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Growth prediction in Class III patients using cluster and discriminant function analysis

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SUMMARY This longitudinal retrospective cephalometric study was undertaken in an attempt to identify subgroups of subjects with Class III malocclusions and to find discriminant functions which would help to differentiate between favourable and unfavourable growers. The material consisted of cephalometric films of 115 Class III untreated patients (59 females and 56 males, with a mean age of 11.6 ± 1.7 and 12.7 ± 1.3 years, respectively) who were observed for a minimum period of 1 year. All subjects were Caucasian and none could achieve an edge to edge occlusion. Hierarchical cluster analysis was used to identify Class III subgroups. Discriminant function analysis (DFA) was first applied to the whole sample and later to each of the clusters produced. Good and poor growers were identified on the basis of the change in Wits measurements with projection on the maxillary/mandibular planes bisector. The cut-off point between good and bad growers was a Wits value of 2.5 mm which was the upper limit of the 95 per cent confidence interval of measurement reproducibility.

Three clinically distinguishable clusters were produced, namely long, short and intermediate facial types. The discrimination percentage (80 per cent) achieved when the DFA was performed on the whole sample was satisfactory. However, when the analysis was used on each of the clusters separately, the equation successfully predicted a good or poor outcome in 92 per cent of cluster I, in 85 per cent of cluster II and in 100 per cent of cluster III.

Introduction

Because the direction and amount of mandibular growth affects both treatment planning and treatment results, a method of predicting mandibular growth would be of great value (Björk, 1963; Lundström and Woodside, 1980). Growth prediction is difficult due to great individuality in craniofacial growth. It should ideally describe the sagittal and vertical intermaxillary relationships at the end of the growth period on the basis of the morphological features at any time during the growth period, and should also estimate the intensity and timing of growth, variation in direction and the ultimate size (Ari-Viro and Wisth, 1983).

Many attempts to predict growth have been reported. These have used family resemblance (Wasson, 1963; Nakata *et al.*, 1973; Harris, 1975; Harris *et al.*, 1975; Harris and Kowalski, 1976; Popovich *et al.*, 1977), appropriate mean changes added to existing variables (Ricketts, 1957, 1972; Hixon, 1968; Broadbent *et al.*, 1975; Johnston, 1975; Schulhof and Bagha, 1975; Popovich *et al.*, 1977), and individualized prediction. Individualized prediction has involved the use of present size to predict future growth (Björk and Palling, 1955; Maj and Luzi, 1964; Björk, 1969; Ödegaard, 1970), the relationships between growth changes (Harvold, 1963; Mereditch, 1965; Björk, 1969; Björk and Skieller, 1972; Bjorn-Jorgensen, 1983) or multiple correlation (Johnston, 1968; Balbach, 1969; Bhatia *et al.*, 1979; Skieller *et al.*, 1984). The computerized growth prediction method used appropriate mean changes added to existing variables (Ricketts, 1972). Some authors have stated that growth prediction according to this method was pattern extension rather than prediction (Johnston, 1968; Schulhof *et al.*, 1977) and that it was often unsatisfactory in Class III cases.

Björk (1969) described a structural method for individualized growth prediction based on information concerning remodelling of the mandible during growth, gained from implant studies (Björk, 1963). He suggested seven structural signs of extreme growth rotation in relation to condylar growth direction: inclination of the condylar head, curvature of the mandibular canal, the shape of the lower border of the mandible, inclination of the symphysis, interincisal angle, interpremolar or intermolar angles and lower anterior face height.

There are studies suggesting that both head posture and cervico-vertebral anatomy are associated with craniofacial growth (Huggare, 1989, 1991; Huggare and Cooke, 1994) but the significance found by combining variables of cervico-vertebral anatomy and head posture is too low to form any definite conclusions about future mandibular growth in an individual case (Huggare and Cooke, 1994).

Björk and Skieller (1972) found a qualitative relationship between the direction of mandibular and maxillary growth rotation during 3 years before and 3 years after the pubertal growth spurt, but only in extreme cases. Bjorn-Jorgensen (1983) developed a computerized system for short-range facial growth prediction and treatment planning based on longitudinal observations of individual growth rate and growth direction over one or more years.

A multivariate regression method for growth prediction was applied by Johnston (1968). He found that the multiple regression equation provided confidence intervals which were about 30 per cent smaller than those obtained from the next most accurate method of prediction. Bhatia *et al.* (1979) attempted growth prediction using cluster analysis of serial radiographs. However, the results indicated that a particular cluster membership at 9 years 6 months was a poor predictor of cluster membership at 17 years 6 months. Skieller *et al.* (1984) attempted to predict the direction and the amount of mandibular growth rotation from an implant study. Using only four variables gave a prognostic estimate of 86 per cent.

