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Morphometric analysis of developing crowns of maxillary primary second molars and permanent first molars in humans

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Abstract

The purpose of this study was firstly to characterize the changes occurring in size and form of the mineralizing maxillary second primary molar and first permanent molar crowns, and secondly to determine if similar changes in size and form characterize enamel apposition in the crowns of these teeth. Twenty-five primary second molars and 20 maxillary permanent first molars at various stages of development, found in archaeological excavations in Israel, were examined for a number of measured variables using image analyser software. Teeth were divided into two groups according to their stage of development: stage 1 included all teeth at an early stage of development in which mesiobuccal-cusp height was less than 5 mm for the primary molar and 5.9 mm for the permanent molar; stage 2 included all teeth in later stages of development where mesiobuccal-cusp height was greater than these values. In the primary molar, a significant increase was found between the two stages in almost all variables. Significant correlations were also found between all intercusp distances and the external variables. Strong correlations between height of the mesiobuccal cusp and all external and internal variables were noted in stage 1, but fewer in stage 2. In the permanent tooth, no increase was observed in intercusp distances and very few correlations were found between and among the variables. The results suggest that a change in the shape of the maxillary primary second molar occurs during formation, with the lingual cusp tips moving lingually and distally, and the distobuccal cusp tips moving distally. No change occurs in the shape of the maxillary permanent first molar during crown formation. Growth of the maxillary primary second and permanent first molar crowns occurs in ‘bursts’ of development.

Keywords: Morphometrics; Primary first molars; Permanent first molars; Crowns; Intercusp distances

1. Introduction

Previous studies have shown a gradient in cusp development of the primary and permanent molar, where the mesiobuccal portion always develops ahead (in order and in shape) of the distolingual portion (Butler, 1967; 1968; Kraus and Jordan, 1965; Peretz and Smith, 1993). Butler (1967; 1968) found that intercusp distances in the maxillary first permanent molar increased after the initiation of calcification. The finding was explained as due to tilting of cusps through continued mitosis of the inner enamel epithelium in the fissures between them. According to this theory, the relation between cusp tips is stabilized only after the slopes of the cusps are bridged by calcification. This has recently been confirmed by serial computed tomographic studies,

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which demonstrated differences in angulations between cusps on mandibular molars (Smith et al., 1996).

A study on maxillary primary first molars using a computerized image analyser demonstrated that enamel apposition consists of two stages (Peretz et al., 1997), early and late, with a significant increase in intercusp distances between them. The investigators postulated that this was related to localized differences in enamel apposition. A preliminary study on the mandibular primary second molar showed no increase in the intercusp distances during tooth development between the ages of 3 months to 1.5 years (second stage of development), which was determined by the height of the mesiobuccal cusp (Peretz and Smith, 1993). However, data on a larger sample which included teeth at an earlier stage of development revealed that, as for the upper first primary molar, intercusp distances in the second stage were greater than in the first stage (Smith et al., 1995). Our purpose now was firstly to characterize the changes occurring in size and form of the mineralizing maxillary second primary molar and first permanent molar crowns, and secondly to determine if similar changes in size and form characterize enamel apposition in the crowns of these teeth.

2. Material and methods

Twenty-five primary second molars and 20 maxillary permanent first molars at various stages of development were examined. The teeth were well preserved, of children aged 0–3 years, recovered from various archeological excavation sites in Israel, and were dated 6000–300 BC. All teeth were unerupted, and were removed from the jaws for examination. Teeth were graded according to crown height development and cuspal bridging, and this was used as an estimate of chronological age after Kraus and Jordan (1965). The following variables were examined on the teeth:

(a) The distance between
  1. The mesiobuccal (mb) and the distobuccal (db) cusps (MB).
  2. The mesiobuccal (mb) and the distolingual (dl) cusps (MDL).
  3. The mb and mesiolingual (ml) cusps (ML).
  4. The db and dl cusps (DB).
  5. The db and ml cusps (DML).
  6. The dl and ml cusps (DL).

