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Growth of the Palate and Maxillary Dental Arch

JOHN F. CLEALL

Department of Preventive Dental Science, University of Manitoba,
Winnipeg 3, Manitoba, Canada

A histological study of rats using bone markers revealed sites and directions of growth of the maxillas.

The alterations that take place with growth of the hard palate, alveolar bone, and dental arches have intrigued dentists and anatomists for many years.[1-3] That structural alterations do take place is not denied; but the subtle interactions between appositional bone growth, growth at the midpalatal suture, and eruption of teeth is as yet poorly understood.

Confining our attention primarily to the coronal plane, it is interesting to speculate which, if any, of the following hypotheses are correct:

1. The dental arch increases in width by growth at the midpalatal suture.
2. Increase in width results from growth of the alveolus in a downward but also diverging manner.
3. The buccal teeth "drift" laterally by apposition of bone on the buccal surface of the alveolus and resorption on the palatal surface.
4. The teeth "erupt" in a divergent manner.
5. Adjustments occur in the surrounding facial sutures, including the midpalatal suture, resulting in a rotation of the halves of the hard palate so that the alveoli move buccally.
6. Combinations of hypotheses 1 to 5.
7. The arch does not alter in width, with or without some, or all the aforementioned changes taking place.

Should we also wish to include the anterior-posterior dimension we might add:

8. Anterior or posterior movements of teeth or alveolus or both resulting in lateral alterations.

Materials and Methods

A histological study was conducted to consider several of the variables involved. Male Long Evans rats were used as the experimental animal.

A series of bone marking agents[4] were injected intraperitoneally into two groups of 20 rats beginning at 90 gm weight (Table 1). All animals were fed on laboratory chow[a] and water ad libitum. Measurements of the arch width in the region of the first molars were made at the time of each injection both clinically and from dental casts using a calibrated micrometer gauge (technique accurate to ± 0.02 mm). After the animals were killed, a series of coronal sections (100 micrometers [μm] undecalcified) were cut of one series of animals with the base plane touching the tip of the upper incisor and the tympanic bulla. Sections in the first molar region were analyzed by measuring the increments of bone growth between successive bone marks directly from a calibrated microscope eyepiece (Figs 1, 2). The

TABLE 1
BONE MARKING SEQUENCE

Time of Injection (days)		Marking Agent	Dosage (mg/kg)
A	0*	Terramycin	70
B	4	Alizarin red S	400
C	11	Trypan blue	300
D	25	Terramycin plus alizarin red S	70 + 400
E	46	Terramycin plus trypan blue	70 + 300
F	77	Animals killed	. . .

* First injection (*A*) made when rats weighed 90 gm.

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[a] Ralston Purina Co., St. Louis, Mo.

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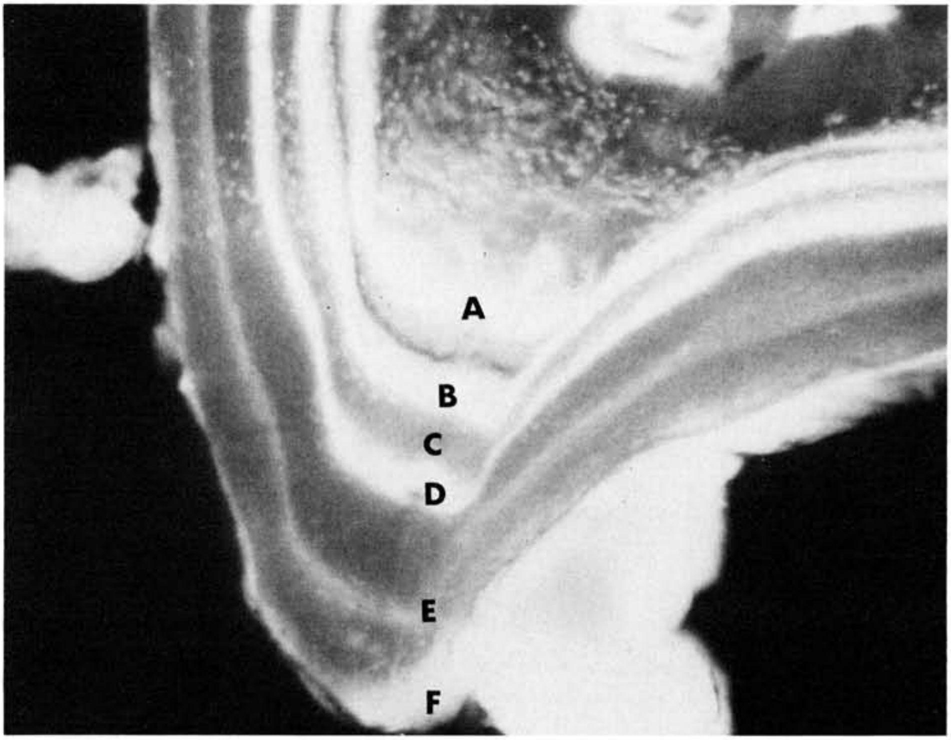