Discriminant function analysis (DFA) is the statistical technique used to derive an equation which will distinguish one group of subjects from another and in the present context to distinguish between poor and good growers. Linear combinations of the independent, sometimes called the predictor, variables are formed and serve as the basis for classifying cases into one of the groups. The DFA yields an equation similar to that obtained using multiple linear regression:

$$D = \mathrm{C} + B_1X_1 + B_2X_2 + ... + B_pX_p$$

where D is the discriminant score, C is a constant, $B_1 – B_p$ are discriminant function coefficients estimated from the data and $X_1 – X_p$ are values of the independent variables.

Hierarchical cluster analysis is a procedure which attempts to identify relatively homogeneous groups of cases based on selected characteristics, using an algorithm that starts with each case in a separate cluster and combines clusters until all cases are in one cluster. The resulting clusters are represented graphically as a ‘linkage tree’ or ‘dendrogram’ (Norusis, 1986).

The deterioration which occurs with growth in many Class III patients is the clinical problem considered in this investigation. The aim of the study was to use DFA to differentiate between the two categories on an individual basis. Taking into consideration that subgroups of subjects with a Class III malocclusion have been said to exist (McCallin, 1955) and in an attempt to derive more accurate discriminant equations, cluster analysis was applied to Class III material first and the DFA was carried out separately on each of the clusters produced.

Material

The sample comprised 115 subjects (59 females and 56 males) referred to the Orthodontic Department of the Belfast Dental School. Cephalometric radiographs were taken initially for analysis of tooth position and facial form and subsequently for facial growth. All subjects had a skeletal Class III base (ANB° ≤ 0) and none could achieve an edge to edge incisor relationship. Two radiographs separated by a minimum observation period of 12 months were available for each subject. The second radiographs were taken to determine growth direction. The cephalometric radiographs were taken with the posterior teeth in maximum intercuspation using the same cephalostat and fixed anode–mid-sagittal plane distance. The average age at initial presentation was 11.6 ± 1.7 years for females and 12.7 ± 1.3 years for males. No orthodontic treatment was carried out during the period of observation, which averaged 3.7 ± 1.9 years.

Methods

All lateral skull radiographs were traced manually on acetate material using a 7H pencil. No more than six radiographs were traced in any 1 hour to reduce operator fatigue. A horizontal line was defined at 7 degrees below the sella–nasion line, intersecting at sella. Thirty-four hard and soft tissue landmarks were identified either by inspection or construction, yielding 60 measurements (41 linear, 18 angular and one proportional). Definitions of the points and measurements are shown in Figure 1. The films were digitized by one investigator (ESJAA) using an SSi/Microcad Lightmaster backlit digitizing system (SSi/Microcad, Pewsey, Wiltshire, UK) with a GTCO T5 16 button Clearvu cursor (GTCO Corporation, Columbia, Maryland, USA) connected to an IBM-compatible computer (Research Machines Ltd, Oxford, UK) using a cephalometric program written in GeLa (Gordon, 1994). The output file from GeLa was then converted into comma delimited form using an ‘awk’ script and read in Excel Version 5.0 where the initial analyses were carried out. All films were retraced after a minimum period of 2 weeks and the mean values of the two measurements used for the major analyses.

Deterioration was measured by changes in the Wits measurement between the first and second films and was taken as an increase in the negative value of Wits. Any distinction between patients who grow favourably and those who do not is inevitably arbitrary in the clinical sense and the precise cut-off point will vary between clinicians. Statistically, the choice between ‘good’ and ‘bad’ growers must take into account the errors in reading measurements. Accordingly, the distinction between favourable and unfavourable growth was set at the upper 95 per cent confidence interval of the standard error of measurements as recommended by Bland (1987). Thus, there was a 95 per cent certainty that any deterioration detected was a true deterioration and not due to measurement error.

The Class III sample was divided into bad and good growers according to the Wits measurement with

