. Significant differences are visualized with different letters ($P < 0.05$).

Table 2 Spearman's rank correlation coefficients (*rs*)

Items	I1 MD	I1 BL	I1 MD BL	I2 MD	I2 BL	I2 MD BL	C MD	C BL	C MD BL	P1 MD	P1 BL	P1 MD BL	P2 MD	P2 BL	P2 MD BL	M1 MD	M1 BL	M1 MD BL	M2 MD	M2 BL	M2 MD BL
I1MD	1.00	0.43	**0.72**	0.55	0.30	0.46	0.46	0.36	0.46	0.62	0.54	0.63	0.55	0.51	0.59	0.56	0.48	0.56	0.44	0.39	0.47
I1BL		1.00	**0.91**	0.46	0.62	0.66	0.40	0.55	0.53	0.30	0.49	0.43	0.31	0.39	0.40	0.33	0.40	0.39	0.38	0.41	0.43
I1MDBL			1.00	0.56	0.57	0.67	0.47	0.55	0.57	0.47	0.56	0.57	0.45	0.48	0.53	0.48	0.48	0.52	0.47	0.45	0.51
I2MD				1.00	0.40	**0.76**	0.33	0.32	0.37	0.48	0.35	0.45	0.45	0.35	0.45	0.43	0.33	0.39	*0.22*	0.31	*0.29*
I2BL					1.00	**0.87**	0.34	0.44	0.44	0.35	0.45	0.42	*0.25*	0.33	0.31	*0.27*	0.35	0.33	0.30	*0.23*	0.30
I2MDBL						1.00	0.40	0.48	0.50	0.49	0.47	0.51	0.40	0.40	0.45	0.40	0.40	0.42	0.31	0.31	0.34
CMD							1.00	0.55	**0.81**	0.58	0.56	0.63	0.53	0.52	0.57	0.56	0.65	0.64	0.50	0.47	0.54
CBL								1.00	**0.92**	0.32	0.57	0.48	0.36	0.49	0.46	0.34	0.47	0.43	0.33	0.51	0.45
CMDBL									1.00	0.48	0.65	0.61	0.48	0.57	0.57	0.47	0.60	0.57	0.43	0.55	0.54
P1MD										1.00	0.70	**0.91**	0.69	0.67	**0.74**	0.57	0.57	0.59	0.42	0.44	0.48
P1BL											1.00	**0.92**	0.58	**0.81**	**0.76**	0.47	0.64	0.57	0.45	0.60	0.57
P1MDBL												1.00	0.69	**0.81**	**0.82**	0.57	0.66	0.64	0.46	0.56	0.56
P2MD													1.00	0.66	**0.92**	0.69	0.58	0.67	0.52	0.58	0.60
P2BL														1.00	**0.89**	0.51	0.62	0.58	0.46	0.57	0.57
P2MDBL															1.00	0.66	0.65	0.69	0.55	0.63	0.65
M1MD																1.00	0.69	**0.92**	0.56	0.64	0.65
M1BL																	1.00	**0.90**	0.49	**0.76**	0.68
M1MDB																		1.00	0.57	**0.76**	**0.73**
M2MD																			1.00	0.62	**0.90**
M2BL																				1.00	**0.88**
M2MDBL																					1.00

Rounded to the second decimal place. Values with $rs > 0.70$ are shown in bold, and values with $rs < 0.30$ are shown in italics. *P*-value less than 0.05 was considered statistically significant.

PCA of each cluster

PCA was performed for all 96 cases and each cluster and the measurement items constituting the primary components of all or each cluster were examined. The contribution rate, cumulative contribution rate, and primary component loadings (PCL), aspects of each primary component are shown (Table 3).

In the PCA of all 96 cases, 21 pieces of information were reduced to four pieces. For the component 1, primary component loadings (PCL) for many items were above 0.70. For the component 2, the absolute value of PCL for I2MDBL was the largest at 0.59. The component 3 has a large absolute value of PCL for CBL and CMDBL. The PCL of M2MD and M2MDBL was large in the component 4. The cumulative contribution rate was 80.2%.

