Three-dimensional hard tissue palatal size and shape: A 10-year longitudinal evaluation in healthy adults

A 10-year longitudinal evaluation of the morphology (size and shape) of hard tissue palate was performed in 6 female and 6 male healthy adults (mean age at the second evaluation was 33 years, SD = 2.2). All subjects had a complete permanent dentition, including the second molars, and were free from respiratory problems. Palatal landmarks were digitized with a computerized 3D instrument, and their coordinates were used to derive a mathematical model of palatal form. Palatal shape (size-independent) was assessed by a fourth-grade polynomial in the sagittal and frontal plane projections. Palatal dimensions in the frontal and sagittal planes were computed and compared between the 2 evaluations by paired Student t tests. A great variability was observed, and no significant modifications in size were found (P > .05 for all variables). No variations in shape were observed. Sex had no significant effect for any variable (Student t for independent samples, P > .05). This study showed that in healthy subjects, hard tissue palatal morphology does not seem to change between the third and the fourth decades of life. (Int J Adult Orthod Orthognath Surg 2002;17:51–58)

The number of adult patients undergoing orthodontic treatment is increasing. To provide the best treatment, and to assess any possible relapse after therapy, an understanding of the normal modifications of the craniofacial complex with aging is mandatory. Indeed, modifications in the dimensions, shape, and arrangement of hard and soft tissue craniofacial structures can be detected even after the attainment of biologic maturity. Even if human permanent dentition (excluding the third molars) completes its eruption by early adolescence, oral structures (both dental and skeletal) still continue to modify. As expected, the changes occur at a slower rate than that observed during the first 2 decades of life.

Most studies analyzed longitudinal modifications in dental arches, but the actual direction and magnitude of these modifications are still debated. Indeed, recent investigations performed until the fifth or sixth decade of life reported opposite results: while Bishara et al and Carter and McNamara found decrements in dental arch widths with aging, Harris and Bodevick found that arch widths increased.

In contrast, quantitative studies on the association between aging and palatal morphology are scanty. Hard tissue palatal dimensions between adolescence and young adulthood have been recently analyzed by Ferrario et al with a cross-sectional design. In adolescent females, overall, palatal form (both size and shape) appeared to have already attained adult characteristics; in males, some modifications between adolescence and young adulthood were measured for both linear and angular dimensions, and for palatal shape. Similar findings for palatal dimensions were reported in a cross-sectional investigation by Redman et al, who also found a significant
increment of palatal height in male subjects after 18 years of age. No recent data on palatal morphology after the third decade of life can be found in the literature. Ten years ago, a group of healthy young adults in their twenties was analyzed in our laboratory. Among the other assessments, an impression of their dental arches was taken, and the two-dimensional size and shape characteristics of the maxillary and mandibular arches were analyzed. Due to technological limitations, no three-dimensional assessments were performed, and no evaluations of palatal morphology were made.

Currently, technology provides three-dimensional digitizers that can be directly used on dental casts to supply the metric coordinates of selected landmarks. The coordinates can be used for any kind of mathematical modeling. Optical devices, electromechanical instruments, and electromagnetic digitizers have all been used to collect three-dimensional data on the human palate in both normal individuals and patients with alterations in craniofacial structures, as recently reviewed by Ferrario et al. All assessments were noninvasive and performed without procedures currently known to involve any present or future biological damage. In both data collections, all subjects were previously informed about all the adopted procedures and gave their consent to the investigation. The study protocol was approved by the local ethics committee.

**Digitization of palates and mathematical equation**

The method was derived from the original description made by Ferrario et al. On each cast, the intersections of the palatal sulci of the right and left first permanent molars (landmarks 16′ and 26′ in Fig 1), premolars (landmarks 15′, 25′, 14′, 24′), and canines (landmarks 13′, 23′) with the gingival margin, the incisive papilla (IP), and the most posterior limit of the palatal raphe (RP) were identified and marked. The intermolar 16′–26′ line and its perpendicular starting...
from IP were traced, and their intersection point was marked as M. On the IP-M, 16′–26′, 15′–25′, 14′–24′, and 13′–23′ lines, approximately 12 to 20 nearly equidistant points were then marked. The x, y, and z coordinates of the landmarks were obtained with an electromagnetic three-dimensional digitizer (3Draw, Polhemus, Colchester, VT) interfaced with a computer. The digitization of landmarks was done by a single operator.

