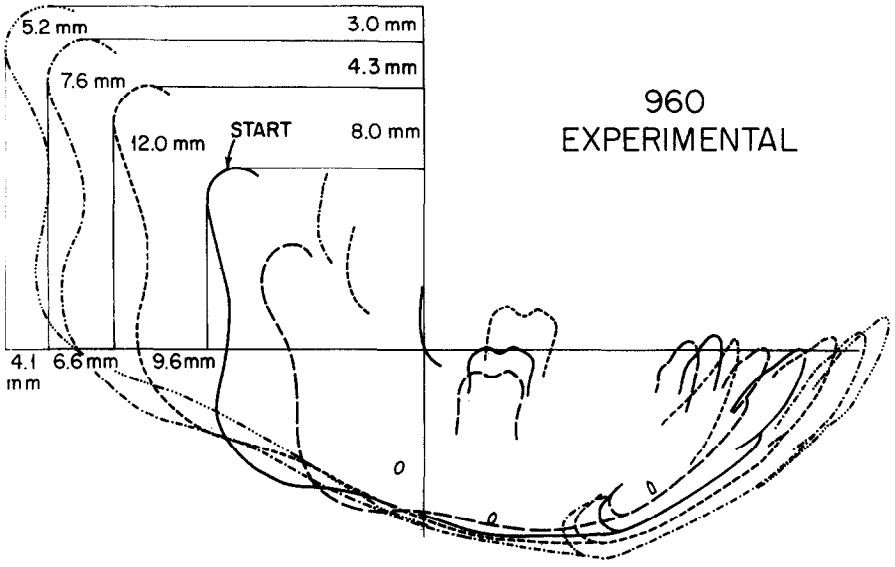

Fig. 4. Typical mandibular adaptations in an experimental animal. This animal had a 48-week control period *(long dashed lines)* before the start of the experiment. *Solid line,* Start of the experiment. *Short dashed line,* Forty-eight weeks. *Dashed-dotted line,* Ninety-six weeks. *Dashed-multiple dotted line,* One hundred forty-four weeks.

from the condyle to the symphysis—70.7 mm in the experimental group versus 66.1 mm in the controls (Table II).

Ninety-six weeks. At the end of this experimental interval, almost all permanent teeth were erupted, except for the third molars and the upper canines, indicating that the animals were roughly equivalent in age to adolescent humans.

The overall growth rate of both the experimental and control animals was reduced from that seen during the first 48 weeks of treatment (Figs. 3 through 5). Only one measure of condylar growth increase was statistically significant—that of the posterior condyle. In the experimental group, the average value was 6.3 mm as compared with 4.7 mm in the control group (Table III, Fig. 6). There was no significant difference between the growth increments observed posterosuperiorly or superiorly in the condyle. An analysis of mandibular length increments and overall mandibular length indicated that if the measurement from infradentale to condylion was used, the experimental animals on the average experienced a 2 mm greater increase in mandibular length than did the controls during the interval from 48 to 96 weeks. This resulted in the overall length of the mandibles of the experimental group being 6.6 mm longer than those of the controls, a statistically significant difference (Table III). If the measurement from the condyle to the symphyseal point was used as an indicator of overall mandibular length, the mandibles of the experimental animals were 5.6

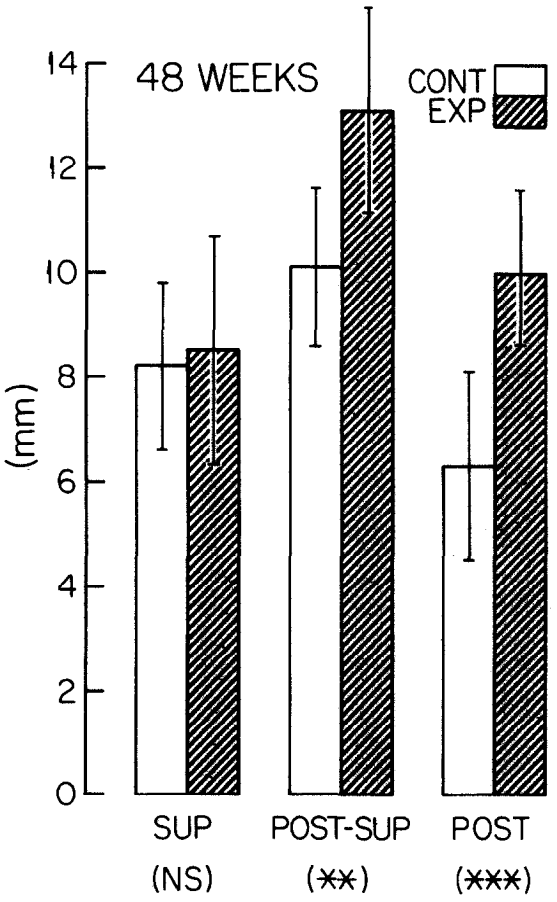

Fig. 5. Condylar growth increments during the first 48 weeks of the study.

