Craniofacial growth and skeletal maturation:
a mixed longitudinal study

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SUMMARY The purpose of this study was to investigate the relationship between craniofacial growth and skeletal maturation. The material consisted of the cephalometric and hand-wrist film pairs of 35 males and 43 females (78 subjects) whose development was followed for a period of 4 to 7 years. The subjects were grouped according to their skeletal maturation. Their mean ages were: Group I 10.27, Group II 11.55, and Group III 14.79 years, respectively, at the beginning of the observation period. Intra- and inter-group differences were examined through paired *t*-tests, and Pearson correlation analysis was used to detect the relationship between craniofacial growth and skeletal maturation (percentage growth potential).

The results show that the middle cranial base (T–W) maintained its stability in all pubertal growth periods. However, posterior cranial base length (T–Ba) increases significantly ($P < 0.001$) throughout the same period. There were similar increases in the vertical dimensions of the face and alveolar height throughout pubertal growth. Despite the intensified increases in both the sagittal and vertical directions, facial characteristics were constant in the sagittal direction.

The skeletal development (percentage growth potential) has clearly been effective in the vertical facial development commencing in Group I and reaching its maximum level in Group II. However Cd–Go was the exception.

Introduction

Growth and development can be regarded as a kind of energy. When should this energy be utilized? The reply to this question would clarify the timing of orthopaedic treatment, which involves guiding the development of dento-alveolar and skeletal structures. Prevention of undesirable growth-related changes and allowing desirable ones constitutes the general principle of orthopaedic treatment. It would therefore be useful to know in detail the growth and development of the various parts of the craniofacial structures.

The best indicator of facial skeletal growth is the annual increase in body height (Björk and Helm, 1967; Helm *et al.*, 1971; Singer, 1980; Baume *et al.*, 1983). However, repeated observations are needed for the prediction of pubertal development on the basis of annual growth in height. This may not always be possible. The maturation of hand-wrist bones is a frequently utilized criterion for the prediction of growth and development (Bambha and Natta, 1963; Chapman, 1972; Grave, 1973; Grave and Brown, 1976; Bowden, 1977; So, 1997a,b; Houston *et al.*, 1979; Hägg and Taranger, 1980; Houston, 1980).

Observation of craniofacial growth on the basis of maturation of hand-wrist bones formed the basis of this study. Thus:

(1) the growth of various parts of the craniofacial structures was examined;
(2) the relationship between skeletal maturation (percentage growth potential) and craniofacial growth was investigated in different skeletal maturation stages.

Subjects and methods

This research was conducted on 35 males and 43 females (78 subjects), who had a normal facial pattern and whose development was followed for a period of 4 to 7 years. In creating the groups, the hand-wrist radiographs taken at annual intervals were used. The mean chronological ages for the groups are shown in Table 1.

The growth periods were identified according to the skeletal development criteria described by Helm *et al.* (1971). Based upon this criteria, the growth potential of each individual corresponding to his/her skeletal age was calculated in terms of percentage values by using the radiographic atlas of Greulich and Pyle (1959).

The individuals were divided into three groups as Group I, Group II and Group III according to their skeletal maturation. The mean ages were 10.27 ± 0.24, 11.55 ± 0.16, and 14.79 ± 0.18 years, respectively. The biological criteria taken into consideration in the assessment of the groups were as follows (Figure 1).

Group I: The skeletal development of the individuals in this group, at a minimum, started at the PP2 period and lasted until the MP3, H and/or S periods, but prior to the MP3cap period.

Group II: Individuals, exceeding MP3cap, DP3u periods, and commencing at the H, S, or MP3 criteria, which is the sign of the end of the first stage were included.

Group III: Those individuals whose skeletal development began at MP3u or PP3u and who were followed to the RU period. Individuals at the DP3u period were not included in this group. At the end of this grouping, cephalometric and hand-wrist film pairs of the longitudinal records of 78 of the individuals were taken into consideration.

Reference points, reference lines, and projectional measurements are shown in Figure 2.

Statistical methods

Paired *t*-tests were used for determining intra- and inter-group differences, and Pearson correlation coefficient was calculated for detecting the relationships between craniofacial growth and skeletal maturation.

