ORIGINAL

Morphological study of the palatal rugae in Japanese

I. Bilateral differences in the regressive evolution of the palatal rugae

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Abstract : The bilateral differences in the type, number, form and distribution of the palatal rugae were studied in 410 maxillary dental casts of Japanese adults to investigate whether the regressive evolution of the rugae proceeds more, in the right or left side of the palate.

1. There was no bilateral difference in the mean number of the primary rugae. However, in the mean number of all the rugae including the primary, secondary and fragmentary rugae, the regressive evolution progressed more in the right side.

2. The distinct postero-anterior changes in the direction, shape, origin and papillate rugae of the primary rugae indicated that the rugae degenerated from the posterior part of the hard palate.

(1) The right rugae of which the direction distinctly inclined backward, degenerated more than the left. (2) The bilateral differences in the shape and origin were observed only on the posterior rugae. The right rugae degenerated more in the shape, but in the origin the left rugae degenerated more. (3) There was no bilateral difference in the papillate rugae, but the regressive evolution was considered to extend to the first rugae because the papillate rugae were observed in the first rugae at the higher frequency of 34~40%.

From the above view, the clear bilateral differences were found in the morphology of the palatal rugae. The results showed that the regressive evolution of the rugae in both sides does not proceed at the same time, but proceeded more in the right side than in the left.

抄録：日本人成人 410 人の上顎歯列模型を資料とし、横口蓋ヒダの種類、数、形および分布の左右差を調べ、左右側のどちらでヒダの退化が進んでいるかを検討した。1. 1 級ヒダの平均数には左右差が認められなかったが、1 級ヒダ、2 級ヒダおよび断片ヒダを含むヒダ総数からみた退化は右側で進んでいた。2. 1 級ヒダの走行、外形、始点および数珠状ヒダに明瞭な順位差が認められ、ヒダは硬口蓋の後方から退化していた。(1) 右側のヒダの走行は後方へ強く傾斜し、左側より退化が進んでいた。(2) ヒダの外形と始点には後方のヒダでのみ左右差が認められ、ヒダの外形では右側で退化が強く、始点では左側で強かった。(3) 数珠状ヒダには左右差が認められなかったが、第 I ヒダに 34~40% の高い頻度で出現したことから、退化は第 I ヒダにも及んでいることが考えられた。以上から、横口蓋ヒダの形態には明瞭な左右差が認められた。また、ヒダの退化は左右側で同時に進行せず、右側のヒダは左側より退化が早いと示唆された。

Introduction

Palatal rugae are found in the anterior part of the hard palate of the human mouth. The human palatal rugae, compared to other mammals, distinctly show the regressive evolution, so the number of rugae is few, and the shape and arrangement are irregular¹⁻³⁾. Most mammals have the well-developed rugae all over the palate which is characteristic of its species. So it is considered because feeding habits largely affect the number and shape of rugae. Generally, herbivorous animals have many well-grown and firm rugae similar to a strap over the palate. On the other hand, carnivorous or omnivorous animals have few and varied rugae similar to a string only in the anterior part of the hard palate⁴⁻⁷⁾. In the human mouth, palatal rugae take part in the digestion process and have supplementary functions in mastication, pronunciation, swallowing and drinking milk during infancy.

With respect to palatal rugae, Schultz³⁾ described that the rugae were first mentioned in scientific writing by Winslow (1753). Since, comparative anatomical and developmental studies have been done⁸⁻¹⁴⁾. Suganuma¹⁵⁾, Okada¹⁶⁾ and Murakami¹⁷⁾ made the earliest morphological studies of the palatal rugae in Japanese, and several morphological or anthropological reports were since made public¹⁸⁻²⁷⁾. Henckel⁸⁾ gave the range of variation in the number of rugae to be 3~6 rugae in Melanesians and Schultz³⁾ reported the number to be 3~7 in Caucasians. Murakami¹⁷⁾ reported 3~6 rugae in Japanese females and 3~7 in Japanese males. But, the human palatal rugae showed the most regressive evolution among the Primates, and its pattern was so widely varied that it looked apparently irregular, asymmetrical and complicated³⁾. Lysell¹¹⁾ determined a system of classification and a detailed method of measurement to treat other morphological observations quantitatively in addition to the number of the rugae, and studied the palatal rugae in Swedes. Yamazaki^{25,26)} observed and measured the Japanese palatal rugae following Lysell's method. He described that the morphological change in order of the postero-anterior direction of the hard palate and the bilateral difference were

recognized, but no sex differences were seen in the form and distribution of the rugae. Almost no difference in the number of the rugae was observed between the Japanese and the Swedes. Todoroki²⁸⁾ has also recently made the anthropological studies of the Korean palatal rugae by the Lysell's method.

Through the history of human evolution, palatal rugae have degenerated inevitably accompanied by the evolution of teeth (in size, form and number) and the reduction of the face. It is of morphological interest whether the bilateral difference exists in the regressive evolution of the rugae. However, no discussions have been made from this point of view.