The files of the coordinates were obtained, and computer programs devised and written by one of the authors were used for all the following calculations.

A common orientation for all palates was obtained by mathematically setting the plane described by IP, 16′, and 26′ as horizontal (X-axis, corresponding to the 16′–26′ line, right-left; Y-axis, anterior-posterior; and Z-axis, caudo-cranial). Actually, this plane is tilted forward, but no assessment of the spatial relationships between hard tissue palate and craniofacial structures was performed. For each palate, the following measurements were obtained:

Sagittal plane:

• Palatal length, horizontal projection of the IP-M line (unit: mm)
• Palatal slope, slope of the maximum palatal height versus the horizontal axis (degrees)
• Maximum palatal height (mm)

Horizontal plane:

• Angle between the IP-RP and the IP-M lines (degrees)

Frontal plane:

• Palatal width and maximum palatal height at the first permanent molars (16′–26′ distance, mm)
• Palatal width and maximum palatal height at the second premolars (15′–25′ distance, mm)
• Palatal width and maximum palatal height at the first premolars (14′–24′ distance, mm)
• Palatal width and maximum palatal height at the canines (13′–23′ distance, mm)

All coordinates were then standardized, in the frontal plane as percentages of the intermolar distance 16′–26′ (x coordinate), and in the sagittal plane as percentages of the horizontal projection of the IP-M distance (y coordinate).

The curve of the palatal surface was fitted to a fourth-degree polynomial \( y = ax + bx^2 + cx^3 + dx^4 \), separately for the sagittal and the frontal (4 curves corresponding to 16′–26′, 15′–25′, 14′–24′, and 13′–23′) plane projections of the three-dimensional standardized (ie, size-independent) coordinates of the digitized landmarks. In the frontal plane projection, the origin of axes was set at 16′; the X-axis corresponded to the right-left transverse line, and the Y-axis to its vertical perpendicular. In the sagittal plane projection, the origin of axes was set at IP, the X-axis corresponded to the horizontal projection of the IP-M distance, and the Y-axis to its vertical perpendicular. The 4 coefficients of the polynomial equation were computed using the least-square method, and the correlation coefficient \( r \) of the curve was also assessed.

Statistical analyses

For each palatal measurement, descriptive statistics for the male and female groups in the 2 assessments (10 years ago and the present) were calculated. Statistics for angular variables were computed using the rectangular components of the angles. The significance of sex-related differences of linear variables was quantified using Student t tests for independent samples, while differences of angular variables were tested using Watson-Williams’ test.

For each subject and variable, the difference between the second (present) and first (10 years ago) measurement was calculated. The significance of the longitudinal modifications was assessed by paired Student t tests. In all cases, 2-tail tests were used, with a level of significance set at 5%.

Error of method

The intraoperator repeatability of the measurements was assessed by Ferrario et al using repeated tracings (landmark
identification) and digitizations of the same casts. For each variable, the error of the method (error percentage) was calculated as the percentage ratio between the variance of the method error (squared Dahlberg’s error) and the population variance of that measurement (squared standard deviation). For landmark identification, the error percentage was always less than 10% of the total biological variance. For landmark digitization, the error percentage ranged between 1.76% and 8.26%.

Results

Table 1 reports the descriptive statistics of all palatal measurements performed in the 2 assessments (10 years ago and the present) separately for men and women. Overall, male and female values appeared similar, and no statistically significant differences were found ($P > .05$ for all variables and in both assessments).

Interindividual differences between the measurements taken in the third (men, mean age 22.4 years, SD = 1.4; women, mean age 23.6 years, SD = 2.5) and fourth (10-year follow-up) decades of life appeared limited, the largest being a 2.4-mm increment in palatal sagittal length (IP-M distance) in woman F048, and a –2.7-degree decrement in raphe inclination in man M051. Moreover, a large variability was found, with almost the same number of increments and decrements in palatal dimensions. A notable exception was observed for palatal slope in the sagittal plane, where 8 out of 12 subjects had a smaller value in the second assessment, with differences ranging between –0.06 degrees and –2.63 degrees.