Results

According to the results (Table 2), the middle cranial base (T–W), completed its growth in the earlier period and its stability maintained in all three developmental phases.

On the other hand, the posterior longitudinal cranial base (T–Ba) showed a substantial increase throughout the same period ($P < 0.001$). The increase in this dimension also showed variances among the developmental stages. However, it was found that the substantial growth differences, were most evident in Group II and least evident in Group III.

There was an intensified increase in the maxillary sagittal dimension (ANS–PNS) throughout the three separate developmental stages.

Substantial increases in the sagittal dimension of the mandible (Go–Pg) were detected throughout the three developmental phases. Similarities were found between the increases in Groups I and II.

Table 1 Descriptive statistics for chronological age at the beginning and end of the observation periods.

Group I ($n = 30$ $X \pm Sx$)		Group II ($n = 65$ $X \pm Sx$)		Group III ($n = 32$ $X \pm Sx$)	
Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
10.27 ± 0.24	12.05 ± 0.21	11.55 ± 0.16	14.99 ± 0.14	14.79 ± 0.18	16.77 ± 0.15

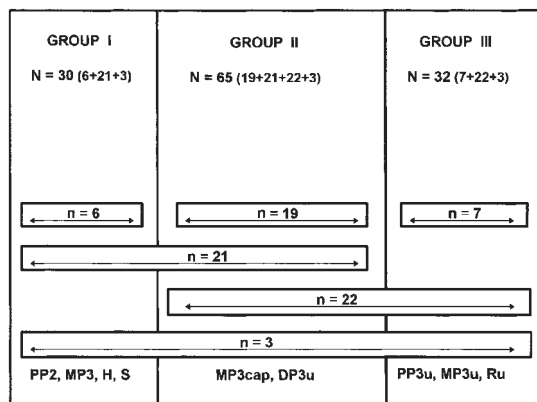Time 1: At the beginning of the observation.
Time 2: At the end of the observation.

Figure 1 Distribution of the 78 individuals regarding skeletal maturation (78 individuals = 6 + 19 + 7 + 21 + 22 + 3).

Figure 2 Anatomical reference points, reference lines and projectional measurements used in the study. Anatomical reference points: N, nasion; T, tuberculum sella; W, the point where the middle cranial fossa is intersected by ala major of the sphenoid bone; A, point-A; ANS, anterior nasal spine; PNS, posterior nasal spine; Sd, supradental point; Id, infradental point; B, point B; Pg, pogonion; Me, menton; Go, gonion; Ba, basion; Cd, condylion; MSd, supradental point of upper first molar; MId, infradental point of lower first molar. Reference lines: HRL, Horizontal Reference Line (from T to W); VRL, Vertical Reference Line (T perpendecular to HRL); ANS–PNS, maxillary plane; Go–Me, mandibular plane. Projection points: Sd', projection point of Sd to ANS–PNS; Id', projection point of Id to ANS–PNS; MSd', projection point of MSd to ANS–PNS; MId', projection point of MId to ANS–PNS; A', projection point of point-A to Vertical Reference Line; B', projection point of point-B to Vertical Reference Line. Projectional measurements: Sd-Sd', upper anterior alveolar height; Id-Id', lower anterior alveolar height; MSd–MSd', upper posterior alveolar height; MId-MId', lower posterior alveolar height. A–A' and B–B' (Arat *et al.*, 1988).

The vertical dimension of ramus (Cd–Go), which was maximized in Group II, showed substantial increases throughout the three phases. However, these increases reflected differences throughout the development phases. The maximum increase was found in Group II ($P < 0.001$).

Even though increases in both anterior (N–Me) and posterior facial heights (T–Go) were found in Group II, throughout the three development phases they showed remarkable significance. The differences between the groups were significant with most of the differences taking place in Group II. Despite this, the Jarabak ratio (TGo/NMe), which indicates the facial vertical characteristics, increased most in Group II ($P < 0.001$), and least in Group I ($P < 0.05$). This change is the indicator of anterior rotation of the mandible. Intensified increases were found in total anterior (TAAH = Sd–Sd' + Id–Id') and posterior alveolar heights (TPAH = MSd–MSd' + MId–MId'). The increases among the groups were clearly different.

