Longitudinal study of relative growth rates of the maxilla and the mandible according to quantitative cervical vertebral maturation

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Introduction: The purpose of this study was to investigate the relative growth rates (RGR) of the maxilla and the mandible according to quantitative cervical vertebral maturation (QCVM) of adolescents with normal occlusion.

Methods: Mixed longitudinal data were used. The sample included 87 adolescents (32 boys, 55 girls) from 8 to 18 years of age with normal occlusion, selected from 901 candidates. Sequential lateral cephalograms and hand-wrist films were taken once a year for 6 consecutive years. The growth magnitude (GM) and RGR of the maxilla and the mandible were measured and analyzed. Results: GM and RGR were not always consistent, because subjects had different periods of time between the QCVM stages. GM was not as reliable as RGR. RGR had no significant sex differences in the maxilla and the mandible, in spite of different decelerating curves. However, statistically significant sex differences were found in the GM of mandibular measurements. The greatest growth potentials were not synchronized between the maxilla and the mandible. For both sexes, the greater RGR of maxillary length and height was in QCVM stage I; then, deceleration occurred. The greatest RGR of mandibular length and height was in QCVM stage II, and the next largest was in QCVM stage I.

Conclusions: Understanding the RGR can provide references for orthodontic treatment and orthognathic surgery. (Am J Orthod Dentofacial Orthop 2010;137:736.e1-736.e8)

Adolescence is a period during which the rate of growth accelerates, reaching a peak velocity and then decelerating until adulthood.1 This pattern can be found in all people, but there are marked individual variations in the start, duration, rate, and amount of growth. Craniofacial growth prediction is an ultimate goal in craniofacial biology and is a major concern in orthodontics, because it is the key point in the diagnosis, prevention, interception, and treatment of malocclusions.2

Hand-wrist radiographs have been used routinely in orthodontics to assess the peak of the growth spurt.3-5 However, there are concerns about extra radiation exposure. In addition, the British Orthodontic Society guidelines state that the use of hand-wrist radiographs to predict the onset of the pubertal growth spurt is not indicated.6 Because of this, cervical vertebral maturation (CVM) has been evaluated for its correlation to skeletal maturity as an alternative to the hand-wrist method.7-9 One obvious advantage of the CVM method is that a lateral cephalometric radiograph is routinely required for orthodontic diagnosis and treatment planning; no additional radiograph is required. But almost all previous evaluations of puberty with the cervical vertebrae on cephalometric radiographs either used or referred to the atlas of Lamparski.10 This was convenient because changes in cervical vertebral bodies can be evaluated with regard to growth in the atlas. However, an atlas cannot be used to evaluate growth in an objective and detailed manner because the results can differ from operator to operator.11

Until now, cervical vertebrae were used only to determine the time of the pubertal growth peak or skeletal age, and no reports have predicted maxillofacial growth in a quantitative way.12-14 To evaluate the rate of maxillary and mandibular growth in various growth stages, a system of quantitative CVM (QCVM) proposed by Chen et al15 was used in this study.
QCVM is a quantitative approach for identifying specific maturational stages over the entire adolescent growth period. Thus, the method used in this study was more objective than those used in most previous studies.

Yearly longitudinal data are of great value to orthodontists interested in the detailed study of facial growth.16 Previous studies investigating maxillary and mandibular growth were based on only cross-sectional data13,17 or focused on the growth magnitude (GM) of craniofacial structures.16,18 Generally, the growth rate has 2 expressions: absolute growth rate and relative growth rate (RGR).4 Absolute growth rate is often limited when comparing different objects, because the size of the object itself and the growth period significantly affect the comparability of results. In this study, RGR—the ratio of absolute growth per unit of time to the original quantity—was used as the potential indicator for biologic growth. Until now, no research of the RGR of craniofacial structures based on the CVM has been reported.

In orthodontics, the use of dentofacial orthopedic appliances is a main modality in the correction of jaw deformities. The effectiveness of these growth modifications depends on skeletal maturity, or, in other words, growth potential. But it is still not clear whether GM and RGR are always consistent. Sometimes, we take for granted that the growth period with the greatest GM has the greatest growth potential.

The purposes of this study, with a mixed longitudinal sample, were to examine the GM, the total increment of craniofacial structures; and to evaluate the RGR of craniofacial structures and compare it with the GM, to provide an accurate index of acceleration and deceleration of growth and to clarify the optimal timing for orthodontic treatment and orthognathic surgery.