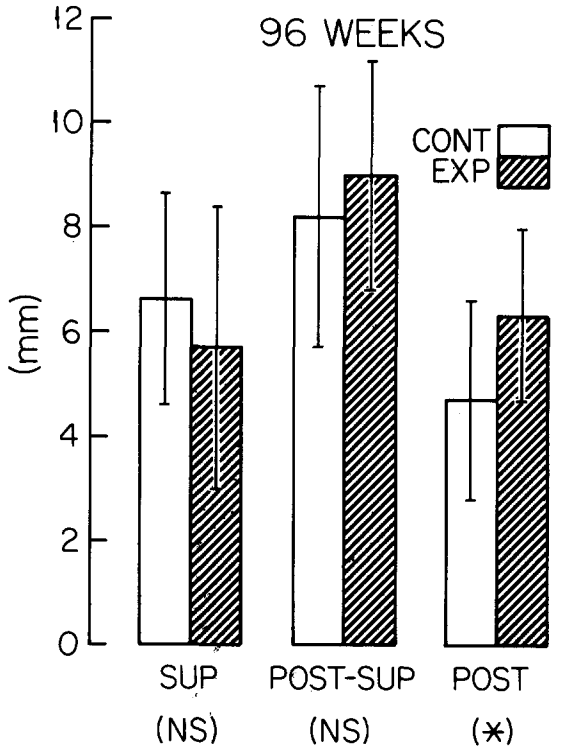

Fig. 6. Condylar growth increments from 48 to 96 weeks of the study.

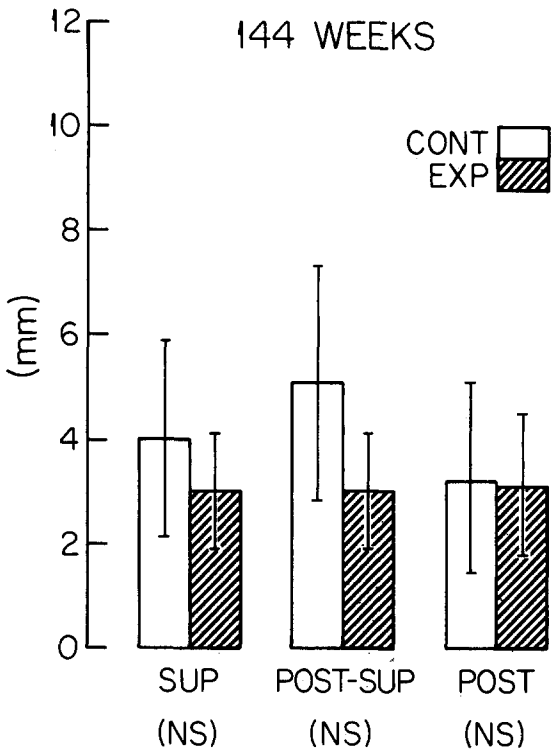

Fig. 7. Condylar growth increments from 96 to 144 weeks of the study.

mm longer than those of the controls, again a statistically significant difference.

In summary, the experimental and control animals were growing at a lesser rate than in the previous time interval. However, there were still indications that the appliance was having an effect on condylar growth and overall mandibular length.

One hundred forty-four weeks. At this time interval, the animals could be classified as adults because all permanent teeth, including third molars, had erupted.

There was no significant difference in the condylar growth increments between the experimental and control groups (Table IV, Fig. 7). In fact, the condylar growth increments in the experimental group tended to be slightly less than those of the controls, although this difference was not statistically significant.

There was also no difference in mandibular length increments in the third year of the experiments. However, at the end of the 144-week period, the mandibles of the experimental animals were still significantly longer than those of the control animals. The greatest difference was seen in the condylion–infradentale measure in which the average length of the mandible was 91.8 mm in the experimental group and 85.8 mm in the controls (Table IV, Fig. 7). When the distance from the condyle to the symphyseal point was measured, the experimental mandibles were, on the average, almost 5 mm longer than the control mandibles.