(b) The angle between:
  1. The db, mb, and ml cusps (>mb).
  2. The mb, db, and dl cusps(>db).

(c) Maximal perimeter of the tooth crown from occlusal view (mp).
(d) Maximal area from occlusal view (ma).
(e) Maximal perimeter of the occlusal table (op).
(f) Maximal area of the occlusal table (oa).
(g) Maximal mesiodistal (md), and buccolingual (bl) dimensions.
(h) Mesiobuccal-cusp height from cusp tip to edge of enamel (mbh).

Fig. 1 shows a schematic representation of cusp arrangement and crown shape of the examined maxillary molars, both primary and permanent (A), and of the intercusp distances (B).

The methods of measurement have been previously described in detail (Peretz and Smith, 1993, Peretz et al., 1996; 1997). In brief, all the variables but the mesiobuccal-cusp height were measured with an image-analyser computer program (CUE 4; Galai, Migdal HaEmek, Israel). A digital caliper with an accuracy of 0.01 mm (Beerendonk, Dentaurum Co., U.S.A.) was used to measure the mesiobuccal-cusp height from the cusp tip to the lowest border of the enamel (or cementum–enamel junction if the crown was complete). All measurements were made by one observer (N.N.). In order to determine intraobserver variation, 20 teeth were measured three times, and the percentage difference between measurements was 1.72%.

A correlation analysis was used to examine association between the variables studied. Scatter plots of all variables against mesiobuccal-cusp height showed that variables separated into two stages of development according to mesiobuccal-cusp height of 5 mm for the primary molar and 5.9 mm for the permanent tooth. The Wilcoxon matched-pair test was used later to compare between the variables in each stage of development. The level of significance was chosen at $p < 0.05$.

3. Results

Cumulative plots of all variables against mesiobuccal-cusp height for the primary and permanent teeth showed that all variables demonstrated an initial but not steady increase in size (Fig. 2a and b, respectively). Teeth were divided into two groups:

1. Stage 1—all teeth at an early stage of development in which mbh was less than 5 mm for the primary molar, or 5.9 mm for the permanent molar.
2. Stage 2—included all teeth in later stages of development, where mbh was greater than 5 mm for the primary molar, and greater than 5.9 mm for the permanent molar.

