

DECREASE AND INCREASE IN RESIDUAL RIDGES AFTER EXTRACTION OF TEETH IN MONKEYS (PART II).

BY

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ABSTRACT

The goal of this study is to reveal (1) the rate of elongation of upper alveolar process after loss of antagonistic teeth, and (2) a change in residual ridge area after extraction of upper elongated teeth. The subjects used in this study were seven crab-eating monkeys, which were divided into two groups; 0U5L group (extracted on $\overline{M_3M_2M_1P_2P_1}$) and 5U5L group (extracted on $\overline{M_3M_2M_1P_2P_1}$) and two years later $\overline{M_3M_2M_1P_2P_1}$). Three monkeys were in each group. In order to observe the morphological changes, impressions were taken before the extraction and at fixed intervals of three weeks, six weeks, three months, six months, one year, two years, and three years (only in the 5U5L group) after the extraction. Casts were made immediately thereafter. Then the changes in the height and cross-sectional area of the alveolar process or the residual ridge were measured. The method was the same as that described in Part I. The results were as follows:

- 1) 0U5L group: In the first six week period after extraction of antagonistic teeth, the height of the upper alveolar process increased rapidly, and thereafter continued to increase over the two year period. Also the change in the cross-sectional area displayed the same tendency as the growth in the height of the alveolar process.
- 2) 5U5L group: In the first three week period after extraction of the elongated teeth, height of the residual ridge decreased rapidly, and from then on, decreased gradually over the next three year period. However, even after the decrease in height over the three year period, the height of the residual ridge was still greater than the process before elongation of the teeth. The residual ridge area displayed the typical pattern of "rapid decrease followed by a gradual decrease". However, even after three years the area was still slightly greater than that before the elongation. Thus it is clear that, unlike the decrease in height and area of the residual ridge following extraction of normally occluded teeth, the decrease in the elongated ridge appeared to be difficult.

INTRODUCTION

We observed in our earlier work¹⁾ that the reduction of residual ridge varied according to the site of the tooth extraction area. In other words, there was no sign of the typical two-stage pattern of a rapid decrease followed by a gradual decrease in some sections of the edentulous area. By examining the dryskull, it is quite clear

that this is due to the increase in size of the alveolar bone along with the elongation and inclination of the neighboring teeth. These phenomena resulted from the loss of the antagonistic teeth. We hypothesize that the elongation of the teeth is the major determining factor. However, the existing literature concerning tooth elongation is sparse²⁻³⁾. Therefore, in this study elongation of the upper molar part

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after the loss of the antagonistic teeth was closely observed. In the hopes of preventing and controlling the residual ridge reduction, the rate of increase due to the elongation process and that of decrease resulting from the reduction process were studied.

MATERIALS AND METHODS

The materials used in this study have already been described in the preceding paper¹⁾. Therefore, a brief outline should suffice.

Seven healthy crab-eating monkeys (*Macaca irus*) were used in the present study and divided into two groups in accordance with the tooth extraction area, as indicated in Table 1. The method of extraction and the time period after which impressions were taken were the same as those reported previously¹⁾. Casts of these impressions were then made immediately.

In Fig. 1, a number of reference points have been designated. The points gI_2 and gM_2 refer to points along the gum line, and cP_1 , cP_2 , cM_1 , and cM_2 refer to the crown

Table 1. Classification of experimental animals. (Three of the monkeys are in both groups.)

Group	Extraction Area	Number and Sex
0U5L	$\overline{M_3M_2M_1P_3P_1}$	♂ 1
		♀ 4
5U5L	2 Years later $\overline{M_3M_2M_1P_3P_1}$	♂ 3
		♀ 2

of the teeth themselves. The casts obtained were standardized by means of the Kubuskraniophor and the diagraph as in Part I¹⁾ (Fig. 2). Subsequently, the diagraph was used to chart the various points along the cross-section of the alveolar process (before extraction) or the residual ridge (after extraction) on a graph paper. The method used to calculate the area was as follows, quoting from Part 1:

First, the line defined by the right and left gI_2 comprises the X axis. The Y axis is drawn perpendicular to the X axis at the median point between the right and left gI_2 (Fig. 3). A straight line (l_0), which is a border line when calculating the area of the residual ridge, is drawn parallel to the