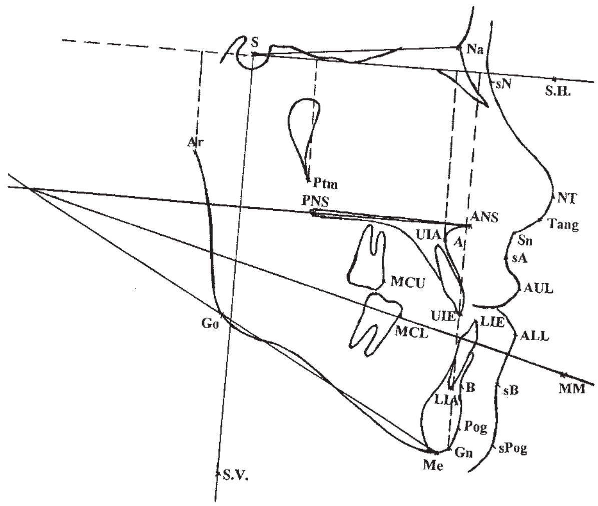

Figure 1 Definition of points and measurements used for the cephalometric analysis. S, sella; N, nasion; Ar, articulare; ANS, anterior nasal spine; PNS, posterior nasal spine, point A; Ptm, pterygomaxillary fissure, point B; Pog, pogonion; Me, menton; Gn, gnathion; go, gonion; S.H., a point located on sella horizontal line; S.V., a point located on sella vertical line; Arp, projected articulare on sella horizontal; Ap, projected point A on sella horizontal; Ptmp, projected pterygomaxillary fissure on sella horizontal; Gnp, projected gnathion on sella horizontal; UIE, midpoint of upper central incisor edge; UIA, apex of upper incisor; LIE, midpoint of lower central incisor edge; LIA, apex of lower central incisor; MCU, mesial contact of upper first molar; MCL, mesial contact of lower first molar; MM, a point located on maxillary/mandibular planes angle; sN, soft tissue nasion; NT, most anterior point of nose tip; Tang, most anterior point on columella of nose; Sn, the point at which nasal septum merges with upper cutaneous lip; sA, soft tissue point A; AUL, most anterior point of upper lip; ALL, most anterior point of lower lip; sB, soft tissue point B; sPog, soft tissue pogonion. Lines and planes: sella–nasion line; maxillary plane; mandibular plane; sella vertical: vertical line through sella, perpendicular to a horizontal 7 degrees below sella–nasion line; sella horizontal: horizontal line through sella 7 degrees below sella–nasion line. Measurements: conventional skeletal and dental measurements were used in addition to: SPA, sella–PNS–ANS; AV, perpendicular distance from point A to sella vertical; PH, perpendicular distance from PNS to sella horizontal; AH, perpendicular distance from ANS to sella horizontal; BV, perpendicular distance from point B to sella vertical; ArH, perpendicular distance from articulare to sella horizontal; GoH, perpendicular distance from gonion to sella horizontal; MeH, perpendicular distance from menton to sella horizontal; SAB, sella–point A–point B; Wits, distance between a perpendicular from point A and point B on maxillary/mandibular planes bisector; ABH, distance between projected point A and point B on sella horizontal; AGoV, distance between projected ANS and gonion on sella vertical; AMeV, distance between projected ANS and menton on sella vertical; LiV, perpendicular distance from lower incisor edge to sella vertical; LiH, perpendicular distance from lower incisor edge to sella horizontal; UiV, perpendicular distance from upper incisor edge to sella vertical; UiH, perpendicular distance from upper incisor edge to sella horizontal; LMV, perpendicular distance from mesial contact of lower molar to sella vertical; LMH, perpendicular distance from mesial contact of lower molar to sella horizontal; UMV, perpendicular distance from mesial contact of upper molar to sella vertical; UMH, perpendicular distance from mesial contact of upper molar to sella horizontal. Soft tissue measurements: AUST, AUL–Sn–Tang; NNP, sN–NT–sPog; NAP, sN–sA–sPog; NV, perpendicular distance from NT to sella vertical; sAV, perpendicular distance from point sA to sella vertical; AUV, perpendicular distance from AUL to sella vertical; ALV, perpendicular distance from ALL to sella vertical; sBV, perpendicular distance from sB to sella vertical; sPV, perpendicular distance from sPog to sella vertical; sPH, perpendicular distance from sPog to sella horizontal; NH, perpendicular distance from NT to sella horizontal.

projection on the maxillary/mandibular planes angle bisector (Hall-Scott, 1994) and comparisons were drawn between measurements made on the initial radiographs.

Method error

Tracings were made and listed in random order. Thirty consecutive tracings spanning the middle of the list were chosen and the method error between the replicate tracings was calculated, as recommended by Dahlberg (1940) and Houston (1983). The Dahlberg formula is $\sqrt{(\Sigma d^2/2n)}$ where d = difference between the two measurements and n = number of radiographs digitized. A one sample *t*-test was applied to detect any systematic errors. A coefficient of reliability was calculated to evaluate the contribution of random errors. The formula used was (BMS – WMS)/(BMS + WMS) where BMS is the between-measurements variance and WMS is the within-measurements variance (Fleiss, 1986). This is similar to the coefficient of reliability quoted by Houston (1983). A one sample *t*-test revealed no systematic errors. The Dahlberg errors varied between 4.3 mm for sPH and 0.4 mm for overjet and from 4.5 degrees for nasolabial angle (AUST) and 0.6 degrees for SNB. The coefficient of reliability ranged from 85 per cent for SPA to 100.0 per cent for facial proportions, with only one value below 90 per cent.