<table>
<thead>
<tr>
<th>Plane</th>
<th>Measurement</th>
<th>Men (n = 6)</th>
<th>Women (n = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Sagittal</td>
<td>IP-M</td>
<td>28.52</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>Slope (deg)</td>
<td>30.29</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>16.78</td>
<td>1.06</td>
</tr>
<tr>
<td>Horizontal</td>
<td>Raphe (deg)</td>
<td>3.31</td>
<td>0.95</td>
</tr>
<tr>
<td>Frontal</td>
<td>16°–26° Width</td>
<td>37.40</td>
<td>3.01</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>17.44</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>15°–25° Width</td>
<td>32.69</td>
<td>1.76</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>14.57</td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td>14°–24° Width</td>
<td>27.13</td>
<td>1.92</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>9.16</td>
<td>2.15</td>
</tr>
<tr>
<td></td>
<td>13°–23° Width</td>
<td>23.70</td>
<td>1.78</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>3.33</td>
<td>1.04</td>
</tr>
</tbody>
</table>

All values are mm unless otherwise noted.
Assessment A = Men, mean age 22.4 years (SD 1.4); women, mean age 23.6 years (SD 2.5).
Assessment B = same patients 10 years later.
No significant sex differences, $P > .05$ (linear variables: Student $t$ test for independent samples, 11 degrees of freedom; angles: Watson-Williams’ test, 1, 10 degrees of freedom).
Men and women appeared to change with a similar pattern, and descriptive statistics for the age-related variations were computed after pooling the sexes (Table 2). The significance of the differences was tested by Student \( t \) test for paired samples, and all values except palatal slope were not significantly different from 0. Indeed, the mean variation in palatal slope was very limited (−0.7 degrees).

Palatal shape independently from size in both the sagittal and frontal planes (canine, premolar, and molar areas) was well reconstructed by the fourth-degree polynomials, with coefficients of correlation \( r \) ranging between 0.91 and 0.99. In all subjects, the curves from 10 years ago and the current curves appeared well superimposable, without any detectable difference. As an example, the size-independent palatal curves obtained from the dental casts of woman F020 and of man M004 are shown in Figs 2 and 3.

**Table 2**

Descriptive statistics of 10-year longitudinal modifications in hard-tissue palatal size in 12 healthy Northern Italians (sex pooled)

<table>
<thead>
<tr>
<th>Plane</th>
<th>Measurement</th>
<th>Mean</th>
<th>SD</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagittal</td>
<td>IP-M</td>
<td>0.47</td>
<td>1.32</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Slope (deg)</td>
<td>−0.70</td>
<td>0.37</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>−0.21</td>
<td>0.37</td>
<td>NS</td>
</tr>
<tr>
<td>Horizontal</td>
<td>Raphe (deg)</td>
<td>0.05</td>
<td>0.42</td>
<td>NS</td>
</tr>
<tr>
<td>Frontal</td>
<td>16’–26’ Width</td>
<td>0.04</td>
<td>0.79</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>−0.11</td>
<td>0.32</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>15’–25’ Width</td>
<td>0.14</td>
<td>0.86</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>0.22</td>
<td>0.97</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>14’–24’ Width</td>
<td>0.02</td>
<td>0.47</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>0.41</td>
<td>1.19</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>13’–23’ Width</td>
<td>−0.09</td>
<td>0.63</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>0.19</td>
<td>0.67</td>
<td>NS</td>
</tr>
</tbody>
</table>

All values are mm unless otherwise noted.

A positive value indicates an increment in palatal dimension.

\( P \) = probability of a significant difference, Student \( t \) test for paired samples, 11 degrees of freedom.

NS = not significant \((P > .05)\).