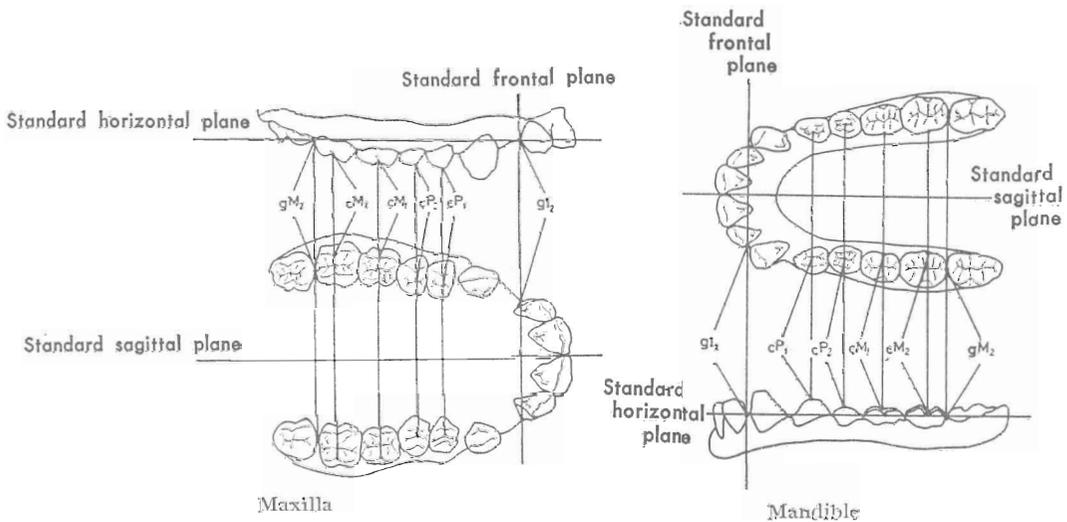


Fig. 1. Reference Points on the Casts

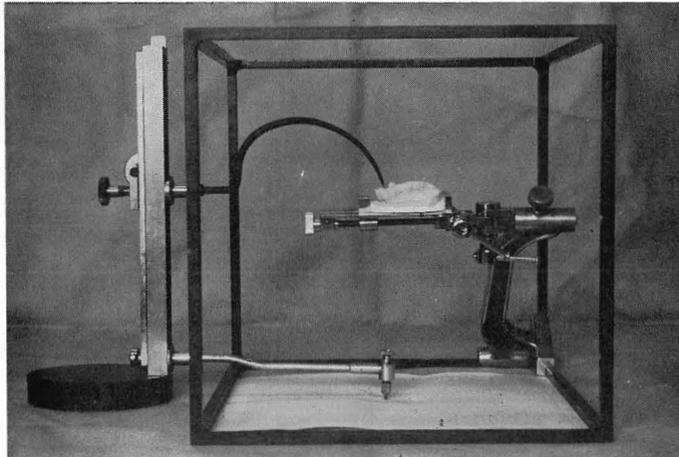
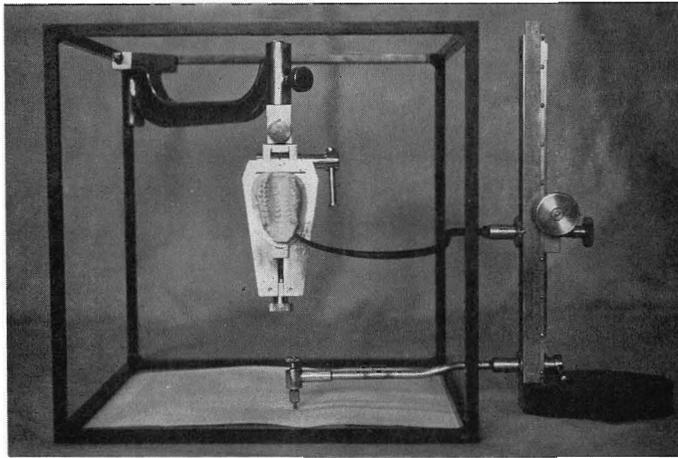


Fig. 2. A Kubuckraniophor and a diagraph

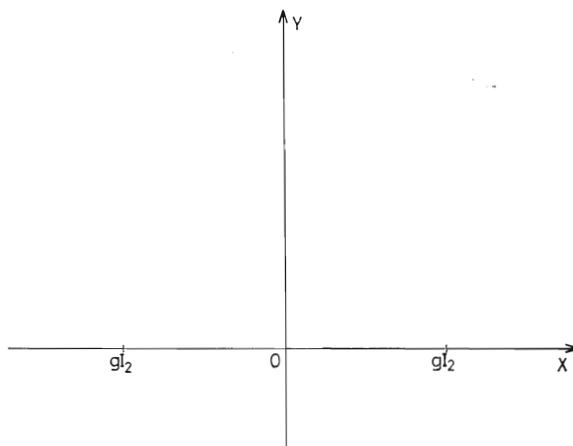


Fig. 3.

