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

BY

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ABSTRACT

The purpose of this study is to prevent and control the reduction of residual ridges. The subjects used in this study consisted of 19 crab-eating monkeys which were divided into four groups according to the extraction area. These categories are 1U0L group (extracted on $\underline{M_1|}$), 1U5L group (extracted on $\underline{M_1|}$ and $\overline{M_3M_2M_1P_2P_1|}$), 0U5L group (extracted on $\overline{M_3M_2M_1P_2P_1|}$), and 5U1L group (extracted on $\underline{M_3M_2M_1P_3P_1|}$ and $\overline{M_1|}$). Impressions were taken before the extraction. Further impressions were taken at three week, six week, three month, six month, one year, and two year intervals after the extraction in order to observe morphological changes. Casts were made immediately thereafter and the cross-sectional areas of the residual ridges were measured by a standardized method with the aid of a Kubuskraniophor and a diagraph. The measurements taken of the right side, which was operated on, and the left side, which served as the control, were compared in order to observe changes in the form of the edentulous area. The results were as follows:

1) Increase in the Residual Ridge Areas: It is highly significant that the measurements of the $\underline{M_2|}$ section of the 1U5L group and the $\overline{M_1|}$ section of the 5U1L group gradually decreased until the sixth week, and then began to increase until the areas were approximately equivalent to the measurements of the areas before the extraction after a two-year period. This may be due to the fact that along with the elongation of the neighboring teeth, the alveolar bone grew to such an extent that the resorption rate was surpassed.

2) Decrease in the Residual Ridges Areas: With the exception of the above-mentioned sections, almost all of other sections responded in the expected manner, that is, there was a sharp decrease in the areas of these sections. The decrease took place rapidly. Seventy to 80% of the total loss occurring over the two-year period took place in the first three months. After a sharp decline in the initial three-month period, the process continued at a slower pace. This gradual decrease after a short period of rapid decrease typifies the standard pattern of the edentulous resorption process.

INTRODUCTION

In the field of prosthodontics, it is very difficult to obtain a favorable prognosis when fitting a patient with a complete or removable partial denture if the patient's residual ridges are in poor condition.

Atwood[1] has stated that the reduction of residual ridges must be recognized as a complex oral disease with identificable characteristics and unwanted sequelae afflicting millions of people. A considerable amount of research[2-4] has been done on the dimensional changes of residual ridges after loss of teeth. There are so many factors[5-8] involved in the reduction process

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that the rate of resorption is not the same for all individuals. This is the reason why reduction of residual ridges is one of the most complex problems in all prosthetic treatments.

The purpose of this study is to contribute toward the ultimate goal of controlling residual ridge reduction.

Materials and Methods

Nineteen normal and healthy crab-eating monkeys (*Macaca irus*) were used in the present study and divided into four groups according to tooth extraction area, as shown in Table 1. All extractions were performed with forceps under general anesthesia with ketamine hydrochloride administered at a level of 1 mg/kg body weight. Postoperatively, the monkeys were given 300,000 I.U. of penicillin and their wounds healed well. Throughout the experiment, the subjects were maintained under identical environmental conditions.

Table 1. Classification of Experimental Animals

Group	Extraction Area	Number and Sex
1U0L	$\underline{M_1}$ |	5 ♂ 2, ♀ 3
1U5L	$\frac{M_1}{M_3M_2M_1P_2P_1}$ |	4 ♂ 2, ♀ 2
0U5L	$\overline{M_3M_2M_1P_2P_1}$ |	5 ♂ 3, ♀ 2
5U1L	$\frac{M_3M_2M_1P_2P_1}{M_1}$ |	5 ♂ 3, ♀ 2

In order to observe the morphological changes, impressions were taken before the extraction and at fixed intervals of three weeks, six weeks, three months, one year, and two years after the extraction. The impressions were taken in Thiocol rubber under general anesthesia using individual trays made of self-curing resin. Casts of these impressions were made immediately.

