European Journal of Orthodontics 20 (1998) 35–44

A proportional analysis of some facial height and depth variables in 10 to 16 year old children

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A method for analysing the horizontal and vertical proportions of the face is described, based on natural head orientation (NHO). It demonstrates how individual deviations from the mean proportions can be quantified both horizontally and vertically. Correlation between facial depth to height (index 1) and the mandibular plane angle was determined and found to be fairly strong and highly significant ($r = 0.5$, $P < 0.001$).

Facial depth to height and lower facial height to total facial height (index 2) relationships were found to be strongly correlated at each age between 10 and 16 years, with only small mean differences. For this reason the norm values presented for 12-year-old children for indices 1 and 2 should be applicable to orthodontic patients within this age range. The relationship between mandible and maxilla (index 3) increases continually between 10 and 16 years in boys, and between 10 and 14 years in girls, about 0.3 units a year. It can provide supplementary information for individual case analysis. For boys the increase was 2.2 units per year between 14 and 16 years of age.

Introduction

In an earlier study by Lundström *et al.* (1993) a graphical method was introduced for analysis of the soft tissue profile. The same type of analysis was earlier used for upper to lower tooth-width series in the Bolton sample (Thurow, 1970). The method was based on percentage index quotients, expressing the relationship between pairs of variables, e.g. facial depth and facial height, calculated horizontally or vertically in relation to natural head position (NHP). The same method will be applied to hard tissue variables in the present paper. Proportions to be studied are (1) facial depth to height, (2) lower facial height to total facial height and (3) antero-posterior relationship between lower and upper apical bases. The first and second proportions express facial form as a whole. The antero-posterior relationship between the jaws is of significance for the diagnosis and treatment of a large number of orthodontic patients. In the following report a method will be described that has the advantage of a graphical display, demonstrating in standard units and in millimetres the degree of disproportion for a given patient.

Literature

Variation and age changes of facial proportions have been studied by several authors over the last 70 years. Results relevant to the variables included in the present study have also been published.

One early and comprehensive work on the subject is that of Hellman (1931). In a semi-longitudinal study involving 526 male and 670 female subjects, the change of proportions was determined by direct head measurements. By presenting the percentage ratios of one variable to another and the change of such a ratio over time Hellman demonstrated, among other things, an increase with age of the lower to upper anterior face height, especially for boys. These changes tended to be greatest during the period of puberty.

Goldstein (1936) gathered similar data from a longitudinal study on 50 Jewish boys investigated biannually between 3 and 21 years of age. His findings were very similar to those of Hellman (1931). Brodie (1940, 1953) undertook a cephalometric study of various linear measurements and angles, often referred to in orthodontic practice. He came to the conclusion that a morphogenetic pattern is established early in life and, once attained, does not change. Lande (1952) examined serial records of 34 male subjects aged 4–17 years who had not received any orthodontic treatment. He found that the convexity of the face almost always decreased with age. No correlation was found between the original facial type at 7 years and the growth changes at gnathion from 7 to 17 years. Lundström and Woodside (1983) found that in mandibular horizontal growers there was an upward and forward rotation of the mandible with increasing age. This finding was accompanied by an increase in the sella–nasion–prognathion angle. In vertical growers, the mandible became more retrognathic with increasing age. Sinclair and Little (1985) found that in male subjects the lower anterior face height increased less than the upper between 9 and 13 years. This pattern was, however, reversed in the period 13–20 years. In females the lower face height increased slightly and continuously during the growth period.

Several studies have presented comprehensive data about means of cephalometric variables on a yearly basis. In some of these annual increments have also been presented. It is possible to calculate comparable differences of increments between two variables which make up a proportion by means of a formula used by Nanda (1955). Bhatia and Leighton (1993) have measured a number of proportions of height and depth at yearly stages as part of a longitudinal cephalometric study from 4 to 20 years. In all they present seven height and six depth variables. One of the mean ratios corresponds closely with index 2 of the present study, lower facial height to total face height.