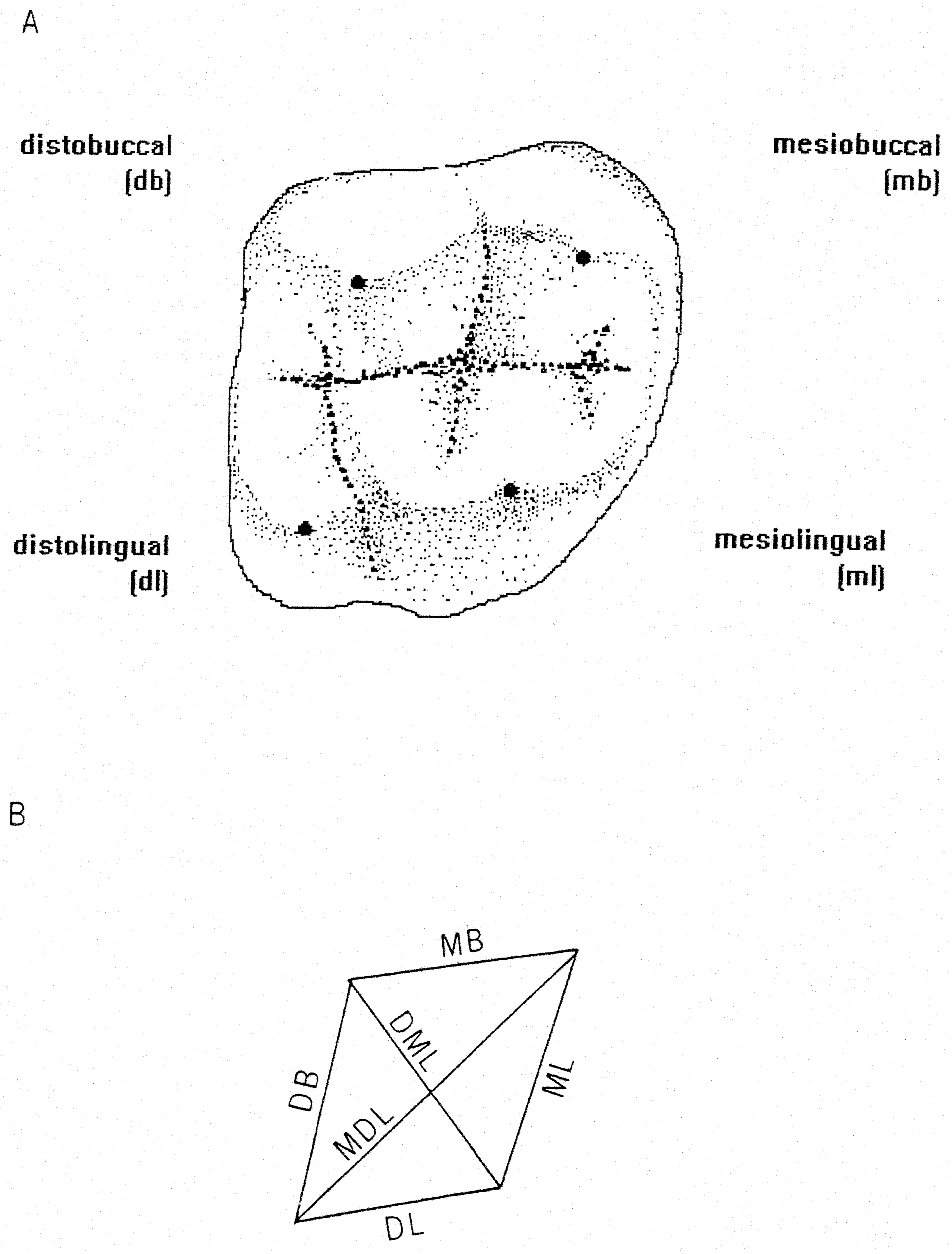

Fig. 1. A schematic representation of (A) Crown shape and cusp arrangement in the maxillary primary second and permanent first molars in humans; (B) The intercusp distances (see text for abbreviations).

The means and SD of the variables for the primary molar in both stages of crown development and for the total developmental process are shown in Table 1. There was a significant increase between stage 1 and stage 2 in the following variables: MB, MDL, ML, DB, DML, op, oa, mp, ma, bl and md. A non-significant increase was observed in DL and in the mb angle (>mb). The db angle (>db) showed a slight decrease. The measurements of the same variables for the permanent tooth are demonstrated in Table 2. A statistically significant increase between stage 1 and stage 2 was found only in mp, ma, bl and md. No other variable showed a significant difference between stages. Tables 3a, 3b and 3c and Tables 4a, 4b and 4c show correlation matrices for most measurements for the primary and permanent molars, respectively. In the