A number of reference points are designated in Fig. 1. 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 crowns of the teeth themselves. The Kubuskraniophor and diagraph used in the measurement are shown in Fig. 2. The Kubuskraniophor was placed on a heavy level marble plate to prevent any movement while taking the measurements. Then the

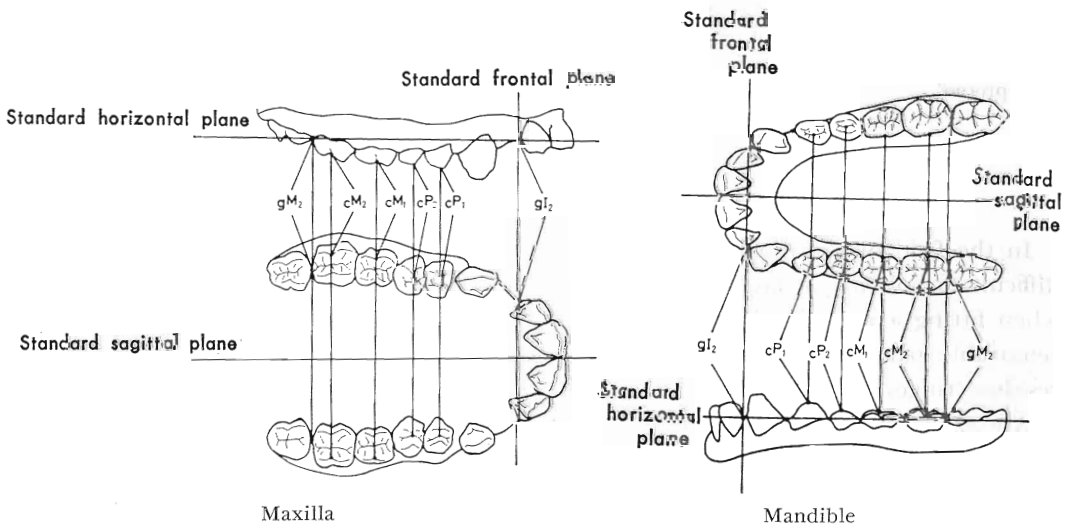
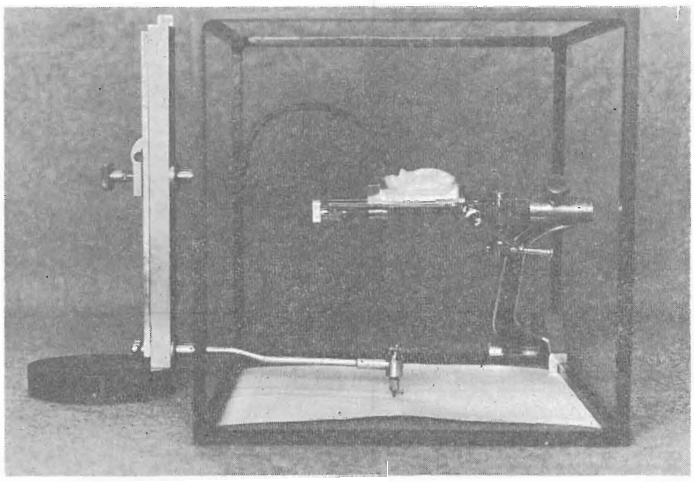


Fig. 1. Reference Points on the Casts

A



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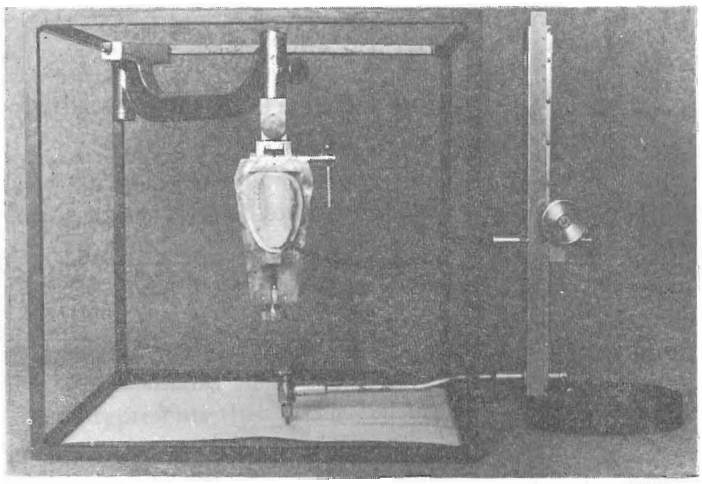

Fig. 2. A Kubuskraniophor and a diagraph

plane defined by the three points of the right and left gI_2 and the left gM_2 was lined up parallel to the plate (Fig. 2-A). Next, the Kubuskraniophor was placed on its side so that the anterior teeth of the cast were pointing downward in the direction of the marble plate. Then, the left and right gI_2 were lined up so that they were equidistant to the marble plate (Fig. 2-B). This resulted in the standardization of the measurements taken from the cast.