It seems appropriate to extend our knowledge on standards and proportional changes with age of male and female faces during childhood and adulthood. The aims of this study were: (i) to calculate means and standard deviations for 12-year-old children for three facial indices based on natural head orientation (NHO) (Lundström *et al.*, 1995): (1) facial depth to height, (2) lower facial height to total facial height and (3) horizontal lower to upper apical base relationship; (ii) to present diagrams illustrating indices 1 and 3, from which individual subjects with malocclusion can be analysed with regard to horizontal and vertical deviations from mean index norms; (iii) to correlate mandibular plane inclination with ratio of facial depth to height (index 1); and (iv) to calculate means and standard deviations of indices 1–3 at 10, 14 and 16 years, and correlations within subjects between 10 and 14 as well as between 14 and 16 years.

Samples

For the study two samples have been used.

1. Cephalometric tracings of profile radiographs of 80 non-selected 12-year-old children (40 boys and 40 girls) of British parents, living in Hong Kong (M. Cooke collection). On the tracings commonly used cephalometric landmarks were marked. Radiographs were taken with subjects in natural head position (NHP) and with a plumbline to indicate the vertical plane (study 1).
2. Cephalometric tracings of 23 boys and 22 girls at approximately 10, 14 and 16 years, randomly selected from orthodontically untreated children in the collections of B.C. Leighton, King's College University, London, and P. Adams, Queen's University, Belfast (study 2).

Method

Study 1

As described in an earlier paper (Lundström and Lundström, 1995) some NHP registrations demonstrated a head position judged to be flexed in a way unsuitable for cephalometric assessment. For this reason two of the authors (A.L. and F.L.) checked together every tracing and reorientated them, if so indicated, into what was defined as NHO. The plumbline was then supplemented with a new vertical line drawn on the tracing. NHO was defined 'as the head orientation of the subject perceived by the clinician, based on general experience, as the natural head position in a standing relaxed body and head posture, when the subject is looking at a distant point at eye level' (Lundström *et al.*, 1995).

Measurements shown in Figure 1 were taken and used for calculation of three indices:

1. Facial depth to facial height: [(S–Pg)/(N–Me)] × 100.
2. Lower facial height to total facial height: [(Sp–Me)/(N–Me)] × 100.
3. Facial depth (B) to facial depth (A): [(S–B)/(S–A)] × 100.

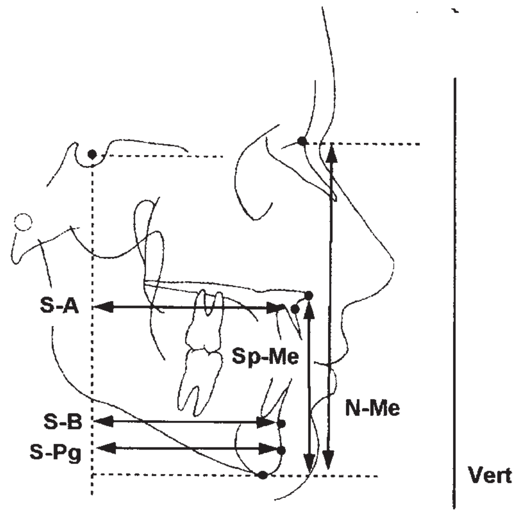

Figure 1 Horizontal and vertical measurements used for calculation of indices 1, 2 and 3, expressing facial form and antero-posterior apical base relationship.

Means and standard deviations were calculated for the three indices as well as for distances (corrected for enlargement to true values), from which the indices were calculated. The ranges of variation for these indices were also determined.

In addition, the mandibular plane inclination (ML/HOR) was included because of its significance in connection with vertical facial variation.