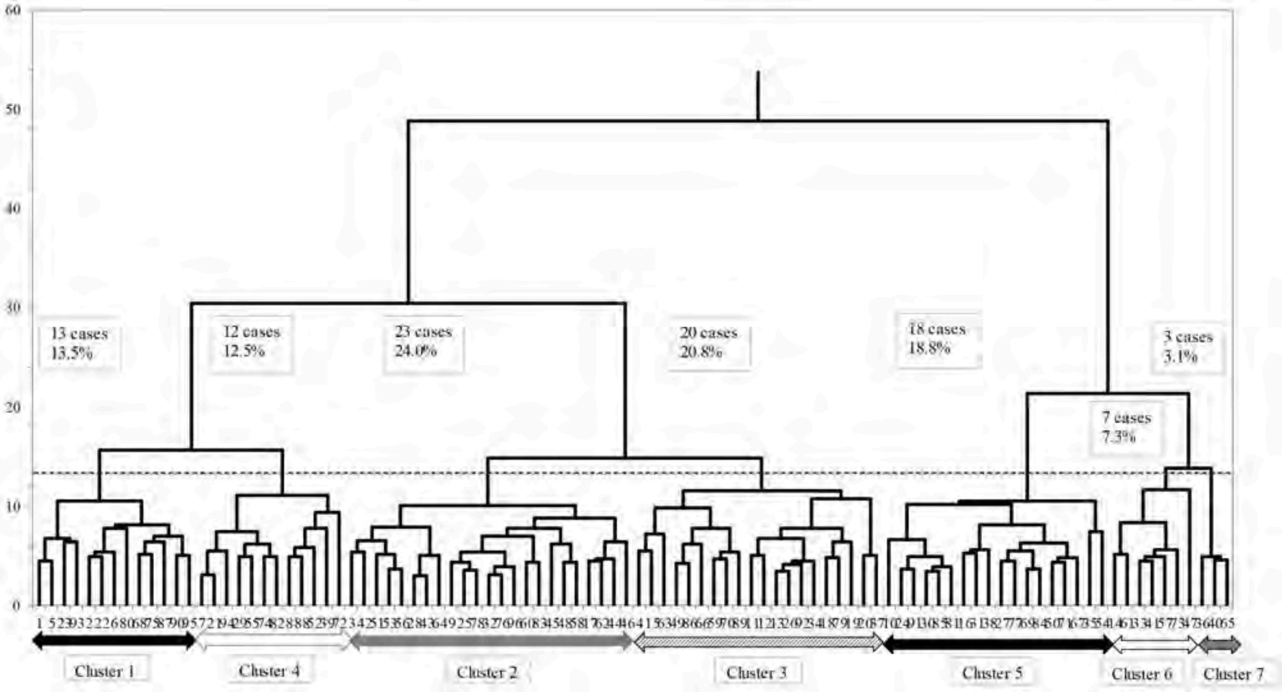

Fig. 2 Dendrogram of maxillary dentitions clustering
The largest cluster was cluster 2 with 23 cases (24.0%), and the smallest cluster was cluster 7 with three cases (3.1%).