FIG 1.—Typical sequence of bone marks in maxilla (under ultraviolet light) adjacent to incisive foramen. *A,* Terramycin; *B,* alizarin red S; *C,* trypan blue (not visible under ultraviolet light); *D,* Terramycin plus alizarin red S; *E,* Terramycin plus trypan blue; *F,* bone edge at death.

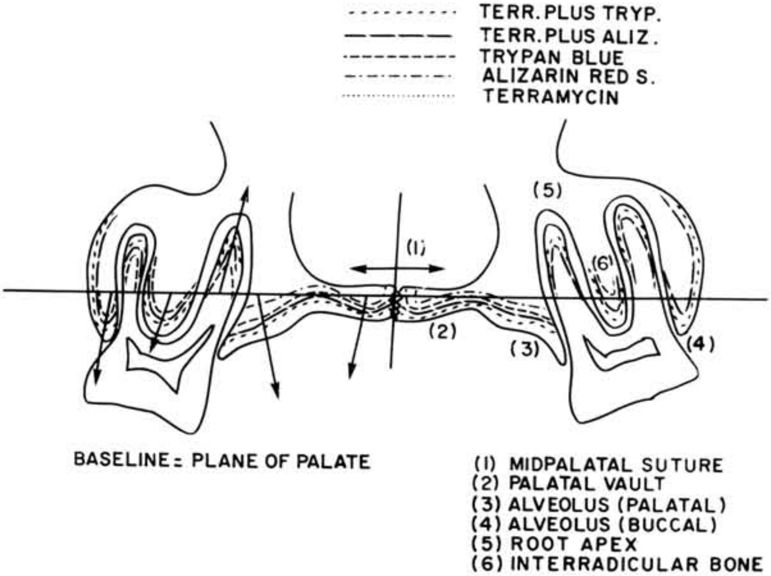

FIG 2.—Diagrammatic representation of coronal section taken in first molar region. Arrows depict direction of growth at each specific growth site.

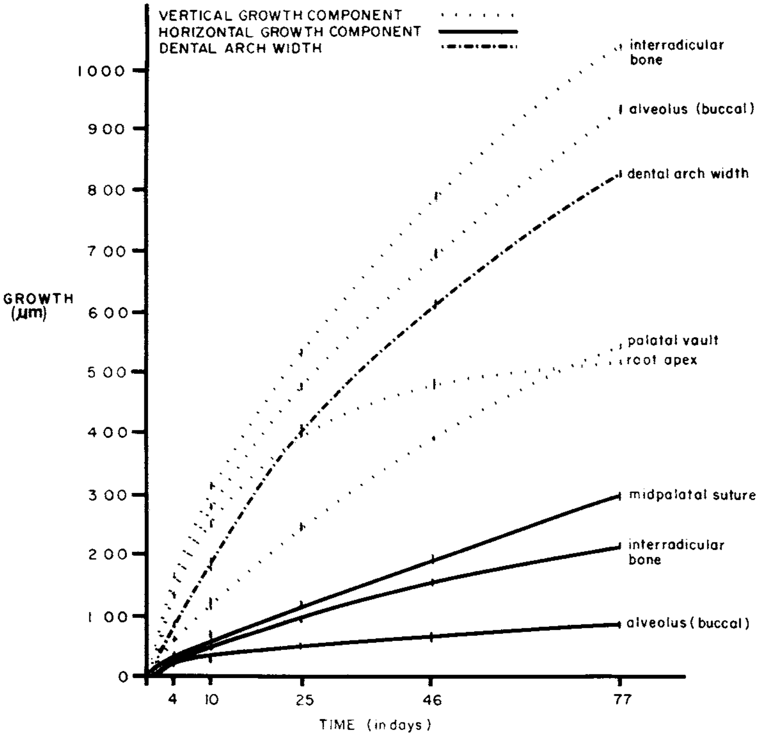

Fig 3.—Incremental growth curves of several sites. "Dental arch width" was measured clinically and from plaster models (see text). Time scale indicates day on which each bone marking agent was injected.