For patients to be analysed the following procedure for NHP registration is recommended. The patient is photographed in profile in a standing, relaxed position, looking into his or her own eyes in a vertical mirror (30 × 40 cm) at a distance of about 2 meters. The camera is positioned at right angles to the patient's mid-sagittal plane with the centre of the picture close to the porion area. A vertical chain in front of the face is registered in the photograph. To ensure a true vertical line it is recommended that the chain is fixed by a coil spring combination attached to the ceiling and to the floor. This ensures that the vertical chain is always fully stretched. A duplicate NHP photograph is strongly recommended, as a means of eliminating gross errors in head positioning. After evaluation of the photographs, the NHO position is established for the subject. A previous study (Lundström and Lundström, 1992) has shown that some individuals tend to be repeatedly flexed during registrations of NHP, keeping their head in a position clearly unsuitable for a cephalometric analysis. In such instances a correction has to be made to the NHO by a trained clinician or auxiliary person. A selected sample of profile photographs, orientated in NHO (by experienced assessors) should be a valuable asset for such training.

If a correction of registered NHP is indicated, a rectangular piece of cardboard with a circular hole (20 cm in diameter) is used. This is positioned over a soft tissue profile tracing, which is turned into a position of NHO satisfaction relative to the right side of the cardboard piece, representing the vertical plane. One upper and one lower cross at the same distance from the vertical side are marked on the tracing. The line connecting the crosses is used as the true vertical on the tracing (Figure 2).

The angle between the vertical and the soft tissue facial plane (N′–Pg′) is then calculated. This angle is used to supply the tracing of the profile cephalogram with a vertical, and at right angles thereto a horizontal line through sella (for details see Lundström and Lundström, 1989).

Study 2

In study 2 the 14-year tracings were NHO-orientated within a rectangular opening (16 × 20

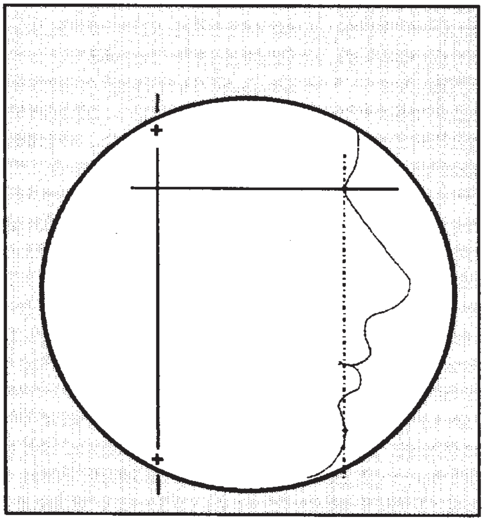

Figure 2 Method for assessing and registration of natural head orientation. A rectangular piece of coloured cardboard with a circular or square hole is used. A profile photograph or soft tissue tracing is placed under the cardboard and rotated to a position estimated as the natural head orientation, with the right side of the cardboard representing the vertical plane. The vertical plane is marked on the profile photograph or tracing and transferred to the profile radiograph by the angle between the soft tissue nasion–pogonion line and the vertical.

cm) cut out of a larger piece of cardboard with the right side representing the vertical plane. Along the left side of the opening a pencil line was drawn on the tracing. Horizontal and vertical dimensions, shown in Figure 1, were measured and index values 1, 2 and 3 calculated. The vertical line for the 10- and 16-year tracings were obtained from the 14-year tracing through superimposition on the anterior cranial base and subsequent transfer of the vertical line.

Results

Study 1

Variability of indices and distances are presented in Tables 1 and 2.

Table 1 Means ($\bar{x}$), standard errors of means (SEM), standard deviations (SD) and ranges of variation at 12 years for three indices expressing facial height and depth relationships (n = 80, 40 boys and 40 girls)

Index	Sex	$\bar{x}$ ± SEM	SD	
S–Pg/N–Me	boys	55.4 ± 0.7	4.2	46.4–63.9
	girls	54.2 ± 0.7	4.3	44.8–62.9
Sp–Me/N–Me	boys	55.4 ± 0.5	3.4	49.1–64.1
	girls	54.5 ± 0.4	2.3	50.0–58.8
S–B/S–A	boys	89.0 ± 0.5	3.4	79.2–94.6
	girls	89.5 ± 0.6	3.8	82.0–96.0