Once these preparations were made, the diagraph was used to chart the various points along the cross-section of the residual ridge on a graph paper which had been placed on the marble plate. The method used to calculate the area of the residual ridge is as follows: First, the line defined by the right and left gI_2 comprised the X axis. The Y axis was 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 borderline when calculating the area of the re-

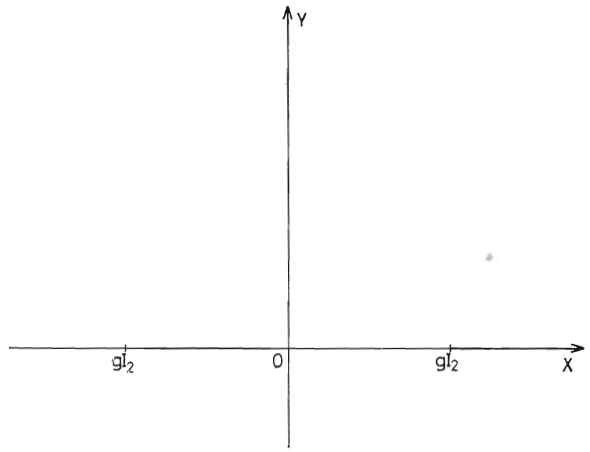

Fig. 3.

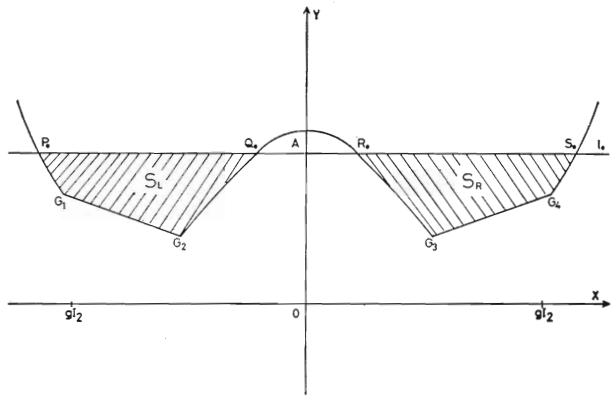

Fig. 4. Cross-Sectional Area before Extraction

sidual ridge, was drawn parallel to the X axis. The distance between l_0 and the X axis was equivalent to 30% of the gI_2-gI_2 portion of the X axis (Fig. 4). Points along the curve of the residual ridge were then marked so that perpendicular lines drawn from each of these points ($P_0, P_1 \cdots P_{n-1}, P_n$) to the X axis would intersect the X axis at 2-mm intervals. Next, a point G was charted in the area between l_0 and the curve of the residual ridge so that the X and Y values of G were equal to the mean values of all the points along the curve from P_0 through P_n, that is, G was the center of gravity. Lines were drawn connecting G to each of the various points P_0, P_1, $P_2 \cdots P_{n-1}$, P_n along the curve (Fig. 5). In order to form a triangle whose area can be measured, straight lines were drawn connecting points P_0 through P_n. This resulted in an infinite number of adjacent triangles. The areas of these triangles were added together to yield the area of the residual ridge with a high degree of accuracy.

The area of the triangles was determined in the following manner: Given a triangle defined by points (X_1, Y_1), (X_2, Y_2), and (X_3, Y_3), the formula for deriving the area is as follows:

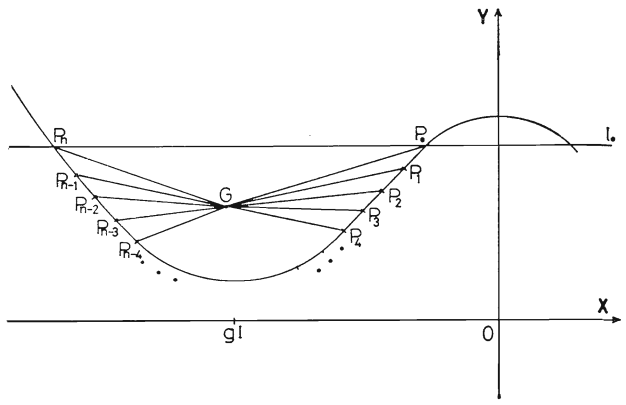

Fig. 5. Method used to calculate the Residula Ridge Area

$$S=1/2\begin{vmatrix}1 & X_1 & Y_1\\ 1 & X_2 & Y_2\\ 1 & X_3 & Y_3\end{vmatrix}=1/2\{(X_2Y_3+X_3Y_1+X_1Y_2)-(X_2Y_1+X_3Y_2+X_1Y_3)\}$$

In calculating the area, an electronic computer, HITAC 8500 (Hitachi Ltd., Tokyo) was used.