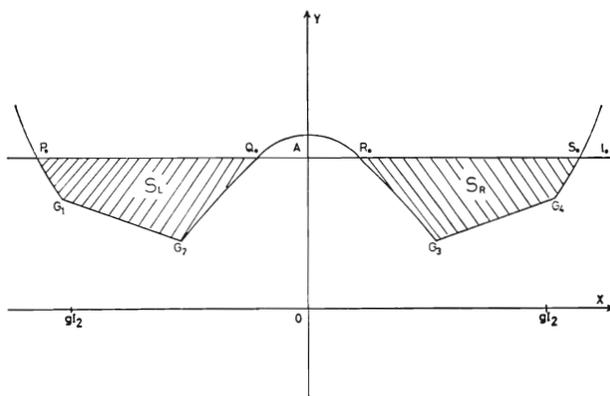


Fig. 4. Cross-sectional area before extraction

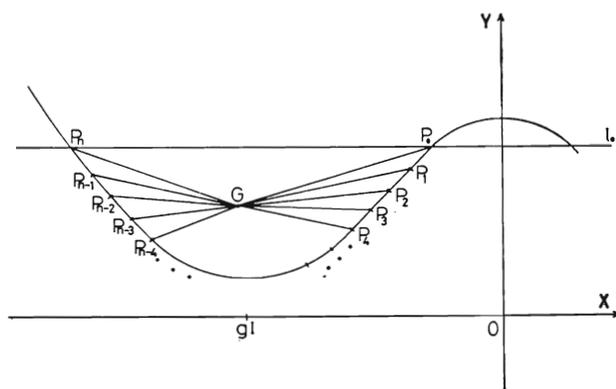


Fig. 5. Method used to calculate the residual ridge area

X axis. The distance between l_0 and the X axis is equivalent to 30% of the $gI_2 \cdot gI_2$ portion of the X axis (Fig. 4). Then, points along the curve of the residual ridge are marked so that perpendicular lines drawn from each of these points ($P_0, P_1, P_2, \dots, P_{n-1}, P_n$) to the X axis will intersect the X axis at 2-mm intervals. Next, a point G is charted in the area between l_0 and the curve of the residual ridge so that the X and Y values of G are equal to the mean values of all the points along the curve from P_0 through P_n . That is to say, G is the center of gravity. Lines are drawn connecting G to each of the various $P_0, P_1, \dots, P_{n-1}, P_n$ points along the curve (Fig. 5). In order to form triangles whose area can be

measured, straight lines are drawn connecting points P_0 through P_n . This results in an infinite number of adjacent triangles. The areas of these triangles are added together to yield the area of the residual ridge with a high degree of accuracy.

On the other hand, the height of the alveolar process (before extraction) or the residual ridge (after extraction) was calculated as in Fig. 6.

In order to minimize the problem of individual variations and errors, the same formula utilized in Part I was applied:

$$\frac{R - (R + L)/2}{(R + L)/2} \times 100 = \frac{R - L}{R + L} \times 100(\%)$$

R is a measurement value taken on the

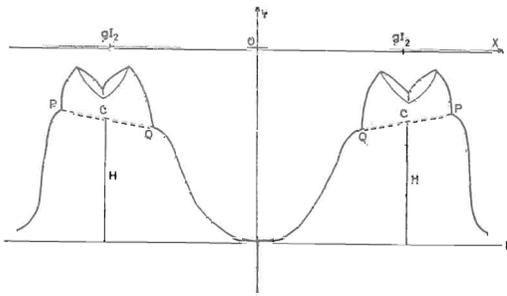


Fig. 6. Method used to calculate the height of the alveolar process or the residual ridge.

H: The height of the alveolar process (residual ridge).

- 1: A line drawn parallel to the X axis through the deepest point of the palate.
- P: A point on the buccal side where the gum meets the tooth.
- Q: A point on the palatal side where the gum meets the tooth.
- C: The median point between P and Q. After extraction it is the highest point on the residual ridge.

right side and L taken on the left side.

This study has attempted to investigate the morphological changes by using the above formula to compare the degree of similarity of the left and right sides of the subjects in both their pre- and post-extraction periods. The student *t*-test was used to determine the statistical significance of the difference between the two periods. The significance levels were denoted as follows:

- *** highly significant ($P \leq 0.01$)
- ** significant ($0.01 < P \leq 0.05$)
- * less significant ($0.05 < P \leq 0.10$)

Then the margin of error in the measuring process was computed in the same way as in Part I (Table 2). It was negligible, leading to the conclusion that the measurements were highly accurate.

RESULTS

1) OU5L group

a) Height of the Cross-section of the Up-

Table 2. Error (%) in measuring process. (UH ... Upper Height, UD ... Upper Area)

Section	Error (%)
UHP ₁	1.45
UHP ₂	1.96
UHM ₁	1.58
UHM ₂	1.73
UDP ₁	2.45
UDP ₂	2.93
UDM ₁	3.70
UDM ₂	3.19

per Alveolar Process (UH)

P₁ Section (UHP₁)

P₂ Section (UHP₂)

M₁ Section (UHM₁) (Table 3, Fig. 7)

M₂ Section (UHM₂)

In the first six week period after the extraction of the antagonistic teeth, the height of all sections increased fairly rapidly. The initial increase amounted to 30-40% of the total increase over the two year period. Thereafter, the height continued to increase throughout and beyond the two year period. When compared with the measurements of the pre-extraction period, the measurements of all sections were statistically significant from the three week period through the two year period.

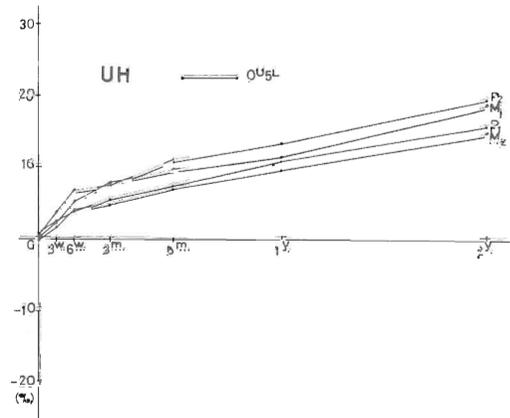


Fig. 7.

