Cusp Size Variability of the Maxillary Molariform Teeth

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Abstract  The morphological differences of tooth crown components among the maxillary molariform teeth were investigated by means of an odontometric method. The second deciduous molar (dm2), and the first and second permanent molars (M1 and M2) were measured on 159 dental casts taken from Japanese males. Measurements taken on the tooth crown included the mesiodistal and buccolingual crown diameters, and the diameters of the four main cusps, the paracone, protocone, metacone and hypocone. In terms of overall crown sizes, dm2 was the smallest of the three teeth. The mesial cusps, the paracone and protocone, were significantly larger in the permanent molars (M1 and M2) than in the dm2 (P < 0.01). The distal cusps, the metacone and hypocone, were significantly larger in the M1 than in the dm2 and M2 (P < 0.01), and were similar in size in the dm2 and M2. The paracone was the most stable of the four main cusps in size. As for relative cusp size, the protocone increased distally from dm2 to M2, but no significant difference was found in the paracone. It is concluded that paracone size is proportionally stable regardless of overall tooth size.

Keywords: deciduous molar, permanent molar, crown dimension, cusp diameter, odontometry

Introduction

Permanent molars do not have predecessors and they do not replace deciduous teeth. So both deciduous and permanent molars belong to the primary dentition from a developmental perspective. There are close morphological resemblances from the first deciduous (dm1) to third permanent molar (M3). The last deciduous molar, the dm2, and the three permanent molars, the M1, M2 and M3, are typically molariform (Koenigswald, 1967). These teeth have similar crown forms and occlusal groove patterns, and have homologous main cusps.

Huxley and de Beer (1934) gave a detailed description of the way in which the concept of biological fields could be used to account for ontogenetic differentiation of regions. Butler (1939) was the first to apply this concept to the dentition in an attempt to explain the close similarities of adjacent teeth. He suggested that there
was an observable mesiodistal gradation of form along the dental arch. Since the members of a molar tooth series are constructed on a common ontogenetic plan, they show serial homology and the differences between them are quantitative rather than qualitative (Butler, 1967). The morphological gradation seen in the molars are thought to be closely related to quantitative changes of the crown components (Kondo et al., 1999).

Although many reports have been published on odontometric descriptions of each tooth class, there are few reports on the overall relationships within the entire series of maxillary molariform teeth (Kageyama et al., 1999). Despite the close morphological resemblance in form and size of the molariform teeth, these teeth are not identical and there exists some morphological differences. The aim of this study is to compare the similarities and/or dissimilarities of crown structure in three molariform teeth, the dm2, M1 and M2, from an odontometric perspective.

Materials and Methods

We used 159 dental casts (61 deciduous and 98 permanent dentitions) taken from Japanese males. These are housed in the Showa University School of Dentistry. Measurements were made on these casts only if the teeth were fully erupted, had no anomalies of crown morphology, and the central pit of a tooth crown was not noticeably eroded.

Mesiodistal and buccolingual crown diameters (Fujita, 1949), and cusp diameters (paracone, metacone, protocone and hypocone) were measured using a sliding caliper to the nearest 0.05 mm (Fig. 1).

Each cusp diameter was defined as the diagonal distance from the central pit to the most protrusive point of each corner of the crown, taken perpendicular to the axis of the tooth (Yamada et al., 1988; Yamada, 1992; Kondo et al., 1996a). For example, the hypocone diameter was measured as the distance from the central pit to the most protrusive point of the distolingual corner of the tooth. Although hypocone diameter defined in this way is larger than the actual cusp size, the measurement is useful as an indicator of cusp size because of its close relation with hypocone variation (Yamada et al., 1988).

Teeth on the right side of the dental arch were usually measured. When a tooth on the right side could not be measured because of absence, abnormality, heavy wear, or other reasons, the corresponding tooth on the left side of the arch was measured.

In the present study measurement error was analyzed by a procedure in which double determination of measurements were made on separate occasions for 30 subjects selected at random. Differences between the first and second determinations were analyzed by computing the standard deviation of a single determination using the method of Dahlberg (1940).