Table 2 Means ($\bar{x}$), standard errors of the mean (SEM), and standard deviation (SD) at 12 years for distances in millimetres used for indices 1–3: inclination of mandibular plane (in degrees)

Variable	Boys (n = 40)		Girls (n = 40)	
	$\bar{x}$ ± SEM	SD	$\bar{x}$ ± SEM	SD
S–Pg	57.8 ± 0.7	4.7	55.1 ± 0.6	3.9
N–Me	104.7 ± 1.0	6.5	102.9 ± 0.8	5.5
Sp–Me	58.1 ± 0.8	5.0	56.0 ± 0.7	4.6
S–A	63.5 ± 0.6	3.6	61.4 ± 0.5	3.7
S–B	56.5 ± 0.7	4.4	54.9 ± 0.6	3.3
ML/HOR	25.7 ± 0.7	4.3	24.8 ± 0.7	4.7

Graphical display. Results regarding indices 1 and 3 are displayed in four graphs (Figures 3 and 5 for boys and Figures 4 and 6 for girls).

The analysis of an orthodontic patient is explained in Figure 5. The individual's S–A and S–B true (corrected for enlargement) distances are plotted in the diagram. The degree of deviation from mean values can thereby easily be quantified for S–A, S–B and also for the index [(S–B)/(S–A) × 100)]. The dotted lines on the graph represent two standard deviation differences from the mean index values.

If a correction of the A/B relationship is considered, the amount of change necessary to achieve a mean index can be obtained in millimetres from distances between the patient coordinates and the mean index line in the diagram, either horizontally for S–A or vertically for S–B, or in a combined way for both distances (Figure 5).

Variation of the mandibular plane inclination was considerable, with a standard deviation of 4.3 degrees in boys and 4.7 degrees in girls (Table 2).

The association between the slope of mandibular plane and index 1 (facial depth to height) was confirmed by correlation coefficients

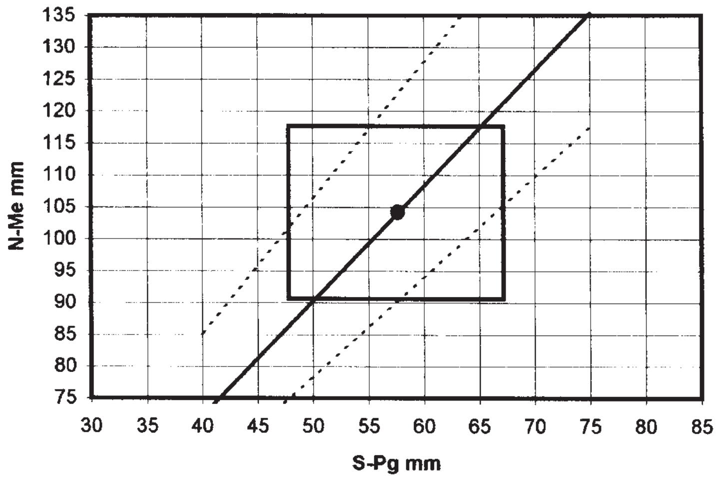

Figure 3 Graph demonstrating mean relationship (index 1) between facial depth and height in millimetres [(S–Pg)/(N–Me) × 100] for 40 12-year-old boys. Dotted lines represent +2 SD deviations from the mean index. The central rectangle illustrates ±2 SD for the S–Pg and N–Me measurements respectively.