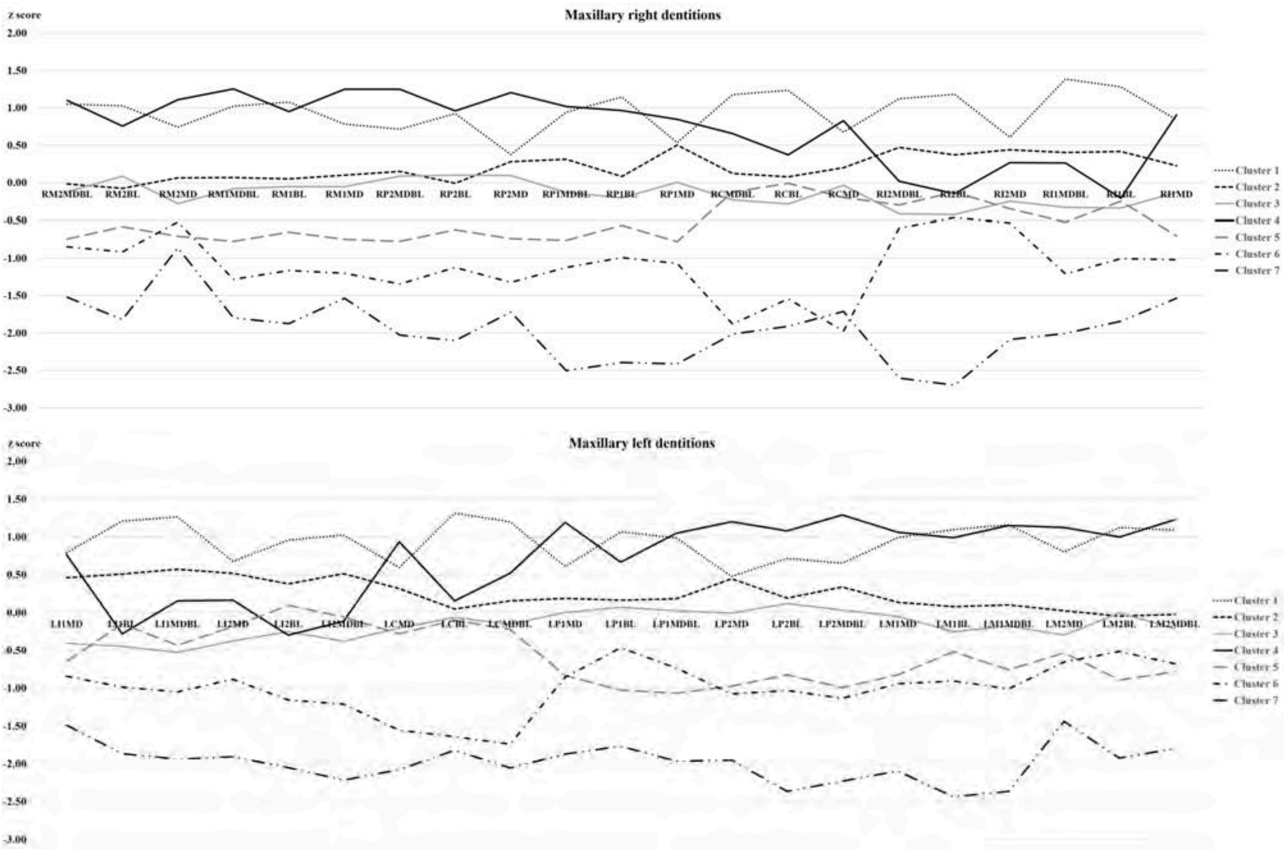

Fig. 3 Graphic drawing of seven clustering groups
Upper: Maxillary right dentitions (second molar to central incisor), Lower: Maxillary left dentitions (central incisor to second molar)

When PCA was performed by cluster, clusters 1 and 4 had four primary components. Clusters 2, 3, and 5 also had five primary components, cluster 6 had three primary components, and cluster 7 had two primary components. The component 1 of cluster 1 shows 0.80 or more for I1BL, CBL, and P1BL PCL. The component 2 showed 0.76 or more of the I2BL and I1MD PCL. All MDBL and M1BL, M2BL were linearly combined. The component 1 of cluster 2 shows 0.75 or more P1BL, P1MDBL, P2BL, and P2MDBL PCL. As for the component 2, the PCL of M2BL and M2MDBL was 0.74 or more. None of the items were linearly combined.

Table 3 Principal component loadings (PCL), contribution ratio, and cumulative contribution ratio of each cluster

All 96 cases	Comprehensive tooth size	Size of molars relative to anterior teeth	Size of incisors and first premolars relative to canine	Size of lateral teeth relative to second molar
Items	Component 1	Component 2	Component 3	Component 4
I1MD	**0.72**	−0.12	0.33	0.06
I1BL	0.67	−0.50	−0.21	0.20
I1MDBL	**0.80**	−0.41	0.00	0.17
I2MD	0.59	−0.47	0.40	0.07
I2BL	0.63	−0.54	−0.03	0.15
I2MDBL	**0.71**	−0.59	0.19	0.14
CMD	**0.72**	0.11	−0.32	−0.20
CBL	**0.70**	−0.23	−0.54	−0.24
CMDBL	**0.78**	−0.10	−0.49	−0.24
P1MD	**0.79**	0.12	0.35	−0.28
P1BL	**0.82**	0.00	−0.06	−0.28
P1MDBL	**0.88**	0.07	0.15	−0.30
P2MD	**0.80**	0.24	0.28	−0.11
P2BL	**0.80**	0.13	0.06	−0.36
P2MDBL	**0.87**	0.22	0.20	−0.25
M1MD	**0.76**	0.30	0.18	0.25
M1BL	**0.82**	0.22	−0.08	0.11
M1MDBL	**0.85**	0.29	0.06	0.20
M2MD	0.64	0.30	−0.09	0.45
M2BL	**0.77**	0.28	−0.23	0.26
M2MDBL	**0.79**	0.33	−0.17	0.40
Contribution ratio	57.9%	9.6%	6.6%	6.1%
Cumulative contribution ratio	57.9%	67.5%	74.1%	80.2%

Cluster 1 Total large (TL) type	Key tooth size for each tooth type	Size of lateral teeth relative to incisors	Size of lateral incisor, canine, second premolar and first molar	Size of incisors and first molar relative to second molar
Items	Component 1	Component 2	Component 3	Component 4
I1MD	0.44	**0.76**	−0.08	−0.38
I1BL	**0.89**	−0.05	−0.28	−0.13
I2MD	0.11	0.50	0.66	−0.30
I2BL	0.19	**0.93**	−0.09	0.09
CMD	0.45	−0.40	0.61	0.19
CBL	**0.81**	−0.25	0.40	0.02
P1MD	0.42	0.42	0.09	−0.14
P1BL	**0.90**	−0.13	−0.21	0.11
P2MD	0.44	0.09	0.57	0.08
P2BL	0.61	−0.61	−0.12	−0.10
M1MD	−0.65	−0.25	0.59	−0.35
M2MD	−0.05	0.40	0.23	**0.85**
Contribution ratio	32.3%	22.5%	15.5%	9.9%
Cumulative contribution ratio	32.3%	54.8%	70.3%	80.3%