Statistical analysis

The data from the first radiographs were analysed using SPSS Windows Version 6.0 Package program (Chicago, Illinois, USA). Hierarchical cluster analysis was carried out using all the 60 variables, applying the Ward method (Norusis, 1986). Analysis of variance (one-way ANOVA) was used to identify the characteristics of the clusters. The significance levels obtained in the analysis were only used to provide an indication of how the groups differed.

The stepwise discriminant analysis using the method of Wilks (Norusis, 1986) was first applied to the whole sample and later to each of the clusters produced to identify the variables that separate bad and good growers. The first variable to be selected is the one with the smallest value of Wilks' lambda, where lambda is the ratio of the within-group sum of squares divided by the total sum of squares. A lambda of 1 occurs when all observed group means are equal. A large value of Wilks' lambda indicates that the group means do not appear to be different and a small value that group means do appear to be different. Subsequent variables are chosen by the recalculation of lambda for each of the remaining variables and the variable giving the largest change in Wilks' lambda is selected, provided this change is significant when assessed using the *F*-test. The *F*-test criterion was set at 3.84. This corresponds to significance at the 5 per cent level. After each new variable is added to the discriminant function, the variables already included in the function are re-assessed and are dropped from the function if the *F*-test criterion is no longer satisfied (i.e. if they no longer contribute significantly to the discrimination). The stepwise operation continues until there are no further variables giving *F*-values greater than the *F* criterion. After variable selection has finished, the coefficient is calculated for each variable, together with the constant. These provide an equation which gives a score for each case. In general, the score for one group is positive and the score for the other is negative. The mean discriminant score represents the average of all cases in the group.

Results

Cluster analysis

Three clusters were produced. There were 36 subjects in the first cluster, 26 subjects in the second and 37 subjects in the third (Figure 2). The means and standard deviations for the variables in each cluster and the level of significance of the differences between the cluster means are shown in Table 1. The significance levels in the final column were obtained from a one-way analysis of variance (ANOVA) for a comparison of the means, and are only included to assist in identification of major differences between groups.

Skeletal measurements. Cranial base: The anterior cranial base length was reduced in cluster II (65.5 ± 2.9 mm) compared with cluster I (70.9 ± 3.8 mm) and cluster III (70.4 ± 4.3 mm). This was accompanied by a short posterior cranial base length (30.2 ± 2.8 mm). The corresponding figures for clusters I and III were 35.1 ± 3.2 and 33.8 ± 3.5 mm, respectively.

Maxilla: Maxillary length was reduced in cluster II. It averaged 43.9 ± 2.4 mm compared with 48.9 ± 3.4 mm in cluster I and 47.0 ± 3.1 mm in cluster III. The position of the maxilla as determined from SNA was posterior in cluster III (75.3 ± 2.4 degrees) compared with 81.5 ± 3.4 and 77.9 ± 3.2 degrees in clusters I and II, respectively.

Mandible: Cluster I represented the largest mandibular dimensions as evidenced from Ar–Gn, Ar–Go, Go–Me and SNB measurements. Cluster I demonstrated a prominent mandible in relation to the cranial base (SNB). It averaged 85.0 ± 3.4 degrees. The mean SNB measurements in clusters II and III were 81.0 ± 4.0 and 77.3 ± 2.0 degrees, respectively.

Intermaxillary relationship: The antero-posterior skeletal discrepancy was largest in cluster I. Wits measurements averaged –13.6 ± 4.1 mm compared with –10.8 ± 3.1 and –12.7 ± 2.7 mm in clusters II and III, respectively. In the vertical plane, cluster III demonstrated a large maxillary/mandibular planes angle (34.2 ± 4.4 degrees), a long lower face height (73.9 ± 4.8 mm) and increased facial proportions (58 per cent).

Dental measurements. Overjet and overbite followed the skeletal pattern. In cluster I the overjet was the most reversed (–3.2 ± 2.0 mm) and in cluster III the overbite was the most reduced (0.1 ± 1.8 mm).

Soft tissue measurements. Soft tissues followed the pattern determined by the skeletal pattern. All antero-posterior soft tissue measurements (NV, AUV, ALV, sBV, sAV, sPV) were increased in cluster I and the measurements in the vertical directions (NH, sPH) were increased in cluster III.

DFA of the whole sample

Stepwise analysis produced a discriminant function based on 10 variables. The constant, the discriminant coefficients and the classification results are shown in Table 2. The variables contributing to the prediction equation were: distance between projected points A and B on sella horizontal (ABH), mandibular length (Ar–Gn), distance from articulare to sella horizontal (ArH), distance between projected articulare and projected gnathion on sella horizontal (Arp–Gnp), nasolabial angle (AUST), horizontal distance between lower incisor edge and A–pogonion line (Li/A–Pog), angle between lower incisor and mandibular plane (Li/Mand), vertical distance from lower incisor edge to sella horizontal (LiH), angle between soft tissue nasion–nasal tip–soft tissue pogonion (NNP), vertical distance from PNS to sella horizontal (PH). The analysis correctly predicted the outcome in 80 per cent of subjects.