**Discussion**

Hard and soft tissue facial dimensions continue to increase even after the third decade of life, as reported both in longitudinal\(^{2,5,8,9,11,14}\) and cross-sectional studies.\(^{3,12}\) Most investigations analyzed the characteristics of dental arches in this time span, but no study measured palatal morphology, apart from a cross-sectional assessment of palatal surface area.\(^3\) Published data on human palate are limited to the first 3 decades of life, and were performed only with cross-sectional designs.\(^{15,17}\) In adolescent females, overall, hard tissue palatal form appeared to have already attained adult characteristics; in males, some modifications (size increments
and shape variations) between adolescence and young adulthood (up to the third decade of life) were found.\textsuperscript{15,17} In contrast, the palatal area did not modify after adolescence.\textsuperscript{3}

In the present study, a longitudinal evaluation assessed the changes in hard tissue palatal size and shape between 20 and 30 years of age in healthy, normal men and women. Unfortunately, the analyzed sample was very limited (12 subjects), and all the following considerations should be taken with caution. Overall, a large interindividual variability in the modification of dental arch dimensions was found, with both increments and decrements, so that no mean difference was larger than ± 0.5 mm (Table 2).

It is difficult to compare the present findings to literature reports, because quantitative investigations of normal palatal size and shape are uncommon. As recently reviewed by Ferrario et al,\textsuperscript{19,20} the main shortcoming seems to be technical: Direct techniques, in which several standardized landmarks are used as endpoints for caliper measurements, are time-consuming and prone to error. Indirect analyses, with the use of two-dimensional projections (radiographs, photographs, or photocopies), are insufficient for the palate. Only three-dimensional computerized analyses can correctly assess palatal morphology.\textsuperscript{19,22} Both surface-based and landmark-based methods have been used. Indeed, most surface-based approaches are time-consuming, requiring several scans for each cast, and while they seem best suited for the analysis of selected patients (for instance, cleft-palate children), they are of difficult application for a wide-scale collection of data. The major limitation of landmark-based methods seems to be the reduced number
of digitized landmarks, which approximates the analyzed structure neglecting most information. In the present investigation, a modification to the original protocol devised by Ferrario et al was introduced, and palatal morphology was analyzed also in the canine and premolar areas, thus supplying a better approximation of the size and shape characteristics (Figs 2 and 3).

The present data can be partly compared to data collected on dental arches. For instance, a large interindividual variability was also reported by Bondevik in his 10-year longitudinal follow-up of the dental arches of Norwegian women and men between the third and the fourth decades of life. Indeed, the mean differences found by Bondevik in maxillary intermolar width (the only measurement comparable to the present ones) were, on average, 0.3 mm in both sexes, a value similar to those found in the current study (Table 2). But, while the Norwegian difference was statistically significant, in the present investigation neither palatal size (sagittal and frontal plane depth, widths, and heights) nor palatal shape (size-independent mathematical reconstruction of the sagittal and frontal plane morphology) appeared to change significantly in the analyzed time span (Table 2; Figs 2 and 3). Only palatal slope in the sagittal plane yielded a statistically significant difference, but the mean variation measured was so small (a decrement of –0.7 degrees) to be of limited anatomical and clinical significance.

Carter and McNamara also found significant longitudinal decrements in maxillary depth measured at the first molars and in maxillary intercanine width (lingual surface), while no significant variations were found for interpremolar and intermolar lingual widths. Indeed, their follow-up period was much longer, with a first assessment at 17 years of age, and a second examination at 48 years. The mean differences in maxillary intercanine width were about 1 mm in females and 1.4 mm in males, while maxillary depth measured at the first molars decreased about 1.1 mm in both sexes.

No significant sexual differences were found in the present study, but the limited number of subjects do not allow any conclusions to be drawn, and the sexual dimorphism in dental and hard tissue palatal dimensions (males larger than females) found in other investigations cannot be rejected on the basis of the present findings. When the present palatal dimensions were compared to previous literature reports performed on Caucasian subjects of comparable age, data were practical superimposable to those recently measured on male and female Italian young adults, and on adult Americans.

In conclusion, while between the third and the fourth decades of life both men and women experience some modifications in their facial hard and soft tissues and in their dental arches, their hard tissue palates did not modify. The dimensions and shape attained at 20 years of age seemed to be maintained at least for a decade. Obviously, the present sample was very small, and further investigations should assess a larger number of normal individuals of both sexes.

Acknowledgments

This study was made possible only by the kind collaboration of all the investigated women and men.

References