In order to minimize the problem of individual variations and errors, the following formula was used,

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

R represents the measurement taken on the right side and L represents that taken on the left. This formula was used to determine the symmetry or asymmetry of the left and right sides of the mouth. If the calculations result in 0%, then this shows that the areas of the left and right sides are identical. If the result is a positive percentage, this indicates that the right side is larger. Conversely, a minus percentage indicates that the left side is larger. In any case, regardless of whether the result is positive or negative, the larger the number, the greater is the disparity between the left and right sides. Thus this study has attempted to investigate the morphological changes of the edentulous area by using the above formula to compare the ratio of the measurements of the left and right sides before extraction with that after extraction. For the purpose of obtaining a statistical estimate of the difference between them, Student's *t*-test was applied. The significance levels are denoted as follows:

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

Needless to say, in any experiment one must allow a certain margin of error. In this experiment, the margin of error in the measuring process can be computed according to the following formula:

$$E(\%)=\sqrt{\sum_{i=1}^{n}(x-xi)^2}\Big/ n\bar{x}\times 100$$
$$\bar{x}=1/2(x_1+x_2+x_3+\cdots+x_n)$$

To insure accuracy of the measuring process, we made two separate impressions, and from two casts of the same subject. The differences between the two casts were computed according to this formula and its result showed that the differences between the two were negligible, as shown in Table 2, leading to the conclusion that the measurements were highly accurate.

Table 2. Errors (%) in Measuring process

Measurement	Error (%)
UDP_1	2.68
UDP_2	2.89
UDM_1	2.54
UDM_2	2.03
LDP_1	2.56
LDP_2	2.92
LDM_1	2.77
LDM_2	2.15

(UD···Upper Area, LD···Lower Area)

RESULTS

1) Area of Cross-Section of Upper Residual Ridge

a) M_1 Section (UDM_1) ... (Table 3, Fig. 6).

The 1U0L and the 5U1L groups exhibited a typical pattern of "rapid decrease followed by a gradual decrease." That is to say, 50% of the total ridge reduction over the two-year period occurred in the first six week period. About 70% of the total reduction had occurred by the end of the third month. From that point on, the reduction rate slowed down.

On the other hand, the 1U5L group manifested an unexpected pattern. In the first six-week period after extraction, there was some reduction in the residual ridge area but it differed from the typical pat-

Table 3. Changes in the Upper Area over the Two-year Period

Section	Period	1U0L (N=5) M (%)	S.D.	t	1U5L (N=4) M (%)	S.D.	t	5U1L (N=5) M (%)	S.D.	t
	Pre-Ext.	− 0.99	6.32		2.24	3.46		− 0.67	2.10	
	3w	−18.89	11.19	3.11***	− 0.64	4.59	1.00	−12.67	5.10	4.70***
	6w	−28.67	11.53	4.71***	− 5.33	8.94	1.56	−18.16	7.48	5.03***
UDM_1	3m	−35.82	13.51	5.22***	− 3.73	10.29	1.10	−23.63	10.54	4.78***
	6m	−36.70	5.95	9.20***	2.91	5.09	0.22	−26.82	8.70	6.53***
	1y	−41.89	14.06	5.93***	− 1.37	12.05	0.58	−31.29	10.10	6.64***
	2y	−50.17	27.21	3.94***	9.34	11.67	1.17	−32.56	9.90	7.05***
	Pre-Ext.							− 1.02	3.10	
	3w							− 8.01	5.17	2.59**
	6w							−14.89	8.68	3.37***
UDP_1	3m							−17.79	9.38	3.84***
	6m							−20.27	5.70	6.63***
	1y							−21.75	5.66	7.18***
	2y							−22.24	5.16	7.88***
	Pre-Ext.							− 0.98	3.12	
	3w							− 9.25	3.50	3.94***
	6w							−20.44	8.39	4.86***
UDP_2	3m							−22.31	6.84	6.34***
	6m							−25.48	9.11	5.68***
	1y							−27.01	9.52	5.81***
	2y							−28.64	8.92	6.54***
	Pre-Ext.							1.03	4.12	
	3w							− 8.99	4.94	3.48***
	6w							−18.16	11.19	3.62***
UDM_2	3m							−21.37	13.38	3.57***
	6m							−24.27	14.54	3.74***
	1y							−27.88	14.76	4.22***
	2y							−28.97	15.89	4.09***