DFA of clusters

Cluster I. Stepwise analysis produced a discriminant function based on four variables. The constant and the discriminant coefficients are shown in Table 3. The variables contributing to the prediction equation were: distance between projected articulare and projected gnathion on sella horizontal (Arp–Gnp), vertical distance from posterior nasal spine to sella horizontal (PH), sella–articulare (S–Ar) and sella–articulare–gonion (SArGo). The analysis correctly predicted the outcome in 92 per cent of subjects.

Cluster II. Stepwise analysis produced a discriminant function based on three variables. The constant, the discriminant coefficients and the classification results are shown in Table 4. The variables contributing to the prediction equation were: angle between lower incisor and mandibular plane (Li/Mand), sella–gnathion (S–Gn) and sella–articulare–gonion (SArGo). The analysis correctly predicted the outcome in 85 per cent of subjects.

Table 1 Means and standard deviations (SD) for each cluster and the significance of the differences between the clusters.

Variable	Cluster I (n = 36)		Cluster II (n = 26)		Cluster III (n = 37)		Significance
	Mean	SD	Mean	SD	Mean	SD	
Skeletal measurements							
Cranial base							
N–S (mm)	70.9	3.8	65.5	2.9	70.4	4.3	***
S–Ar (mm)	35.1	3.2	30.2	2.8	33.8	3.5	***
NSAr°	120.3	4.7	122.9	5.6	124.8	5.1	**
Maxilla							
Ptm–A (mm)	48.9	3.4	43.9	2.4	47.0	3.1	***
Ptmp–Ap (mm)	47.8	3.5	42.5	2.1	44.8	3.0	***
SPA°	119.2	4.2	118.5	3.5	116.7	4.6	*
SNA°	81.5	3.4	77.9	3.2	75.3	2.4	***
AV (mm)	68.6	5.2	59.8	3.3	61.4	4.0	***
PH (mm)	44.7	1.9	40.7	2.5	44.6	2.4	***
AH (mm)	44.1	3.3	41.3	3.1	46.2	2.3	***
Mandible							
Ar–Gn (mm)	116.1	7.2	103.1	5.8	113.4	6.0	***
Arp–Gnp (mm)	87.4	7.9	73.6	6.4	71.8	6.7	***
Ar–Go (mm)	46.8	4.6	42.5	4.2	45.8	3.9	***
Go–Me (mm)	76.8	4.8	68.4	4.4	73.6	5.7	***
S–Gn (mm)	139.5	7.2	127.3	9.5	136.8	6.7	***
ArGoMe°	131.9	5.0	130.9	4.5	135.8	4.3	***
SArGo°	140.0	6.3	141.4	7.2	142.5	6.3	NS
SNB°	85.0	3.4	81.0	4.0	77.3	2.0	***
BV (mm)	73.4	6.7	61.3	6.0	58.9	4.7	***
ArH (mm)	32.1	3.0	27.0	2.5	29.8	3.7	***
GoH (mm)	76.7	5.4	68.3	5.0	74.8	4.7	***
MeH (mm)	109.4	5.8	100.7	6.5	118.1	5.5	***
SGoMe°	114.8	4.8	115.2	4.5	120.0	4.2	***
SNPog°	85.8	3.6	81.8	3.7	77.9	2.3	***
Intermaxillary							
ANB°	–3.6	2.9	–3.2	1.9	–2.2	1.9	*
SAB°	132.6	7.5	130.3	5.9	127.4	4.4	**
Wits (mm)	–13.6	4.1	–10.8	3.1	–12.7	2.7	**
ABH (mm)	–5.6	4.0	–3.2	2.5	–3.2	2.1	**
Max/Mand°	25.9	4.4	27.6	3.9	34.2	4.4	***
AGoV (mm)	32.4	5.3	26.7	3.9	28.4	4.4	***
AMeV (mm)	65.3	5.2	59.3	4.0	71.8	5.0	***
N–Me (mm)	118.2	6.0	109.0	6.6	128.0	5.6	***
LFH (mm)	65.7	5.2	60.2	4.0	73.9	4.8	***
FP%	56	3	55	1	58	2	***
Y–axis°	62.7	3.1	65.6	3.3	71.4	2.2	***
Dental measurements							
Li/Mand	84.4	9.4	83.0	5.7	80.6	6.0	NS
Ui/Max	113.5	5.9	112.7	6.8	110.8	5.1	NS
LiV	76.5	6.6	64.5	5.9	65.0	4.3	***
LiH	69.9	4.6	64.5	5.0	77.2	3.1	***
UiV	73.8	7.0	62.7	3.9	65.0	4.1	***
UiH	71.6	4.1	66.9	5.1	77.3	3.4	***
Li/A–Pog	6.1	3.3	4.1	3.8	5.8	3.1	NS
LMV	51.6	6.1	40.5	4.6	42.0	4.3	***
LMH	72.2	4.3	65.5	4.6	76.1	3.2	***
UMV	46.8	5.0	38.8	3.5	38.8	3.3	***
UMH	62.7	3.8	56.9	4.3	66.2	3.1	***
Ui/Li°	136.3	14.3	136.9	7.7	134.6	7.9	NS
Overjet (mm)	–3.2	2.0	–3.1	2.4	–1.4	1.3	***
Overbite (mm)	1.6	3.3	2.0	2.7	0.1	1.8	**
Soft tissue measurements							
AUST°	103.2	11.9	106.6	13.4	106.9	11.1	NS
NNP°	138.8	5.5	137.8	3.9	135.2	5.7	*
NAP°	172.9	5.2	173.8	3.9	170.8	4.5	*
NV (mm)	101.0	6.8	89.9	4.3	96.8	7.0	***
AUV (mm)	89.5	6.6	76.9	5.0	80.6	4.3	***
ALV (mm)	91.1	7.0	77.2	6.7	78.5	4.8	***
sBV (mm)	85.3	7.2	71.5	6.4	71.1	5.0	***
sAV (mm)	85.9	6.4	74.6	4.4	78.2	4.7	***
sPV (mm)	87.8	8.1	72.9	6.9	71.5	5.9	***
NH (mm)	36.9	3.2	35.8	4.0	42.2	2.9	***
sPH (mm)	100.8	6.0	95.3	6.0	110.2	5.3	***