The authors have investigated in detail a large number of materials about the type, number, form and distribution of palatal rugae, and have attempted to clarify whether any bilateral difference in their characteristics exists or not, especially on which side of the hard palate, the rugae have a greater tendency to degenerate more.

Materials and Methods

The materials in this study were 410 maxillary dental casts of Japanese adults aged 19 to 24 years (205 females and 205 males), who have no missing teeth and malalignment except for the third molars. More materials are necessary to observe exactly the morphological changes of the posterior rugae, because fewer rugae were observed in the further posterior parts of the hard palate. Accordingly, many materials on the males and females were examined, and were given careful consideration for the study.

The method primarily used, was the one described by Lysell¹¹⁾, Yamazaki²⁵⁾ and Todoroki²⁸⁾, however the classification of the primary rugae and the standard of observations were partially modified by the authors.

1. Classification and numeration of the rugae

The rugae (palatal rugae) were classified into 3 groups as primary, secondary and fragmentary.

Primary ruga : This ruga is a basic type for human ruga and its prominence was high. This corresponds to the ordinary primary ruga which was classified by

Lysell, not including the extra primary ruga. The primary ruga had 3 conditions as follows.

1) The ruga was 5 mm or more in length. The length, which was represented as the distance between the origin and termination of the ruga, was measured with a slide caliper accurate within 0.05 mm.

2) The whole or most part of the prominence was not conspicuously lower compared to the anterior ruga. As to the width, the rugae generally have a tendency to become narrow in order of the antero-posterior direction of the hard palate, but the narrow ruga was sometimes included.

3) The origin existed within the medial 3/4 of the ruga zone.

Secondary ruga : All the rugae which were 3 mm or more in length and had narrow and low prominences were classified as secondary rugae. The extra pri-

mary ruga which was defined by Lysell (it was 5 mm or more in length but its prominence was low) was classified as a secondary ruga.

Fragmentary ruga : The ruga was 2 mm or more and under 3 mm in length.

The origin and termination of the ruga mean the medial and lateral ends of the ruga, respectively. The medial margin of the ruga zone was set on the median line of the hard palate, which was drawn between the anterior point near the first rugae and the posterior point near the first molars on the palatine raphe. The lateral margin was made by the line joining the terminations of the rugae in the most lateral part of the ruga zone (Fig. 1).

Only the primary rugae were numbered in order of the antero-posterior direction for each side of the hard palate. The right first ruga, second ruga...were

Fig. 1 Classification of the rugae. The primary ruga is 5 mm or more in length and the origin exists within the medial 3/4 of the ruga zone. RI and LI, and L II/L III are classified as the branched rugae and the united rugae with common origin, respectively. The distance (a) represents the bilateral difference of the posterior limit of the ruga zone.

Fig. 2 Variety in the shape of the ruga.

denoted as R I, R II...and the left first ruga, second ruga...as L I, L II...etc. Since it was sometimes difficult to decide the order of the rugae, the orders were made according to the relative positions of the mid-points on the rugae. Where two rugae crossed, the orders were so as to be similar. Where another primary ruga existed between the twigs of the branched ruga, the branched ruga was given the lower number. The detailed morphological studies were made about the primary rugae I-IV, but the fifth and sixth rugae were excluded from the observations because few casts had these rugae.

Before the observation and photography were started, the casts were prepared to be written on, the outlines along the ruga prominences and two points on the palatine raphe which needed to draw the median line with a slender-writing propelling pencil.

2. Observation of the form of the primary rugae

1) Shape

The shapes were classified into 3 types as curved, angular and straight (Fig. 2). The curved type had a simple form which curved gently. Sometimes it bent on a small scale at the termination. If it had not spoiled an impression of a curved form, it was classified as curved type. The angular type bent with one or more angles and ran in a complicated fashion as a whole. The straight type ran straight from the origin to the termination. Where the twigs of the branched ruga were different types, if at least the one was angular type, it was classified as angular. In the same way, where the twigs showed straight and curved, the

Fig. 3 Papillate rugae. The grooves (arrows) cross on the ruga prominences. Bar=1 mm

ruga was classified as curved.

2) Papillate rugae

The ruga whose grooves crossed in part or as a whole of its prominence was observed often, and such a ruga was recorded as papillate (Fig. 3). The weakest type, which had only one transverse groove but whose stroke must cross the prominence from one side to the other, was classified as a papillate ruga.

3) Branched rugae

The branched ruga had one origin and several terminations and its termination existed more lateral to the junction of the twigs. Their twigs were 2 mm or more in length and the twigs under 2 mm were excluded from the observation. If the junction point coincided with the origin, it was classified as united ruga, not as branched ruga.

4) United rugae

The united rugae whose two rugae joined were classified into 2 types as common and separate origins. The rugae which began from the same origin but immediately diverged were classified as common origin. The rugae with different origins which joined on the lateral portion out of the origin were classified as separate origins. But if there was a deep groove between two rugae and their prominences were not fused, the rugae were considered as a contacted type and not classified as united.