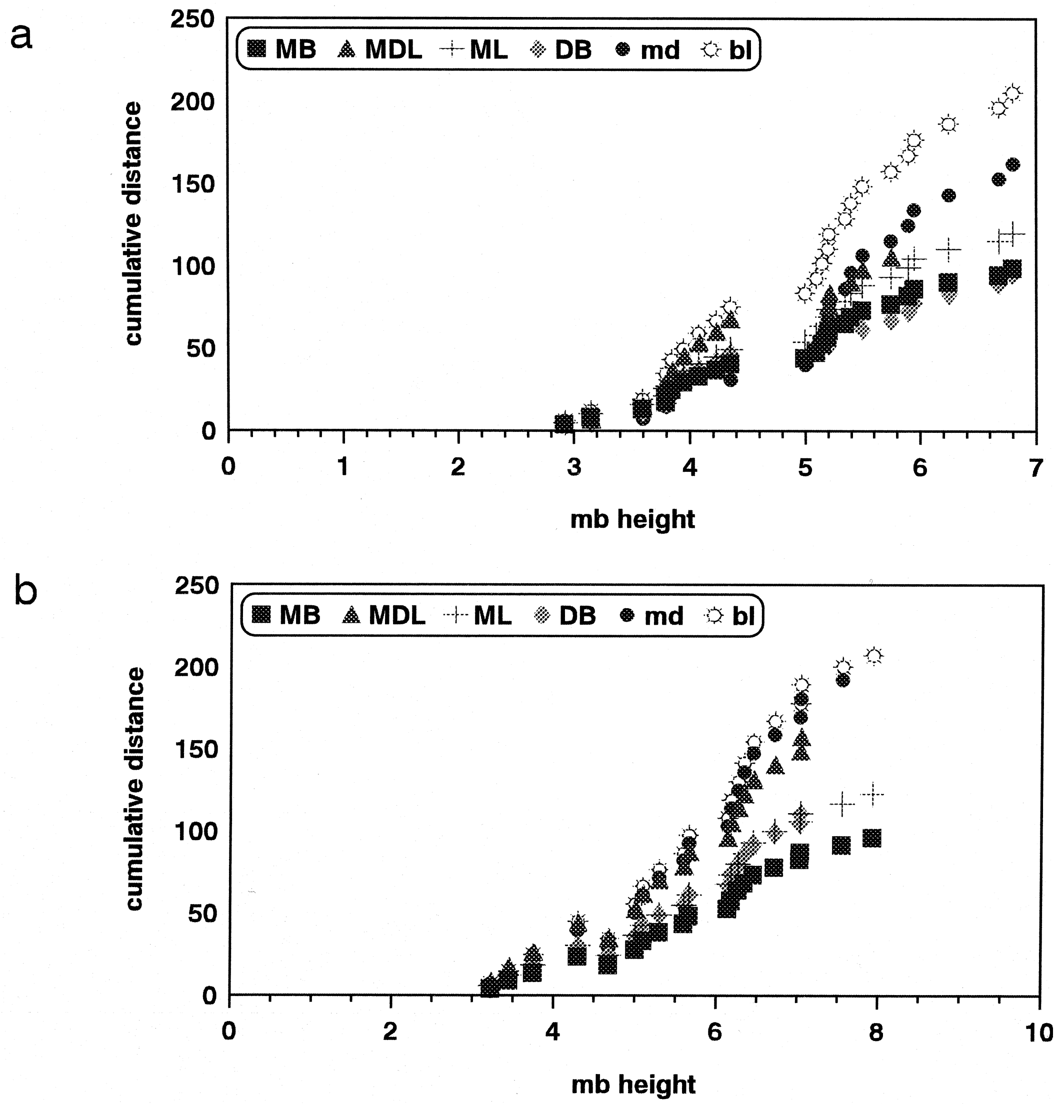

Fig. 2. Cumulative plots of some variables for the maxillary primary second molar (a) and for the maxillary permanent first molar (b) (see text for abbreviations).

primary molar, for the total developmental process (Table 3a), strong and significant correlation was found between all intercusp distances (except DL) and the external variables of the crown (bl, md). Weak correlations were seen between mbh and the other variables. Separate correlation matrices for stages 1 and two revealed a strong correlation between mbh and all external and internal variables in stage 1 (Table 3b), but fewer significant correlation in stage 2 (Table 3c). Also, among intercusp distances, more significant correlations were found in stage 1. In the permanent tooth, for the total developmental process (Table 4a), very few significant correlations were noted between and among variables. Also, in stage 1 (Table 4b), fewer significant correlations were observed than in stage 2 (Table 4c).

