Orthodontic Status and Head Morphology in Young Males

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Abstract Complete anthropometrical data on a sample of 111 Russian males aged 20.0 ± 2.3 years were obtained to investigate craniofacial morphology according to individual orthodontic status (OS). Subsample analyses were performed, using a variety of grouping factors. a) 1–spacing on both dental arches; 2–absence of crowding, spacing, rotation, or displacement of teeth on both dental arches; 3–crowding on both dental arches; b) 1–spacing on mandible; 2–absence of crowding, spacing, rotation, or displacement of teeth on mandible; 3–crowding on mandible; c) 1–spacing on maxilla; 2–absence of crowding, spacing, rotation, or displacement of teeth on maxilla; 3–crowding on maxilla. Wilks' Lambdas were found to be 0.29 to 0.59; all were significant.

Conclusions:

1. Significant positive and negative correlations were found between craniofacial measurements and an individual's OS.
2. Measurements exhibited statistically significant differences between the groups with different OS at the $p < 0.05$ level and some at $p < 0.01$.
3. Using forward stepwise discriminant analysis, a high difference in craniofacial architecture between the groups with different OS was found. Canonical discriminant analysis indicates the face pattern connected to crowding: relatively high medial vertical mandible height in combination with a vertically long and narrow face; to spacing: a wide face with wide nose and high upper lip is combined with shortened medial vertical mandible height.
4. Depending upon the grouping factor, 10 to 12 variables were chosen in the canonical discriminant model. Classification functions and means of canonical roots were calculated; morphological interpretations of canonical roots were performed.
5. Definitive OS is a complicated product of interaction during the ontogenesis of jaws between the time of teeth eruption and the growth of two growth fields (alveolar and corpus) under the simultaneous influence of hormonal status and the chronological age of the individual. *J Physiol Anthropol* 26(3): 387–402, 2007 <http://www.jstage.jst.go.jp/browse/jpa2>
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Introduction

The origins of malocclusions during latter stages of human evolution have been discussed elsewhere. In general, three theories have been developed to explain the high prevalence of dental crowding in modern cosmopolitan populations. One theory is that an evolutionary trend towards diminution of growth in the facial skeleton has occurred without a corresponding change in tooth dimensions (Hooton, 1947). Recently Moore et al. (1968) compared dimensions of teeth and mandible measurements from Neolithic to modern times and offered support for Hooton's model. Alternatively, Brash (1956) suggested that dental irregularities in modern cosmopolitan populations is high in comparison to a modern but traditional-living (aboriginal) population because the diet is composed of less fibrous and tough-to-chew foods. This produces a diminution of the mechanical stimuli for growth of the facial skeleton. Brader (1972) concluded that primary determinants of arch form morphology are the muscle forces in resting and functioning states. It has been shown experimentally by Weijs and Hillent (1986) that a decrease in jaw muscle size in various animals has a similar effect on facial width and mandibular length. Their results support the hypothesis that in humans the jaw muscles affect facial growth and partly determine final facial dimensions. They also hint that the role of each muscle on facial growth is different. Although habitual activity of the masseter muscle in natural environments is not influenced by the vertical craniofacial morphology (Farella et al., 2005), we cannot be sure from this study that people with different types of vertical morphology have the same rate of masticatory activity.

Another theory discussed by Brash (1956) suggests that present-day populations represent an intermingling of peoples from diverse and physically dissimilar stocks. Interbreeding leads to skeletal disharmonies. Furthermore, Lundström (1951) presented evidence for independent genetic controls of teeth relative to jaws. Thus, it is possible that such a mechanism

might result in discrepancies between the size of jaw and dentition.

A study comparing the crowding index from an historic population of the 19th century and a modern population showed a significant difference, with greater crowding in the modern population ($p < 0.05$) (Vyslozil and Jonke, 1994, cited by Moskers et al., 2004). The ancient population of Roaix differs considerably from these data, crowding being clearly greater in this prehistoric population than in the population of the 11th century and in modern populations (Moskers et al., 2004). Furthermore, all adults of this prehistoric population showed dental crowding, while crowding in the modern population has been reported to be 70–80% (Sinclair and Little, 1983; Proffit et al., 1998). These findings are in contrast to the results of Andrik (1963, cited in Moskers et al., 2004), who reported that malocclusions were rare in prehistoric populations and noted a crowding prevalence of only 1 percent from the Bronze Age; and Mirgazitov et al. (1998) who showed that during the last three thousand years dental arch structural anomalies increased to tenfold. Thus, crowding may be of genetic origin and might not be caused by excessive tooth size or changes in environmental factors (masticatory activity), at least in isolated populations (Moskers et al., 2004).

Crowding is one of the most frequent types of malocclusion in children and also the chief complaint of many parents referred to orthodontic departments. In Russia, it often remains untreated in adults—so the need for orthodontic treatment is high. Crowding and spacing are identified as a discrepancy between the mesiodistal tooth widths of the four permanent incisors and the available space in the alveolar process. A review of the literature indicated conflicting results regarding factors contributing to crowding and spacing.

Schwarz (1960) concluded from his cephalometric and gnathometric analysis that every malocclusion can be combined with all natural variations of skull morphologies and there is no connection between the two (cited after Siriawat and Jarabak 1985). Shudy (1965) found no correlation between morphologic pattern and specific types of occlusion in 270 subjects. But he found that in 400 malocclusions the occlusion/mandibular plane angle and Sella-Nasion/mandibular angle were excellent indicators of facial type. Howe et al. (1983) and Sinclair and Little (1983) also found no clinically significant associations between various mandibular parameters and incisor crowding. Miethke and Behm-Mentzel (1988) reported that cephalometric measurements of patients with and without crowding did not differ significantly. They did not find any correlation between mandibular anterior crowding and vertical craniofacial configuration and sagittal lower incisor inclination. In view of their results, they suggest lower incisor crowding is a “local, independent, genetically determined discrepancy between tooth width and size of supporting bone.”

Sakuda et al. (1976) reported a significant correlation between an increase in lower incisor crowding and high mandibular plane angles, short mandibular body lengths,

greater upper face height, and small vertical dimensions in the upper posterior segments. Leighton and Hunter (1982) compared the skeletal morphology of cases with spacing, with moderate crowding and severe crowding of lower incisors. They reported shorter posterior facial heights and mandibular bodies for cases with crowding; mandibular prognathism increased more in the spaced cases.