N: Number, M: Mean, S.D.: Standard Deviation, t: t-Test (Compared with Pre-Ext. Measurements, *** $P \leqq 0.01$, ** $0.01 < P \leqq 0.05$, * $0.05 < P \leqq 0.10$)

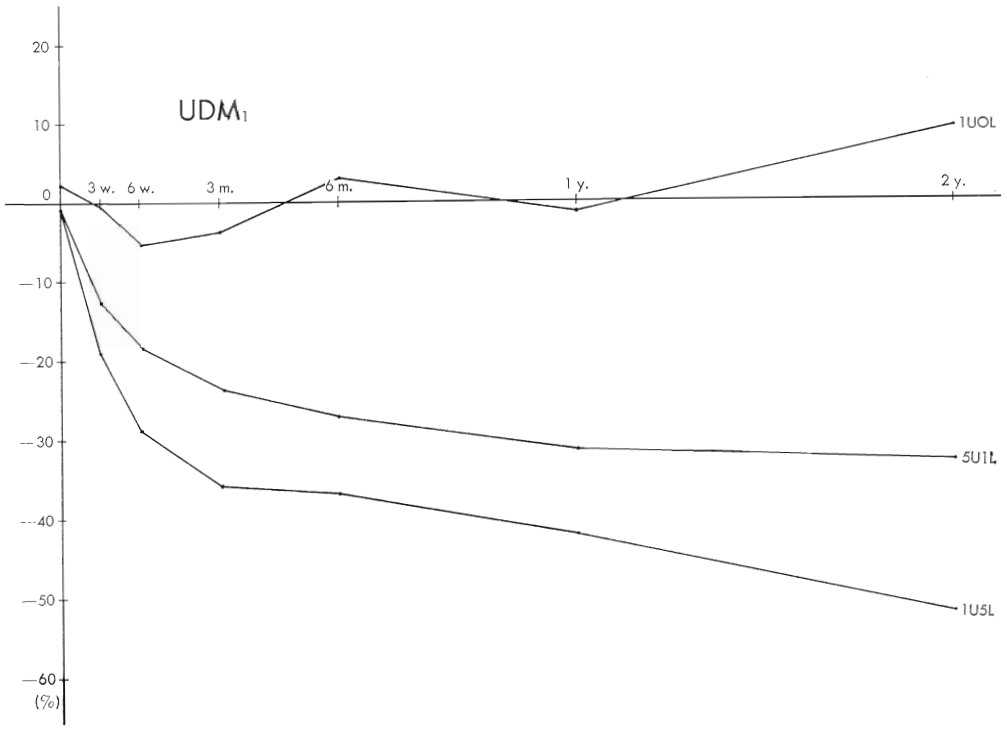

Fig. 6.

tern. From the sixth week on, the area of the residual ridge actually began to increase until it was greater than it was before extraction at the end of the two-year period. This unusual pattern is not due to any abnormality in the subjects, but may reflect the loss of the antagonistic teeth. When comparing the 1U5L groups, the differences were already apparent from the third week. The residual ridge area of the 1U0L group had declined by negative 18.89%, but the 1U5L group declined a mere negative 0.64%. Moreover, from the sixth week, the residual ridge area of the 1U5L group began to increase, although that of the 1U0L group continued to decline. At each of the fixed intervals, the differences exhibited by the two groups were statistically significant.

b) $\underline{P_1|}$ Section (UDP_1)

$\underline{P_2|}$ Section (UDP_2) (Table 3, Fig. 7).

$\overline{M_2|}$ Section (UDM_2)

These three sections exhibited the typical pattern. However, a remarkable elongation of the antagonistic teeth was observed.

2) Area of Cross-Section of Lower Residual Ridge

a) $\overline{M_1|}$ Section (LDM_1) (Table 4, Fig. 8).

The 1U5L and the 0U5L groups exhibited the typical pattern of "rapid decrease followed by a gradual decrease". However, the results in the 5U1L group were of great interest. Through the first three weeks after extraction, there was a sharp decline in the residual ridge area. This decline seemed to stabilize from the third to the sixth week. From the sixth week on, the area began to increase and continued to increase throughout the two-

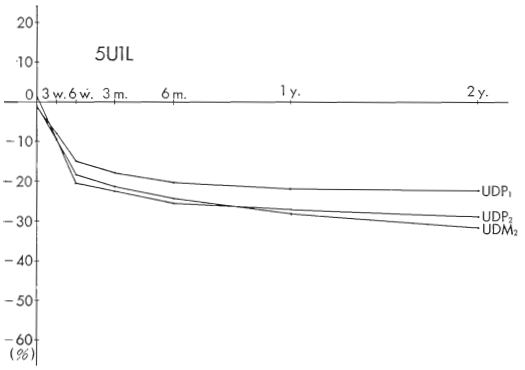

Fig. 7.