The measurements indicating the location of the maxillary and the mandibular basal arches (AA' and BB') significantly increased in Groups I and II ($P < 0.001$). In Group III, while AA' dimension remained stable, the BB' dimension showed a relatively small, but statistically significant increase ($P < 0.05$). The AA'–BB' 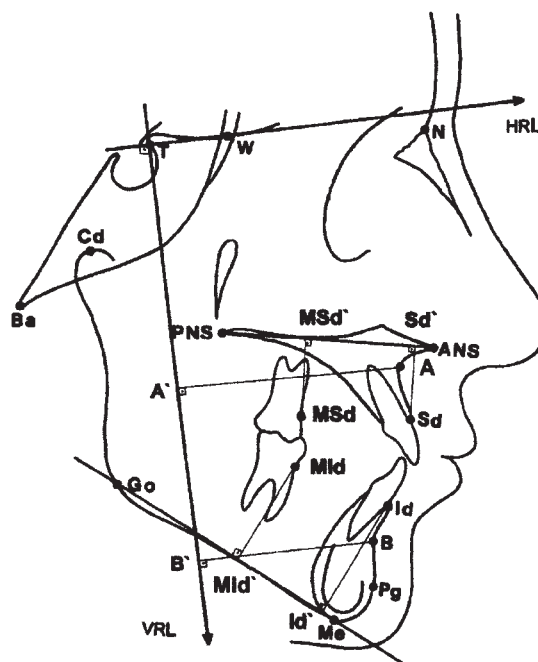measurement (the differences between AA' and BB' distances, used as an alternative to the ANB angle) remained constant in Groups I and II, but decreased in Group III ($P < 0.05$). Such a result is based upon the fact that even though the AA' dimension was stable, the BB' dimension showed an increase. Despite these findings, no differences were found between the growth

Table 2 The results of paired *t*-test for intra- and inter-group differences.

Parameters	Group I (n = 30) D ± S$_D$ (P)	Group II (n = 65) D ± S$_D$ (P)	Group III (n = 32) D ± S$_D$ (P)	Group I–II (n = 21) D ± S$_D$ (P)	Group II–III (n = 22) D ± S$_D$ (P)
T–W	–0.01 ± 0.13 (NS)	0.01 ± 0.01 (NS)	–0.01 ± 0.02 (NS)	–0.01 ± 0.03 (NS)	0.00 ± 0.03 (NS)
T–Ba	2.70 ± 0.03 (***)	2.97 ± 0.23 (***)	0.86 ± 0.18 (***)	–0.82 ± 0.39 (*)	1.46 ± 0.38 (***)
ANS–PNS	2.75 ± 0.29 (***)	3.70 ± 0.24 (***)	0.99 ± 0.24 (***)	–1.38 ± 0.54 (*)	2.44 ± 0.47 (***)
AA'	1.12 ± 0.28 (***)	1.80 ± 0.28 (***)	0.22 ± 0.19 (NS)	0.53 ± 0.70 (NS)	1.56 ± 0.38 (***)
BB'	1.71 ± 0.33 (***)	2.24 ± 0.47 (***)	0.75 ± 0.29 (*)	0.51 ± 0.84 (NS)	0.10 ± 0.68 (NS)
AA'–BB'	–0.59 ± 0.30 (NS)	–0.43 ± 0.35	–0.53 ± 0.24 (*)	1.04 ± 0.57 (NS)	0.56 ± 0.59 (NS)
T–Go	3.83 ± 0.42 (***)	8.66 ± 0.47 (***)	1.92 ± 0.30 (***)	–6.19 ± 1.12 (***)	5.80 ± 0.75 (***)
N–Me	4.35 ± 0.57 (***)	8.25 ± 0.50 (***)	1.21 ± 0.21 (***)	–6.64 ± 0.96 (***)	5.76 ± 0.71 (***)
T–Go/N–Me	0.01 ± 0.00 (*)	0.02 ± 0.00 (***)	0.01 ± 0.00 (**)	–0.01 ± 0.01 (NS)	0.02 ± 0.01 (**)
TPAH	2.82 ± 0.38 (***)	6.02 ± 0.36 (***)	1.34 ± 0.21 (***)	–4.58 ± 0.82 (***)	3.64 ± 0.51 (***)
TAAH	2.87 ± 0.47 (***)	4.80 ± 0.30 (***)	0.50 ± 0.22 (*)	–3.01 ± 0.77 (***)	3.95 ± 0.57 (***)
TPAH/TAAH	0.01 ± 0.01 (NS)	0.04 ± 0.01 (***)	0.02 ± 0.01 (**)	–0.04 ± 0.02 (NS)	0.01 ± 0.01 (NS)
Cd–Go	1.58 ± 0.56 (**)	6.48 ± 0.44 (***)	1.29 ± 0.41 (**)	–5.48 ± 1.14 (***)	4.13 ± 0.73 (***)
Go–Pg	3.77 ± 0.54 (***)	4.85 ± 0.38 (***)	0.95 ± 0.39 (*)	–2.11 ± 1.08 (NS)	2.92 ± 0.84 (**)
Growth potential	6.32 ± 0.53 (***)	10.76 ± 0.44 (*)	1.11 ± 0.10 (***)	–5.61 ± 0.10 (***)	8.73 ± 0.72 (***)
Skeletal age	1.83 ± 0.15 (***)	3.31 ± 0.20 (***)	1.98 ± 0.19 (***)	–1.16 ± 0.37 (**)	1.57 ± 0.49 (**)