second series of animals were sectioned parasagittally and the sections analyzed in the region of the alveolus (Fig 4). In both series, three slides were measured on each side and averaged for each animal.

The vectors of growth for each of several sites were measured from standardized photographic prints prepared from each slide. By means of a computer program the measurements of incremental growth measured on the sections were converted into vertical and horizontal components; this was done for both coronal and parasagittal sections.

Results

It was noted that very little differential growth was occurring in the midpalatal suture, suggesting that this suture was growing fairly uniformly from top to bottom, and thereby, largely discounting the suggestion that increase in arch width is due to rotation of the maxillary halves during growth.

TABLE 2
Maxillary Dental Arch Width

	A 0 days	*B* 4 days	*C* 10 days	*D* 25 days	*E* 46 days	*F* 77 days
Average width (mm)	5.20	5.25	5.35	5.60	5.78	6.01

	Increments				
	A–B	*B–C*	*C–D*	*D–E*	*E–F*
Mean (mm)	0.05	0.10	0.25	0.18	0.23
SD (mm)	0.04	0.08	0.05	0.04	0.05

Note: Distance is from left to right distopalatal cusps of first molars.

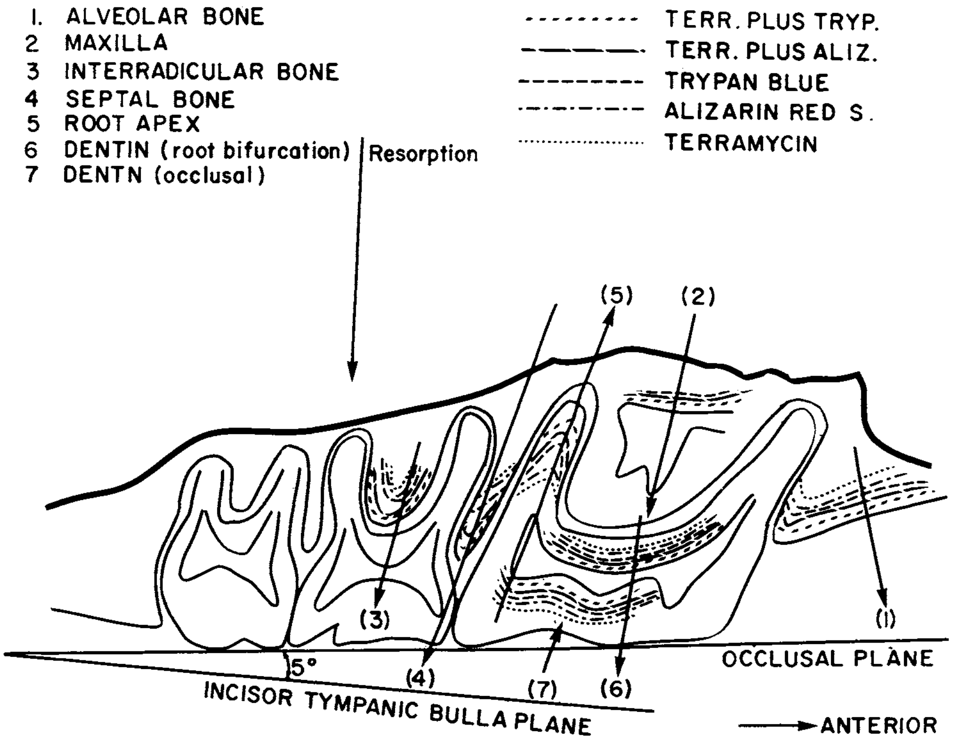

FIG 4.—Diagrammatic representation of parasagittal section taken through alveolus. Most bone marking lines have been excluded for clarity. Arrows depict direction of growth at each site where detailed incremental measurements were made.