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

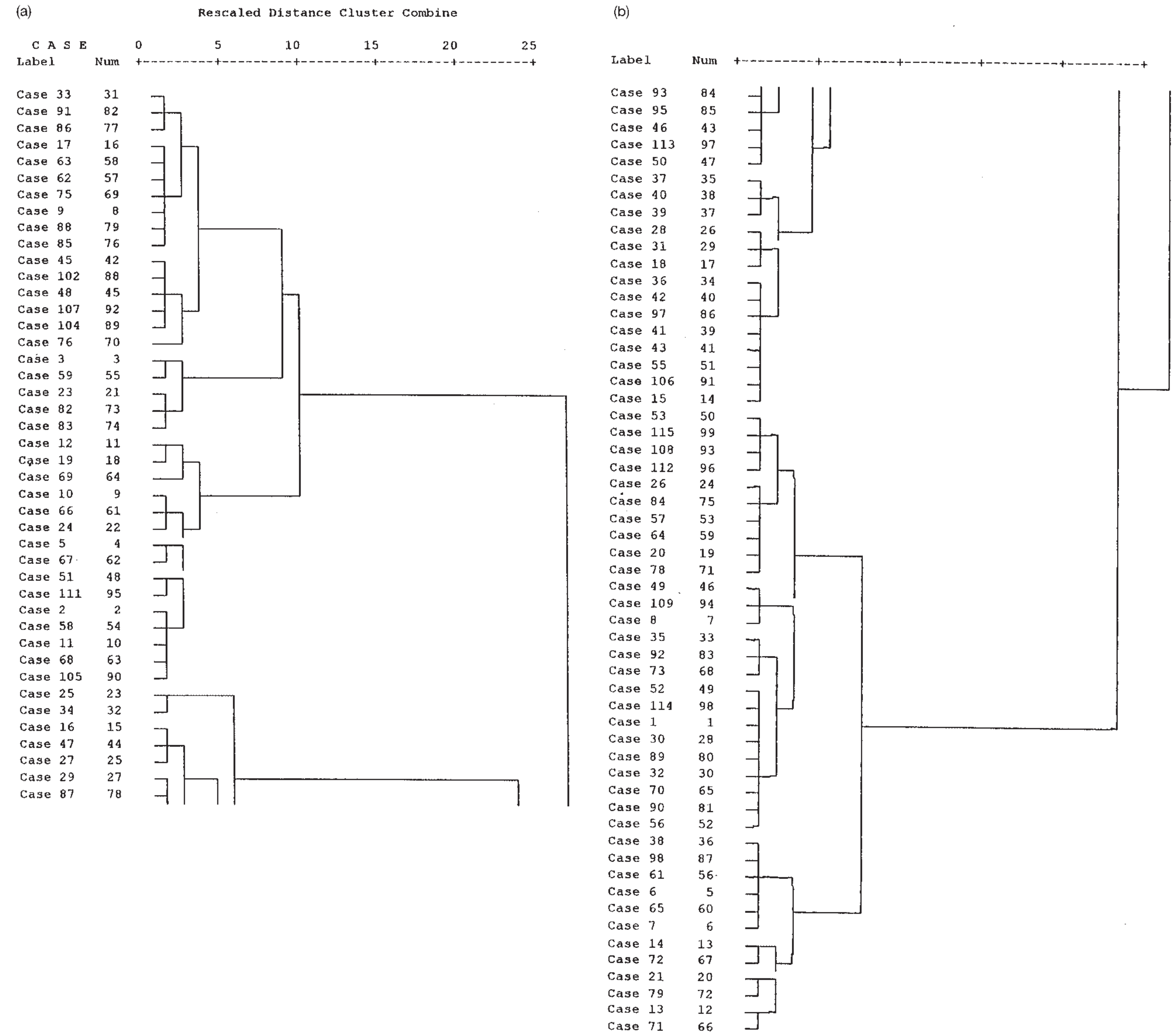

Figure 2 Dendogram using the Ward method (Norusis, 1986). Cluster I: cases 33–105; cluster II: cases 25–15; cluster III: cases 53–71.

Table 2 Constant and discriminant function coefficients for the whole sample.

Predictive variable	Non-standardized canonical discriminant function coefficients
Constant	–30.5482571
ABH (mm)	–0.1647672
Ar–Gn (mm)	0.6974873
ArH (mm)	0.6263459
Arp–Gnp (mm)	–0.5435488
AUST°	0.0351061
Li/A–Pog (mm)	0.1790398
Li/Mand°	0.1078528
LiH (mm)	–0.5850788
NNP°	0.1082739
PH (mm)	–0.1800858

Table 3 Constant and discriminant function coefficients for cluster I.

Predictive variable	Non-standardized canonical discriminant function coefficients
Constant	5.8368326
Arp–Gnp (mm)	–0.0751293
PH (mm)	–0.5836690
S–Ar (mm)	0.3940235
SArGo°	0.0927344

Table 4 Constant and discriminant function coefficients for cluster II.

Predictive variable	Non-standardized canonical discriminant function coefficients
Constant	–51.7788028
Li/Mand°	0.2627486
S–Gn (mm)	0.0997744
SArGo°	0.1220837

Table 5 Constant and discriminant function coefficients for cluster III.

Predictive variable	Non-standardized canonical discriminant function coefficients
Constant	14.8279379
AGoV (mm)	0.3152642
Li/Mand°	–0.2170097
LiV (mm)	0.5859036
NH (mm)	–0.3681995
Overbite (mm)	0.4285386
SAB°	–0.1230706
SArGo°	0.2411222
SAV (mm)	–0.3664111

Cluster III. Stepwise analysis produced a discriminant function based on eight variables. The constant, the discriminant coefficients and the classification results are shown in Table 5. The variables contributing to the prediction equation were: distance between anterior nasal spine and gonion projected on sella vertical (AGoV), angle between lower incisor and mandibular plane (Li/Mand), horizontal distance from lower incisor edge to sella vertical (LiV), vertical distance from nose tip to sella horizontal (NH), overbite, sella–point A–point B (SAB), sella–articulare–gonion (SArGo) and horizontal distance from soft tissue point A to sella vertical (sAV). The analysis correctly predicted the outcome in 100 per cent of subjects.

Discussion