3. Observation of the distribution of the primary rugae

The observation and measurement in the distribu-

tion of the rugae were performed on the photographs of the maxillary dental casts which were printed in 1.5-fold enlargement for the standard size. By taking the standard photographs of them, the horizontal plane which was represented by 3 points (the incisal edge of the maxillary left central incisor and the mesiolingual cusp tips of the right and left first molars) coincided with the standard plane of the dental cast. The Nikon Micro-Nikkor 200 mm f/4 lens was set so vertical to the standard plane under the conditions of 120 cm working distance and f/32 that the light ray axis of lens may pass about the middle of the ruga zone.

1) Origin

The origins were classified into 3 types as raphe origin, medial half and lateral half. The raphe origin included the ruga which began from the palatine raphe and contacted with it. The mid-line, which bisected the median line and the lateral margin, separated the ruga zone into medial and lateral halves. The ruga whose origin existed in the medial half and on the mid-line was classified as the medial half and the one whose origin existed in the lateral half was classified as the lateral half. Lysell and Yamazaki classified such a ruga which contacted with a narrow process which grew out of the raphe as a raphe origin, however the authors classified the ruga which did not contact with the palatine raphe as the medial half.

2) Direction

The direction was represented as the angle between the line, which joined the origin and termination of the ruga, and the line perpendicular to the median line. The angle for the ruga which was perpendicular to the median line was zero, and the forward and backward inclined rugae were denoted to have positive (+) and negative (−) values, respectively. The direction of the branched ruga which had several terminations was given by the mean angle of several twigs.

3) Position of the posterior limit of the ruga zone

The posterior limit of the primary or all ruga zones was represented as the line perpendicular to the median line from the most posterior point on the ruga and was investigated as the position in relation to the teeth (Fig. 4). The position where the perpendicular line passed was recorded as the mesial and distal

Fig. 4 Measurement of the posterior limit of the ruga zone. The proximal zone 4/5 or 5/6 includes the area within 1 mm on the mesial and distal sides of the contact point.

zones of the first premolars (4 m, 4 d), the proximal zone (within 1 mm on the mesial and distal sides of the contact point) of the first and second premolars (4/5), the mesial and distal zones of the second premolars (5 m, 5 d), the proximal zone of the second premolar and first molar (5/6), the mesial and distal zones of the first molars (6 m, 6 d). In the case where the perpendicular line passed on the boundary between the mesial and distal zones was included into the mesial zone.

4) Bilateral difference of the posterior limits of the ruga zone

The bilateral difference (a) of the posterior limits was measured as the distance between the right and left limits (Fig. 1). At the base of the left limit, the cases where the right limit were anterior and posterior to the left were denoted to have positive (+) and negative (−) values, respectively. The relative position of the right limit was also recorded.

Statistics

The statistical analysis of the bilateral difference was performed using Student's or Welch t-test for the

Table 1 Mean number of the primary, secondary and fragmentary rugae.

Rugae	Right (N=410)		Left (N=410)		<i>t</i> -test
	Mean	S.D.	Mean	S.D.	
Primary rugae	3.4	0.8	3.4	0.8	N.S.
Secondary rugae	1.9	1.3	2.2	1.3	*
Fragmentary rugae	0.1	0.4	0.1	0.4	N.S.
All rugae	5.5	1.3	5.7	1.5	*

N.S. : no significance, * $P < 0.05$ **Table 2** Frequency of the various numbers of the primary rugae.

Number of primary rugae	Right (N=410)		Left (N=410)		χ^2 -test
	Obs. No.	%	Obs. No.	%	
2	41	10.0	31	7.6	N.S.
3	177	43.2	205	50.0	*
4	159	38.8	141	34.4	N.S.
5	30	7.3	28	6.8	N.S.
6	3	0.7	5	1.2	N.S.

N.S. : no significance, * $P < 0.05$

mean values, and chi-square test was used for the frequencies.

Results

1. Number of each ruga

There were an average 3.4 primary rugae on both the right and left sides with no significant bilateral difference (Table 1). There were an average 1.9 secondary rugae on the right side and 2.2 on the left. The right side had 0.3 fewer with a significant bilateral difference ($P < 0.05$). There were an average 0.1 fragmentary rugae on both sides with no significant bilateral difference. There were 5.5 all rugae on the right side and 5.7 on the left. The right side had 0.2 fewer with a significant bilateral difference ($P < 0.05$).

The number of the primary rugae ranged from 2 to 6 on each side. Most of the dental casts had 3 or 4 primary rugae and accounted for 82.0% of all casts on the right side and 84.4% on the left (Table 2). But the casts with 2 rugae accounted for 10.0% on the right side and 7.6% on the left. The casts with 5 or 6 rugae

Table 3 Bilateral distribution of the primary rugae.

	Number of primary rugae		(N=410) Obs. No.	%
	Right	Left		
R < L	2	3	23	5.6
	2	4	7	1.7
	2	6	1	0.2
	3	4	57	13.9
	3	5	8	2.0
	3	6	1	0.2
	4	5	13	3.2
	4	6	3	0.7
R = L	2	2	10	2.4
	3	3	98	23.9
	4	4	65	15.9
	5	5	6	1.5
R > L	3	2	13	3.2
	4	2	7	1.7
	4	3	71	17.3
	5	2	1	0.2
	5	3	12	2.9
	5	4	11	2.7
	6	3	1	0.2
	6	4	2	0.5

R and L : right and left sides

Table 4 Symmetry in the number of the primary rugae.