The clinical measurements of the dental arches in the region of the first molar are shown in Table 2 which shows that the maxillary dental arch width did indeed increase approximately 0.8 mm over the experimental period.

The changes taking place in the animals cut in coronal sections at the region of the first molar are shown in Figures 2 and 3 and Table 3.

The table of measurements shows that the growth at the midpalatal suture resulted in no vertical component of growth. This growth site, however, was noted to contribute a considerably greater amount in width as did the horizontal component of alveolar growth as measured on the buccal surface.

Figure 2 shows the direction of growth at each site measured. With the exception of the midpalatal suture, most sites measured in the coronal sections showed a predominantly downward vector of growth. The alveolar growth was much greater than the appositional growth on the palate. This led to a progressive increase in palate depth.

Figure 3 shows that the curves of the vertical and horizontal components of growth of the apical regions of the molar roots are different from the curves of bone growth. A relatively fast initial rate was followed by a rapidly reducing rate of apical formation.

Finally, the combination of growth at the midpalatal suture plus the horizontal contribution made by the growth of the alveolus, if multiplied by a factor of two (left and right sides), approximates the amount of increase in dental arch width measured clinically.

These observations on the coronal sections would suggest that:

1. the dental arch increases in width by some growth at the midpalatal suture;
2. the diverging growth pattern of the alveolus also results in increased width; and
3. the growth of the alveolus and apical growth of the roots of the molars are to some extent independent in their modes of growth.

TABLE 3

CORONAL SECTIONS (increments in micrometers, N = 20)

Marker Lines		Site of Measurement					
		Midpalatal Suture	Palatal (Vault)	Alveolus (Palatal)	Alveolus (Buccal)	Root Apex	Interradicular Bone
A–B							
Vertical component	**Mean**	0.0	40.9	78.2	98.1	–116.7	113.5
	SD	0.0	2.0	20.2	17.3	19.7	25.1
Horizontal component	**Mean**	20.1	10.8	–15.7	9.6	22.7	20.9
	SD	20.1	6.5	6.5	12.2	10.2	17.5
B–C							
Vertical component	**Mean**	0.0	64.9	115.7	157.3	–140.3	169.7
	SD	0.0	8.0	23.0	38.1	31.3	39.5
Horizontal component	**Mean**	30.6	17.5	–24.2	13.8	27.3	32.1
	SD	35.6	11.5	12.2	18.6	13.0	26.5
C–D							
Vertical component	**Mean**	0.0	117.8	175.1	190.0	–130.5	225.5
	SD	0.0	15.0	48.2	53.2	21.3	57.0
Horizontal component	**Mean**	60.8	31.6	–36.2	17.3	25.3	44.8
	SD	30.0	15.0	15.8	22.7	11.3	35.9
D–E							
Vertical component	**Mean**	0.0	167.1	230.2	232.3	88.3	250.0
	SD	0.0	33.4	50.8	80.2	11.6	40.4
Horizontal component	**Mean**	85.6	40.7	–49.1	21.9	16.3	45.8
	SD	48.4	16.6	25.2	31.2	5.8	36.0
E–F							
Vertical component	**Mean**	0.0	164.2	204.3	241.8	–41.8	286.0
	SD	0.0	59.4	49.6	54.7	4.8	58.6
Horizontal component	**Mean**	92.6	38.3	–41.7	20.0	8.1	53.3
	SD	59.0	15.5	21.9	27.7	3.7	45.0
Vertical component	**Mean Totals**	0.0	554.9	803.5	919.5	–517.6	1,044.7
Horizontal component	**Mean Totals**	289.7	138.9	–166.9	82.6	99.7	196.9

The correction of the growth increments by measuring the direction of bone growth at each site would seem to be useful for interpretation in that it is possible to consider each site in its horizontal and vertical components. In the coronal sections, this correction did not, however, consider the effect of any possible anteroposterior growth of the structures. The second series of rats was, therefore, sectioned parasagittally, and detailed measurements were made in the region of the alveolus. The base line used to assess the direction of growth at each site was the occlusal plane. This plane was corrected to the incisor-tympanic bulla plane which was used to orient and cut the sections (Table 4 and Figs 4, 5).