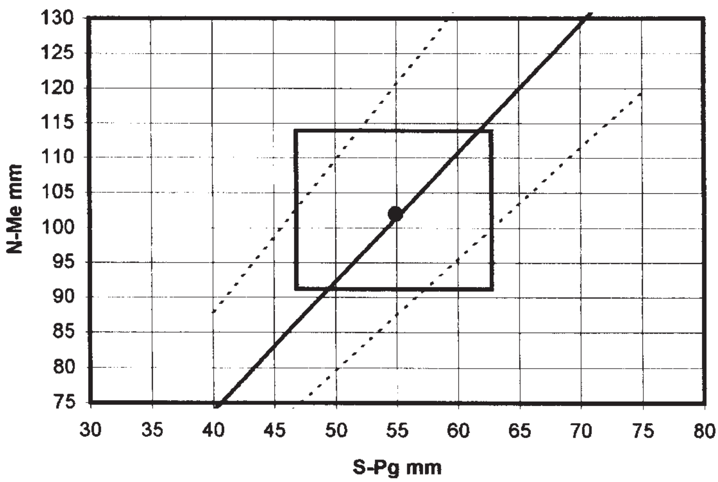

Figure 4 Same as Figure 2 for 40 12- year-old girls.

(Bravais–Pearson) of $r = 0.53$ in boys and $r = 0.55$ in girls ($P < 0.001$ for both).

Study 2

If standards determined for 12-year-olds are to be applicable to patients younger or older than that age, three conditions must be fulfilled.

1. Mean proportions concerned do not change with age.
2. The variability of proportions does not increase or decrease with age.
3. Covariation of facial proportions between relevant ages is strong, showing stability of growth patterns.

This study was designed to determine whether these preconditions were true.

Results

In Table 3 and Figures 7–9 mean indices and standard deviations are presented.

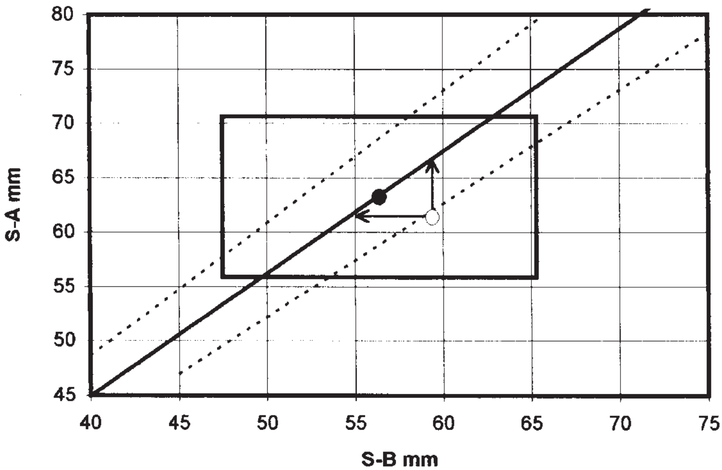

Figure 5 Graph demonstrating mean relationship between antero-posterior distances in millimetres from sella to points A and B [(S–B)/(S–A) × 100] for 40 12-year-old boys. Dotted lines represent ±2 SD deviation differences from the mean index. The most extreme subject in the sample is plotted in the diagram. The deviation (in millinetres) between his A and B distances and the mean index line are also demonstrated.

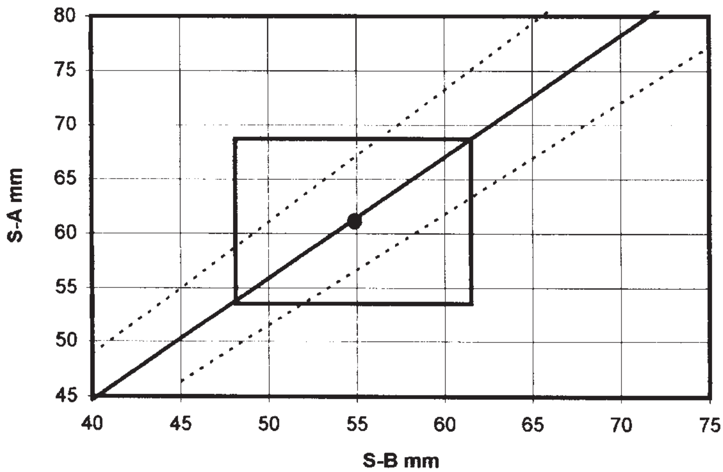

Figure 6 Same as Figure 5 for 40 12-year-old girls.