Determination of factors contributing to anterior spacing or crowding, especially in the early mixed dentition stage and predicting permanent incisor crowding at an early stage are of great importance for orthodontic treatment planning. Towards this aim, several longitudinal studies evaluating mandibular dental crowding were performed during the primary, mixed, and permanent dentition stages. (Sanin and Savara, 1973; Howe et al., 1983; Hunter and Smith, 1972; Doris et al., 1983; Leighton and Hunter, 1982; Sampson and Richards, 1985; Berg, 1986; Bishara et al., 1986, 1995, 1998a, 1998b; Melo et al., 2001). Melo et al. (2001) evaluated indicators of crowding found in primary dentition, which could lead to future mandibular anterior crowding in the mixed dentition stage. They found that crowding is often related to arch dimensions. Few studies have evaluated the relationship between crowding and cephalometric measurements made on cephalograms and we were not able to access studies based on anthropometric measurements of any human population. Previous research into the origins of lower incisor crowding has not yet established the part played by skeletal morphology in its development. Berg (1986) compared cephalometric variables of patients with and without crowding and found that variables related to lower jaw dimensions had significantly smaller values in the crowded group. Several other reports have also indicated that crowding occurred more frequently in less prognathic cases (Ronnerman and Thilander, 1988; Leighton and Hunter, 1982; Lundström, 1975).

Although crowding is considered as the most prevalent form of malocclusion (Helm, 1970; Tang, 1994; Proffit et al., 1998; Otuyemi et al., 1999; Thilander et al., 2001), a period of slightly crowded mandibular incisors is accepted as part of normal development. Sanin and Savara (1973) evaluated 150 children and reported that 89% of those with crowding in early mixed dentition also had crowding in permanent dentition, with only 11% showing complete correction. Except for two cases, the other self-correcting cases had no more than 0.5 mm crowding in the early mixed dentition. Tanabe et al. (2002) show that at ages 3, 4, and 5 years old the mean profiles of children remain similar in shape although the size of each profile enlarged with age. Sagittal skeletal relationships remained constant from early to late mixed dentition (mean age 9.31 ± 1.52 years). No significant differences were found between the observed developmental stages. Bishara and Jakobsen (1985) demonstrated that 77% of people maintained their facial types from 5 to 25.5 years of age. Other longitudinal studies comparing growth of open-bite and deep-bite subjects have demonstrated that, although there are differences in the magnitude and direction of growth changes, they follow

similar patterns (Bishara and Jakobsen, 1985; Nanda, 1988, 1990; Karlson, 1995). Longitudinal craniofacial growth curves based on multilevel procedures can accurately describe population and individual growth curves, and 5-year predictions with this method are highly accurate and externally valid. Correlations between predicted and actual values ranged from 0.81 to 0.96, explaining the 66% to 92% of variation (Chvatal et al., 2005).

Cherdantsev (2003) stated that there are two ways to investigate morphogenetic variance: longitudinal observation of individual ontogenetic processes or comparison of the same age individuals. The second way is more convenient because the sample is easier to collect and the sample size is limited only by the investigator's patience. That is why we assume that studying a trait in its definitive state may shed light on mechanisms of its formation during ontogenesis. Thus, we suppose that if some morphological patterns in head and face architecture do exist at the mature stage, there were indications of this pattern during the growth period. Also, selection of discriminating traits is easier when morphology of the region of interest (craniofacial in our case) is already formed. Then we can choose meaningful variables for future study to follow during development, armed with the knowledge of head and face architecture that related to precise final orthodontic status, such as crowding, spacing, or harmonious development. Gathering data on adults also is much easier regarding time consumption because smaller sample sizes and fewer repeated observations are needed. Furthermore, it is easier regarding ethical considerations since adults can decide for themselves whether to participate in a study or not and there is less need for explanation.

Incisor crowding is not merely a tooth-arch size discrepancy, but a discrepancy among many variables (Sanin and Savara, 1973). Several factors can be assumed to affect the development and severity of crowding, such as direction of mandibular growth (Bjork, 1963; Perera, 1987), early loss of deciduous molars (Ronnerman and Thilander, 1978), mesiodistal tooth and arch dimensions (Howe et al., 1983), the oral and perioral musculature and incisor and molar inclination (Sanin and Savara, 1973), and human growth hormone (Sarnat et al., 1988; Kjellberg et al., 2000). Opinions about relations between the human growth hormone (GH) and severity of dental crowding were tested on patients with dwarfism. Kjellberg et al. (2000) stated that short-statured boys might be in greater need of orthodontic treatment due to their higher percentage of dental crowding. The main findings of Sarnat et al. (1988) were that human GH therapy did not accelerate dental age but enhanced bone age; the mandible was significantly smaller in the untreated group but no significant difference was found between the groups in the maxilla; and crowding was less prevalent than expected and the mesiodistal width of the teeth seemed to be smaller. No articles with notes about crowding in acromegaly patients were available.

It has been argued that growth of the face is modular and is governed by growth of multiple contiguous soft tissues and

functioning spaces (functional matrices). Brader (1972) considers that the dental arch form of an individual is a predictable module of a larger morphogenetic pattern—a harmonious part of the total craniofacial architecture. The particular architecture can be affected by mechanical and nervous stimulation along with the inherited potential to grow. Despite the trigeminal nerve exerting a trophic influence on the craniofacial complex; the conclusion that trophic effects constitute a major factor in the regulation of craniofacial growth cannot be supported (Behrents and Johnston, 1984).

The aims of this study were: 1. To examine associations between facial morphology and malocclusions; 2. To determine the possible indicators of crowding and spacing in the permanent dentition from anthropometric measurements; 3. To describe dentofacial morphological patterns of males with and without crowding or spacing; 4. To make *a priori* conclusions about affecting factors that might be associated with spacing and crowding.