Table 3 continued

Cluster 2 Anterior slightly large (ASL) type	Size of premolars	Size of lateral incisor relative to molars	Size of second premolar and first molar relative to canine and second molar	Size of central incisor relative to lateral incisor and canine	Size of canine and first premolar relative to lateral incisor
Items	Component 1	Component 2	Component 3	Component 4	Component 5
I1MD	−0.27	−0.24	−0.16	−0.48	−0.36
I1BL	0.20	0.19	0.50	−0.38	0.25
I1MDBL	0.01	0.03	0.41	**−0.74**	0.01
I2MD	−0.05	−0.63	−0.02	0.38	0.14
I2BL	0.61	−0.19	0.26	0.22	0.50
I2MDBL	0.39	−0.57	0.17	0.43	0.45
CMD	0.32	−0.09	0.42	0.57	−0.50
CBL	−0.24	0.15	**0.72**	0.33	−0.07
CMDBL	0.01	0.04	**0.73**	0.53	−0.33
P1MD	0.66	−0.09	−0.12	0.10	−0.64
P1BL	**0.78**	0.05	0.18	−0.23	0.04
P1MDBL	**0.87**	−0.02	0.03	−0.06	−0.38
P2MD	0.35	0.51	−0.37	0.04	−0.24
P2BL	**0.86**	0.01	−0.05	−0.24	0.24
P2MDBL	**0.76**	0.32	−0.26	−0.12	−0.01
M1MD	−0.36	0.41	−0.52	0.32	−0.07
M1BL	0.42	0.66	−0.19	0.25	0.20
M1MDBL	−0.06	0.66	−0.50	0.38	0.05
M2MD	−0.20	0.44	−0.57	−0.29	−0.23
M2BL	−0.04	**0.77**	0.25	0.18	0.33
M2MDBL	−0.14	**0.74**	0.49	−0.05	0.07
Contribution ratio	20.9%	17.3%	15.3%	12.3%	9.1%
Cumulative contribution ratio	20.9%	38.2%	53.4%	65.7%	74.9%

Cluster 3 Incisor slightly small (ISS) type	Size of molar relative to lateral teeth	Size of canine relative to incisors and premolars	Size of central incisor	Buccolingual crown diameter of second premolar relative to lateral incisor and first molar	Mesiodistal crown diameter of second molar relative to central incisor
Items	Component 1	Component 2	Component 3	Component 4	Component 5
I1MD	0.16	−0.56	0.21	−0.34	−0.64
I1BL	0.17	0.49	**0.75**	0.05	0.21
I1MDBL	0.26	0.13	**0.84**	−0.16	−0.18
I2MD	0.16	**−0.70**	0.50	0.26	−0.13
I2BL	0.46	−0.34	0.18	0.56	0.46
I2MDBL	0.36	−0.63	0.42	0.47	0.18
CMD	0.03	0.38	−0.17	0.50	−0.37
CBL	0.69	0.62	0.15	0.00	0.06
CMDBL	0.61	0.68	0.07	0.20	−0.09
P1MD	0.47	−0.55	−0.27	0.01	0.31
P1BL	**0.89**	0.20	0.05	−0.16	−0.01
P1MDBL	**0.88**	−0.11	−0.09	−0.11	0.13
P2MD	−0.29	−0.30	0.21	0.04	−0.07
P2BL	0.60	0.17	0.22	−0.49	0.03
M1MD	−0.43	−0.22	0.47	0.24	−0.39
M1BL	−0.16	0.60	−0.15	0.64	−0.18
M2MD	−0.66	−0.06	0.19	−0.15	0.47
M2BL	−0.47	0.53	0.40	−0.06	0.04
M2MDBL	**−0.75**	0.25	0.35	−0.13	0.38
Contribution ratio	26.4%	20.0%	13.6%	9.6%	8.2%
Cumulative contribution ratio	26.4%	46.3%	59.9%	69.6%	77.8%