Table 3. Changes in the upper alveolar height over the three year period. N: Number, M: Mean, S.D.: Standard deviation, t: Student *t*-Test (Compared with pre-extraction period, ***... $P \leq 0.01$, **... $0.01 < P \leq 0.05$, *... $0.05 < P \leq 0.10$)

Section	Period	0U5L (N=5)			5U5L (N=5)		
		M. (%)	S.D.	t	M. (%)	S.D.	t
UHP ₁	Pre-Ext.	0.63	1.97		21.73	4.20	
	3w.	2.21	2.49	1.11	18.68	3.53	1.24
	6w.	3.43	3.71	1.49	18.05	3.66	1.48
	3m.	5.47	3.37	2.77**	17.48	4.47	1.55
	6m.	7.39	3.51	3.76**	17.63	4.82	1.43
	1y.	10.83	5.14	4.14**	17.27	4.66	1.59
	2y.	15.97	5.12	6.25**	16.60	4.15	1.78
	3y.	—	—	—	15.90	4.23	2.19*
	Pre-Ext.	0.20	2.04		19.68	5.21	
UHP ₂	3w.	3.43	2.58	2.20*	15.96	5.71	1.08
	6w.	6.43	2.24	4.60**	15.60	5.78	1.17
	3m.	7.12	3.67	3.69**	15.81	5.82	1.11
	6m.	10.71	3.98	5.26***	15.15	5.70	1.31
	1y.	13.40	4.75	5.71***	14.96	5.61	1.38
	2y.	17.17	5.16	6.84***	14.77	5.64	1.43
	3y.	—	—	—	14.72	6.20	1.37
	Pre-Ext.	0.64	2.74		18.53	5.09	
	UHM ₁	3w.	1.97	2.73	1.12	15.35	5.40
6w.		4.87	3.02	2.65*	14.74	4.11	1.29
3m.		7.41	2.96	4.07**	15.05	4.24	1.17
6m.		9.23	3.48	4.64***	15.19	4.95	1.05
1y.		11.55	5.15	4.41**	15.03	4.86	1.11
2y.		16.02	5.78	5.59***	14.69	4.90	1.21
3y.		—	—	—	14.93	4.11	1.23
Pre-Ext.		-0.46	2.46		15.70	6.32	
UHM ₂		3w.	1.31	2.33	1.17	12.49	6.23
	6w.	3.54	1.26	3.24**	12.86	6.07	0.72
	3m.	4.87	1.90	3.84**	12.91	6.08	0.71
	6m.	7.00	1.58	5.70***	13.15	6.28	0.64
	1y.	9.65	3.48	5.31***	12.75	6.39	0.73
	2y.	14.61	4.74	6.31***	12.62	6.49	0.76
	3y.	—	—	—	12.01	6.20	0.93

b) Area of the Cross-section of the Upper Alveolar Process (UD)

P₁ Section (UDP₁)

P₂ Section (UDP₂)

M₁ Section (UDM₁) (Table 4, Fig. 8)

M₂ Section (UDM₂)

After extraction of the antagonistic teeth, the area of the UDP₁ increased markedly during the three week period. The area of the UDP₂, the UDM₁, and the UDM₂ sections showed a similar tendency during the

three month period. Thereafter, the area of all sections increased constantly just as the height of the alveolar process and continued to increase even after the end of the two year period.

When compared with the measurements of the pre-extraction period, the measurements of the UDP₁ section from the third month on, the measurements of the UDP₂ section from the sixth week on, and the measurements of the UDM₁ and the UDM₂ sections from the third week on were highly

Table 4. Changes in the upper alveolar area over the three year period.
 N: Number, M: Mean, S.D. Standard deviation, t: Student *t*-Test
 (Compared with pre-extraction period, ***... $P \leq 0.01$, **... $0.01 < P \leq 0.03$, *... $0.5 < P \leq 0.10$)