N	Symmetry		Asymmetry		χ^2 -test
	Obs. No.	%	Obs. No.	%	
410	179	43.7	231	56.3	***

*** $P < 0.001$

accounted for under 7.3% and were observed in fewer cases.

There were great variations in the bilateral distribution of the number of primary rugae. The casts with 3 rugae on both sides accounted for 23.9% and in second place the casts with 4 rugae on the right side and 3 rugae on the left accounted for 17.3% (Table 3). As for the symmetry in the number of primary rugae, the asymmetrical casts (56.3%) were more observed than the symmetrical ones (43.7%) with a significant difference ($P < 0.001$) (Table 4). In the asymmetrical casts, the number of casts with more primary rugae on the right side were almost equal to the ones with

Table 5 Frequency of the shape of the primary rugae.

Ruga	N		Shape	Right		Left		χ^2 -test
	Right	Left		Obs. No.	%	Obs. No.	%	
I	410	410	Curved	258	62.9	282	68.8	N.S.
			Angular	128	31.2	123	30.0	N.S.
			Straight	24	5.9	5	1.2	***
II	410	410	Curved	162	39.5	177	43.2	N.S.
			Angular	224	54.6	210	51.2	N.S.
			Straight	24	5.9	23	5.6	N.S.
III	369	379	Curved	129	35.0	146	38.5	N.S.
			Angular	231	62.6	216	57.0	N.S.
			Straight	9	2.4	17	4.5	N.S.
IV	192	174	Curved	75	39.1	86	49.4	*
			Angular	112	58.3	81	46.6	*
			Straight	5	2.6	7	4.0	N.S.

N.S. : no significance, * $P < 0.05$, *** $P < 0.001$ **Table 6** Frequency of the papillate primary rugae.

Ruga	N		Right		Left		χ^2 -test
	Right	Left	Obs. No.	%	Obs. No.	%	
I	410	410	165	40.2	140	34.1	N.S.
II	410	410	279	68.0	265	64.6	N.S.
III	369	379	306	82.9	316	83.4	N.S.
IV	192	174	170	88.5	152	87.4	N.S.

N.S. : no significance

more rugae on the left.

2. Form of the primary rugae

1) Shape

The frequencies of the curved type were 62.9% on R I and 68.8% on L I. But they decreased to 39.5% on R II and 43.2% on L II, to 35.0% on R III and 38.5% on L III (Table 5). This curved type tended to decrease gradually as on the posterior third ruga from the first ruga. The frequencies of the angular type were 31.2% on R I and 30.0% on L I. But they increased to 54.6% on R II and 51.2% on L II, to 62.6% on R III and 57.0% on L III. The angular type showed a tendency to increase on the posterior ruga in contrast to the decrease of the curved type. The frequencies of the curved type were at the bottom on the third rugae of all rugae I-IV, but the ones of the angular type in contrast to the curved type were at the

peak. There were no significant bilateral differences in both the curved and angular types on the rugae I-III. However only on the fourth rugae, significant bilateral differences ($P < 0.05$) were observed. The curved type was less observed, while the angular type was more observed on the right side. The frequencies of the straight type were low on the rugae I-IV and this type was observed on comparatively shorter ruga. There was a significant bilateral difference ($P < 0.001$) only on the first ruga. The straight type was more observed on the right side than on the left.

2) Papillate rugae

The frequencies of the papillate rugae were 40.2% on R I and 34.1% on L I and were the lowest on the first rugae of the rugae I-IV (Table 6). The papillate ruga increased as on the posterior fourth ruga. The frequencies became the highest on the fourth rugae and were 88.5% on R IV and 87.4% on L IV, twice as

Table 7 Frequency of the branched primary rugae.

Ruga	N		Right		Left		χ^2 -test
	Right	Left	Obs. No.	%	Obs. No.	%	
I	410	410	71	17.3	68	16.6	N.S.
II	410	410	27	6.6	30	7.3	N.S.
III	369	379	11	3.0	19	5.0	N.S.
IV	192	174	4	2.1	3	1.7	N.S.

N.S. : no significance

Table 8 Frequency of the united primary rugae.

United rugae	N		Origin	Right		Left		χ^2 -test
	Right	Left		Obs. No.	%	Obs. No.	%	
I / II	410	410	Common	34	8.3	13	3.2	**
			Separate	29	7.1	52	12.7	**
II / III	410	410	Common	8	2.0	2	0.5	N.S.
			Separate	7	1.7	8	2.0	N.S.
III / IV	369	379	Common	0	0.0	0	0.0	N.S.
			Separate	3	0.8	1	0.3	N.S.
I / III	410	410	Common	2	0.5	0	0.0	N.S.
			Separate	2	0.5	0	0.0	N.S.
II / IV	410	410	Common	1	0.2	1	0.2	N.S.
			Separate	0	0.0	1	0.2	N.S.