4. Discussion

The maxillary primary second molar showed an increase in size in almost all internal variables (within the occlusal table), and external variables (outside the occlusal table) from stage 1 to stage 2 of crown development, with the exception of DL and the mesiobuccal angle. These findings, and the correlations found

Table 1
Means and SD of the variables at each developmental stage for the total process of the primary maxillary second molar (all in mm except > mb and > db in degrees)

Variable	Stage	*n*	Mean	SD	Min.	Max.	*p*
MB	1	13	3.78	0.64	2.9	5.28	0.049
	2	12	4.19	0.53	3.6	5.2	
	Total	25	3.98	0.61			
MDL	1	7	7	0.64	6.3	8.2	0.05
	2	12	7.5	1.28	3.9	8.7	
	Total	19	7.32	1.09			
ML	1	13	4.7	0.51	3.98	5.68	0.041
	2	12	5.2	0.59	4.5	6.1	
	Total	25	4.95	0.59			
DB	1	7	4.81	0.5	4	5.5	0.019
	2	12	5.46	0.53	4.8	6.4	
	Total	19	5.23	0.6			
DML	1	13	4.48	0.8	3.38	6.49	0.003
	2	12	5.62	0.9	4.3	7.6	
	Total	25	5.03	1.01			
DL	1	7	3.57	0.45	3	4.4	0.136
	2	12	3.9	0.5	3.2	4.6	
	Total	19	3.78	0.5			
> mb	1	13	63.66	8.83	46.5	72.7	0.091
	2	12	74.42	18.9	60.7	132.8	
	Total	25	68.83	15.3			
> db	1	7	116	7.99	105	129.7	0.014
	2	12	107.02	15.91	51	116.5	
	Total	19	64.82	11.0			
op	1	7	23.97	1.62	23.2	27.03	0.02
	2	12	26.09	2.01	22.6	28.55	
	Total	19	25.31	2.11			
oa	1	7	30.66	5.28	25.7	39.98	0.01
	2	12	39.57	6.34	32.5	50.73	
	Total	19	36.29	7.3			
mp	1	7	30.62	2.66	26.5	34	0.01
	2	12	34.19	1.96	30.3	36.51	
	Total	19	32.87	2.8			
ma	1	7	54.06	10.3	37.1	68.35	0.001
	2	12	71.32	7.5	60.2	85.61	
	Total	19	64.96	11.94			
bl	1	13	7.82	1.05	6	9.21	0.0001
	2	12	9.49	0.38	8.96	10.05	
	Total	25	8.62	1.16			
md	1	7	8.3	0.94	7.22	9.9	0.01
	2	12	9.58	0.62	8.82	10.84	
	Total	19	9.12	0.97			
mbh	Total	25	4.86	1.07			

Key to Tables 1 and 2: MB, mb and db cusps; MDL, mb and dl cusps, ML, mb and ml cusps, DB, db and dl cusps; DML, db ml cusps, DL, dl and ml cusps, > mb, angle between db, mb and ml cusps, > db, angle between mb, db and dl cusps; op, occlusal-table perimeter; oa, occlusal-table area; mp, maximal crown perimeter; ma, maximal crown area; bl, maximal buccolingual dimensions; md, maximal mesiodistal dimensions; mbh, mesiobuccal cusp tip height from cusp tip to edge of enamel.

between all variables, suggest either an asymmetrical apposition of enamel along the cusp slopes or divergence between cusp tips. The increase in the external perimeter of the crown is most probably due to continued apposition of enamel on the outer surface of the tooth after enamel apposition on the cusp tips is completed. This finding is in agreement with previous findings on the postnatal growth of the maxillary first

Table 2
Means and SD of the variables at each developmental stage for the total process of the permanent maxillary first molar (all in mm except >mb and >db in degrees)