Section	Period	0U5L (N=5)			5U5L (N=5)		
		M. (%)	S.D.	t	M. (%)	S.D.	t
UDP ₁	Pre-Ext.	-1.35	3.14		21.19	5.52	
	3w.	1.41	2.89	1.44	10.26	6.17	2.28*
	6w.	1.66	2.23	1.75	9.58	6.06	3.17**
	3m.	4.15	3.54	2.60**	6.58	7.89	3.39***
	6m.	8.04	5.83	3.17**	1.67	4.29	6.24***
	1y.	10.83	5.79	4.13***	2.72	4.76	5.67***
	2y.	17.72	6.63	5.81***	1.44	6.11	5.36***
	3y.	—	—	—	0.43	5.59	5.91***
UDP ₂	Pre-Ext.	-0.56	3.89		21.93	7.26	
	3w.	4.94	5.47	1.77	12.76	7.09	2.02*
	6w.	6.04	5.11	2.30**	8.28	8.53	2.75**
	3m.	9.74	6.79	2.94**	4.30	5.56	4.31***
	6m.	13.22	9.51	3.00**	3.88	4.40	4.82***
	1y.	15.96	8.40	3.99***	1.12	4.57	5.42***
	2y.	23.73	7.49	6.44***	0.03	4.16	5.85***
	3y.	—	—	—	-0.53	4.25	5.97***
UDM ₁	Pre-Ext.	-1.59	3.49		21.24	7.04	
	3w.	3.10	4.18	1.92*	11.88	7.27	2.06*
	6w.	11.42	4.93	4.81***	8.85	7.48	2.69**
	3m.	13.07	6.50	4.44***	5.79	8.12	3.21**
	6m.	15.99	5.03	4.06***	5.76	6.73	3.54***
	1y.	20.89	7.05	6.39***	2.50	8.54	3.77***
	2y.	26.42	8.91	6.54***	1.98	8.51	3.89***
	3y.	—	—	—	0.01	9.20	4.10***
UDM ₂	Pre-Ext.	-1.65	3.14		23.64	8.15	
	3w.	4.40	3.99	2.65**	13.09	7.45	2.13*
	6w.	7.12	3.69	4.05***	11.93	6.86	2.45**
	3m.	10.76	6.51	3.84***	7.87	8.82	2.94**
	6m.	15.68	4.53	4.75***	5.28	8.68	3.44***
	1y.	21.33	5.84	7.75***	2.55	9.58	3.75***
	2y.	27.28	10.47	5.92***	1.75	9.58	3.89***
	3y.	—	—	—	1.77	8.95	4.04***

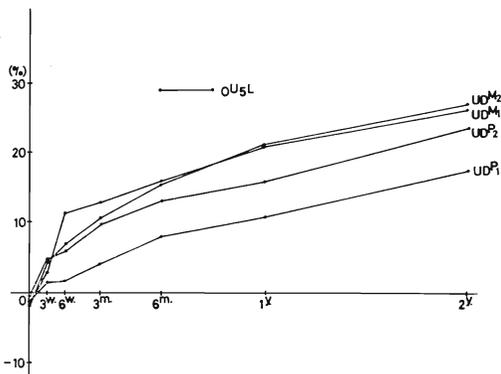


Fig. 8.

significant.

It can be hypothesized that the growth in height and area of the alveolar process was due to the growth of the alveolar bone along with the elongation of the upper teeth.

2) 5U5L group

a) Height of the Cross-section of the Upper Residual Ridge (UH)

P₁ Section (UHP₁)

P₂ Section (UHP₂)

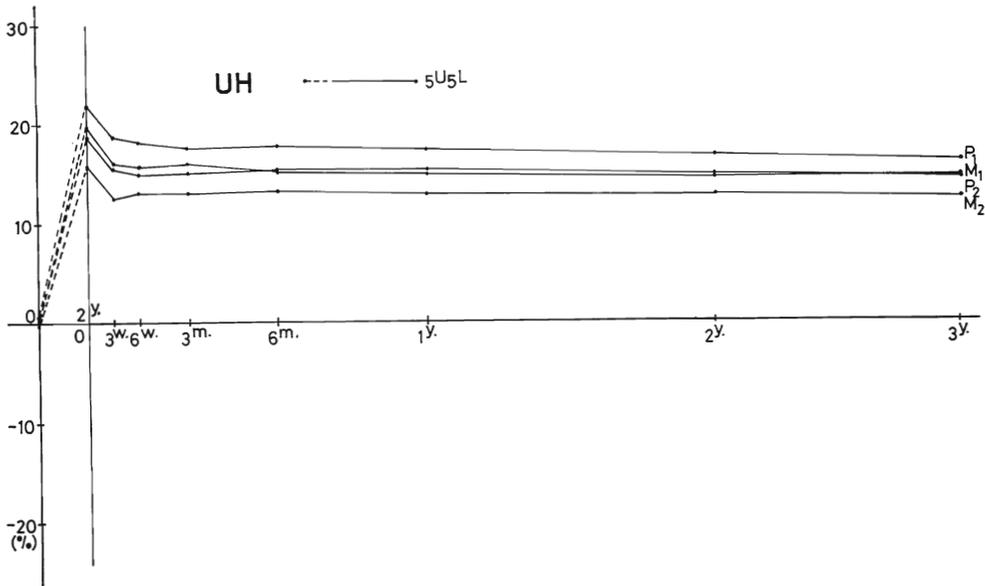


Fig. 9.

M₁ Section (UHM₁) (Table 3, Fig. 9)
 M₂ Section (UHM₂)

In the first three week period after extraction of the elongated teeth, the height decreased markedly in all sections, amounting to 80–90% of the total decrease over the three year period. From the third week on, the decline became more gradual. However, even after three years, the measurements of all sections surprisingly exhibited a positive 15%.