Index 1

Facial depth to height was found to increase by 0.9 index units in boys and 1.6 index units in girls from 10 to 16 years. The main changes occurred between the ages of 10 and 14. For all three age stages the index means were somewhat larger for boys than girls.

Covariation was determined through correlation coefficients between age stages. They were found to vary from $r = 0.76$ to $r = 0.90$ (Table 4).

Index 2

Lower facial height to total facial height did not change between 10 and 14 years, but changed to a small extent between 14 and 16 years. Correlation coefficients between ages varied from 0.70 to 0.90 (Table 4.)

Index 3

Apical base relationship showed more anterior growth in the mandible than in the maxilla. In

Table 3 Means ($\overline{x}$), and standard deviations (SD) for indices 1, 2 and 3 for boys (n = 23) and girls (n = 22) at 10, 14 and 16 years

Age	Index 1		Index 2		Index 3	
	$\overline{x}$	SD	$\overline{x}$	SD	$\overline{x}$	SD
Boys						
10	52.3	5.7	54.2	2.0	88.1	4.6
14	53.6	5.0	54.3	2.4	90.0	4.9
16	53.2	6.2	55.0	2.1	91.0	5.8
Girls						
10	50.7	4.5	53.2	1.3	87.9	3.6
14	51.9	4.8	53.4	1.8	90.4	3.8
16	52.3	4.7	53.8	1.8	90.6	3.7

Table 4 Correlation coefficients for covariation between age-stages for indices 1, 2 and 3 (study 2)

Sample	10/14 years	14/16 years
Index 1 (facial depth/ facial height)		
Boys	0.82	0.88
Girls	0.76	0.90
Index 2 (lower facial height/total facial height)		
Boys	0.83	0.70
Girls	0.78	0.90
Index 3 (antero-posterior apical base relationship, mandible/maxilla)		
Boys	0.80	0.82
Girls	0.61	0.86

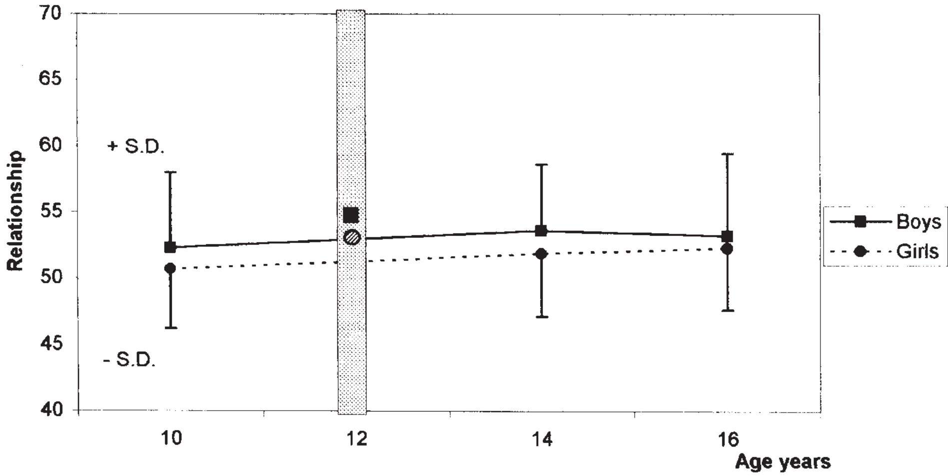

Figure 7 Index 1. Means and standard deviations for facial depth to height in boys and girls at 10, 14 and 16 years. For boys the positive SD is presented and for girls the negative. Corresponding values at 12 years from study 1 are added for comparison.

total from 10 to 16 years the index change was 2.9 units for boys and 2.7 units for girls (Table 3). Correlation coefficients varied from 0.61 to 0.86 (Table 4).