The measurement errors ranged from 0.08 mm to 0.15 mm (Table 1). These val-
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![Diagram of tooth measurements](image)

**Figure 1.** Measurement of crown dimensions and cusp diameters.
MD: mesiodistal crown diameter; BL: buccolingual crown diameter; Pa: paracone diameter; Pr: protocone diameter; Me: metacone diameter; Hy: hypocone diameter.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>dm2</th>
<th>M1</th>
<th>M2</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD</td>
<td>30</td>
<td>0.09</td>
<td>0.07</td>
<td>0.09</td>
</tr>
<tr>
<td>BL</td>
<td>30</td>
<td>0.08</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>Pa</td>
<td>30</td>
<td>0.08</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>Pr</td>
<td>30</td>
<td>0.12</td>
<td>0.09</td>
<td>0.15</td>
</tr>
<tr>
<td>Me</td>
<td>30</td>
<td>0.09</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Hy</td>
<td>30</td>
<td>0.12</td>
<td>0.10</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Table 1. Measurement errors of the crown dimensions in the maxillary molars (mm)

Error estimated as standard deviation of a single determination according to Dahlberg (1940):

$$\text{Error} = \sqrt{\frac{\sum d^2}{2N}}$$

where $d =$ difference between 2 determinations

$N =$ number of double determinations

Abbreviations of the crown dimensions are summarized in Fig. 1.

Values were extremely small compared with the mean values, and comparable with the errors of 0.14 mm for hypocone diameter reported by Yamada et al. (1988). Thus the errors were assumed not to affect the statistical analysis.

In this study, relative cusp size was expressed by the cusp diameter index, which was defined as the cusp diameter divided by the square root of the crown area (mesiodistal diameter multiplied by the buccolingual diameter). Cusp index was calculated as:
Table 2. Basic statistics of crown dimensions (mm) and the results of multiple comparisons test

<table>
<thead>
<tr>
<th></th>
<th>dm2 (N = 61)</th>
<th>M1 (N = 98)</th>
<th>M2 (N = 88)</th>
<th>Tukey-Kramer HSD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>SD</td>
<td>CV</td>
<td>mean</td>
</tr>
<tr>
<td>Crown diameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD</td>
<td>9.44</td>
<td>0.42</td>
<td>4.47</td>
<td>10.67</td>
</tr>
<tr>
<td>BL</td>
<td>10.35</td>
<td>0.45</td>
<td>4.34</td>
<td>11.76</td>
</tr>
<tr>
<td>Cusp diameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pa</td>
<td>4.78</td>
<td>0.25</td>
<td>5.28</td>
<td>5.44</td>
</tr>
<tr>
<td>Pr</td>
<td>4.77</td>
<td>0.36</td>
<td>7.46</td>
<td>5.57</td>
</tr>
<tr>
<td>Me</td>
<td>4.71</td>
<td>0.30</td>
<td>6.38</td>
<td>5.23</td>
</tr>
<tr>
<td>Hy</td>
<td>5.56</td>
<td>0.41</td>
<td>7.34</td>
<td>6.56</td>
</tr>
</tbody>
</table>

**: P < 0.01, *: P < 0.05, NS: not significant
Abbreviations of the crown dimensions are summarized in Fig. 1.

\[
\text{Cusp index} = \frac{\text{cusp diameter}}{\sqrt{\text{MD} \times \text{BL}}} \times 100
\]

Descriptive statistics including distribution parameters were calculated with JMP statistical software (SAS Institute, Ver. 3.2.6 for Windows) on a personal computer. Differences between measurements were analyzed with multiple comparisons tests (Tukey-Kramer HSD).

Results

The mesiodistal diameter of the M1 was significantly larger than those of the dm2 and M2 (P < 0.01) (Table 2). M2 had a slightly larger buccolingual diameter than M1 on the average, but the difference was not significant. The buccolingual diameter of the dm2 was significantly smaller than those of both permanent molars, the M1 and M2 (P < 0.01).

As for the mesial cusps, the paracone and protocone, the cusp diameter measurements were significantly larger in the permanent molars than in the dm2 (P < 0.01). The paracone was approximately the same size in the M1 and M2, and the protocone was significantly larger in the M2 than in the M1 (P < 0.01). The distal cusps, the metacone and hypocone, were very similar in size in the dm2 and M2, while the M1 had significantly larger distal cusp diameters (P < 0.01).