**MATERIAL AND METHODS**

Longitudinal population data were obtained from the Research Center of Craniofacial Growth and Development at Beijing University. More than 900 patients born in 1977 and 1978 were reviewed. The final study group included 87 adolescents (32 boys, 55 girls) from 8 to 18 years of age with normal occlusion. They were divided into 2 groups with different beginning ages of observation. In group 1 (43 subjects; 16 boys, 27 girls), the beginning age was 8 to 9 years; in group 2 (44 subjects; 16 boys, 28 girls), it was 12 to 13 years. Sequential lateral cephalograms and hand-wrist films were taken once a year for 6 consecutive years. Informed consent was obtained from all subjects and their parents. The study protocol was reviewed and approved by the institutional review board of Beijing University. The selection criteria were (1) deciduous, mixed, or permanent dentition; (2) normal occlusion (<3 mm overjet and overbite less than one-third coverage of the mandibular incisors); (3) harmonious facial profile and lip competence at rest; and (4) no orthodontic treatment before and during this study.

The sequential lateral cephalograms were divided into 11 maturation groups by a calibrated technician according to the Fishman skeletal maturity indicators (SMI) assessed from the hand-wrist films (Table I).4 Based on the SMI and the QCVM, SMI 1 to 3 were merged into QCVM I (period of accelerating velocity), SMI 4 to 7 were merged into QCVM II (period of high velocity), SMI 8 and 9 were merged into QCVM III (period of decelerating velocity), and SMI 10 and 11 were merged into QCVM IV (period of decelerating velocity).15 Thus, the GM in SMI stages 1 to 3 represented that in QCVM stage I. Similarly, the GMs in SMI stages 4 to 7, 8 and 9, 10 and 11 represented those of QCVM stages II, III, IV, respectively.

Fourteen cephalometric measurements (Figs 1-3) indicating the longitudinal growth changes of the maxilla and mandible were measured exactly at SMI stages 1, 4, 8, 10, and 11. Measurements and GM were recorded, and the RGR was analyzed. RGR provided an accurate index of acceleration and deceleration of growth over a specific time (Table II). This required the measurement value (M) recorded at each record stage. The RGR formula was RGR = \( \frac{(M_n - M_{n-1})}{t} \times \frac{100}{M_{n-1}} \). For example, RGR in QCVM I = \( \frac{(SMI 4 - SMI 1)}{t} \times \frac{100}{SMI 1} \).

All cephalometric radiographs were taken with the same x-ray machine. Cephalometric landmarks were identified by 1 observer (L.L.C.) under optimal conditions and then measured with micrometer calipers. When double projection gave rise to 2 points, or the right and left sides did not superimpose, the midpoint was used. Absolute values and GMs of linear and angular cephalometric measurements were recorded and

**Table I. Demographic distribution of lateral cephalograms of the 5 groups according to the SMI (mean ± SD)**

<table>
<thead>
<tr>
<th>SMI</th>
<th>n</th>
<th>Girls</th>
<th>Boys</th>
<th>Age range (y)</th>
<th>Girls</th>
<th>Boys</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>41</td>
<td>8.21 ± 1.07</td>
<td>9.21 ± 1.41</td>
<td>8.00-10.49</td>
<td>8.83-11.25</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>44</td>
<td>11.18 ± 1.19</td>
<td>12.28 ± 0.60</td>
<td>10.07-13.17</td>
<td>12.00-13.57</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>45</td>
<td>12.98 ± 0.61</td>
<td>14.19 ± 1.23</td>
<td>12.05-13.75</td>
<td>13.00-16.07</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>48</td>
<td>14.93 ± 0.90</td>
<td>16.22 ± 1.10</td>
<td>13.88-16.33</td>
<td>14.93-17.50</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>62</td>
<td>16.41 ± 1.39</td>
<td>17.60 ± 0.50</td>
<td>13.98-17.92</td>
<td>16.00-18.18</td>
<td></td>
</tr>
</tbody>
</table>
analyzed. The measuring points and reference lines used, shown in Figures 1 through 3, are defined in the corresponding legends to the figures.

Statistical analysis

The statistical analysis was performed with SPSS software for Windows (version 13.0, SPSS, Chicago, Ill). The arithmetic mean and standard deviation were calculated for each variable. Analysis of variance (ANOVA) and paired t tests were used. The level of significance was $P \leq 0.05$. Intraobserver reliability and reproducibility of the digitizer were checked on 20 randomly selected cephalometric radiographs that were retraced and redigitized 2 weeks later. The errors did not exceed 0.2 mm for the linear variables and 0.5° for the angular variables.