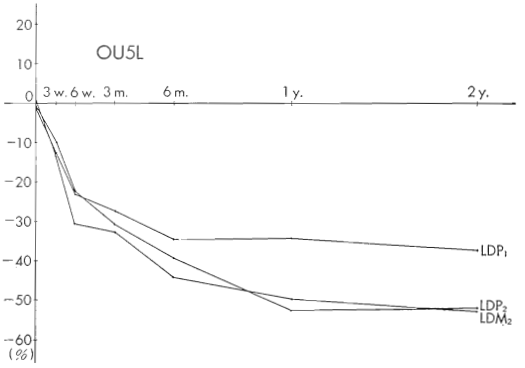

Fig. 9.

year period. This may also be due to the growth of the alveolar bone along with elongation of the lower neighboring teeth in response to the loss of the antagonistic teeth.

b) $\overline{P_1|}$ Section (LDP_1)
$\overline{P_2|}$ Section (LDP_2) (Table 4, Figs. 9, 10).
$\overline{M_2|}$ Section (LDM_2)

These three sections in both the 1U5L and the 0U5L groups exhibited the typical pattern. Both groups, regardless of the section of residual ridge, displayed a drastic reduction over the two-year period. Sixty to 80% of the total ridge reduction occurred by the third month. Thereafter, the reduction rate declined gradually.

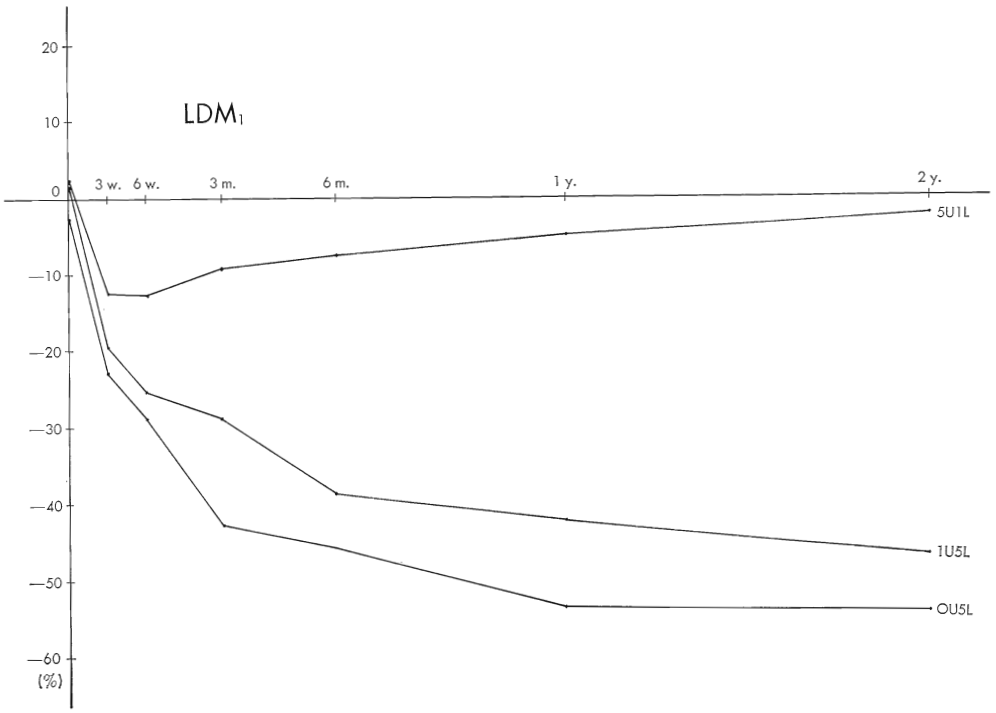

Fig. 8.

Table 4. Changes in the Lower Area over the Two-year Period.