Coefficients of variation showed that the cusp diameters were more variable than the mesiodistal and buccolingual diameters. The paracone was the most stable of the four main cusps. The protocone was more variable than the paracone. With the exception of the M1, the hypocone was more variable than the metacone. The crown dimensions of the M2 were the most variable among the three teeth, and the hypocone showed the largest coefficient of variation.
Table 3. Basic statistics of the cusp indices and the results of multiple comparisons test

<table>
<thead>
<tr>
<th></th>
<th>dm2 (N = 61)</th>
<th>M1 (N = 98)</th>
<th>M2 (N = 88)</th>
<th>Tukey-Kramer HSD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>SD</td>
<td>mean</td>
<td>SD</td>
</tr>
<tr>
<td>Paracone index</td>
<td>48.43</td>
<td>2.59</td>
<td>48.58</td>
<td>2.50</td>
</tr>
<tr>
<td>Protocone index</td>
<td>48.32</td>
<td>3.14</td>
<td>49.71</td>
<td>3.11</td>
</tr>
<tr>
<td>Metacone index</td>
<td>47.69</td>
<td>2.71</td>
<td>46.67</td>
<td>2.54</td>
</tr>
<tr>
<td>Hypocone index</td>
<td>56.30</td>
<td>3.46</td>
<td>58.59</td>
<td>3.12</td>
</tr>
</tbody>
</table>

*: P < 0.01, *: P < 0.05, NS: not significant

Table 4. Rotated factor pattern of the principal component analysis

<table>
<thead>
<tr>
<th></th>
<th>PC I</th>
<th>PC II</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD</td>
<td>0.590</td>
<td>0.703</td>
</tr>
<tr>
<td>BL</td>
<td>0.880</td>
<td>0.306</td>
</tr>
<tr>
<td>Pa</td>
<td>0.816</td>
<td>0.276</td>
</tr>
<tr>
<td>Pr</td>
<td>0.874</td>
<td>0.204</td>
</tr>
<tr>
<td>Me</td>
<td>0.196</td>
<td>0.880</td>
</tr>
<tr>
<td>Hy</td>
<td>0.253</td>
<td>0.820</td>
</tr>
<tr>
<td>Eigen value</td>
<td>3.892</td>
<td>0.915</td>
</tr>
<tr>
<td>Proportion (%)</td>
<td>64.864</td>
<td>15.244</td>
</tr>
</tbody>
</table>

Abbreviations of the crown dimensions are summarized in Fig. 1.

The paracone index showed similar mean values among the three teeth (Table 3). The protocone index was the highest in the M2, followed by the M1, and was the lowest in the dm2. The metacone index was significantly smaller in the M2 than in the dm2 and M1 (P < 0.01), but dm2 and M1 had similar values of the index. The hypocone index was the highest in the M1, followed by dm2, and the lowest in the M2.

Principal component analysis was performed to investigate factors influencing the variation in crown dimensions of the molariform teeth. After varimax rotation, each factor was interpreted. Variance of the two principal component factors accounted for 80.1% of the total variance (Table 4). The first component concerns the buccolingual and the mesial cusp (paracone and protocone) diameters, while the second component concerns the mesiodistal and distal cusp (metacone and hypocone) diameters. Figure 2 shows the scatter plots of the mean values of the principal component scores and the 95% confidence intervals. The first component score was larger in the permanent molars than in the dm2, and the second component score was larger in the M1 than in the dm2 and M2. These differences of the mean values among the three teeth were significant (P < 0.01). These results indicate that the mesial cusp diame-
Figure 2. Plots of the mean values of the first and second principal component scores. The ellipse shows the 95% confidence interval.

Teeth were larger in the permanent molars than in the dm2, and the distal cusp diameters were larger in the M1 than in the dm2 and M2.

Discussion

Tooth crowns of maxillary molariform teeth, in general, consist of four main cusps. The odontometric characteristics of each molariform tooth is thought to be cumulative of cuspal dimensions (Kanazawa et al., 1985). Each cusp has an independent growth pattern (Kraus and Jordan, 1965) and different evolutionary background (Osborn, 1907; Patterson, 1956). For example, the protocone differentiates from a cingulum, and the metacone differentiates from the ridge of a prior existing cusp, the paracone (Sakai, 1982). The results of this study are therefore discussed from both ontogenetic and phylogenetic viewpoints.

The odontometric difference among the molariform teeth is summarized here from two aspects; the difference between deciduous and permanent molars, and the difference between mesial and distal permanent molars.

With respect to the difference between deciduous and permanent molars, in terms of overall crown size, the dm2 was the smallest among the three teeth, but metacone size was similar in the dm2 and M2 (Table 2). In the permanent molars the metacone was the smallest of the four cusps, while in the dm2 the protocone was the smallest.
These results indicate that dm2 has a proportionally larger metacone and smaller protocone than the permanent molars.