Variable	Stage	*n*	Mean	SD	Min.	Max.	*p*
MB	1	10	5.02	0.48	4.4	6.1	0.167
	2	11	4.74	0.32	4.2	5.4	
	Total	21	4.88	0.43			
MDL	1	8	8.77	0.34	8.3	9.3	0.502
	2	10	8.62	0.37	7.8	9.1	
	Total	18	8.69	0.36			
ML	1	10	6.13	0.34	5.4	6.7	0.75
	2	11	6.07	0.55	4.9	7.1	
	Total	21	6.1	0.47			
DB	1	8	6.07	0.43	5.4	6.9	0.964
	2	10	6.16	0.51	5.6	6.9	
	Total	18	6.12	0.47			
DML	1	10	6.39	0.6	5.6	7.2	0.888
	2	11	6.42	0.66	5.5	7.5	
	Total	21	6.45	0.61			
DL	1	8	4.32	0.35	3.9	4.9	0.687
	2	10	4.37	0.28	3.9	4.7	
	Total	18	4.35	0.31			
>mb	1	10	69.05	7.19	59.1	80	0.460
	2	11	71.57	4.87	61.62	77.4	
	Total	21	70.81	5.87			
>db	1	8	102.91	6.17	94.8	111.5	0.789
	2	10	103.46	5.07	98.9	105.7	
	Total	18	103.22	3.31			
op	1	8	29.04	1.58	27.25	31.74	0.248
	2	10	30.25	2.25	26.88	34.94	
	Total	18	29.72	2.02			
oa	1	8	48.42	5.5	38.4	54.72	0.183
	2	10	53.84	8.24	42.81	68.88	
	Total	18	51.44	7.49			
mp	1	8	36.63	2.37	31.71	39.52	0.02
	2	10	39.36	2.2	36.05	43.94	
	Total	18	38.15	2.61			
ma	1	8	81.39	12.85	51.19	91.78	0.001
	2	10	98.81	8.99	86.43	118	
	Total	18	91.97	13.79			
bl	1	10	9.3	1.49	7.14	10.43	0.003
	2	11	11.01	1.5	7.14	12.82	
	Total	21	10.36	1.59			
md	1	8	10.26	0.65	8.81	10.84	0.006
	2	10	11.00	0.36	10.27	11.47	
	Total	18	10.68	0.62			
mbh	Total	21	5.71	1.33			

primary molar (Peretz et al., 1997), the mandibular second primary molar (Smith et al., 1995), and prenatal growth in the primary molars (Butler, 1967; 1968; 1992).

The cumulative plots indicate that the localization of enamel apposition varies over the surface of the developing crown, and occurs in 'bursts'. This finding is also in accordance with previous findings on the primary first molar (Peretz et al., 1997). It seems that enamel apposition around cusp tips is greater in the first stage of crown development, and is formed in a more regular pattern, as seen by the correlations among all internal variables. This may reflect a strong genetic influence at this stage.

The increase in the distobuccal angle, with no increase in the mesiobuccal angle, suggests a change in

Table 3a
Correlation matrix for variables—primary maxillary second molar

	MB	MDL	ML	DB	DML	DL	> mb	> db	bl	md	mbh
MB	1										
MDL	*0.63*	1									
ML	*0.88*	*0.66*	1								
DB	*0.69*	*0.64*	*0.70*	1							
DML	*0.63*	0.03	*0.58*	*0.63*	1						
DL	*0.55*	*0.55*	0.41	*0.69*	0.44	1					
> mb	0.03	*0.65*	0.11	0.13	*0.73*	0.11	1				
> db	0.18	*0.54*	0.08	0.23	*0.83*	0.32	*0.94*	1			
bl	*0.69*	*0.46*	*0.61*	*0.70*	*0.57*	0.43	0.12	0.29	1		
md	*0.68*	0.31	*0.63*	*0.61*	*0.67*	*0.51*	0.28	0.38	*0.80*	1	
mbh	*0.22*	*0.52*	*0.13*	*0.23*	*0.17*	*0.44*	0.34	0.41	*0.20*	0.11	1