The table of growth increments corrected for direction of growth shows that with the exception of the secondary dentin in the occlusal region of the molar pulp chambers all vertical growth was downward. In the horizontal aspect, however, most structures were growing predominantly in a posterior direction as shown by the negative signs. The anterior part of the alveolus and the growth site measured in the basal aspect of the maxilla, however, were noted to be growing slightly forward in direction (Fig 4).

Figure 5 shows the growth curves derived from the incremental data of the parasagittal sections. The data suggest that the vertical contribution to growth by structures related to the teeth and alveolus are about two to three times that of the downward growth of the maxilla. (This is consistent with the finding for the alveolus and palate seen from the coronal sections.) The development of the root apexes showed similar rates of growth to those noted in the coronal sections and were likewise dissimilar to the other curves for bone growth. While, in general, the modes of bone growth were similar to those noted in the coronal sections, the horizontal components of growth were much less than the vertical components in the parasagittal sections. This last point means, in effect, that the growth vectors deviated only

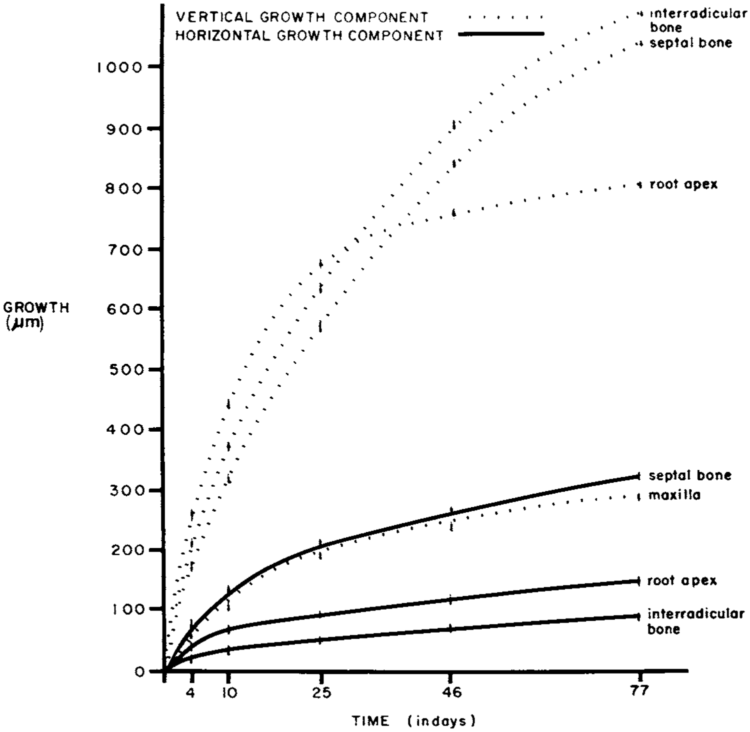

FIG 5.—Incremental growth curves show horizontal and vertical amounts of growth occurring at several of sites measured. Time scale indicates day on which each bone marking agent was injected.

TABLE 4
PARASAGITTAL SECTIONS (increments in micrometers)

Marker Lines		Alveolar Bone	Maxilla	Interradicular Bone	Septal Bone	Root Apex	Dentin (Root Bifunction)	Dentin (Occlusal)
A–B								
Vertical	Mean	69.0	50.5	187.5	187.7	226.4	19.5	–71.8
	SD	38.8	19.0	24.7	31.0	38.5	27.0	19.1
Horizontal	Mean	12.8	0.6	–17.1	52.8	–44.5	1.3	–4.5
	SD	9.0	6.5	14.4	12.1	15.6	5.3	4.6
B–C								
Vertical	Mean	112.0	75.3	200.3	180.4	250.0	38.8	–81.8
	SD	90.9	24.8	42.2	55.9	98.6	42.9	11.6
Horizontal	Mean	19.3	0.4	–26.6	–74.9	–47.5	1.2	–4.2
	SD	17.9	10.5	24.1	18.4	20.9	8.2	4.7
C–D								
Vertical	Mean	170.6	70.4	250.2	231.2	178.6	42.2	–94.7
	SD	133.1	16.2	161.6	83.4	43.8	76.6	28.0
D–E								
Vertical	Mean	198.7	87.4	267.4	290.2	95.2	35.6	. . .
	SD	66.0	27.8	23.3	43.5	42.8	46.3	. . .
Horizontal	Mean	36.9	0.7	–24.0	–108.6	–25.9	2.7	. . .
	SD	17.8	10.4	14.7	18.3	9.0	8.2	. . .
E–F								
Vertical	Mean	146.1	49.7	250.2	280.0	40.0	. . .	. . .
	SD	30.5	8.6	20.1	94.5	32.2	. . .	. . .
Horizontal	Mean	29.7	0.1	. . .	–83.6	–24.4	. . .	. . .
	SD	15.9	6.5	. . .	22.1	14.1	. . .	. . .
Vertical	Mean Totals	696.4	331.3	1,154.6	938.3	612.2	136.1	–248.3
Horizontal	Mean Totals	127.0	3.7	–90.9	–384.1	–172.6	11.1	–14.0