The clinical problem addressed is predicting spontaneous skeletal, dental and soft tissue changes occurring in patients with a Class III malocclusion on a Skeletal III dental base. Clearly defined cut-off points were established in choosing the sample of Class III cases. The subjects had to show a skeletal base Class III relationship defined as a zero or negative ANB angle. None could achieve an edge to edge occlusion.

Wits measurement was chosen to divide the Class III sample into poor and good growers. Wits appraisal was measured using the maxillary/mandibular planes angle bisector instead of the functional occlusal plane, as the latter changes with growth and is difficult to identify (Hall-Scott, 1994) so giving an unreliable Wits value.

McCallin (1955) suggested three types of Class III malocclusion: long face, average face and postural Class III. In recognition of the fact that subgroups of Class III malocclusion have been said to exist and in an attempt to derive accurate discrimination, the Class III material was analysed using cluster analysis (Norusis, 1986). Cluster analysis has been used by Bhatia *et al.* (1979) to predict facial growth using cephalograms of patients at 9.5 and 17.5 years. They found no close association between clusters at 9.5 years and those at 17.5 years. In the present study, three clinically distinguishable clusters were produced. The first cluster represented a large horizontal intermaxillary discrepancy. The anterior and posterior cranial base lengths were increased, and the cranial base angle was reduced. The maxilla was increased in length. The mandibular length was increased in both the body and the ramus. The mandible was prominent. The posterior lower face height and jaw angle were increased. The *Y* axis angle was reduced, indicating a sagittal growth tendency. The teeth accompanied the skeletal discrepancy, with both incisors and molars anteriorly positioned. The soft tissues followed the skeletal morphology. A concave profile was evidenced, both upper and lower lips and chin were more anteriorly positioned. In broad clinical terms this cluster might be described as a horizontal discrepancy case.