The ramus–corpus relationship

The relationship of both the condyle and the ramus to the body of the mandible was determined by the angle of intersection of the occlusal reference line with a line drawn from the posterior border of the condyle through the most posterior point on the ramus (Figs. 8 and 9). This angle was termed the condylar–ramus–occlusal (CRO) angle.[22] The mandibular plane could not be used for reference because of the generalized apposition along the lower border of the mandibular corpus and the irregular remodeling of the gonial angle as the animal increased in age.

A progressive closure of the CRO angle occurred in the control group (Table V, Figs. 8 and 10). The average CRO angle in the control group at the start of the experiment was 96.3°. By the end of 144 weeks, this angle had closed to 87.5°.

The opposite finding was observed in the experimental animals (Figs. 9 and 10). The average initial

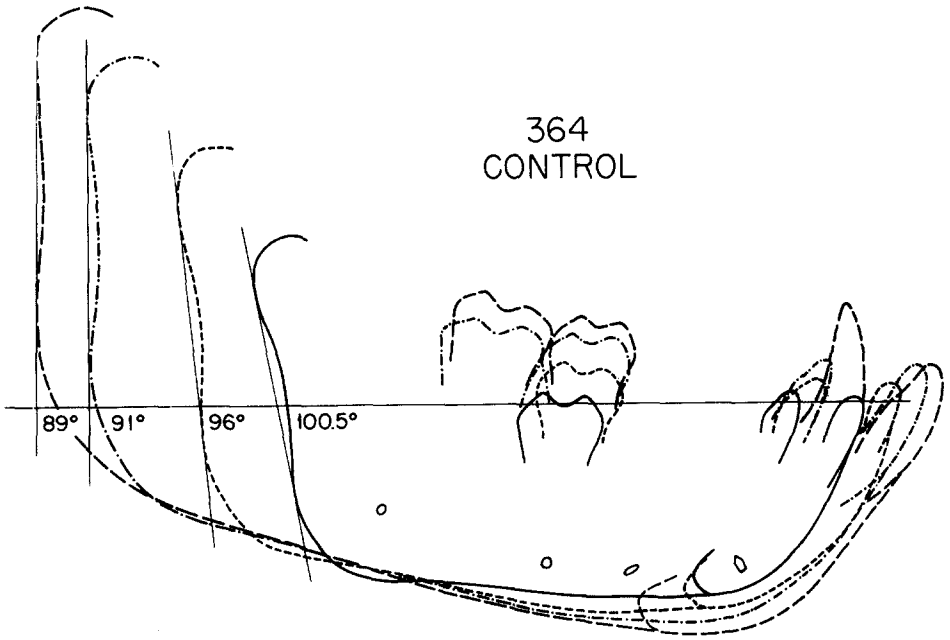

Fig. 8. Normal closure of the CRO angle in a control animal. *Solid line,* Start of experiments. *Small dashed line,* Forty-eight weeks. *Dashed and dotted line,* Ninety-six weeks. *Long dashed line,* One hundred forty-four weeks.

Table IV. One-hundred-forty-four-week mandibular length

	Control (N = 12)				*Experimental (N = 9)*				
	$\bar{X}$	*SD*	*Minimum*	*Maximum*	$\bar{X}$	*SD*	*Minimum*	*Maximum*	*Significance*
ΔSup cond	4.0	1.9	1.0	7.6	3.0	1.1	1.5	4.6	NS
ΔP.S. cond	5.1	2.2	1.7	8.5	3.0	1.1	1.5	4.6	NS
ΔPost cond	3.2	1.9	0.9	7.8	3.1	1.4	1.8	5.4	NS
ΔCo-sym	4.6	1.9	1.6	7.0	4.0	1.4	2.2	6.6	NS
ΔCo-inf	5.4	2.0	2.3	8.3	4.8	1.4	3.3	7.4	NS
Co-inf	85.8	4.4	77.0	91.3	91.8	3.5	86.3	96.7	***
Co-sym	78.7	3.7	71.2	84.1	83.6	2.9	78.9	87.0	***