slightly from the vertical components and the effect of this deviation would be to reduce the amount of growth recorded in the coronal sections a similarly small amount. This factor plus the amount of variation (as reflected by the large standard deviations) suggested that it was unwarranted to apply a further correction factor to the coronal data.

Discussion

The increase in width of the dental arch in the molar region demonstrated in this study is consistent with the findings of Isotupa.[5] His alizarin staining experiment of the growth of the rat skull included data on the width of the dental arch derived from measurements from the palatal surfaces of the first molars. Over a comparable time period an increase in this measurement of 0.8 mm was recorded. This figure is identical with the value obtained in the present study.

Few detailed studies on postnatal palatal growth are available in the literature. Keith and Campion[6] felt that the midpalatal suture was the major factor in the growth in width of the human palate, but Brash[7] was of the opinion that a combination of both sutural and surface appositional growth was involved.

Animal studies have shown that the median palatal suture does undergo growth changes postnatally. For example, Craven[8] showed that in the rhesus monkey alizarin stain was deposited throughout this suture and he suggested that this was a secondary reaction and in response to the diverging nature of growth of the palatine bones and maxillas. In a vital staining study of growing rats, Baer[9] considered that incremental growth at the edges of the intermaxillary suture resulted in an increase in palate width and also in the distance between the molars. However, he did not provide the age span involved. The present study demonstrates some of the interactions between the changes at the midpalatal suture and the divergent growth pattern of the alveolar portions of the maxilla and further suggests that this region cannot be considered simply in terms of sutural or appositional growth. The interactions of these and other modes and sites of growth also are important. For example, Anderson[10] found endochondral growth in the midpalatal suture (also noted in this study) which suggests that a multiplicity of interrelated factors are involved in the growth in width of the palate. Although no measurements were made, a study by Dixon[11] using radioactive calcium as a marker for assessing bone growth in the rat demonstrated that Ca^{45} deposited was more pronounced on the lingual surface of the molar sockets than on the buccal surface. This presumably suggested that the molars are to a degree "drifting" buccally through the alveolus. This observation was not made in the present study, but does again suggest that we are dealing with a complex growth model.

Considering the findings in general terms, note should be made of the fact that no assessment was made of the translation of the whole maxillary complex. Cephalometric[12] and other histological studies[8] would suggest that the maxillary complex is translated downward and forward relative to the cranial base. The present study shows that as this occurs various detailed changes take place locally in the maxillary complex including an increase in dental arch width, increase in palatal height, and slight distal repositioning of the buccal segments.

A further point is the assumption that the growth vectors approximate a straight line. These are actually slight curves (Fig 1) in the coronal plane and in the satittal planes. The resulting three dimensional curves are only roughly approximated by tangents to these curves in the separate coronal and sagittal planes as measured in this study. Whether the errors associated with this compromise would justify the sophistication of applying the required three dimensional curved surface geometry to studies of this kind is questionable. However, at least the recognition and demonstration that growth is three dimensional and nonlinear is of considerable importance to those working in the field.

Conclusions

This study suggests that in the rat the maxillary dental arch widens with growth, over the period studied, by a combination of growth at the midpalatal suture and the downward and outward growth of the alveolus. Distal movement of the teeth concomitant with vertical growth of the alveolus, although measureable, is unlikely to influence the increase in width by any great amount.

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