Table 3 continued

Cluster 4 Molar large (ML) type	Size of incisor and premolars	Size of second molar relative to canine	Size of premolar relative to central incisor	Size of lateral incisor relative to second molar
Items	Component 1	Component 2	Component 3	Component 4
I1MD	0.48	0.11	**−0.70**	0.18
I1BL	0.65	−0.06	0.56	−0.27
I2MD	**0.70**	0.04	−0.12	−0.52
I2BL	0.61	−0.26	0.20	0.43
CMD	−0.02	**0.84**	0.15	0.34
CBL	−0.58	**0.71**	−0.13	0.18
P1MD	**0.83**	0.20	−0.34	0.31
P1BL	0.58	0.35	0.62	0.14
P2MD	**0.86**	0.04	−0.44	−0.03
P2BL	0.32	0.63	0.35	−0.23
M2MD	0.13	-0.57	0.38	0.51
Contribution ratio	33.9%	19.8%	16.9%	10.3%
Cumulative contribution ratio	33.9%	53.7%	70.6%	80.9%

Cluster 5 Central incisor & molar slightly small (I1MSS) type	Size of first premolar relative to incisors	Size of canine and first molar relative to lateral incisor and premolars	Size of central incisor relative to first premolar and second molar	Mesiodistal crown diameter of second premolar	Mesiodistal crown diameter of first premolar
Items	Component 1	Component 2	Component 3	Component 4	Component 5
I1MD	0.56	0.04	−0.53	0.33	0.37
I1BL	**0.87**	0.20	−0.12	0.19	0.03
I1MDBL	**0.84**	0.16	−0.30	0.27	0.19
I2MD	0.49	−0.47	−0.33	0.00	−0.20
I2BL	0.64	0.20	0.53	−0.39	0.08
I2MDBL	**0.82**	−0.02	0.34	−0.37	−0.02
CMD	0.10	0.65	−0.03	0.13	0.34
CBL	0.48	−0.67	0.08	−0.10	0.25
P1MD	−0.54	0.33	0.21	0.25	0.63
P1BL	0.14	−0.67	0.57	0.40	−0.01
P1MDBL	−0.14	−0.44	0.63	0.51	0.30
P2MD	0.13	0.08	0.30	**−0.75**	0.47
P2BL	−0.36	−0.50	0.34	−0.32	0.09
M1MD	0.04	**0.84**	0.35	−0.13	−0.27
M1BL	−0.04	0.66	0.23	0.26	−0.14
M2MD	0.21	0.38	0.66	0.25	0.02
M2BL	0.34	−0.07	0.64	0.28	−0.35
Contribution ratio	23.5%	20.4%	17.1%	11.2%	7.8%
Cumulative contribution ratio	23.5%	43.9%	61.0%	72.2%	80.0%

Cluster 6 Canine small (CS) type	Size of the non-canine teeth	Size of canine and first premolar	Size of second premolar relative to central incisor
Items	Component 1	Component 2	Component 3
I1MD	**0.72**	−0.40	0.54
I1BL	**0.81**	−0.23	0.39
I2MD	**0.87**	0.20	0.32
I2BL	**0.74**	0.12	−0.19
CMD	−0.59	0.58	0.34
CBL	−0.37	**0.79**	0.39
P1MD	0.65	0.59	−0.16
P1BL	0.65	0.61	−0.16
P2MD	0.64	0.11	−0.44
Contribution ratio	47.0%	21.9%	12.2%
Cumulative contribution ratio	47.0%	68.9%	81.1%

Table 3 continued

Cluster 7 Smallest (S) type	Central incisor size	Size of buccolingual crown diameter relative to mesiodistal crown diameter of central incisor
Items	Component 1	Component 2
I1MD	**0.86**	0.51
I1BL	**0.86**	−0.51
Contribution ratio	74.0%	26.0%
Cumulative contribution ratio	74.0%	100.0%

When rounded to the second decimal place (PCL), the numerical values showing the primary component loadings PCL of ±0.70 or more are indicated in bold.