Materials and Methods

Full anthropometrical data of head and face measurements of 111 males aged 20.0 ± 2.1 years was selected from records obtained as part of a larger ongoing study. These were used to investigate relationships between dentofacial and postcranial morphology according to individual orthodontic condition. 81.4% of participants were Russians from different regions of the Russian Federation, and 18.6% were of other ethnicity, but all were Caucasian. Frequencies from different nations corresponded to a census of enumeration in 2002. None of the subjects had undergone previous orthodontic treatment. This age group was chosen because at this early mature stage growth organism is complete, head and face dimensions are stable, aging is not yet significant, and the DMFT index of caries, especially the number of missing teeth, remains low.

The DMFT index and the presence of crowding or spacing on the maxilla and mandible were assessed using dental casts. Even very small deviations from smooth dental arch, linear displacement of the anatomical contact points, like incisor inclinations, were attributed to crowding and the presence of any space between teeth was attributed to spacing. Other cases were considered as normal.

For each of three discriminant analyses three subgroups were formed, using the following grouping factors:

- a) 1—spacing on both dental arches; 2—absence of crowding, spacing, rotation, or displacement of teeth on both dental arches; 3—crowding on both dental arches;
- b) 1—spacing on mandible; 2—absence of crowding, spacing, rotation, or displacement of teeth on mandible; 3—crowding on mandible;
- c) 1—spacing on maxilla; 2—absence of crowding, spacing, rotation, or displacement of teeth on maxilla; 3—crowding on maxilla.

Presence of spacing and crowding, along with normal dentition constitutes a contiguous variable—teeth size-dental

arch size discrepancy. In our study we used them as one parametric variable with three possible values, called “orthodontic status” (OS). Note, that in one analysis we used OS on both dental arches, and we excluded subjects with different OS on the maxilla and mandible to emphasize differences across subsamples, and to achieve better discrimination.

Descriptive statistics of measurements and several indices, including mean and standard deviation, were computed for each group. Two-sample t-tests were calculated to compare the means of different groups at a 95% confidence interval. Discrimination between groups was performed by multivariate forward stepwise discriminant analysis based on Mahalanobis distances, using the program Statistica 6.0. Canonical discriminant analysis was used to visualize the patterns of variability in chosen groups and to show the location of each individual case in two-dimensional space of canonical roots. Only elemental variables were used in discriminant analyses to avoid high tolerance. In all statistical calculations casewise deletion of missing data was used.

Results

The average DMFT indexes for both arches ($DMFT_{total}$), for the maxilla ($DMFT_{maxilla}$) and for the mandible ($DMFT_{mandible}$) were found on the models according to WHO methods (Table 1). The average $DMFT_{total} = 3.57 \pm 2.45$ indicates that evidence of caries among young Russian men has a value comparable with that of developed countries such as the United Kingdom, Israel, and Australia (Richardson and McIntyre, 1996; Sgan-Cohen et al., 2000; Hopcraft and Morgan, 2003). 11.11% of subjects were found caries-free and 54.63% had $DMFT_{total} = 3$.

Statistical comparison of groups

Descriptive statistics including mean and standard deviation were computed for each variable. Two-sample t-tests were calculated to compare the means of different groups at a 95% confidence interval. Statistical comparison of the groups is shown in Table 3. Many measurements exhibited statistically significant differences between the groups at $p < 0.05$ level and some of them at $p < 0.01$.

Distribution of cases among the groups is shown in Table 2.

Correlations of measurements

Correlations of measurements are shown in Table 4. Many significant positive and negative correlations were found between measurements and individual OS. Positive correlation means that the variable has a bigger value in the crowded group; negative correlation means that the variable has a bigger value in the spaced group.

High correlations between dimensions of dental arches and cranial measurements (unpublished data) along with moderate correlations between OS and craniofacial measurements are prerequisites for the existence of common growth and development factors for both morphological systems. The

Table 1 Index of caries DMFT

	$DMFT_{maxilla}$	$DMFT_{mandible}$	$DMFT_{total}$
N	111	111	111
Mean $\pm$ SD	1.37 ± 1.41	2.20 ± 1.55	3.57 ± 2.45
Min–Max	0–7	0–7	0–14

Distribution of cases among the groups is shown in Table 2.

Table 2 Frequency of malocclusions (%), N=111

Mandible	Spaced	25.4
	Normal	27.6
	Crowded	47.0
Maxilla	Spaced	38.1
	Normal	32.8
	Crowded	29.1
Both arches have the same feature	Spaced	19.4
	Normal	16.4
	Crowded	20.9
	Cr $\uparrow$ Sp*	14.9

*Spacing on one arch and crowding on another arch

presence of significant correlations of measurements with spacing and crowding, along with significant t-tests between groups, allows us to suppose that associations between patterns of craniofacial architecture and crowding or spacing will be found by discriminant analysis.

Discriminant analysis

Forward stepwise discriminant analysis

Forward stepwise discriminant analysis was performed using all variables to obtain better differentiations between groups. Although Wilk's Lambdas (λ) of standard discriminant analysis were a bit smaller (which affords better discrimination), we used a forward stepwise discriminant analysis to decrease the number of variables in the model. Wilk's Lambdas (λ) of three discriminant analyses are shown in Table 5. All analyses demonstrated highly significant levels of discrimination at $p < 0.001$.

Using the further mentioned variables, 79.7% (2 arches), 61.0% (maxilla) and 68.0% (mandible) of the original grouped cases were correctly classified by each forward stepwise discriminant analysis (Table 6). Table 7 presents constants and Fisher's linear discriminant functions coefficients for all variables used in the models.