Table 3b
Correlation matrix for variables—primary maxillary second molar—stage 1

	MB	MDL	ML	DB	DML	DL	> mb	> db	bl	md	mbh
MB	1										
MDL	*0.98*	1									
ML	*0.91*	*0.95*	1								
DB	*0.82*	*0.89*	*0.89*	1							
DML	*0.81*	*0.88*	*0.89*	*0.99*	1						
DL	*0.87*	*0.92*	*0.85*	*0.90*	*0.93*	1					
> mb	0.26	0.37	0.39	*0.72*	*0.75*	*0.60*	1				
> db	*0.52*	*0.58*	*0.56*	*0.85*	*0.89*	*0.67*	*0.90*	1			
bl	*0.87*	*0.89*	*0.79*	*0.85*	*0.81*	*0.81*	0.43	*0.67*	1		
md	*0.83*	*0.86*	*0.87*	*0.71*	*0.66*	*0.64*	0.09	0.34	*0.84*	1	
mbh	*0.71*	*0.68*	*0.56*	*0.67*	*0.61*	*0.52*	0.30	*0.62*	*0.83*	*0.65*	1

Table 3c
Correlation matrix for variables—primary maxillary second molar—stage 2

	MB	MDL	ML	DB	DML	DL	> mb	> db	bl	md	mbh
MB	1										
MDL	0.39	1									
ML	*0.89*	*0.55*	1								
DB	0.46	*0.54*	*0.62*	1							
DML	0.48	*0.55*	0.36	0.14	1						
DL	0.02	0.09	0.02	0.02	0.00	1					
> mb	0.17	*0.94*	0.30	0.27	*0.77*	0.32	1				
> db	0.08	*0.85*	0.10	0.12	*0.88*	0.16	*0.95*	1			
bl	*0.53*	0.25	0.49	*0.66*	0.36	0.06	0.00	0.15	1		
md	0.48	0.11	0.42	0.43	*0.69*	0.44	0.41	0.46	*0.78*	1	
mbh	0.31	*0.69*	0.36	*0.73*	0.24	0.34	*0.52*	0.45	*0.58*	0.35	1

For numbers underlined, $p < 0.05$.

Table 4a
Correlation matrix for variables—permanent maxillary first molar—total process

	MB	MDL	ML	DB	DML	DL	>mb	>db	bl	md	mbh
MB	1										
MDL	*0.55*	1									
ML	0.19	*0.68*	1								
DB	0.07	*0.62*	0.46	1							
DML	0.19	*0.50*	*0.69*	*0.75*	1						
DL	0.00	0.18	0.17	0.27	*0.60*	1					
>nb	0.30	0.08	0.09	*0.61*	*0.72*	*0.65*	1				
>db	0.46	0.21	0.03	*0.62*	*0.51*	0.09	*0.51*	1			
bl	0.15	0.61	0.18	0.36	0.38	0.13	0.42	0.29	1		
md	0.06	0.08	0.00	0.36	0.24	0.10	0.36	0.36	*0.88*	1	
mbh	0.17	0.27	0.03	0.02	0.16	0.13	0.28	0.05	*0.19*	0.01	1

Table 4b
Correlation matrix for variables—permanent maxillary first molar—stage 1

	MB	MDL	ML	DB	DML	DL	>mb	>db	bl	md	mbh
MB	1										
MDL	0.27	1									
ML	*0.59*	0.15	1								
DB	0.10	*0.61*	0.34	1							
DML	0.07	0.06	0.26	*0.72*	1						
DL	0.33	0.28	0.08	0.26	*0.71*	1					
>mb	0.20	0.17	0.16	0.62	*0.96*	*0.83*	1				
>db	*0.65*	0.20	0.19	*0.68*	*0.65*	0.14	*0.54*	1			
bl	0.13	*0.60*	0.24	0.34	0.10	0.05	0.11	*0.55*	1		
md	0.14	0.00	0.07	0.09	0.05	0.05	0.44	0.00	0.70	1	
mbh	0.15	0.30	0.23	0.05	0.51	*0.57*	0.46	*0.54*	0.46	*0.66*	1