Table 4 Characteristics of each cluster

Cases	Types	Characteristics of components
All 96 cases	—	Component 1: The PCL of many items is 0.70 or more. Component 2: Negative PCL values for the incisors and canines, and positive values for the molars. The smaller the lateral incisor, the higher the primary component score (PCS). Component 3: When the larger the PCS, it is tended that the smaller the canines and second molars, and conversely, the larger the MD of the incisors and first premolars. Component 4: When the larger the PCS, it is tended that the smaller the canines and premolars, and conversely, the larger the second molars.
Cluster 1	Total large (TL) type	Component 1: A large absolute value of PCL for the key teeth of each tooth type, and when the central incisor, canine, and first premolar are large, the mesiodistal crown diameter of the first molar tends to be small.
Cluster 2	Anterior slightly large (ASL) type	Component 2: The PCL of the molars shows positive, while the PCLs of I2MD and I2MDBLwere negative. Therefore, if the molars are large, the lateral incisors tend to be small. Component 3: The canine PCL was positive, while the M1MD and the M1MDBL PCLs were negative. The first molar tends to be small when the canine is large.
Cluster 3	Incisor slightly small (ISS) type	Component 1: The tendency for the second molars to be small when the canines and first premolars are large. Component 2: Small canines and second molars when incisors and first premolars are large.
Cluster 4	Molar large (ML) type	Component 1: Only the canine PCL showed a negative value, when the lateral incisors and premolars were large, the canines tended to be small. Component 2: When PCS was large, the mesiodistal crown diameter of the second molar tended to decrease. Component 4: M2MD was 0.51 while I2MD was −0.52. When the mesiodistal crown diameter of the lateral incisor was small, that of the second molar was large.
Cluster 5	Central incisor & molar slightly small (I1MSS) type	Component 1: The PCL of P1MD showed −0.54. The first premolar tended to be small when the incisor was large. Component 2: The PCL of M1MD showed 0.84. The first premolar tended to be small when the first molar was large.
Cluster 6	Canine small (CS) type	Component 1: Negative values only for canine PCL. Component 2: Negative values only for central incisor PCL. Central incisor and canine trend opposite to that of the other tooth sizes presumably associated with the features of dentition.
Cluster 7	Smallest (S) type	Component 1: The PCLs of I1MD and I1BL had the same value. Component 2: The absolute PCL values of I1MD and I1BL were the same.

As for the component 1 of cluster 3, the PCL of P1BL and P1MDBL showed 0.88 or more. As for the component 2, the PCL of I2MD showed −0.70. P2MDBL and M1MDBL were linearly combined. The component 1 of cluster 4 showed a PCL of 0.83 or more for P1MD and P2MD and a PCL of 0.70 for I2MD. The component 2 showed 0.84 for CMD PCL and 0.71 for CBL PCL. All MDBL and M1MD, M1BL, and M2BL were linearly combined. As for the component 1 of cluster 5, the PCL of I1BL, I1MDBL, and I2MDBL showed 0.82 or more. As for the component 2, the PCL of M1MD showed 0.84. CMDBL, P2MDBL, M1MDBL, and M2MDBL were linearly combined. In the component 1 of cluster 6, the PCLs of I1MD, I1BL, I2MD, and I2BL were 0.72 or more. As for the component 2, the PCL of CBL was 0.79. All MDBL, P2BL, M1MD, M1BL, M2MD, and M2BL were linearly combined. As for the component 1 of cluster 7, the PCL of I1MD and I1BL showed 0.86. The component 2 showed 0.51 for I1MD PCL and −0.51 for I1BL PCL. Other items were linearly combined. The types and characteristics of components for each cluster are shown in Table 4.

Table 5 Results of statistical analysis

Parametric test				
Objective variables	Bartlett's test			One-way ANOVA
	χ^2	DOF	*P*-value	*F*-value, *P*-value
I1MD	5.03	6	0.54	F (6, 92) = 18.17, $P < 0.001$
I1BL	4.26	6	0.64	F (6, 92) = 20.81, $P < 0.001$
I1MDBL	11.67	6	0.07	F (6, 92) = 30.09, $P < 0.001$
CMD	10.00	6	0.12	F (6, 92) = 26.90, $P < 0.001$
CMDBL	4.64	6	0.59	F (6, 92) = 36.96, $P < 0.001$
P2BL	4.14	6	0.66	F (6, 92) = 30.98, $P < 0.001$
P2MDBL	8.23	6	0.22	F (6, 92) = 50.38, $P < 0.001$
M1MD	4.77	6	0.57	F (6, 92) = 29.45, $P < 0.001$
M1BL	7.16	6	0.31	F (6, 92) = 29.66, $P < 0.001$
M1MDBL	3.48	6	0.75	F (6, 92) = 45.47, $P < 0.001$
M2BL	2.78	6	0.84	F (6, 92) = 3.34, $P < 0.001$

Non-parametric test				
Objective variables	Bartlett's test			Kruskal-Wallis test
	χ^2	DOF	*P*-value	χ^2, *P*-value
I2MD	−	−	−	χ^2 (6) = 36.64, $P < 0.001$
I2BL	−	−	−	χ^2 (6) = 47.94, $P < 0.001$
I2MDBL	−	−	−	χ^2 (6) = 54.49, $P < 0.001$
CBL	−	−	−	χ^2 (6) = 52.74, $P < 0.001$
P1MD	17.34	6	0.01	χ^2 (6) = 7.59, $P < 0.001$
P1BL	−	−	−	χ^2 (6) = 63.34, $P < 0.001$
P1MDBL	14.10	6	0.03	χ^2 (6) = 67.91, $P < 0.001$
P2MD	16.66	6	0.01	χ^2 (6) = 4.37, $P < 0.001$
M2MD	−	−	−	χ^2 (6) = 50.46, $P < 0.001$
M2MDBL	−	−	−	χ^2 (6) = 64.61, $P < 0.001$

−: No tested. There were some data not to follow a normal distribution.