Table 8 presents mean values of discriminant analyses canonical variables. The difference of the first root between the centers of groups “spacing” and “norm” is 1.29SD, “spacing” and “crowding” is 2.8 SD, “norm” and “crowding” is 1.51 SD in analysis using the OS of 2 arches (the same on both). The difference of root 1 between the centers of groups “spacing” and “norm” is 1.1 SD, “spacing” and “crowding” is 1.38 SD,

Table 3–1 Descriptive statistics and paired *t*-test comparison of anthropometric measurements between groups with different OS¹

	Using OS of 2 arches together (same status on both)										
Group	1 (Spaced) (N=18)		2 (Normal) (N=16)		3 (Crowded) (N=23)		All (N=111)		Σ (1+2+3) (N=57)		t-test is significant
Measurement	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Age	19.8	1.3	21.3	2.3	19.7	1.6	20.0	2.3	20.2	1.9	
girth of head ²	57.4	0.8	56.4	1.5	56.2	1.3	56.4	1.4	56.6	1.3	1>2*, 1>3**
skin fold on cheek ²	11.3	2.6	9.6	2.3	9.7	2.0	10.1	2.6	10.2	2.3	
head length (g-op) ²	196.8	5.4	191.3	7.1	194.3	6.1	193.2	7.7	194.2	6.4	1>2*
head width (eu-eu) ²	159.6	5.1	158.0	4.0	155.9	5.5	156.9	5.4	157.7	5.2	1>3*
head index ((eu-eu)/(g-op))*100	81.2	4.1	82.7	2.8	80.3	3.8	81.3	3.9	81.3	3.8	
forehead width (ft-ft) ²	113.4	4.3	110.9	4.0	110.1	3.4	110.6	4.2	111.4	4.1	1>3**
max width of eye-sockets (ex-ex) ²	110.5	4.0	111.1	4.5	107.5	4.6	108.1	4.6	109.4	4.6	1>3*
zygomatical diameter (zy-zy) ²	148.0	6.3	145.6	3.9	142.4	4.2	143.5	5.2	145.1	5.4	1>3**
gonial width (go-go) ²	113.9	4.8	111.6	6.1	109.7	5.3	110.1	5.5	111.6	5.6	1>3*
lower jaw length (gn-go) ²	106.7	4.4	104.1	4.3	102.4	4.6	103.9	4.7	104.2	4.7	1>3**
full face height (gn-tr)	182.1	6.5	177.4	7.9	184.0	11.8	182.0	9.4	181.5	9.6	
mophological face height (gn-gl)	124.0	4.6	121.5	6.3	124.7	7.6	124.3	6.0	123.6	6.4	
forehead height (go-tr) ²	58.1	4.9	55.9	7.2	59.2	7.2	57.8	6.7	57.9	6.6	
horizontal face index ((gn-gl)/(zy-zy))*100	83.9	4.3	83.5	4.0	87.6	4.6	86.7	4.3	85.3	4.7	1<3*
nose height (sn-g) ²	55.6	3.4	56.7	3.3	56.1	4.1	56.6	3.6	56.1	3.6	
sagittal nose height (sn-pn) ²	25.0	2.6	25.9	2.9	25.1	2.4	25.2	2.9	25.3	2.6	
upper lip height (ls-sn) ²	16.0	1.5	14.4	1.6	14.4	1.9	14.9	2.0	14.9	1.8	1>2*, 1>3**
medial vertical mandible height (gn-li) ²	34.6	5.3	33.5	3.9	36.7	4.9	35.2	4.3	35.1	4.9	
lips height (ls-li) ²	17.8	2.9	17.0	2.9	17.6	3.4	17.8	3.1	17.5	3.1	
interorbital diameter (en-en) ²	34.9	2.8	35.4	3.0	33.8	2.9	34.4	2.9	34.6	2.9	
pupil-pupil ²	59.4	3.0	60.2	3.2	58.7	3.4	59.1	3.0	59.3	3.2	
nose width (al-al) ²	35.7	2.3	34.7	1.7	33.6	2.4	34.5	2.4	34.6	2.3	1>3**
nose index ((al-al)/(sn-g))*100	64.4	5.8	61.4	4.5	60.3	6.6	61.2	5.8	61.9	6.0	1>3*
mouth width (ch-ch) ²	51.2	2.9	50.8	3.4	49.2	3.1	50.0	3.3	50.3	3.2	1>3*
vertical face index ((gn-gl)/(gn-sn))*100	0.55	0.03	0.53	0.02	0.55	0.03	0.55	0.02	0.55	0.03	1>2*

* $p<0.05$; ** $p<0.01$. ¹ Comparisons of groups at non-significant p -level are not shown in the table.² These variables were later used in discriminant analyses.

Table 3–2 Descriptive statistics and paired *t*-test comparison of anthropometric measurements between groups with different OS¹

Group	Using OS of maxilla separately							Using OS of mandible separately						
	1 (Spaced) (N=51)		2 (Normal) (N=43)		3 Crowded (N=43)		<i>t</i> -test is significant	1 (Spaced) (N=34)		2 (N=36) (Normal)		3 (Crowded) (N=62)		<i>t</i> -test is significant
Measurement	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD	
Age	20.4	2.8	20.1	2.1	19.6	1.8		20.8	3.1	19.8	2.2	19.8	1.9	
girth of head ²	56.9	1.3	56.1	1.5	56.2	1.4	1>3*	57.1	1.1	56.4	1.5	56.1	1.4	1>3**
skin fold on cheek ²	10.7	2.9	10.1	2.5	9.5	2.2		11.1	2.8	9.4	2.3	10.1	2.6	1>2*
head length (g-op) ²	192.9	8.2	193	8	193.9	6.6		195.3	7.1	192.1	8	192.8	7.7	1>3*
head width ² (eu-eu)	158.1	5.5	156.5	4.1	155.6	6.1	1>2*, 1>3**	158.5	4.8	156.2	6	156.4	5.1	
head index ((eu-eu)/(g-op))* 100	82.1	4.3	81.2	3.3	80.3	3.6		81.2	3.8	81.4	4.2	81.2	3.7	
forehead width (ft-ft) ²	111.6	4.8	109.6	3.6	109.9	3.5	1>2*, 1>3*	111.9	4.1	109.7	4	110.2	4.1	
max width of eye- sockets (ex-ex) ²	108.7	3.9	108.3	4.7	106.9	5.1	2>3*, 1>3*	109.4	3.9	107.6	4.8	107.8	4.4	1>3*
zygomatinal diameter (zy-zy) ²	144.5	6.4	143.5	4	142.3	4.7	1>3*	145.7	6.1	142.7	5	142.8	4.7	1>3**
gonial width (go-go) ²	110.4	5.8	110	5.4	109.6	5.4		111.3	5.6	109.1	5.9	110	5.2	
lower jaw length (gn-go) ²	105.1	5	103.6	4.3	102.6	4.5	1>3**	106	4.6	103.2	4.4	103.2	4.7	1>3*
full face height (gn-tr)	182.7	7.8	181	9.5	181.8	11.1	1>2*	182.1	9.7	179.4	8.4	183.2	9.7	
mophological face height (gn-gl)	124.9	5.4	123.7	6.5	124.1	6.3		124.7	5.6	122.3	5.2	125.2	6.5	
forehead height (go-tr) ²	58	5.5	57.4	6.8	57.8	8		57.7	6.5	57.3	7.8	58	6.3	
horizontal face index ((gn-gl)/ (zy-zy))*100	86.5	4.5	86.3	4.6	87.2	3.9	2<3*	85.7	4.9	85.8	4.3	87.7	4	1<3*, 2<3**
nose height (sn-g) ²	56.7	3.8	57	3.2	55.9	3.8		56	3.3	56.6	3.2	56.8	4	
sagittal nose height (sn-pn) ²	25	2.6	25.4	3.1	25	2.6		24.7	2.6	25.4	3.1	25.1	2.7	
upper lip height (ls-sn) ²	15.2	1.9	14.6	1.9	14.8	2.3	1>2*	15.4	1.7	14.8	1.9	14.7	2.2	1>3*, 1>2*
medial vertical mandible height (gn-li) ²	35.1	4	34.7	4.1	35.5	4.7		34.7	4.6	33.4	3.2	36.2	4.3	1<3*, 2<3**