Table 4c
Correlation matrix for variables—permanent maxillary first molar—stage 2

	MB	MDL	ML	DB	DML	DL	>mb	>db	bl	md	mbh
MB	1										
MDL	*0.66*	1									
ML	0.41	*0.83*	1								
DB	0.05	*0.66*	*0.58*	1							
DML	0.35	*0.82*	*0.91*	*0.79*	1						
DL	0.37	*0.64*	0.40	0.32	0.51	1					
>nb	0.50	0.01	0.07	*0.66*	0.42	0.15	1				
>db	0.33	0.26	0.05	*0.57*	0.35	0.04	0.45	1			
bl	0.14	0.23	0.22	*0.69*	*0.59*	0.37	*0.91*	*0.62*	1		
md	0.01	0.12	0.00	*0.54*	0.40	0.31	*0.80*	*0.72*	*0.94*	1	
mbh	0.38	*0.61*	0.39	0.15	0.24	*0.63*	0.36	0.36	0.31	0.38	1

For numbers underlined, $p < 0.05$.

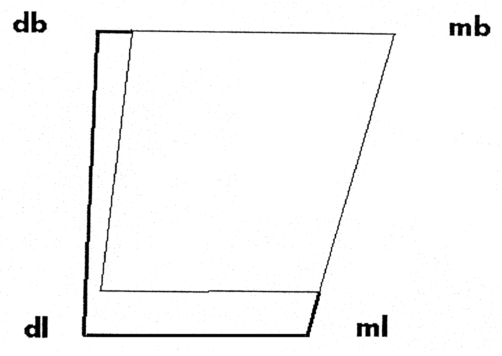

Fig. 3. A schematic representation of the change in cusp arrangement during crown development in the maxillary primary second molar. The heavy line represents the increase in size and shape. See text for abbreviations.

shape of the cusp tips from the occlusal view (Fig. 3). It is difficult to determine the exact direction of cusp divergence, but when taking the angle formed between the distobuccal, mesiobuccal and mesiolingual cusps as a reference point (as the mesiobuccal cusp is the first to form), and projecting the final cusp arrangements, it is logical to assume that the lingual-cusp tips are moving lingually and distally, and the distobuccal-cusp tip is moving distally.

The maxillary permanent first molar did not show a significant change in shape between the two stages of development. This, and the lack of correlation between size (external variables) and cusp relations, suggest that the two processes develop in an independent pattern and rate. On this tooth, no significant change in cusp-tip arrangement occurs during development despite the much greater enamel thickness of this tooth relative to the primary molar. The intercusp distances are determined early in mineralization, before crown height reaches its maximum dimension, presumably because the cusps are aligned in a more parallel fashion. This means that distances between them do not change with additional deposition of enamel (even though the size and shape of the cusps during development may be modified). However, the external dimensions of the crown, as measured by buccolingual and mesiodistal dimensions, do increase as enamel is laid down along the cervical border of the developing crown.

In a study on serial computerized tomographic images of permanent and primary molars, Smith et al. (1996) demonstrated difference in angulation between cusps on the primary and permanent molar teeth. They concluded that, in the permanent tooth, very few mitoses occur in the area of the groove between the cusps, following initial mineralization on cusp tips; thus the direction of growth is more parallel, and despite apposition of enamel, intercusp distances do not change. In the primary molar, the rapid pace of growth causes the angle between the cusps to 'diverge', leading to an increase in intercusp distances, as more enamel is deposited. In light of our present findings, we conclude that the process of development in the growth of the maxillary primary molar differs from that of in the maxillary permanent first molar.

As existing data suggest that dental development is modified in people with various diseases (Garn et al., 1979; Townsend, 1983; Brown and Townsend, 1984; Peretz et al., 1988; 1996), our present and previous findings may assist in expanding the range of standards against which to assess the timing of developmental problems in utero and in the first postnatal months.

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