Jørgensen (1956) reported that the metacone was somewhat larger than the paracone in the *Australopithecus* dm2. Kondo et al. (1996b) described the metacone to be well developed in the dm2 of the great apes and humans. From these facts, a large metacone seems to be a primitive trait of the deciduous molars.

Peretz et al. (1998) investigated the changes that occur in size and form of the mineralizing crowns of the dm2 and M1, and showed that the lingual cusp tips moved linguually and distally in the dm2, while no change occurred in the shape of the M1 during crown formation. The weaker development of the mesiolingual corner of the dm2 crown may be the result of the distal shift of the protocone during development.

As for the difference between mesial and distal permanent molars, the mesiodistal diameter was significantly larger in the M1 than in the M2, but the buccolingual diameter was not significantly different (Table 2). Macho and Moggi-Cecchi (1992) had previously reported the same results. These results were supported by the fact that the most frequent molar size sequence of the buccolingual diameter is M2 > M1 (Yamada, 1990).

The distal cusps, the metacone and hypocone, were significantly larger in the M1 than in the M2 (Table 2). As to the mesial cusps, the paracone was approximately the same size in the M1 and M2, and the protocone was significantly larger in the M2 than in the M1 (*P* < 0.01). These results represent mesial prominence and distal reduction in the M2. Yamada and Brown (1988) measured distances from the central pit to the perimeter of the crown contour in the maxillary molars of Australian Aborigines. The radii of the mesial region did not differ significantly among the three permanent molars, but the radii of the distal region showed a graded reduction from M1 to M3. Macho and Moggi-Cecchi (1992) described the mesial cusp areas as slightly larger in the M2 than in the M1, while distal cups areas were significantly larger in the M1 than in the M2. These results are in accordance with those of the present study.

In all three molariform teeth, the dm2, M1 and M2, the coefficient of variation of paracone diameter was the smallest among the four main cusps (Table 2). Of the four cusps, the paracone is formed and calcified at the earliest stage of development (Kraus and Jordan, 1965), and is regarded as a successor of the single cone of the reptilian haplodont (Patterson, 1956). Thus, the paracone is the first cusp to differentiate both ontogenetically and phylogenetically.

An opposite relationship is seen in the hypocone. The hypocone was found to be metrically the most variable cusp in the M2. The hypocone also shows various expressions in shape, especially in the M2, its variability being classified as 4, 4−, 3+ and 3 by Dahlberg (1949). It is known that the hypocone differentiates ontogenetically later than the other main cusps, and that phylogenetically it was the last cusp to
develop.

Corruccini (1979) mentioned an association between early cusp calcification and low cusp-size variability in anthropoid primates. He noted that the mesial cusps, the paracone and protocone, were more stable in size than the distal cusps, the metacone and hypocone, because of the difference in timing of onset of calcification. His findings are in overall accordance with ours, but there was a slight difference between the results of the two studies. Our results showed that the protocone was more variable than the paracone, while the difference in the coefficient of variation of the two cusps was unclear in Corruccini’s results. This discrepancy is thought to have resulted from the difference of measurement methods. Corruccini measured cusp areas, while we measured cusp diameter between the central pit and the most protrusive point of each corner of the crown.

As for our measure of relative cusp size which is expressed as the cusp index of this study, the protocone increased proportionally from mesial to distal, but no significant change was found in the paracone (Table 3). The distal cusps were relatively smaller in the M2 than in the dm2 and M1. Kageyama et al. (1999) analyzed three molariform teeth of Australian Aborigines using moiré contourography. They reported that the cusp area and volume of the distal cusps were proportionally smaller in the M2 than in the dm2 and M1. The proportional size of the protocone was found to increase distally from dm2 to M2, but the paracone showed small difference among the molars. Their results were consistent with ours. It is concluded that paracone diameter is proportionally stable regardless of overall tooth size.

Conclusions

The mesial cusps, which appear at an earlier stage ontogenetically and phylogenetically, are comparatively stable metrically, and occupy a larger area of the crown in the distal molar. The distal cusps, which form at a later stage, tend to be more variable, and their relative sizes are more reduced in the distal molar. It is concluded that metric variability and relative sizes of the cusps tend to correspond with the timing of cusp formation in both ontogeny and phylogeny.

References


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