Table 3–2 Descriptive statistics and paired t-test comparison of anthropometric measurements between groups with different OS¹

	Using OS of maxilla separately							Using OS of mandible separately						
Group	1 (Spaced) (N=51)		2 (Normal) (N=43)		3 Crowded) (N=43)		<i>t</i> -test is significant	1 (Spaced) (N=34)		2 (N=36) (Normal)		3 (Crowded) (N=62)		<i>t</i> -test is significant
Measurement	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD	
lips height (ls-li) ²	17.9	2.8	17.5	3.5	17.9	3.2		18.5	3.1	17.4	2.6	17.6	3.4	
interorbital diameter (en-en) ²	34.3	2.5	34.8	3.1	33.8	2.9		34.7	2.7	34	2.8	34.3	3	
pupil-pupil ²	59.2	2.8	59.2	3.3	58.7	3.2		59.3	3.1	59.3	3	58.8	3.1	
nose width (al-al) ²	34.7	2.4	34.8	2.5	33.9	2.2	1>3*	35	2.5	34.7	2.1	34.1	2.4	1>3*, 2>3*
nose index ((al-al)/(sn-g))* 100	61.5	6.4	61.2	5.4	60.6	5.5		62.7	6.2	61.4	4.3	60.2	6.2	1>3**
mouth width (ch-ch) ²	50.4	3.4	50	3.2	49.5	3.1		51.1	3	50	3.3	49.5	3.3	1>3**
vertical face index ((gn-gl)/ (gn-sn))*100	0.55	0.02	0.54	0.02	0.55	0.03		0.55	0.02	0.54	0.02	0.55	0.03	1>2*

* $p < 0.05$; ** $p < 0.01$. ¹ Comparisons of groups at non-significant p -level are not shown in the table.

² These variables were later used in discriminant analyses.

Ågnorm” and “crowding” is 0.37 SD in analysis using the OS of the maxilla. The difference of root 1 between the centers of groups “spacing” and “norm” is 1.14 SD, “spacing” and “crowding” is 2.1 SD, “norm” and “crowding” is 0.96 SD in analysis using the OS of the mandible. The differences of the second root in all analyses ranged from 1.1 SD to 1.39 SD. It describes only from 20.0% to 38.2% of variation and will not be taken into consideration in our paper. Scatterplots of canonical scores of each case are shown in Figs 1, 2, and 3.

Among the measurements, 10 variables were chosen in the model by canonical discriminant analysis using the OS of 2 arches (Table 9). The first root describes 80.0% of total variation and can be morphologically interpreted. In the group “spacing,” girth of head, zygomatic width, nose width, forehead width, gonial width, and height of upper lip are enlarged and combined with slightly reduced medial vertical mandible height. Enlarging of face diameters is observed; this is not due to the tendency of this group to increased development of adipose tissue, but results from increased growth of the skull in the horizontal plane, since the skin fold on the cheek was not chosen for the model by this particular analysis. So here we can see the combination of a wide face with shortened height of the mandible and a higher maxilla.

In the group “crowding,” increased height of the lower jaw and decreased height of the upper lip in combination with a narrow face are marked. In this group, the tendency to higher development of bony tissue of the postcranial skeleton is

presented (unpublished data). This could be an explanation for the observed form of the mandible which is more associated with somatic type of growth within the craniofacial complex. The group “normal” has a well-balanced face. We propose to name this the “harmonious type of face.” Notable is that the normal group has much less intragroup variability in comparison with the spaced or crowded groups (Fig. 1). This may occur due to a better morpho-functional balance of the craniofacial complex of that group as a base for OS.

Ten variables were chosen in the model by canonical discriminant analysis using the OS of the maxilla. The first root describes 61.8% of total variation and has the following interpretation. In the group “spacing,” head width, forehead width, maximum width of eye-sockets, upper lip height, nose width, lower jaw length, and girth of head are enlarged and combined with slightly reduced medial vertical mandible height. We can see almost the same tendency, as in the previous analysis: a wide face with a wide nose and high upper lip is combined with shortened height of the mandible in the spaced group and vice versa in the crowded group.

12 variables were chosen in the model by canonical discriminant analysis using the OS of the mandible. The first root describes 79.0% of total variation. In the group “spacing,” zygomatic width, forehead width, mouth width, upper lip height, girth of head, head length, and lower jaw length are enlarged and combined with slightly reduced medial vertical mandible height. We can see the same tendency, as in two

Table 4 Pearson's correlation coefficients of the measurements with OS, used in discriminant analyses of samples with the same OS on both of the 2 arches, with OS of the maxilla and OS of the mandible