N.S. : no significance, ** $P < 0.01$

much as the ones on the first rugae. There were no significant bilateral differences on the rugae I-IV.

3) Branched rugae

The branched rugae were observed in fewer cases compared to the papillate rugae. Most of them were observed on the first rugae and the frequencies were 17.3% on R I and 16.6% on L I (Table 7). The frequencies on the rugae II-IV were 1.7~7.3% and were extremely low. There were no significant bilateral differences on the rugae I-IV.

4) United rugae

The united ruga which combined with the first and second rugae was observed most in all combinations and the frequencies summing up the ones with common and separate origins were 15.4% on the right side and 15.9% on the left (Table 8). The frequencies of other combinations than this were 0.2~3.7% and were extremely low. There were no significant bilateral differences in all ruga combinations. But the united rugae were divided by the joined position into 2 types,

common and separate origins, and significant bilateral differences ($P < 0.01$) were observed in both types only on the combination with the first and second rugae. The common origin which joined the origins was more observed on the right side. Conversely the separate origins which joined on the lateral portion out of the origin was observed more on the left side.

3. Distribution of the primary rugae

1) Origin

The raphe origin were observed mostly on the first rugae and the frequencies were 94.1% on R I and 96.1% on L I (Table 9). But as on the more posterior rugae the origins separated from the palatine raphe, and the frequencies of the raphe origin became the lowest on the fourth rugae and were 37.0% on R IV and 23.6% on L IV. On the posterior rugae, the medial and lateral halves rather than the raphe origin increased gradually. The frequencies of the medial half whose origin existed in the medial were 5.4% on R I

Table 9 Frequency of the origin of the primary rugae.

Ruga	N		Origin	Right		Left		χ^2 -test
	Right	Left		Obs. No.	%	Obs. No.	%	
I	410	410	Raphe origin	386	94.1	394	96.1	N.S.
			Medial half	22	5.4	16	3.9	N.S.
			Lateral half	2	0.5	0	0.0	N.S.
II	410	410	Raphe origin	176	42.9	162	39.5	N.S.
			Medial half	154	37.6	175	42.7	N.S.
			Lateral half	80	19.5	73	17.8	N.S.
III	369	379	Raphe origin	144	39.0	105	27.7	**
			Medial half	170	46.1	203	53.6	*
			Lateral half	55	14.9	71	18.7	N.S.
IV	192	174	Raphe origin	71	37.0	41	23.6	**
			Medial half	86	44.8	83	47.7	N.S.
			Lateral half	35	18.2	50	28.7	*

N.S. : no significance, * $P < 0.05$, ** $P < 0.01$

Table 10 Direction of the primary rugae.

Ruga	N		Right		Left		<i>t</i> -test
	Right	Left	Mean	S.D.	Mean	S.D.	
I	410	410	+ 1.6	12.2	+11.7	12.8	***
II	410	410	-15.7	18.3	+ 5.6	19.3	***
III	369	379	-19.4	17.4	+ 0.3	18.4	***
IV	192	174	-23.0	17.9	- 1.7	19.4	***

Unit : angle (degrees), *** $P < 0.001$, + : forward inclination, - : backward inclination

and 3.9% on L I and were the lowest. But they became the highest on the third rugae and were 46.1% on R III and 53.6% on L III. The frequencies of the lateral half whose origin existed in the lateral were the lowest on the first rugae. However they became the highest on the posterior rugae and were 19.5% on R II and 28.7% on L IV. There were no significant bilateral differences in 3 types on the first and second rugae. However, significant bilateral differences ($P < 0.01$) were observed in the raphe origin on the third and fourth rugae. The frequencies of the raphe origin on the left side decreased 11.3% and 13.4%, respectively. Unlike the decrease of the raphe origin, the medial half increased 7.5% on the third ruga and the lateral half increased 10.5% on the fourth ruga with significant bilateral differences ($P < 0.05$).

2) Direction

The first rugae on both sides inclined forward and the directions were +1.6° on R I and +11.7° on L I. The left first ruga distinctly inclined more forward than the right one (Table 10). The directions changed gradually to the backward inclination as on the more posterior fourth rugae from the first rugae. The directions on the fourth rugae showed the most backward inclination and were -23.0° on R IV and -1.7° on L IV. In addition to this, the right rugae inclined more backwards than the left on all the rugae I-IV and there were distinct significant bilateral differences ($P < 0.001$).

The direction of the right ruga rapidly changed from the forward inclination to the backward on the second ruga and the sum of angles changed from the ruga R I to R IV was 24.6° larger than the 13.4° of the left one. The left ruga changed the direction to back-

Table 11 Position of the posterior limit of the ruga zone.