This fact shows that the height of the right residual ridge remained greater than that of the normally occluded left side, despite a constant decline, through the entire three year period after extraction. The measurements show a clear decrease of about 0.5–1.0 mm during the initial three week period. However, with the exception of the measurements of the UDP₁ section over the three year period, all subsequent measurements were found to be not significant when compared with the pre-extraction period. In other words, the decrease in height of the residual ridge after the ex-

traction of the elongated teeth seemed to be difficult, unlike the marked decrease of the residual ridge after the extraction of normally occluded teeth.

b) Area of the Cross-section of the Upper Residual Ridge (UD)

P₁ Section (UDP₁)

P₂ Section (UDP₂)

M₁ Section (UDM₁) (Table 4, Fig. 10)

M₂ Section (UDM₂)

The area of every section exhibited a sharp decline in the first three weeks after extraction, amounting to 50% of the total decrease over the three year period. During the first three months, about 70% of the total decrease occurred. Thereafter, decrease of the area slowed down. That is to say, the residual ridge after the extraction of the elongated teeth exhibited a typical pattern of “rapid decrease followed by a gradual decrease.” When compared with the measurements of the pre-extraction period, the measurements of all sections were highly significant at all times. How-

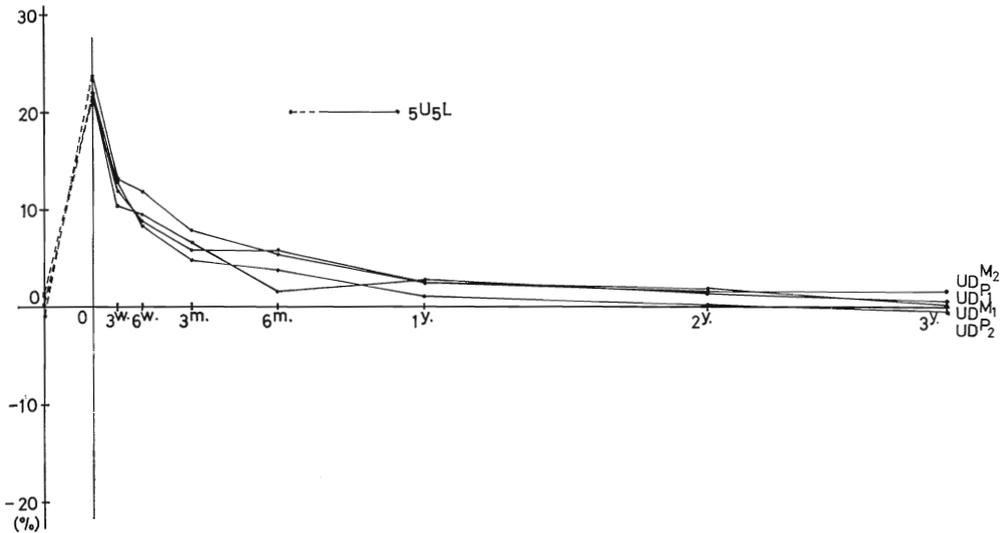


Fig. 10.

ever, even after three years, the measurements of $(R-L)/(R+L) \times 100\%$ remained about zero and did not become negative. This implies that the area of the upper right residual ridge after extraction of the elongated teeth did not become smaller than the area of the upper left alveolar process which was normally occluded.

DISCUSSION

The present study clearly demonstrated (1) the rate of elongation of the upper alveolar process after the loss of antagonistic teeth (0U5L group), and (2) changes in the residual ridge after extraction of the upper elongated teeth (5U5L group).

1) 0U5L group

First, the height of every section (UHP₁, UHP₂, UHM₁, and UHM₂) increased after loss of the antagonistic teeth. Moreover, judging from the increase during the past two year period, it can be surmised that the elongation of the alveolar process would probably continue. Since the increase in height closely mirrored the elon-

gation of the teeth⁴⁾, it can be hypothesized that there was a close relationship between the two. In addition, changes in the area (UDP₁, UDP₂, UDM₁, and UDM₂) over the two-year period were roughly equivalent to the changes in height. The authors here calculated the coefficient of correlation in order to determine whether they were correlated or not (Table 5). It was thereby discovered that there was a very high positive correlation between them. That is to say, after loss of the antagonistic teeth, the height and area of the alveolar process may increase along with the elongation of the teeth (Fig. 11).

2) 5U5L group

After extraction of the elongated teeth, the height of every section (UHP₁, UHP₂, UHM₁, and UHM₂) exhibited a rapid decrease followed by a gradual decrease. The rate of decrease in height of the elongated residual ridge after extraction is very similar to the pattern of decrease displayed by the typical residual ridge after extraction³⁾ (Table 6, Fig. 12). However, when com-

Table 5. Coefficient of correlation between the UH and the UD.