***<0.001.

Table V. Condylar–ramus–occlusal angle

	Control					*Experimental*					
	N	$\bar{X}$	*SD*	*Minimum*	*Maximum*	*N*	$\bar{X}$	*SD*	*Minimum*	*Maximum*	*Significance*
Initial	12	96.3°	4.0°	90.0°	101.5°	11	95.3°	4.0°	90.0°	104.0°	NS
48 week	12	91.7°	4.7°	83.5°	100.0°	11	99.3°	3.1°	93.5°	104.0°	***
96 week	12	89.2°	4.3°	81.0°	96.0°	9	97.4°	4.0°	89.5°	101.0°	***
144 week	12	87.5°	3.4°	82.0°	92.5°	9	98.1°	5.0°	87.5°	104.0°	***
Δ48 week	12	−4.6°	3.2°	−9.5°	2.0°	11	4.0°	3.8°	−4.0°	9.0°	***
Δ96 week	12	−2.5°	2.7°	−5.0°	4.0°	9	−1.4°	2.8°	−5.0°	3.0°	NS
Δ144 week	12	−1.7°	2.5°	−8.0°	0.1°	9	0.7°	2.6°	−4.0°	4.0°	*

*<0.05.
***<0.001.

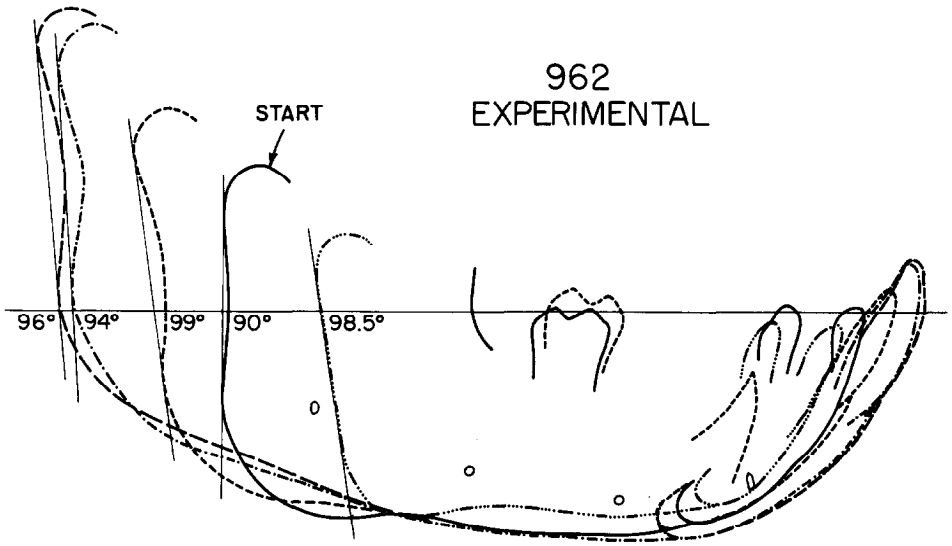

Fig. 9. The effect of treatment on the CRO angle. This animal had a 48-week control period before the onset of the experiment. Note the 8.5° decrease in the CRO angle during that time. During the 144-week experimental period, there was an opening of the CRO angle, which is the opposite of what would occur during normal growth. *Dashed and multiple dotted line,* Control period. *Solid line,* Start of experiment. *Small dashed line,* Forty-eight weeks. *Dashed and dotted line,* Ninety-six weeks. *Large dashed line,* One hundred forty-four weeks.

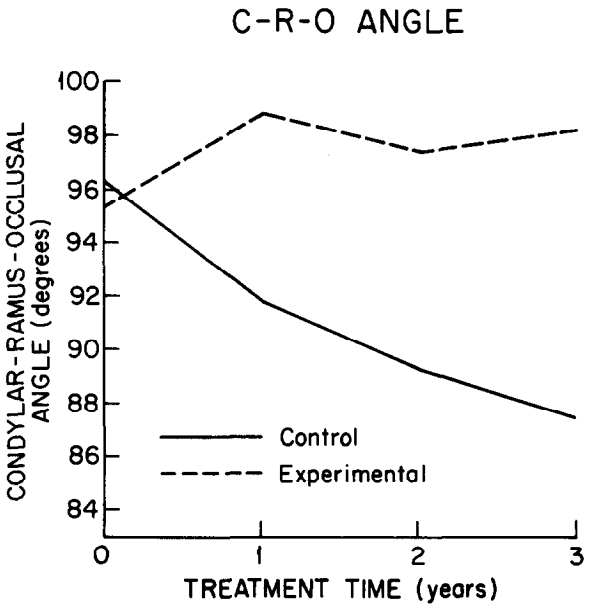

Fig. 10. Graphic representation of the change in the CRO angle during the 144-week experimental period. Note the gradual decrease in the CRO angle in the control animals, which is the opposite of what is occurring in the experimental animals.