	OS of 2 arches N=57	<i>P</i>	OS of maxilla N=111	<i>P</i>	OS of mandible N=111	<i>P</i>
girth of head ¹	-0.39	0.003	-0.30	0.003	-0.23	0.023
skin fold on cheek ¹	-0.28	0.035	-0.12	0.228	-0.19	0.068
head length (g-op) ¹	-0.15	0.274	-0.20	0.054	-0.01	0.934
head width (eu-eu) ¹	-0.31	0.018	-0.21	0.036	-0.30	0.003
head index ((eu-eu)/(g-op))*100	-0.12	0.385	0.02	0.820	-0.19	0.063
forehead width (ft-ft) ¹	-0.34	0.009	-0.18	0.076	-0.24	0.017
max width of eye-sockets (ex-ex) ¹	-0.29	0.027	-0.21	0.036	-0.21	0.039
zygomatrical diameter (zy-zy) ¹	-0.44	0.001	-0.34	0.001	-0.24	0.018
gonial width (go-go) ¹	-0.32	0.017	-0.14	0.168	-0.19	0.063
lower jaw length (gn-go) ¹	-0.38	0.004	-0.23	0.023	-0.28	0.006
full face height (gn-tr)	0.10	0.451	0.10	0.326	0.03	0.797
mophological face height (gn-gl)	0.06	0.637	0.12	0.235	0.01	0.955
forehead height (go-tr) ¹	0.09	0.527	0.03	0.796	0.03	0.768
horizontal face index ((gn-gl)/(zy-zy))*100	0.35	0.007	0.34	0.001	0.16	0.118
nose height (sn-g) ¹	0.05	0.713	0.13	0.205	-0.04	0.695
sagittal nose height (sn-pn) ¹	0.01	0.958	0.07	0.486	0.04	0.698
upper lip height (ls-sn) ¹	-0.36	0.006	-0.21	0.034	-0.14	0.187
medial vertical mandible height (gn-li) ¹	0.20	0.143	0.26	0.009	0.09	0.363
lips height (ls-li) ¹	-0.02	0.864	-0.16	0.118	0.01	0.925
interorbital diameter (en-en) ¹	-0.16	0.227	-0.05	0.610	-0.12	0.255
pupil-pupil ¹	-0.10	0.442	-0.05	0.640	-0.08	0.414
nose width (al-al) ¹	-0.38	0.000	-0.29	0.004	-0.24	0.016
nose index ((al-al)/(sn-g))*100	-0.29	0.029	-0.28	0.006	-0.14	0.160
mouth width (ch-ch) ¹	-0.28	0.037	-0.25	0.014	-0.03	0.739
vertical face index ((gn-gl)/(gn-sn))*100	0.00	0.985	-0.04	0.682	0.04	0.672

¹ These variables were later used in discriminant analyses; significant correlations are marked in **bold**.

Table 5 Discriminant analyses: Wilk's Lambdas (λ)

Grouping variable:								
OS of 2 arches (the same on both) N=57			OS of maxilla N=97			OS of mandible N=97		
λ	$p<$	F	λ	$p<$	F	λ	$p<$	F
0.29	0.0000	F(20.9)=3.79	0.59	0.0006	F(20.17)=2.55	0.47	0.0000	F(24.17)=3.16

Table 6 Classification results of forward stepwise discriminant analyses

Groups	Original group count	Predicted group membership		
Grouping variable: OS of 2 arches (the same on both)				
	Percentage	Spaced	Normal	Crowded
Spaced	72.2	13	2	3
Normal	76.5	3	13	1
Crowded	87.5	1	2	21
Total	79.7	17	17	25
Grouping variable: OS of maxilla				
	Percentage	Spaced	Normal	Crowded
Spaced	68.4	26	4	8
Normal	56.3	8	18	6
Crowded	56.7	7	6	17
Total	61.0	41	28	31
Grouping variable: OS of mandible				
	Percentage	Spaced	Normal	Crowded
Spaced	66.7	16	4	4
Normal	42.9	4	12	12
Crowded	83.3	4	4	40
Total	68.0	24	20	56

previous analyses, with the addition of a prolonged lower jaw, high nose, and wide mouth. A wide high upper lip is combined with shortened height of the mandible in the spaced group and vice versa in the crowded group.

Discussion

Organisms must be analysed as integrated wholes, with Bauplane so constrained by phyletic heritage, pathways of development and general architecture.

S. Gould and R. Lewontin 1979

Many attempts have been made to find causes of crowding and correlate this condition of dental apparatus with anthropometrical parameters of human jaws, skulls and, much more rarely, body shapes.

The genetic and environmental basis of occlusion variation has been discussed for more than a hundred years. Many theories have been put forth to explain the high prevalence of dental crowding in modern civilized populations. Studies have adopted various methodologies and many contradictory conclusions have been reached.

This could be due to a lack of comprehensive studies on the heterochrony of human skull development and its causes. In our opinion, genetic and environmental aspects of variation can not be easily separated and indicated, as many authors suppose, even using twin data, because many additional hidden factors cannot be observed, estimated, and taken into consideration.

All available studies on the subject were performed using radiograms implicating mostly profile measurements. Another disadvantage of this method is exposure. The rate of subjects' agreement to participate in lateral cephalograms, posterior-anterior skull radiograms, and panoramic films for study purposes is only 41.7% (Johannsdottir et al., 2004). That is why only cephalograms made for treatment purposes are usually available for research. This limits the validity of data because the sample is not randomized and is influenced by health status.

In this study we used a method of anthropometrical measurement which does not share the limitations of radiograms. In our study the rate of refusal to participate was 0.9% (1 of 112 participants). The resulting sample was random and matched by age because it was collected during temporary military service. We used mostly measurements of the frontal plane of the skull; the only 3 measurements were in the sagittal plane (head length (g-op), sagittal nose height (sn-pn), and mandible corpus length (gn-go)). We found that all canonical discriminant analyses accord with each other and the results do not depend on grouping factors and sample size.