Section	Period	0U5L (n=5)		
		r	t	
UH	P ₁	3w.	0.831	2.58*
		6w.	0.842	2.71*
		3m.	0.915	3.96**
		6m.	0.965	6.82***
		1y.	0.888	3.36**
		2y.	0.916	3.97**
	P ₂	3w.	0.945	4.94**
		6w.	0.888	3.35**
		3m.	0.905	3.69**
		6m.	0.892	3.41**
		1y.	0.905	3.67**
		2y.	0.935	4.76**
UD	M ₁	3w.	0.840	2.75*
		6w.	0.913	5.37**
		3m.	0.876	3.15**
		6m.	0.945	5.03**
		1y.	0.899	3.57**
		2y.	0.973	7.54***
	M ₂	3w.	0.831	2.59*
		6w.	0.940	4.70**
		3m.	0.973	7.54***
		6m.	0.861	2.92*
		1y.	0.879	3.82*
		2y.	0.971	6.87***

Table 6. Changes in the upper alveolar height over the two year period. N: Number, M: Mean, S.D.: Standard deviation, t: Student t-Test (Compared with pre-extraction period, ***... P ≤ 0.01, **... 0.01 < P ≤ 0.05, *... 0.05 < P ≤ 0.1)

Section	Period	5U1L (N=5)			
		M. (%)	S.D.	t	
UHP ₁	Pre-Ext.	2.09	1.62		
	3w.	-2.16	2.84	2.91**	
	6w.	-2.68	1.94	4.22***	
	3m.	-2.39	1.96	3.94***	
	6m.	-2.48	2.27	3.66***	
	1y.	-2.46	1.98	3.98***	
	2y.	-2.59	1.74	4.40***	
	Pre-Ext.	-0.37	2.26		
	3w.	-4.47	1.73	3.32**	
	6w.	-4.22	1.54	3.15**	
	3m.	-3.99	1.17	4.18**	
	6m.	-4.16	1.19	3.31**	
UHP ₂	1y.	-4.72	0.97	3.96***	
	2y.	-4.87	1.10	4.00***	
	Pre-Ext.	1.20	1.62		
	3w.	-3.98	1.94	4.57***	
	6w.	-4.31	1.90	4.93***	
	3m.	-4.18	1.79	4.98***	
	6m.	-4.42	1.71	5.34***	
	1y.	-4.49	1.81	5.24***	
	2y.	-4.76	1.27	6.47***	
	Pre-Ext.	1.39	1.78		
	3w.	-3.90	1.67	4.85***	
	6w.	-3.89	2.23	4.14***	
3m.	-3.48	1.85	4.24***		
6m.	-3.82	1.89	4.49***		
UHM ₁	1y.	-3.92	2.43	3.94***	
	2y.	-4.13	2.31	4.23***	
	UHM ₂	Pre-Ext.	1.20	1.62	
		3w.	-3.98	1.94	4.57***
6w.		-4.31	1.90	4.93***	
3m.		-4.18	1.79	4.98***	
6m.	-4.42	1.71	5.34***		
1y.	-4.49	1.81	5.24***		
2y.	-4.76	1.27	6.47***		

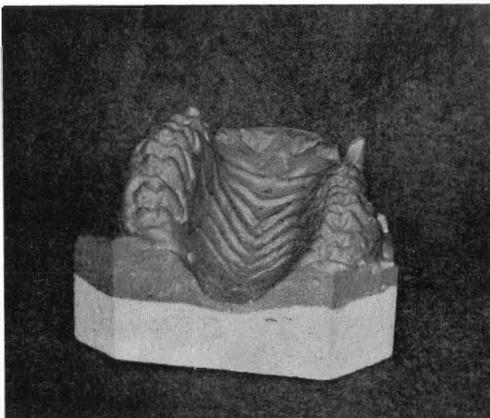


Fig. 11. A cast showing the remarkable increase in height and area over the two years after extraction of antagonistic teeth (0U5L group).

pared with the measurements of the pre-extraction period, while the height of every section decreased significantly in the typi-

cal residual ridge, the height of the elongated residual ridge did not decrease significantly. This may indicate that it is more difficult for the height of the elongated ridge to decrease than it is for that of the typical residual ridge (Fig. 13).

With respect to the residual ridge area after extraction of the elongated teeth, every section exhibited the typical pattern of "rapid decrease followed by a gradual decrease". However, when the measurements of the residual ridge which resulted after 2 years are examined, the area of the

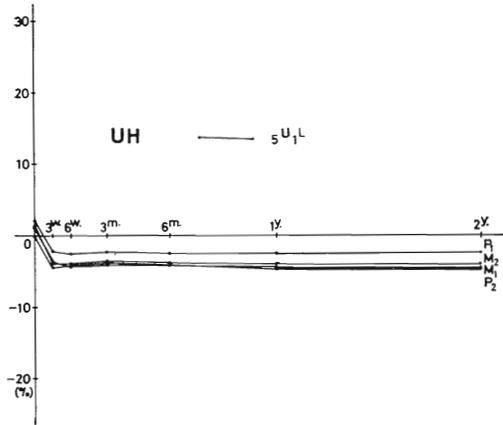


Fig. 12.