RESULTS

As shown in Table III, SNA angle did not change significantly with QCVM for both sexes, but SNB angle increased and ANB angle decreased significantly, especially in the boys ($P < 0.05$). There were no significant sex differences in ANB and SNB angles during QCVM stage I. In QCVM stages II and III, the changes of ANB and SNB angles were greater for the boys than for the girls ($P < 0.05$).

Throughout the study period, changes of SA/SN or SGn/SN angle showed no significant differences for either sex ($P > 0.05$). This suggested that the growth directions of the maxilla and the mandible were stable. We can predict the total growth direction of the maxilla and the mandible with SA/SN or SGn/SN angle.

The inclination of the palatal plane (PNS-ANS/SN) was also stable. This indicates that the palatal plane can be used as a reference plane in lateral cephalometric radiographs to evaluate the maxillomandibular relationship.

The OP/SN angle was significantly different in QCVM stages I and II, but there was no significant difference in QCVM stages III and IV. These results suggest that posterior occlusal distance increases during the mixed dentition period because of the replacement of deciduous teeth and growth. The changes of the OP/SN angle became smaller gradually and were maintained after the replacement of all deciduous teeth.

The increment in mandibular length (Ar-Gn) was almost 2.5 times as great as the increment in the maxillary length (ANS-PNS $\perp$ SN) from QCVM stages I to IV (mandible: boys, 17.57 mm; girls, 13.62 mm; maxilla: boys, 7.04 mm; girls, 5.82 mm) for both sexes. In QCVM stage I, the growth increments of the maxilla and the mandible were nearly the same. In stage II, the growth of the mandible exceeded that of the maxilla and continued in stages III and IV, whereas the maxilla had no more growth. The GM of Ar-Gn and Go-Gn.
increased drastically in QCVM stage II for both sexes, but statistically significant sex differences were found in QCVM stages III and IV. For girls, the GM decreased quickly, but, for the boys, there was some growth potential even in QCVM stage IV (Table III).

The relationship between mandibular vertical growth (Ar-Go) and skeletal maturation was closely correlated. The trend was toward accelerating velocity, then high velocity, followed by decelerating velocity, and completion of velocity from QCVM stages I to IV. There were significant differences between the maxilla and the mandible in the vertical relationship. The height of the mandible (Ar-Go) continued to increase in stage III, with more GM than in stage I. Anterior and posterior maxillary height (ANS \( \perp SN' \) and PNS \( \perp SN' \)) increased at the same speed for both sexes. The height significantly increased in stages I and II and slightly increased in stages III and IV, indicating that vertical maxillary growth almost ended during the medium term of growth and development.

Interestingly, GM and RGR were not always consistent (Tables III and IV). The greatest GM of all linear measurements was found in QCVM stage II for both sexes, and the least was in QCVM stage IV. The next largest growth was in QCVM stage I with the exception of the boys’ mandibular measurements, whose next largest growth was in QCVM stage III. However, the largest RGR of maxillary measurements was in QCVM stage I, then in QCVM stage II, and the lowest RGR was in QCVM stage IV (Fig 4). The largest RGRs of mandibular measurements were in QCVM stage II and then in QCVM stage I (Fig 5).

### Table II. Time periods of QCVM stages I through IV (mean ± SD)

<table>
<thead>
<tr>
<th>QCVM I (y)</th>
<th>QCVM II (y)</th>
<th>QCVM III (y)</th>
<th>QCVM IV (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys</td>
<td>1.80 ± 0.47</td>
<td>2.58 ± 0.81</td>
<td>2.03 ± 0.37</td>
</tr>
<tr>
<td>Girls</td>
<td>1.70 ± 0.31</td>
<td>2.27 ± 0.41</td>
<td>1.95 ± 0.50</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Correct use of growth potential involves guiding the development of dentoalveolar and skeletal structures. Preventing undesirable growth-related changes and allowing desirable ones are the general principles of dentofacial orthopedic treatment. It would therefore be useful to know in detail the growth and development of the various parts of the craniofacial structures.

Longitudinal research is an essential method for in-depth study of craniofacial growth and development, which can determine a patient’s unique development type and make a continuous comparison. But investigations with this method are limited because of the problems of longitudinal radiographic recordings.

The 87 adolescents in this study included 2 groups with different beginning ages of observation: 8 to 9 and 12 to 13 years of age, respectively. Sequential lateral cephalograms and hand-wrist films were taken once a year for 6 consecutive years. Thus, we had mixed longitudinal data from ages 8 to 18 years, including the whole period of growth and development. The subjects were divided into 11 maturation groups by skeletal maturity. It was believed that, in this respect, the investigation maintained its longitudinal character. Certainly, the study would be more convincing if it were based on pure longitudinal data from 8 to 18 years of age, but it is more difficult to obtain these data.