*P < 0.05; **P < 0.01; ***P < 0.001; NS, not significant.

phases in the relationship of the jaws. In general, the sagittal relationship of the jaws showed a tendency to remain stable during pubertal growth.

The correlation between the growth rate of the craniofacial structures and hand-wrist bone maturation, were also investigated. As can be seen from the Pearson correlation analysis, growth potential showed significant correlation with the dimensional changes of the posterior cranial base (T–Ba) in Group II (Table 3).

The changes in ANS–PNS were not found to be related to skeletal maturation. However, mandibular growth, both sagittally and vertically, was related to skeletal maturation.

The sagittal location of upper (AA') and lower basal arches (BB') and the sagittal relationship of the jaws (AA'–BB') were not affected by skeletal maturation. However, skeletal maturation was found effective in vertical facial dimensions and facial characterization in Group II.

Discussion

Longitudinal growth studies frequently examine craniofacial growth on the basis of chronological age (Bishara *et al*., 1984; Bishara and Jakobsen, 1985; Love *et al*., 1990; Van der Beek *et al*., 1991; Athanasiou *et al*., 1992). However, physiological criteria are more appropriate for evaluating craniofacial growth (Lewis and Roche, 1972, 1974; Pancherz and Hägg, 1985; Arat *et al*., 1988).

The subjects included in this study were grouped on the basis of skeletal maturity (Helm *et al*., 1971). Some individuals were followed during a single period of development: six subjects in Group I, 19 in Group II, and seven in Group III, whilst 21 subjects were consecutively observed in both Groups I and II, 22 in Groups II and III, and only three in all periods of pubertal growth (Figure 1). It is believed that in this respect, the investigation maintained its longitudinal character.

The findings of this study show (Table 2) that the length of mid-cranial base (T–W) remained unchanged in all periods of pubertal growth. The mid-cranial base is known to complete its growth early and at 10 years of age virtually no change occurs in this dimension (Björk, 1955; Nakamura *et al*., 1972; Solow, 1980). This finding once more proved the reliability of the T–W line in cephalometric superimpositions. However, significant increases were observed in the posterior cranial base in all three periods.