Ruga zone		Right (N=410)		Left (N=410)		χ^2 -test
		Obs. No.	%	Obs. No.	%	
Primary ruga	4 d	5	1.2	7	1.7	N.S.
	4/5	30	7.3	48	11.7	*
	5 m	99	24.1	110	26.8	N.S.
	5 d	133	32.4	127	31.0	N.S.
	5/6	88	21.5	79	19.3	N.S.
	6 m	53	12.9	38	9.3	N.S.
	6 d	2	0.5	1	0.2	N.S.
All ruga	5 m	14	3.4	21	5.1	N.S.
	5 d	90	22.0	84	20.5	N.S.
	5/6	113	27.6	114	27.8	N.S.
	6 m	176	42.9	177	43.2	N.S.
	6 d	17	4.1	14	3.4	N.S.

N.S. : no significance, * $P < 0.05$

ward gradually and showed the first backward inclination on the fourth ruga. In this way, the distinct bilateral difference in the direction were observed and also the sum of angles changed from the ruga R I to R IV was different from the left one. The remarkable asymmetry with respect to the direction was observed.

3) Position of the posterior limit of the ruga zone

The posterior limit of the primary ruga zone of most of the dental casts on both sides reached the distal zone of the second premolar (5d) and the frequencies were 32.4% on the right side and 31.0% on the left (Table 11). In the second place the casts whose posterior limit reached the mesial zone of the second premolar (5 m) accounted for 24.1% on the right side and 26.8% on the left. The casts whose posterior limit reached the proximal zone of the second premolar and first molar (5/6) accounted for 21.5% on the right side and 19.3% on the left. There were no significant bilateral differences in all but one case whose posterior limit reached the proximal zone of the first and second premolars (4/5).

The posterior limit of the all ruga zone of most of the dental casts on both sides reached the mesial zone of the first molar (6 m) and the frequencies were 42.9% on the right side and 43.2% on the left. Secondary, the casts whose posterior limit reached the proximal zone of the second premolar and first molar

(5/6) accounted for 27.6% on the right side and 27.8% on the left. The casts whose posterior limit reached the distal zone of the second premolar (5 d) accounted for 22.0% on the right side and 20.5% on the left. There were no significant bilateral differences in the position of the posterior limit of the all ruga zone.

4) Bilateral differences of the posterior limits of the ruga zone

The bilateral difference (a) of the posterior limits of the primary ruga zone was measured on an average for -1.29 mm and the right limit was posterior to the left one (Table 12). The dental casts whose right limit was posterior to the left accounted for 59.3% and were observed twice as the much as the 28.3% of the casts whose right limit was anterior with a significant difference ($P < 0.001$). The casts with equal limits on both sides were observed in fewer cases and the frequency was 12.4%.

The bilateral difference of the posterior limits of the all ruga zone was measured on an average for -0.84 mm. Similar to the one of the primary ruga zone, the right limit was posterior to the left. The casts whose right limit was posterior to the left accounted for 56.1%, twice as much as the 26.1% of the one whose right limit was anterior with a significant bilateral difference ($P < 0.001$). The casts with equal limits on both sides were observed in fewer cases, with a frequency of 17.8%.

Table 12 Bilateral difference of the posterior limits of the ruga zone.

Ruga zone	Bilateral difference(N=410)		R posterior to L(-)		R equal to L(0) [†]		R anterior to L(+)	
	Mean (mm)	S.D.	Obs. No.	%	Obs. No.	%	Obs. No.	%
Primary ruga	-1.29	2.72	243	59.3***	51	12.4	116	28.3
All ruga	-0.84	2.25	230	56.1***	73	17.8	107	26.1

[†] : $-0.5 \text{ mm} \leq a < 0.5 \text{ mm}$, *** $P < 0.001$: a significant difference between R posterior and anterior to L, R and L : right and left sides

As the above results indicate, the significant bilateral differences were observed in the mean number of secondary and all rugae, shape, types of the united rugae, origin, direction and position of the posterior limit of the ruga zone.

Discussion

The human palatal rugae looked apparently irregular and complicated, however, in the results the morphological change in order of the postero-anterior direction of the hard palate (the postero-anterior change) and bilateral difference were observed in many cases. Schultz³⁾ studied the morphology of the palatal rugae in many primates including the human and described that in the human, the numbers of the rugae were few, the rugae pattern was variable and irregular and the rugae were the most degenerated compared to other primates. With respect to these human palatal rugae, how the degree of the regressive evolution is different between the right and left sides of the hard palate will primarily be discussed.

The mean number of the primary rugae (3.4) was close to the values (3.30~3.72) in males or females of Japanese adults reported by Yamazaki²⁵⁾. He reported that in females, the right value was smaller than the left one with a significant bilateral difference. However, in the present study, there was no significant bilateral difference in the mean number of the primary rugae. There was, however, a significant bilateral difference ($P < 0.05$) in the mean number of the secondary rugae (1.9 on the right side and 2.2 on the left), with the right value being smaller than the left one. These values were also larger than Yamazaki's values (0.59~0.86). Lysell¹¹⁾ and Yamazaki distinguished between the extra primary ruga and the

ordinary primary ruga to include one of the extra primary rugae into the primary rugae and the others into the secondary rugae. However, the authors did not divide the extra primary ruga and classified rugae which were 5 mm or more in length but with a low prominence, as the secondary ruga. These large values in the number of the secondary rugae in the present study were considered to be attributable to the differences in the system of classification of the primary rugae. The mean number of the fragmentary rugae (0.1) was close to the values (0.15~0.28) by Yamazaki and there was no significant bilateral difference. The mean number of all the rugae (5.5 on the right side and 5.7 on the left) was smaller on the right side than on the left with a significant bilateral difference ($P < 0.05$). The decrease of the number of all the rugae on the right side was caused by the decrease of the secondary rugae, which were remarkably regressive types. Consequently, based on the result in the number of all the rugae, the regressive evolution of the rugae was considered to proceed more on the right side than on the left side.