The potential of craniofacial growth was compared in this study by the RGR. The RGR formula used here was selected for its applicability for demonstrating percentage changes in the growth of the selected facial measurements. This method also allowed easier comparison of a subject’s growth pattern with group data. By including
the elapsed time in the formula, growth changes over varying periods of time were all converted to annual rates, so that the growth rates could be compared.

**Sagittal RGR of the maxilla and the mandible**

The GM and RGR were not always consistent. The greatest GM of ANS-PNS ⊥ SN' was in QCVM stage II for both sexes, but the greatest RGR was in QCVM stage I (Fig 4). The reason for this observation was that the subjects had different periods of time between the QCVM stages (Table II). The findings showed that, in maxillary protraction treatment for maxillary deficiency, the orthopedic treatment of Class III malocclusion was more effective when it began at an early

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Sex</th>
<th>QCVM I</th>
<th>QCVM II</th>
<th>QCVM III</th>
<th>QCVM IV</th>
<th>I-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNA (°)</td>
<td>Male</td>
<td>0.34 ± 0.10</td>
<td>0.33 ± 0.11</td>
<td>0.07 ± 0.03</td>
<td>0.02 ± 0.02</td>
<td>0.76 ± 0.09</td>
</tr>
<tr>
<td>SNB (°)</td>
<td>Male</td>
<td>0.82 ± 0.15</td>
<td>2.02 ± 0.25*</td>
<td>1.48 ± 0.21*</td>
<td>0.20 ± 0.03</td>
<td>4.52 ± 0.32*</td>
</tr>
<tr>
<td>ANB (°)</td>
<td>Male</td>
<td>0.71 ± 0.14</td>
<td>1.41 ± 0.31†</td>
<td>0.13 ± 0.12†</td>
<td>0.07 ± 0.02</td>
<td>2.91 ± 0.28†</td>
</tr>
<tr>
<td>SA/SN (°)</td>
<td>Male</td>
<td>0.22 ± 0.06</td>
<td>0.24 ± 0.07</td>
<td>0.09 ± 0.04</td>
<td>0.19 ± 0.08</td>
<td>0.26 ± 0.05</td>
</tr>
<tr>
<td>Go-Gn (mm)</td>
<td>Male</td>
<td>2.88 ± 0.42*</td>
<td>2.05 ± 0.60*</td>
<td>1.36 ± 0.73*</td>
<td>0.47 ± 0.13</td>
<td></td>
</tr>
<tr>
<td>PNS-ANS/SN (°)</td>
<td>Male</td>
<td>3.45 ± 0.83*</td>
<td>7.61 ± 0.53*</td>
<td>4.19 ± 0.87*</td>
<td>2.32 ± 0.19*</td>
<td>17.57 ± 0.99*</td>
</tr>
<tr>
<td>Ar-Gn (mm)</td>
<td>Male</td>
<td>2.95 ± 0.32*</td>
<td>2.39 ± 0.51†</td>
<td>0.62 ± 0.15*</td>
<td>0.29 ± 0.21</td>
<td></td>
</tr>
<tr>
<td>Go-Gn (mm)</td>
<td>Male</td>
<td>2.08 ± 0.79*</td>
<td>3.09 ± 1.12*</td>
<td>2.00 ± 0.62*</td>
<td>1.57 ± 0.49*</td>
<td></td>
</tr>
<tr>
<td>ANS ⊥ SN (°)</td>
<td>Male</td>
<td>2.49 ± 0.40*</td>
<td>3.27 ± 0.91*</td>
<td>2.17 ± 0.47†</td>
<td>1.10 ± 0.28†</td>
<td></td>
</tr>
<tr>
<td>PNS ⊥ SN (°)</td>
<td>Male</td>
<td>4.35 ± 1.13*</td>
<td>3.20 ± 0.83*</td>
<td>0.87 ± 0.34</td>
<td>0.59 ± 0.20</td>
<td></td>
</tr>
<tr>
<td>Ar-Go (mm)</td>
<td>Male</td>
<td>4.53 ± 0.89*</td>
<td>3.61 ± 0.94†</td>
<td>0.87 ± 0.41</td>
<td>0.53 ± 0.18</td>
<td></td>
</tr>
</tbody>
</table>

*P <0.05, significant difference between adjacent stages; †P <0.05, significant difference between the sexes (ANOVA).
skeletal developmental phase (QCVM stage I or, at least, stage II) because the maxilla was significantly hypoplastic, and the midpalatine suture was incompletely fused.21 The findings of Wong et al22 agreed with our study.