Our results and those published previously by Driscoll-

Table 7 Variables in the model and classification discriminant functions

Measurement	Grouping variable								
	OS of 2 arches			OS of maxilla			OS of mandible		
	Spaced	Normal	Crowded	Spaced	Normal	Crowded	Spaced	Normal	Crowded
Zygomatic width (zy-zy)	−2.38	−2.42	−2.54	–	–	–	2.40	2.19	2.07
upper lip height (ls-sn)	3.73	3.05	2.77	5.37	4.98	5.14	5.33	4.89	4.81
medial vertical mandible height (gn-li)	−4.75	−4.64	−4.40	−1.33	−1.30	−1.21	−2.46	−2.37	−2.11
nose width (al-al)	10.65	10.38	9.99	3.36	3.14	3.07	–	–	–
head length (g-op)	−5.01	−5.09	−4.58	−2.06	−2.06	−1.87	−2.58	−2.73	−2.58
girth of head	74.54	74.10	71.79	31.45	31.19	30.27	41.36	42.10	40.94
nose height (sn-g)	2.00	2.13	2.31	–	–	–	1.41	1.56	1.68
interorbital diameter (en-en)	−13.17	−12.65	−12.83	–	–	–	–	–	–
forehead width (ft-ft)	6.10	5.83	5.95	0.69	0.46	0.65	−0.98	−0.91	−0.78
gonial width (go-go)	4.38	4.25	4.21	–	–	–	–	–	–
head width (eu-eu)	–	–	–	4.85	4.70	4.77	–	–	–
max width of eye-sockets (ex-ex)	–	–	–	−0.41	−0.15	−0.37	–	–	–
mandible corpus length (gn-go)	–	–	–	2.33	2.34	2.23	2.80	2.66	2.62
mouth width (ch-ch)	–	–	–	0.63	0.83	0.73	1.17	1.16	0.99
skin fold on cheek	–	–	–	–	–	–	−3.45	−3.67	−3.44
lips height (ls-li)	–	–	–	–	–	–	3.10	2.88	2.91
sagittal nose height (sn-pn)	–	–	–	–	–	–	1.75	1.95	1.92
Constant	−2029.44	−1949.77	−1904.87	−1312.08	−1274.48	−1256.50	−1298.10	−1275.04	−1239.80

–variable is not in the model

Table 8 Means of canonical discriminant analyses canonical variables

Grouping variable:	OS of 2 arches (same on both)		OS of maxilla		OS of mandible	
	Root 1 Mean	Root 2 Mean	Root 1 Mean	Root 2 Mean	Root 1 Mean	Root 2 Mean
Spaced	1.49	0.45	−0.74	−0.14	−1.31	0.37
Normal	0.20	−0.94	0.27	0.67	−0.17	−0.73
Crowded	−1.31	0.30	0.64	−0.49	0.79	0.23

Gilliland et al. (2001) show that changes in lower incisor crowding in adults and adolescents were related to growth in the vertical dimension. What reasons can we presume for the existence of typical face patterns connected to different OS?

We conclude that developing a precise OS is a product of interactions during the ontogenesis of jaw between the time of teeth eruption and growth along two growth fields (alveolar and corpus). Likewise Gould and Lewontin (1979) considered the chin to be a product of interaction between growth of the alveolar processes and the corpus of the mandible. Mostly, previous studies dealt with mandibular crowding, although some growth changes were described for the maxilla.

As previously demonstrated, humans have a growth-maturity gradient across multiple craniofacial measurements, with the most mature components associated with neural growth

Fig. 1 Canonical discriminant analysis of head and face measurements, grouping variable-OS of both dental arches.

Fig. 2 Canonical discriminant analysis of head and face measurements, grouping variable-OS of maxilla.

Fig. 3 Canonical discriminant analysis of head and face measurements, grouping variable-OS of mandible.

(neurocranial), the least mature associated with somatic growth (mandible), and viscerocranial growth falling somewhere between these two. Tanner (1962), Buschang et al. (1983), and Thilander (1995) postulated that the craniofacial complex expresses a continuous pattern of variation in maturity, or differential growth, and called this the craniofacial growth maturity gradient. This variation in maturity is manifest between structures as relative maturity (i.e., percentage of adult status attained) for a particular structure at a given time. In this context, less mature structures would be expected to grow more rapidly at a given time than more mature structures under the factors which affect growth rate and velocity, for example human growth hormone (GH).

Animal studies show that measures (body weight, limb measures, posterior mandible corpus length, ramus height, and nasal length) with the greatest overall absolute and relative growth potential showed the largest response to GH supplementation: i.e., the least mature components had the greatest treatment effects. It was interesting that GH altered the growth rate even in measures presumed to have relatively little response to GH during this time span. In three measures (total mandibular length, ramus height, and posterior neurocranial height), the stimulation was very great, whereas, for the other 2 (anterior mandibular corpus length and occipital length), it was much more modest (Vandeberg et al., 2004; Singleton et al., 2006). Likewise, insults or therapy might produce differing results based on the relative maturity of the structure (Douglas et al., 2005).

Development of dentition is an integral part of craniofacial

growth, even though it is not closely related to other maturational processes. Teeth eruption and dental age seem little affected, while dental maturation does not appear to be influenced by GH. In contrast to skeletal maturation, dental age was not delayed in patients with dwarfism. The general growth retardation is, apparently, reflected to a differential extent within the craniofacial complex, while dental maturation appears to be a distinct process tightly linked to chronological age and independent of general growth, bone age, and GH influence (Van Erum et al., 1997, 1998a 1998b; Haas et al., 2001). Formation and eruption of teeth are processes that are not closely related to general growth. In contrast to dental maturation, bone maturation was delayed in the majority of the studied cases. Low correlations also have been reported between dental and skeletal ages in "normal" subjects (Demirjian et al., 1985; Lewis, 1991).

Here we found an excellent explanation of face pattern connected to crowding: the relatively high medial vertical mandible height (gn-li) in combination with a long and narrow face. We assume that the posterior part of the mandibular corpus and alveolar process, and the mandibular ramus, were affected in more different ways during ontogenesis by human GH than the anterior part of the mandibular corpus and anterior part of the alveolar process in combination with normal changing to permanent dentition in accordance with chronological age. This is confirmed by the study of Corruccini and Potter (1980) who found that the posterior (postcanine) and anterior (canine and incisor) components of the dental arch behave differently from each other. Additional