Discussion

Natural head position has gained an increasing interest as a basic reference in orthodontics (Moorrees, 1995). There are, however, few studies presenting cephalometric norm values based on this concept. Houston (1991) stated that 'Clearly is it desirable that norms for different population groups are obtained from radiographs taken in NHP.' One such study was presented by Lundström and Lundström (1989) for the angles nasion–A-point and nasion–B-point to the horizontal plane in NHP, and another by Cooke and Wei (1988) for five cephalometric variables. The present study adds to such knowledge by data for some facial proportions.

The method described depends on the reliability of the NHO assessments for calculation of norm values as well as individual patient determinations. Reproducibility regarding such

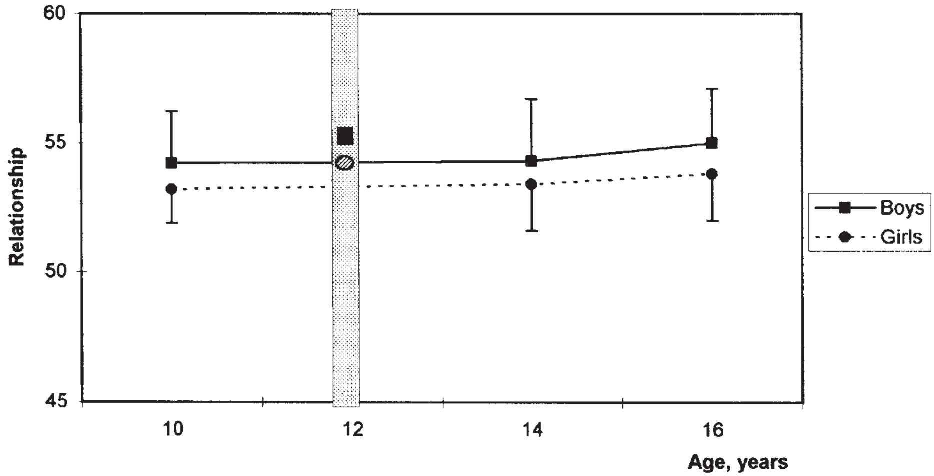

Figure 8 Index 2. Means and standard deviations for lower facial height to total facial height in boys and girls at 10, 14 and 16 years.

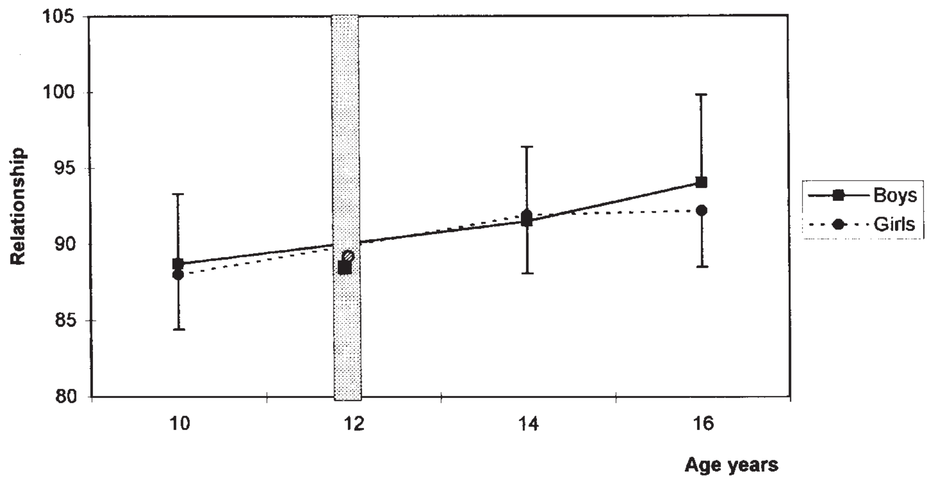

Figure 9 Index 3. Means and standard deviations for lower apical base to upper apical base relationship in boys and girls at 10, 14 and 16 years.

assessments was analysed in two previous investigations (Lundström and Lundström, 1995; Lundström *et al.*, 1995) and found to be acceptable. NHO positioning of circularly cut photographs performed independently by authors C.F.A.M. and AL were found to be highly correlated ($r = 0.96$, with a mean difference of 1.3 degrees), a finding indicating reliability of the method used for this investigation.