The RGR also provided information to the clinician in assessing the timing for orthognathic surgery. For example, for some maxillary skeletal deformities that affect the patient’s quality of life, orthognathic surgery can be done in QCVM stage IV, even though the patient is still young.23 For girls who want a face with both stable occlusion and a beautiful look as soon as possible, we can begin presurgery orthodontic treatment in QCVM stage III, because the growth potential of girls in QCVM stages III and IV is small.

In our study, there were 2 mandibular sagittal parameters—Ar-Gn and Go-Gn—for overall length and body length. Mandibular length was previously defined as the linear distance between condylion (most superior point on the head of the condyle) and gnathion (most anterior-inferior points on the chin).17 Haas et al24 established the validity of using artiulare as a substitute for condylion in measurements of overall mandibular length. Articulare was defined as the point of intersection of the images of the posterior border of the ramal process of the mandible and the inferior border of the basilar part of the occipital bone. In this study, we used articulare because it can be easily located on the traditional lateral cephalogram.

All craniofacial lengths had statistically significant incremental growth changes in both sexes from QCVM stages I to IV. There were significant differences between maxillary and mandibular growth. This finding supported the observations of Ochoa and Nanda.25 There were significant differences between the sexes in both the maxilla and the mandible. More GM and longer growth duration were found in the boys, especially in mandibular growth. With growth, the facial profiles of the boys became straighter as the chins became more prominent. The girls had less incremental growth and shorter duration, so that their profiles remained more convex. This trend was consistent with that of the ANB angle.

The RGR of Ar-Gn and Go-Gn showed the trend toward accelerating velocity, then high velocity, decelerating velocity, and no velocity from QCVM stages I to IV (Fig 5). But there were some sex differences in QCVM III. For girls, GM decreased dramatically in QCVM stages III and IV. However, for boys, some growth potential was evident even in QCVM stage IV. As stated, treatment for a retrognathic mandible with dentofacial orthopedic appliances is more effective during the peak of growth.26 Our findings provide the basis for evaluation of the timing for growth-modification treatment. If a patient is in QCVM stage II, it is an optimal time for growth modification, and the maximum growth response to treatment can be expected. If the stage is III, growth modification can still be performed,
but the growth response might be less, especially in girls. If the stage is I or below, the patient should be re-viewed at 3-month intervals.

Clearly, the greatest growth potential was not consistent between the maxilla and the mandible (Fig 6). The greatest RGRs were in QCVM stage I for the maxilla and QCVM stage II for the mandible. This is an important reference value for clinical orthodontics. For example, for some skeletal Class II dentofacial deformities in QCVM I, the focus of orthopedic treatment can be on inhibition of sagittal maxillary growth, and the mandible can maximize the potential of its natural growth. In contrast, for some skeletal Class III dentofacial deformities in QCVM I, the maxilla should maximize the potential of its natural growth.

**Vertical RGR of the maxilla and the mandible**

This study showed that the best intervention period for maxillary height (ANS $\perp$ SN’ and PNS $\perp$ SN’) growth was in QCVM stage I and then in stage II, since vertical maxillary growth almost came to an end during the medium term of growth and development. This finding did not fully agree with that of Krogman, who stated that growth in width was completed first, then growth in length, and, finally, growth in height. But our results are consistent with those of Yavuz et al., who studied the longitudinal posteroanterior changes in transverse and vertical craniofacial structures in subjects between 10 and 14 years of age.

The height of the mandible (Ar-Go) continued to increase in QCVM stage III with even more GM than that in stage I. This indicates that the best intervention period for posterior mandibular vertical growth is in QCVM stage II, but there is still some potential for intervention in QCVM stage III.

**CONCLUSIONS**

The main discoveries of this study were the following.

1. GM and RGR are not always consistent, because each subject had a different period of time between the various QCVM stages. GM was not as reliable as RGR.
2. RGR did not show any significant sex differences in the maxilla and the mandible, despite different decelerating curves. However, statistically significant sex differences were found in the GM of mandibular measurements.
3. The greatest growth potential was not synchronized between the maxilla and the mandible. For both sexes, the greatest RGR of maxillary length and height was in QCVM stage I, and then deceleration were observed. The greatest RGRs of mandibular length and height was in QCVM stage II, and the next largest was in QCVM stage I.

Understanding the RGR can provide some references for orthodontic treatment and orthognathic surgery. Certainly, more information and study of craniofacial growth and skeletal maturation are required to further increase our knowledge in this important area.

We thank Sheldon Peck, Harvard School of Dental Medicine, Boston, for his helpful suggestions regarding this manuscript.

**REFERENCES**