Dimensional increases in the posterior cranial base may be associated with spheno-occipital synchondrosis activity (Lewis and Roche, 1972, 1974). This dimensional increase was most pronounced in Group II and was found to be highly related to growth potential only during this period (Table 3). It has been reported that acceleration occurs in the growth of the cranial base during the pubertal spurt and this acceleration is closely related to skeletal age (Lewis and Roche, 1972, 1974; Roche and Lewis, 1974). Such reports support the findings of the present investigation regarding the posterior cranial base. In this study both maxillary and mandibular basal dimensions (ANS–PNS, Go–Pg) increased in all three periods. The increases in maxillary base were not found to be related to skeletal maturation. However, the mandibular base (Go–Pg) continued to grow in both Groups I and II. On the other hand, the ramus height (Cd–Go) increased in Group II, in relation to growth potential. Accordingly, it can be suggested that mandibular growth is parallel to skeletal maturity (Pancherz and Hägg, 1985).

Maxillary growth occurs through sutural and appositional activity (Björk, 1966; Björk and Skieller, 1974, 1977); however, maxillary growth is also affected by differential growth of different functional cavities and environmental factors (Solow, 1980).

Used as an alternative to SNA, SNB, and ANB, the AA', BB', and AA'–BB' measurements used in this study, indicated that both maxillary (AA') and mandibular basal arches (BB') had been displaced forward. Despite this, the maxilla and mandible maintained a stable relationship in the sagittal direction until the third stage. BB' measurement continued to increase in Group III. This indicates that mandibular growth dominated maxillary growth (Love et al., 1990), leading to a decreased AA'–BB' measurement.

Throughout the study period, facial heights (N–Me, T–Go) increased considerably. It is known that vertical facial growth is related to skeletal maturation and somatic growth (Bergersen, 1972; Baume et al., 1983; Van der Beek et al., 1991). It is also known that anterior facial height is affected by respiratory function, alveolar development and mandibular

remodelling (Scott, 1958; Krieg, 1987). The findings in this study indicate that anterior facial height, where growth starts at an earlier period, increases in Groups I and II, while posterior facial height increases in Group II in relation to growth potential (Table 3).

Environmental factors are believed to be instrumental in the growth of facial height in Group III. Total anterior and posterior alveolar height increases were found to be significantly related to growth potential in Group II. However, alveolar ratio changed independent of skeletal maturation (Table 3).

The alveolar structure is a flexible area located between the facial skeleton and occlusal dynamics. Maintaining its growth (Tallgren and Solow, 1991) for many years, this structure tries to establish and maintain occlusal relationships on the basis of changing mandibular and maxillary relationships. This so-called 'dentoalveolar compensatory mechanism' spontaneously masks skeletal deviations. On the other hand, the alveolar structure is also instrumental in controlling development of the jaws. The high capacity of adaptation of the alveolar structure accounts for the fact that it does not only change with skeletal maturation.

Table 3 The correlation between percentage growth potential and craniofacial growth.

Parameters	Group I ($n = 30$)	Group II ($n = 65$)	Group III ($n = 32$)
T–W	0.068	–0.059	0.100
T–Ba	0.028	0.444***	0.121
ANS–PNS	0.256	0.168	–0.184
AA'	0.152	0.168	0.016
BB'	–0.016	0.082	0.117
AA'–BB'	0.158	0.024	–0.131
T–Go	0.296	0.529***	0.154
N–Me	0.631***	0.637***	0.121
T–Go/N–Me	–0.245	0.529***	0.267
TPAH	0.383*	0.406***	–0.040
TAAH	0.242	0.561***	0.043
TPAH/TAAH	0.110	–0.044	–0.057
Cd–Go	0.150	0.246*	0.291
Go–Pg	0.391*	0.348*	–0.042

*$P < 0.05$; ***$P < 0.001$.

Conclusions

1. The period in which craniofacial growth is most intensive coincides with that in which MP3cap and DP3u occur. This stage may be considered suitable for the treatment of skeletal irregularities, regarded as Group II.

2. During the third stage craniofacial changes are minimal, but significant. This may be accepted as an advantage for young adults. However, in no way can it be recommended that the treatment of skeletal deviation be postponed until the third stage.

3. The findings in this study concern development, that is, spontaneous changes. Involved orthopaedic therapy will be interventions to steer development in dentofacial structure. When such interventions are carried out, growth patterns and potentials of the elements of dentofacial structures should be taken into consideration. Such an approach is of great importance that will affect not only the therapeutic course, but also stability.

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