Test of difference between clusters

Regarding the normality of the data, the Kruskal-Wallis test was performed for I2MD, I2BL, I2MDBL, CBL, P1BL, M2MD, and M2MDBL because they did not follow a normal distribution. The Kruskal-Wallis test was also conducted for P1MD, P1MDBL, and P2MD because they could not be assumed to be equally distributed, although they did follow a normal distribution. For the other items, one-way ANOVA was conducted to test for differences between clusters (Table 5).

Discussion

The MD and the BL of the teeth within 96 maxillary dentitions were measured. Some significant differences were observed in the mean values between the left and right corresponding teeth (Table 1). However, there is also a report that there is no significant difference in MD and BL of the corresponding teeth [10].

The CV looks at the size of the relative variability with respect to the average value. In this study, though the CV of lateral incisors was larger than that of other teeth, the CV of the central incisor MD and first molar BL showed the lowest value overall. In this regard, Dahlberg [8] suggests that there are separate fields of development and growth for incisors, canines, premolars, and molars, each field being strongest in the mesial or key teeth of the tooth types. The central incisors are most centrally positioned among the incisors and were most strongly affected at the site of incisor formation, suggesting less variability in size and morphology [11]. Sofaer et al. [3] found that, except for the mandibular incisors, the most distal teeth of each tooth type grow later than the most mesial teeth. Therefore, it is affected by fluctuations in available space. In addition, it has been reported that even among the same tooth types, teeth that grow later have greater variation than teeth that grow faster [12]. Since the lateral incisors grow slower than the central incisors, it can be said that the variation in teeth is large.

Rs also showed a different tendency for lateral incisors compared to other teeth. Townsend et al. stated that as the lateral incisors are formed near the boundary between the primary palate and the maxillary process, there might be related to variations in the size and morphology of the maxillary lateral incisors [13].

On the other hand, I1MD showed a moderate or higher positive correlation with MD of other teeth. The central incisor may affect the length of the dental arch [4]. Together, these results and reports by Brook [12] and Townsend [13] suggest that the determination of the MD of the central incisor may at least increase lateral incisor size variability. In addition, Kondo et al. [14] stated that variations in maxillary lateral incisor morphology could be explained by genetic, acquired, and environmental factors. Regarding the "Inhibitory cascade model" [15], he reported it is thought central incisors inhibit the development of lateral incisors, and when the central incisors are large, the lateral incisors become small, and when the central incisors are small, the lateral incisors become large [14]. Almost premolars and molars showed *rs* of 0.50 or more between the same type of teeth, which can also be explained by Dahlberg's theory [8].

The maxillary dentition was classified according to characteristics using the tooth measurement values, resulting in seven classifications (Fig. 2). The number of clusters was set so that the characteristics of each cluster were as clear as possible. When the status of each cluster was presented in graphic drawing, the graphic drawing of all clusters showed similar shapes on the left and right (Fig. 3). As a result of testing the difference between clusters for the items of the maxillary dentition classified into seven, significant differences were observed for all items. Therefore, this suggests a difference in the pattern of the dentition structure for each cluster.

In the PCA of all 96 cases, 21 measurement items were reduced to 4 items (Table 3). The component 1 represents the "comprehensive tooth size" (Tables 3, 4). This was similar to the report by Harris [16]. The component 2 showed when anterior teeth become larger, the molars become smaller. Therefore, it is expressed as "size of molars relative to anterior teeth" (Tables 3, 4). This was almost same kind of reports by Hanihara [17], which generally supports the results of this study. The component 3 expresses “size of incisors and first premolars relative to canine” (Tables 3, 4). The component 4 expresses “size of lateral teeth relative to second molar" (Tables 3, 4). This was similar to reports by Harris [16], which generally supports the results of this study. Regarding the size and configuration of teeth within a single maxillary dentition, there was on the possibility of a relationship in which one tooth becomes larger while the other becomes smaller.

Next, the characteristics and components for each cluster were considered (Fig. 3, Tables 3, 4). The dentition of cluster 1 is composed of large teeth overall. Therefore, it is expressed as the “total large (TL) type”. In the cluster 2, this dentition has the characteristics the anterior teeth are slightly larger than the overall average but the posterior teeth tend to approach the overall average. Therefore, it is described as the “anterior slightly large (ASL) type”.