Table 9 Factor structure of canonical discriminant analyses

Grouping variable	OS of 2 arches		OS of maxilla		OS of mandible	
	Root 1	Root 2	Root 1	Root 2	Root 1	Root 2
zygomatic width (zy-zy)	0.41	−0.02			−0.43	0.09
upper lip height (ls-sn)	0.32	0.40	−0.30	−0.32	−0.26	0.23
medial vertical mandible height (gn-li)	−0.17	0.32	0.10	−0.27	0.31	0.38
nose width (al-al)	0.34	0.01	−0.38	0.21	–	–
head length (g-op)	0.12	0.53	−0.07	−0.28	−0.24	0.26
girth of head	0.34	0.25	−0.42	−0.08	−0.36	0.03
nose height (sn-g)	−0.04	−0.17	–	–	0.16	−0.21
diameter (en-en)	0.14	−0.27	–	–		
forehead width (ft-ft)	0.30	0.19	−0.45	−0.11	−0.22	0.17
gonial width (go-go)	0.27	0.05	–	–	–	–
head width (eu-eu)	–	–	−0.53	0.02	–	–
max width of eye-sockets (ex-ex)	–	–	−0.28	0.43	–	–
mandible corpus length (gn-go)	–	–	−0.44	0.23	−0.28	0.10
mouth width (ch-ch)	–	–	−0.01	0.22	−0.29	−0.20
skin fold on cheek	–	–	–	–	−0.16	0.51
lips height (ls-li)	–	–	–	–	−0.19	0.23
sagittal nose height (sn-pn)	–	–	–	–	0.09	−0.34
variation explained (%)	80.0	20.0	61.8	38.2	79.0	21.0

– variable is not in the model

confirmation is provided by Tata (1976), who reports that in common with other growth-promoting hormones, peptide hormones (including GH) evoke multiple biochemical responses in their target tissues. These can be divided into two groups: (a) rapid effects involving permeability properties of the target cell to amino acids, sugars, and ions or changes in key intracellular metabolites, like cyclic nucleotides; (b) slow responses based on the stimulation of RNA and protein synthesis. He suggests that more than one species of hormone receptor exists and that the final expression of growth and maturation results from the cooperative interaction of rapid and slow responses of the target cell to the hormone (Tata, 1976).

The opposite trait, spacing, may occur in slightly low level GH individuals with sufficient growth of the anterior alveolar component, which is connected with the whole width-directional growth of the face.

GH is thought to begin to influence growth by 9 months of

age in humans. Because GH is known to be a potent stimulator of cartilage-mediated growth, most previous studies have attributed its growth-promoting effects to its action on interstitial growth at cartilaginous growth centers. Although this effect is undoubtedly important, the results of Douglas et al. (2005) suggest that GH also stimulates growth of measures that primarily involve intramembranous or sutural growth. In Van Erum et al.'s (1998) study of craniofacial growth, in GH-treated children born small for gestational age, high-dose GH supplementation over a 2-year period led to significant craniofacial catch-up growth, particularly in posterior total facial height, cranial base length, and overall mandibular length. These measurements also demonstrated an age-dependent effect of the treatment on velocity: i.e., the younger the age, the more pronounced the effect. Craniofacial growth, and particularly growth of the neurocranium, would be affected differently than if therapy began during or before puberty (Van Erum et al., 1998). The other extreme case, acromegaly,

represents an endocrine disease which includes somatic and metabolic disorders secondarily resulting from augmentation of GH secretion after growth cartilages close (in adults). Pituitary gland disease and GH deficiency induce changes in various vital organs. Among them is a change in occlusion. As a result, the craniofacial skeleton has a specific configuration, the mandible is developed to excess and relationships between the maxilla, the mandible, and the skull are strongly modified. These, along with structural bony troubles and bony asymmetries, involve periodontal, muscular, and articular disturbances (Morarasu et al., 1997).

We propose that during the individual's ontogenesis of the jaws a discrepancy between the dental arch size and the sum of mesiodistal diameters of teeth may occur as a result of heterochrony of evolutionary reduction as well as of individual growth or because of the interaction of two. The dependence of the GH effect on relative maturity suggests that different craniofacial morphologies may result depending on the timing of the GH peak during adolescence and its interactions with other hormones such as sex or thyroid hormones. It was confirmed that thyroxin augments the effect of growth hormone on the mandibular condyle just as at other osteogenetic centers, for example the proximal tibial epiphysis (Hoskins and Asling, 1997). Biologically important interrelations exist between GH and sex hormones. They are operative not only at the pituitary and gonadal levels but also in peripheral tissues, where sex hormones modify the metabolic and growth-promoting effects of GH. GH is also important for an optimal androgenic effect of testosterone in the development of secondary sexual characteristics (Zachmann, 1992).

Individual OS may depend on the mechanical forces of the masseter, human GH, and other growth-promoting hormone titers, interactions of hormones during ontogenesis, and individual hormonal profiles, velocity of maturation, and tissue receptor sensitivity to growth-promoting hormones in different parts of the jaws. In other words, the heterochrony may occur between the bone and dental maturation, resulting from some disbalance or disorder in the growing organism. It can also be a mark of the microevolutionary process in contemporary human populations. In modern settings, it is not necessary to perform considerable mastication and may need higher functional loads on the masticatory apparatus to improve its development and balance.

Last, we must draw attention to the fact that the group with both normal dental arches has much less intragroup variability in comparison with groups with spacing on both arches or crowded on both arches (Fig. 1). This may be due to better morpho-functional balance of the craniofacial complex of that group as a base for a good OS. From the other side, the development of spacing or crowding can be the result of heterochrony and different rates of reduction of teeth, alveolar process, and mandibular corpus during phylo- and ontogenesis.

Conclusion

1. Many significant positive and negative correlations were found between craniofacial measurements and individual OS.
2. Many measurements exhibited statistically significant differences between the groups with different OS at the $p < 0.05$ level and some of them—at $p < 0.01$.
3. Using forward stepwise discriminant analysis, a high difference in craniofacial architecture between the groups with different OS was found. Canonical discriminant analysis indicates the face pattern connected to crowding: relatively high medial vertical mandible height in combination with a vertically long and narrow face; and to spacing: a wide face with wide nose and high upper lip is combined with shortened medial vertical mandible height.
4. Depending on the grouping factor, 10 to 12 variables were chosen in the canonical discriminant model. Classification functions and means of canonical roots were calculated; morphological interpretations of canonical roots were performed.
5. Definitive OS is a complicated product of interaction during the individual's ontogenesis of the jaws between the time of teeth eruption and the growth of two growth fields (alveolar and corpus) under the simultaneous influence of hormonal status and the chronological age of the individual. It can be also a mark of microevolutionary processes in contemporary human populations.

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