The postero-anterior change was found in the shape of the rugae and most of the curved types, which showed the simple form with a weak forward curve, observed on the anterior rugae. In contrast to the decrease of the curved type on the posterior rugae, the angular type which bent with angles increased. Yoshida & Hitotsumachi⁶⁾ and Iwaku⁷⁾ reported that many simian had symmetrical string-like rugae with a weak forward curve, but gibbon (*Hylobates syndactylus*) and orang-utan (*Pongo pygmaeus*) had asymmetrical rugae which bent in a complicated fashion. Consequently, it was speculated that the deformation or reduction of the rugae strongly appear in humans compared to many simian and the results in

the present study support this. Significant bilateral differences ($P < 0.05$) in the shape of the rugae were observed on the fourth rugae. The regressive evolution of the rugae was considered to proceed more on the right side than on the left, because the angular type was observed more often on the right side than on the left.

The postero-anterior change was similarly observed in the papillate rugae. Gegenbaur²⁹⁾ described the first observation in his developmental study of the rugae in human embryo that the papillate ruga was formed as a result of the recess on the posterior or anterior wall of the prominence becoming deeper and also as one result of regressive phenomena of the rugae. In the present study, the papillate rugae were observed more on the posterior rugae than on the anterior. This observation indicated that the regressive evolution of the rugae proceeded in order of the postero-anterior direction of the hard palate. The papillate rugae accounted for as much as 34~40% of the first rugae, so the regressive evolution of the rugae extended to these first rugae as well as to the posterior rugae. The frequencies (34.1~88.5%) of the rugae I-IV were higher than Yamazaki's values (4.4~61.5%)

. That the recent development in the impression materials has an influence on these values may be a possible explanation. The bilateral differences in the regressive evolution of the rugae were not found in the papillate rugae.

The postero-anterior change was also found in the origin of the rugae. Many posterior rugae as compared to the anterior rugae began from the medial or lateral halves of the ruga zone and their origins separated from the palatine raphe. Yoshida & Hitotsumachi⁶⁾ reported in their morphological study of the simian palatal rugae that the right and left rugae of the squirrel-monkey (*Saimiri sciurea*) in a lower class simian joined on the median line, by contrast to, the rugae of many simian in the anterior part of the palate joined on the median line but separated in the posterior part, and all the rugae of the orang-utan (*Pongo pygmaeus*) in anthropoid were completely separated.

Sugiyama³⁰⁾ described in his morphological study of

Fig. 5 Changes in the direction of the primary ruga I-IV. The positive value (+) and negative value (-) represent the forward and backward inclinations of the ruga, respectively.

rugae in the human fetus (between 5 and 9 months of gestational age) that the right and left first rugae in many fetuses joined on the median line, and at an older gestational age the groove entered on the median line and the rugae on both sides were separated. In the present study, not a single ruga had prominences on both sides joining on the median line. There were significant bilateral differences on the third and fourth rugae. The raphe origin which began from the palatine raphe was more observed on the right side than on the left. Consequently, the regressive evolution of the rugae was considered to proceed slower on the right side than on the left based on the result of the origin of the rugae. This interpretation contradicts the one based on the number of all the rugae, shape and direction of the rugae stated next.

In the direction of the rugae, Suganuma¹⁵⁾, Murakami¹⁷⁾ and Weldt¹⁰⁾ early reported the backward inclination of the rugae. Lysell¹¹⁾, Sato²²⁾ and Yamazaki²⁵⁾ reported about the morphological change in order of the postero-anterior direction of the hard palate and bilateral difference in the direction. The evident postero-anterior change and bilateral differ-

Table 13 Bilateral difference of the position of the upper first molars (mesiolingual cusp tips).

Tooth	Bilateral difference (N=410)		R posterior to L(-)		R equal to L(0) [†]		R anterior to L(+)	
	Mean (mm)	S.D.	Obs. No.	%	Obs. No.	%	Obs. No.	%
First molar	-0.82	1.82	252	61.5***	63	15.4	95	23.2

[†] : $-0.5 \text{ mm} \leq a < 0.5 \text{ mm}$, *** $P < 0.001$: a significant difference between R posterior and anterior to L, R and L : right and left sides

ence ($P < 0.001$) were also found in the present study (Fig. 5). The rugae patterns in many casts were asymmetrical, irregular and variable. Such an impression seemed to be given by this evident bilateral difference in the direction and by the complexity in the shape. Because the more posterior rugae showed the more backward inclination and the right rugae inclined more to the back than the left, the regressive evolution of the rugae was considered to proceed more on the right side than on the left. However, it could not be considered that the distinct backward inclination and bilateral difference are produced only by the regressive evolution of the rugae itself.