Section	Period	0U5L (N=5) M (%)	S.D.	t	1U5L (N=4) M (%)	S.D.	t	5U1L (N=5) M (%)	S.D.	t
	Pre-Ext.	− 2.25	6.94		1.80	5.01		2.43	3.63	
	3w	−23.02	6.00	5.06***	−19.34	4.96	5.96***	−12.50	6.31	4.59***
	6w	−28.81	7.11	5.06***	−25.20	7.42	6.03***	−12.61	6.02	4.78***
LDM_1	3m	−42.78	11.76	6.34***	−28.84	5.93	7.89***	− 9.12	8.35	2.83***
	6m	−48.24	12.80	7.06***	−38.64	5.63	10.72***	− 7.44	9.79	2.11*
	1y	−53.18	9.51	9.67***	−42.08	12.38	6.57***	− 4.79	8.77	1.70
	2y	−53.67	10.73	9.00***	−48.92	11·53	8.07***	− 1.75	13.68	0.66
	Pre-Ext.	− 1.22	3.70		3.01	4.11				
	3w	−10.14	3.78	3.95***	−13.14	6.78	4.08***			
	6w	−23.11	6.23	6.76***	−16.46	7.94	4.35***			
LDP_1	3m	−27.53	10.29	6.95***	−21.62	6.10	6.69***			
	6m	−34.53	7.61	6.81***	−28.18	10.43	4.49***			
	1y	−34.20	8.10	8.28***	−32.66	11.09	6.93***			
	2y	−37.09	10.44	7.24***	−34.97	12.55	6.03***			
	Pre-Ext.	− 1.82	5.04		0.20	2.47				
	3w	−12.86	3.18	4.14***	− 9.34	5.95	2.96***			
	6w	−22.87	7.99	4.98***	−20.94	7.05	5.65***			
LDP_2	3m	−30.90	12.62	4.79***	−22.38	8.35	5.17***			
	6m	−39.35	11.03	6.92***	−30.40	10.05	5.91***			
	1y	−52.42	16.79	6.45***	−34.32	7.92	8.32***			
	2y	−51.79	15.02	7.05***	−42.00	17.63	4.74***			
	Pre-Ext.	0.18	3.81		− 1.16	3.30				
	3w	−13.58	6.52	4.97***	−23.17	16.78	2.57**			
	6w	−30.61	7.36	8.30***	−28.94	7.09	7.10***			
LDM_2	3m	−32.63	6.45	9.48***	−32.88	12.27	5.01***			
	6m	−44.21	3.10	20.20***	−32.99	6.39	8.85***			
	1y	−49.61	9.83	10.55***	−33.60	8.88	6.85***			
	2y	−52.74	11.98	9.41***	−47.58	14.88	6.09***			

N: Number, M: Mean, S.D.: Standard Deviation, t: t-Test (Compared with Pre-Ext. Measurements, *** $P \leqq 0.01$, ** $0.01 < P \leqq 0.05$, * $0.05 < P \leqq 0.10$)

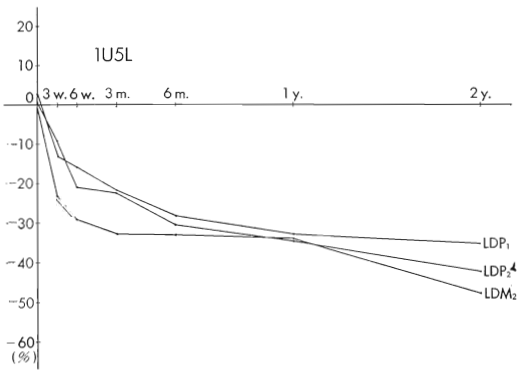

Fig. 10.

Discussion

This study revealed the existence of two types of changes in the edentulous area, one where the residual ridges increased and the other where they decreased after the extraction. The sections in which the ridge area decreased included the UDP_1, UDP_2, UDM_1, and UDM_2 sections of group 5U1L, and the LDP_1, LDP_2, LDM_1, and LDM_2 sections of groups 1U5L and the UDM_1 section of group 1U0L. The changes observed in these sections displayed a pattern of rapid decrease through the third month, followed by a more gradual decline thereafter. These results corroborate the findings of previous research in this field[10-13]. For example, Tallgren[13] followed the progress of complete denture wearers over a period of 25 years and found that the