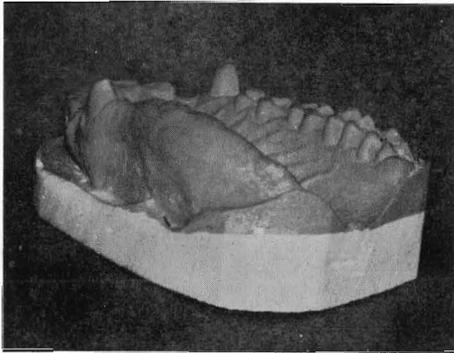


Fig. 13. A cast showing the reduction of residual ridge over the three years after extraction of elongated teeth (5U5L group). The height of the residual ridge are much greater than that of the non-extracted side.

normal residual ridge is much smaller than the non-extracted side¹⁾, while the area of the elongated residual ridge is the same size as the non-extracted side. Further, when measurements of the area obtained at each time period after extraction were compared with those of the area before elongation, the difference in the significance levels observed up to six weeks after extraction were no longer evident (Table 7). This indicates that the cross-sectional area of the elongated residual ridge became the same size as that of the alveolar process before elongation. In other words, this

Table 7. Comparison of the area between the pre-elongation (pre-extraction measurements of the 0U5L group) and the post-elongation (Measurements after extraction of the upper elongated teeth).

Section	Period	t
UDP ₁	Pre-Ext.	7.00***
	3w.	2.92**
	6w.	2.74**
	3m.	1.41
	6m.	0.21
	1y.	0.61
	2y.	0.9
UDP ₂	Pre-Ext.	6.08***
	3w.	3.46***
	6w.	1.86*
	3m.	1.15
	6m.	1.46
	1y.	0.03
	2y.	0.54
UDM ₁	Pre-Ext.	6.29***
	3w.	3.39***
	6w.	2.45**
	3m.	1.46
	6m.	1.72
	1y.	0.57
	2y.	0.44
UDM ₂	Pre-Ext.	6.52***
	3w.	4.05***
	6w.	4.00***
	3m.	2.16*
	6m.	1.55
	1y.	0.79
	2y.	0.61
3y.	0.58	

indicates that the rate of increase due to the elongation process was the same as the rate of decrease resulting from the reduction process.

However, it was of great importance to determine whether the alveolar bone had undergone morphological changes along with the changes in the residual ridge. Therefore, three dry skulls from the 0U5L group and three dry skulls from the 5U5L group were made and measured directly to investigate further the changes in the alveo-

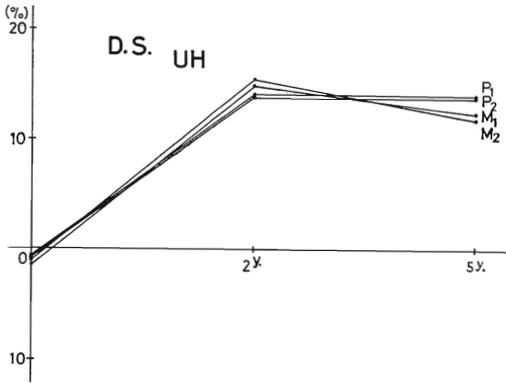


Fig. 14. Changes in the upper alveolar bone on the dry skull over the five year period. "2y." represents the changes of the 0U5L group. "5y." represents the changes of the 5U5L group.

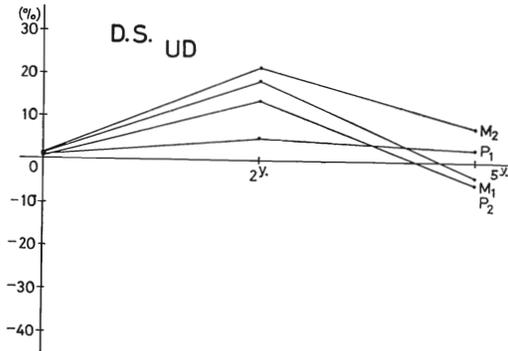


Fig. 15. Changes in the upper alveolar bone area on the dry skull over the five year period. "2y." represents the changes of the 0U5L group. "5y." represents the changes of the 5U5L group.

lar bone itself (Figs. 14 and 15). In these graphs, the "2y." represents the change in the 0U5L group and the "5y." represents those in the 5U5L group after extraction. Using this procedure, the authors concluded that changes in the cast were in fact reflected in the alveolar bone itself (Fig. 16).



Fig. 16. A dry skull showing the reduction of residual ridge over the three years after extraction of elongated teeth (5U5L group). Note the height of the residual ridge which is much greater than that of the non-extracted side.

CONCLUSION

1) After the loss of the antagonistic teeth, the height and area of the upper alveolar process increased following the pattern of a "rapid increase followed by a gradual increase" accompanying elongation of the teeth.

2) The residual ridge after the extraction of the elongated teeth exhibited the typical pattern of a "rapid decrease followed by a gradual decrease". However, even after three years, the height of the elongated residual ridge remained much greater than that before elongation.

Also, the cross-sectional area decreased only until it reached approximately the same size as the non-extracted side.

3) From measuring the dry skulls, it is clear that changes in the alveolar bone did reflect the changes observed in the casts.

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