CRO angle in this group was 95.3°. However, instead of steadily decreasing in value, the CRO angle increased at the end of 48 weeks to 99.3°. At 96 weeks it was 97.4° and at 144 weeks it was 98.1°. Thus, the effect of the appliance was to reverse the normal pattern of closure of the CRO angle.

DISCUSSION

The results of this study indicate that in the rhesus monkey the growth of the mandible can be increased to such an extent that the adult mandible is greater in overall length than it would have been without experimental intervention. Of particular interest is the magnitude of the size change.

The most dramatic indicator of mandibular length increase was the measurement from infradentale to condylion. At the end of 144 weeks, when the animals had reached maturity, the overall mandibular length was 5 to 6 mm longer in the experimental animals than in the controls. This represents a 6% to 7% increase in overall mandibular length, a percentage that compares favorably with the 5% to 8% overall increase in mandibular length observed by Petrovic[13] in his recent study of the postural hyperpropulsor.

Another interesting phenomenon is the relationship of maturational level to the amount of adaptation in the condyle and the overall changes in mandibular length. In a previous study in our laboratory,[21] it was shown that the amount of temporomandibular joint adaptation was related to the age and maturational level of the animal. The greatest amount of condylar growth increase was observed in infant and juvenile animals,

while no significant changes in mandibular length could be observed in the adult animals. These findings were verified on a longitudinal basis by the results of this study.

A decreasing amount of condylar growth and increases in mandibular length were observed in the control animals on a longitudinal basis. The increments of condylar growth and the changes in mandibular length during the second (adolescent) year were 75% to 82% of the values observed during the first year of the study. During the third year, the growth increments were only 43% to 51% of those observed in the control animals during the first 48 weeks of the study.

When the experimental and control animals were compared during the first year, the greatest amount of increase in condylar increments was 59% along the posterior aspect of the condyle and a 30% increase in the posterosuperior condylar growth increment. No difference could be seen in the amount of vertical growth between the experimental and control groups.

During the second year, the only significant amount of change in condylar growth was in the posterior condyle in which the amount of growth was 34% greater in the experimental animals than the controls. There was, in fact, a 14% decrease in condylar growth along the superior aspect of the condyle relative to control averages.

Clinical significance

It is, of course, improper to make a direct comparison between a nonhuman primate study and craniofacial growth in a human population. However, it should be noted that even in the rhesus monkey, values of significance to clinicians were observed in this experimental study (that is, overall increases in the mandibular length averaged 5 to 6 mm). The relative size of the mandible in the rhesus monkey can be compared with that in a human population to determine the size relationship between the two species. The average length of a human mandible, as measured from condylion to anatomic gnathion, is 120 mm for an adult female and 130 mm for an adult male.[24] If the adult length of the control monkey mandible, as measured either from the condyle to infradentale (85.8 mm) or from the condyle to the mandibular symphyseal point (78.7 mm), is used for comparison (Table IV), the adult monkey mandible appears to be approximately two thirds as large as the human mandible. In this experiment an average 7% increase in mandibular length (as measured from the condyle to infradentale) was noted and one could hypothesize that a similar proportional increase in a human mandible of 8 or 9 mm might be possible. Because most occlusal problems in humans are in the range of 6 mm and the average surgical mandibular advancement is carried out in the 5- to 7-mm range, this type of potential growth augmentation is of clinical significance. However, it should be stressed that in contrast to a clinical situation, in which patient cooperation is often a factor, the protocols of the present study were performed under controlled experimental conditions. These conditions are not often duplicated in clinical practice.

SUMMARY AND CONCLUSIONS

Twenty-three male juvenile rhesus monkeys were used in an experimental study of mandibular adaptation following induced functional protrusion. At the end of the 144-week experimental period, the mandibles of the experimental monkeys were, on the average, 5 to 6 mm longer than those of the controls. Most of the intergroup differences were obvious after 48 weeks.

The research outlined in this article, taken together with the work of Petrovic and associates, indicates that significant adaptations can occur in the temporomandibular joint region of a growing animal. These adaptations are more observable when the animal is in the mixed dentition stage and tend to become less dramatic as the animal becomes older. The results of this study clearly show that not only is the difference in mandibular growth rate of the experimental and control animals statistically and biologically significant, it may be clinically significant as well.

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