The dentition of cluster 3 has characteristics of the size of the teeth after the canines approach the overall average and the size of the incisors is slightly smaller than the overall average, so it is defined as the “incisor slightly small (ISS) type”. The dentition of cluster 4 is composed of large teeth as a whole except for the lateral incisors. This tendency is particularly conspicuous in the posterior region, so it was expressed as the “molar large (ML) type”. The dentition of cluster 5 has characteristics that the lateral incisor and canine are values close to the overall average, but the central incisor and molars are slightly small. They were set as “the central incisor & molar slightly small (I1MSS) type”.

The dentition of cluster 6 was set as the “canine small (CS) type”, and the cluster 7 was named the “smallest (S) type” because all teeth were significantly smaller than the average. Most of the items were linearly combined, and it was composed of the MD and BL of the central incisors. Since the number of cluster 6 samples is 7 and the number of cluster 7 samples is 3, they will be necessary to increase the number of samples and add further examinations.

By the way, looking at the first principal component of each cluster, the absolute value of PCL was high for incisors in cluster 4, cluster 5, cluster 6, and cluster 7, and for premolars in cluster 2, cluster 3, and cluster 4 (Table 3). In this study, the incisors or premolars were found to have the most information out of the total information in the composition of the dentition. Hanihara [17] cited the relative size of the incisors and premolars as a factor characterizing a geographically isolated Japanese population. Ueno et al. [4] also reported the length of the dental arch is mainly influenced by the mesiodistal diameters of the central incisors and second premolars in the upper jaws. It is suggested that the influence of incisors and premolars on the composition of the maxillary dentition cannot be ignored.

From the result 4, significant differences were observed among the seven clusters in all items. In some cases, tooth sizes tend to be similar overall within a cluster, and in other cases, there is a relationship that if a certain tooth or a certain tooth type becomes larger, the other becomes smaller.

It is suggested that differences in tooth size between teeth or tooth types are observed within at least one dentition, and similar tendencies, such as large or small tooth sizes, are found in all dentitions, suggesting that there is some mutual influence on tooth size in the whole dentition.

However, in this study, the arch length or the arch width were not measured. Therefore, the relationship between tooth size and dental arch size was not compared. In addition, since the presence or absence of third molars is also unknown, the presence or absence of compensatory growth of other teeth due to the absence of third molars was not examined [18]. Kondo et al. [14] suggested that the large left-right asymmetry of the maxillary lateral incisors is related to the compensatory growth of the lateral incisors, suggesting that the tendency for degeneration and compensatory growth is limited within tooth type and rarely appears in the entire dentition.

On the other hand, there is a report that the maxillary lateral incisors may grow to compensate for the size of the maxillary central incisors [19], and there is also a report that compensatory growth is also observed in premolars [20]. In our results, there was a tendency to compensate for tooth size between anterior and posterior teeth. The results of this study alone cannot tell whether teeth are undergoing compensatory growth. However, there is room for further investigation because there is a possibility that the tooth size in the entire dentition has some influence on each other.

This study focused on the size of the teeth that make up one dentition. Lundstrom stated that the morphology of the dental arch is strongly genetically controlled [21]. Menezes et al. reported that the relative magnitude of the influence of environmental and genetic factors changed over time, with environmental factors probably being more important [22]. Mizoguchi [23] reported that teeth with low genetic diversity had been controlled by the most common genes throughout human evolution. Kondo et al. [14] reported that size is more heritable than morphology for the regression of maxillary lateral incisors in a twin model. Furthermore, the growth of distal teeth of each tooth type is affected by the determination of the crown width of key teeth in the growth field of each tooth type [8]. These results suggest that although tooth size and arch morphology are determined by genetic characteristics, environmental factors particularly affect the arch length, resulting in variations in the size of the distal teeth of each tooth type.

The inhibition cascade model states that the early-developing first molar suppresses the growth of the late-developing second molar [15]. Kondo et al. [14] stated that this model may also be applicable to incisors and premolars. As research progresses from an embryological point of view, it is expected that factors, including the inter-tooth relationship and the influence on dentition, will be elucidated.

The present study demonstrated that, the maxillary dentition is composed of the size of each tooth and the size of the teeth within the same tooth type or between different tooth types, and there are two groups: one group has a constant size trend of each tooth and the other group has a combination of size trends of teeth. Moreover, the incisors or premolars were found to have the most information out of the total information in the composition of the dentition. This suggests that it is especially useful to consider the size of incisors and premolars in treatment planning in pediatric dentistry and orthodontic treatment.

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Conflicts of Interest
The authors declare no conflicts of interest.

Author contributions
AF: conceptualization; investigation; methodology; visualization; writing – original draft, SH: conceptualization; methodology; writing – review and editing, MN: supervision; formal analysis; writing – review and editing

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