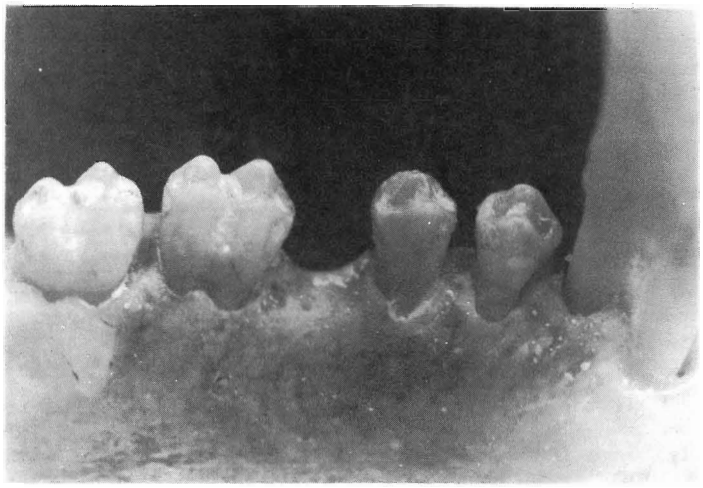

Fig. 11.

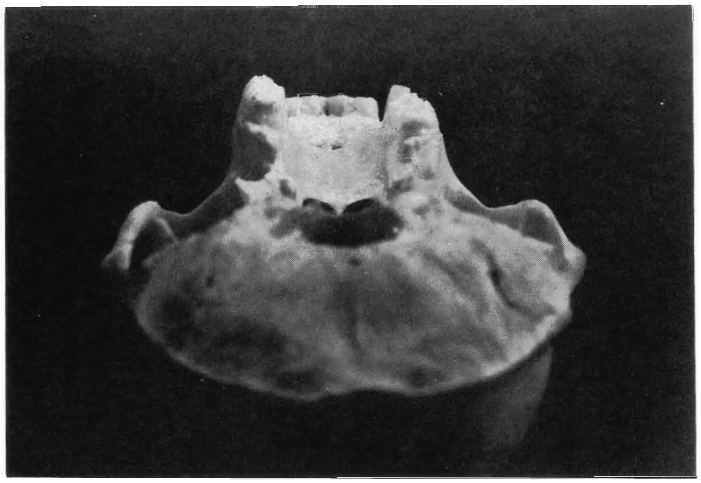

Fig. 12.

edentulous area decreases drastically in the six month to one year period following the insertion of the denture. From this point, the reduction slows down considerably; however, gradual reduction of the edentulous area continues throughout the entire 25-year period.

The sections in which the edentulous area increased included the LDM_1 section of group 5U1L and the UDM_1 section of group 1U5L. This pattern of an increase in the edentulous area has not been noted in previous studies. Both groups, after a slight reduction in the edentulous area in the first six weeks, experienced a process whereby the edentulous area actually began to increase. In other words, there is no sign of the typical two-stage pattern of a sharp decline in the edentulous area followed by a gradual decline. The reason for this may be that, having lost the antagonistic teeth, the alveolar bone increased in size along with the elongation of the neighboring teeth. This, of course, would account for the increase in the ridge area. If one examines this further, the neighbor-

ing teeth not only elongated, but they also began to incline toward the edentulous area (Fig. 11). It is hypothesized that, along with the movement of the neighboring teeth, the height of the alveolar bone had increased, and this increase was greater than the reduction rate in the residual ridges. In order to confirm this hypothesis, four dry skulls of the monkeys in groups 1U5L and 5U1L were made and then measured. The result was that along with the elongation of the neighboring teeth, the alveolar bone demonstrated a most striking increase in volume (Fig. 12).

Despite the fact that both the UDM_1 section of group 1U5L and the LDM_1 section of group 5U1L displayed the typical pattern, there was a slight difference in the response of the two groups. The total increase in the area of UDM_1 section surpassed that of the LDM_1 section. This is probably because it is easier for an upper tooth to grow downward than for a lower tooth to grow upward. It is usually assumed that the lower teeth only incline toward the edentulous area without elongating; however, the present study demonstrated the fact that there are cases in which the alveolar bone increases in height along with elongation of the lower teeth.

Conclusions

1) In almost all sections of the residual ridge areas, there was a rapid decrease followed by a gradual decrease.

2) A remarkable elongation of those teeth which had lost their antagonistic teeth was observed. The total elongation of upper teeth surpassed that of the lower teeth.

3) In the $\underline{M_1|}$ section of the 1U5L group and the $\overline{M_1|}$ section of the 5U1L group, there was no sign of the typical two-stage pattern. The ridge area of these sections gradually decreased until the sixth week; however, they began to increase until, at the end of the two year period, the areas were approximately equivalent to the measurements before the extraction. In this case, the primary reason was that, having lost the antagonistic teeth, the alveolar bone increased in size along with elongation of the neighboring teeth.

4) In measuring the dry skulls, the height of the alveolar bone increased along with the elongation of the teeth.

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