Linden³¹⁾ studied the dimensional and positional growth changes in children (between 6 and 16 years of age) in relation to the teeth and the adjacent rugae, and described that the upper canine maintained a relatively constant relationship with the adjacent rugae in the sagittal direction, but the posterior teeth underwent the distinct dimensional and positional growth changes during growth. He considered this growth change to be produced by the mesial migration of the upper first molar associated with the replacement of the deciduous molar by the premolar. On the other hand, the longitudinal changes in the length of the ruga or inter-ruga distances were examined by Namba et al.³²⁾ and Simmons³³⁾. Namba et al. reported in their longitudinal study in children that the length of the ruga and inter-ruga distance increased as a whole during growth (from 4 to 10 years of age) and the growth in the lateral direction was somewhat larger than the one in the sagittal direction. Consequently, the direction of the posterior rugae, as compared to the one of the anterior rugae, should be considered to be influenced by the positional relationship between the rugae and the posterior teeth related to the replacement of the teeth, by the growth and

developmental changes of the palate and other influence, in addition to the regressive evolution of the rugae itself.

The posterior limit of the primary ruga zone measured in relation to the teeth reached the distal zone of the second premolar (5 d) and was more anterior to the proximal zone of the second premolar and first molar (5/6) by Yamazaki. But the posterior limit of the all ruga zone reached the mesial zone of the first molar (6 m) and was the same as Yamazaki's result. Because the number of all the rugae was smaller on the right side, it was speculated that the right posterior limit of the all ruga zone existed anterior to the left one. However, no significant bilateral differences were found in the position of the posterior limit in relation to the teeth. On the contrary, the results in the bilateral difference of the posterior limits indicated that the right limits of both the primary and all ruga zones conversely reached posterior to the left ones in many casts. This result was contrary to the speculation. Lysell and Yamazaki referred to Lundström's study³⁴⁾ about the asymmetry with respect to the upper first molars, that the upper first molar on the right side was posterior to the corresponding tooth on the left side, and pointed out that the difference in the position of the teeth on both sides could explain this contradiction.

The result showed that in the measured bilateral difference of the upper first molars (mesiolingual cusp tips), the casts whose right first molar was posterior to the left one accounted for 61.5% of all casts (Table 13). This frequency was close to one whose right posterior limit of the ruga zone was posterior to the left one. Consequently, the contradiction between two results could be caused by the difference in the position of the teeth on both sides. The right posterior limit was posterior to the left one, nevertheless, the

positions of the right and left limits in relation to the teeth were the same. The results seem to suggest that rugae have a close relationship with the position of teeth. Also the difference in the position of teeth, the right tooth was posterior to the left tooth, could be considered to influence the bilateral difference in the direction of the rugae.

In other observations except those described above, there was a significant bilateral difference ($P < 0.01$) in the type of the united rugae. The rugae which joined on the origins were observed more on the right side than on the left, and the rugae which joined on the lateral portion out of the origin were more on the left side. Yamazaki also reported that the rugae which joined on the origins were more observed on the right side in males. The cause of this bilateral difference is not clear, whether originated in the regressive process of the rugae or in the growth and developmental process of the palate secondarily. The bilateral differences were not found in the branched rugae. It is difficult to speculate about the regressive evolution of the rugae from the results in the types of the united rugae and branched rugae.

With respect to the regressive evolution of the palatal rugae, Yamazaki²⁵⁾ and Todoroki²⁸⁾ described that the postero-anterior changes, which were seen in the shape, origin and papillate rugae of the ordinary primary rugae, indicated the rugae to degenerate in order of the postero-anterior direction. Nevertheless, they did not mention whether the bilateral differences in regressive evolution would exist. Based on the clear postero-anterior changes were observed in the direction, shape, origin and papillate rugae of the primary rugae, the authors suggested that the changes in these observations indicated the basic process of the regressive evolution of the rugae. In addition to this, the authors considered that the bilateral difference in the regressive evolution of the palatal rugae existed, on the basis that bilateral differences were found in the number of the rugae, the distinct direction, and also in the shape, and origin on the posterior third and fourth rugae, but were not observed in the papillate rugae.

From the above view, the regressive evolution of the palatal rugae was considered to proceed as follows : the ruga prominence became lower with many

grooves, separated from the palatine raphe gradually, changed the simple form with forward curve to the angular form which bent in a complicated fashion and inclined more towards the back. It was also suggested that in all of the observations, these regressive evolutions on both sides do not proceed at the same time, but the right rugae degenerate more than the left rugae. However, with respect to the direction of the rugae, it should be noted that it was influenced by the formation of the dental arch associated with the replacement of the teeth and by the growth and developmental changes of the palate.

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