Moorrees and Kean (1958) determined NHP for senior students in the same way as in the present study, i.e. through a combination of registrations and correction of the head position when indicated.

Duplicate assessments by Bass (1991) of the 'aesthetic position' of the head is an evaluation closely related to the NHO concept of this paper and resulted in a method error of ±1.4 degrees. An error of that magnitude does not invalidate the use of NHO as a basis for cephalometry but emphasizes the need for caution in clinical applications of the method.

It should be stressed that the proportional analysis described is intended as a diagnostic tool. Individual treatment goals depend on a comprehensive evaluation of the complete history of the patient. What is analysed is the facial character of the subject under consideration, with index 1 to assess if he or she has a long or short face, index 2 for lower facial height to total facial height, and index 3 for the antero-posterior apical base relationship. Such information should be of use to assist in making choices between possible treatment alternatives.

The correlation between facial depth to height (index 1) and the mandibular plane angle (r = 0.53 for boys and r = 0.55 for girls) was highly significant ($P < 0.001$), but not strong. Coefficients of determination (r^2) of 0.28 and 0.30 respectively, indicate that some 30 per cent of the variation in mandibular plane angle can be explained by the variation of index 1.

This proportional analysis can also be used for the evaluation of treatment results, when this has been given with the purpose of reducing facial disharmony. Such comparisons should use the NHO registration of the pre-treatment cephalogram, with the skull base transferred to the post-treatment cephalogram, in order to reduce the error component. Possible growth changes must also be considered if the treatment time has not been short.

In study 2 the material from London and Belfast represented corresponding patient selection and was therefore grouped together for further analysis. It showed a small increase with age for index 1 of 0.3 units per year from 10 to 14 years in boys as well as girls. From 14 to 16 years there was no corresponding increase (Figure 7). Index 2 showed only small changes during the period 10 to 16 years (Figure 8). The apical base relationship, index 3, showed an annual increase of 0.3 units from 10 to 16 years in boys and from 10 to 14 years in girls. For boys the increase was 1.2 units per year between 14 and 16 years (Figure 9). For patients aged 10–16 years the standards for 12 years (study 1) thus seem to be relevant, with a possibility of correction according to age. An investigation on a larger sample would be desirable for confirmation of these findings.

It might be asked whether it is possible to instruct the patient before the photographic registration to keep the head in NHO, so that the subsequent correction need not be used. To reach such precision requires experience and assumes that the operator is completely familiar with the NHO concept and is thus able to instruct the patient to maintain correct head orientation at the moment of film exposure. Such a procedure would, however, seem to be more subjective than the one recommended above.

To register head position in a cephalostat may be difficult due to the disturbing influence a cephalostat has on a relaxed head orientation. Siersbæk-Nielsen and Solow (1982) have, however, shown that the method is able to give good and repeatable registrations of NHP. In combination with an NHO evaluation and necessary correction of the head position registration, this method might be an alternative.

The method used by Bass (1991) with fixation to the cheek of a horizontally levelled metal rod, before taking the cephalogram, requires special operator training to avoid accidental and systematic errors. It is, furthermore, dependent on the same NHO assessment as in our method.

The results presented in Tables 1 and 2 are representative for 12-year-old children. Indices 1 and 2 should be useful for diagnoses of facial height/depth abnormality for the orthodontic patients in the age range of 10–16 years. The apical base relationship was found to be less stable for girls between 10 and 14. It is possible that difficulty in locating point A, in particular, might explain, in part at least, the lack of stability of index 3. Another difficulty is the skull base identification for transferring the true vertical to new cephalograms. In some instances the subtraction method desribed by McWilliam (1982) might be of value.

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Acknowledgement

We express our gratitude to Michael S. Cooke at the University of Hong Kong for permitting us to use copies of his cephalometric tracings for this study.

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