The second cluster represented the least severe Class III discrepancy. The anterior and posterior cranial base lengths and cranial base angle were all reduced. The maxilla was short and superiorly positioned. The total face height was reduced. The positions of the teeth and soft tissues followed the skeletal morphology. This cluster would be intermediate between the first and third clusters.

The third cluster had a moderate intermaxillary discrepancy. The anterior cranial base length was increased. The maxilla was retrusive in relation to the cranial base and inferiorly positioned. The mandibular body length was increased but the projected mandibular length was reduced, reflecting a more vertical growth pattern. The mandible was positioned inferiorly. The intermaxillary discrepancy was moderate compared with the other clusters. The total face height and facial proportions were markedly increased. The maxillary/mandibular planes angle and the *Y* axis angle were both increased, reflecting a vertical direction of growth. The overjet was moderately reversed and the overbite was reduced. The soft tissue profile angle was slightly increased due to the vertical growth pattern. The lower lip and chin were not prominent. The vertical direction of growth also explains these findings. In broad clinical terms this cluster might represent the long face type of Class III.

Multivariate statistical approaches have been used to predict facial growth (Skieller *et al.*, 1984) and treatment outcome (Battagel, 1993) in Class III subjects. Skeiller

Table 6 Variable centroids for the three clusters.

Variable	Cluster I centroid	Cluster II centroid	Cluster III centroid
N–S (mm)	0.4	–0.9	–0.3
S–Ar (mm)	0.5	–0.8	0.1
NSAr°	–0.4	0.1	0.4
Ptm–A (mm)	0.6	–0.8	0.0
Ptmp–Ap (mm)	0.7	–0.8	–0.1
SPA°	0.3	0.1	–0.3
SNA°	0.8	–0.1	–0.7
AV (mm)	–0.9	0.7	0.4
PH (mm)	0.4	–1.0	0.3
AH (mm)	0.0	–0.8	0.6
Ar–Gn (mm)	0.5	–1.0	0.2
Arp–Gnp (mm)	0.9	–0.4	–0.6
Ar–Go (mm)	0.3	–0.6	0.1
Go–Me (mm)	0.6	–0.8	0.0
S–Gn (mm)	0.5	–0.9	0.2
ArGoMe°	–0.2	–0.4	0.5
SArGo°	–0.2	0.0	0.2
SNB°	0.9	0.0	–0.8
BV (mm)	–0.9	0.4	0.7
ArH (mm)	0.6	–0.8	0.0
GoH (mm)	0.5	–0.9	0.2
MeH (mm)	–0.1	–1.1	0.9
SGoMe°	–0.4	–0.3	0.6
SNPog°	0.9	0.0	–0.8
ANB°	–0.3	–0.1	0.3
SAB°	0.4	0.1	–0.4
Wits (mm)	0.3	–0.5	0.1
ABH (mm)	0.5	–0.3	–0.3
Max/Mand°	–0.6	–0.3	0.8
AGoV (mm)	0.6	–0.5	–0.2
AMeV (mm)	–0.1	–1.0	0.8
N–Me (mm)	–0.1	–1.1	0.9
LFH (mm)	–0.2	–1.0	0.9
FP%	–0.3	–0.4	0.6
Y–axis°	–0.8	–0.2	1.0
Li/mand°	0.2	0.1	–0.3
Ui/max°	0.2	0.1	–0.3
LiV (mm)	–0.9	0.6	0.5
LiH (mm)	–0.2	–1.0	0.9
UiV (mm)	0.9	0.7	0.4
UiH (mm)	–0.2	–0.9	0.8
Li/A–pog (mm)	–0.2	0.4	–0.1
LMV (mm)	–0.9	0.7	0.4
LMH (mm)	0.1	–1.1	0.7
UMV (mm)	–0.9	0.5	0.5
UMH (mm)	0.0	–1.1	0.7
Ui/Li°	0.1	0.1	–0.1
Overjet (mm)	–0.4	–0.3	0.5
Overbite (mm)	0.2	0.3	–0.4
AUST°	–0.2	0.1	0.1
NNP°	0.3	0.1	–0.4
NAP°	0.1	0.3	–0.3
NV (mm)	–0.6	0.9	0.0
AUV (mm)	0.9	0.8	0.3
ALV (mm)	–0.9	0.6	0.5
sBV (mm)	–0.9	0.5	0.6
sAV (mm)	0.8	0.8	0.3
sPV (mm)	–0.9	0.5	0.6
NH (mm)	–0.4	–0.7	0.8
sPH (mm)	–0.3	–0.9	0.9

et al. (1984) used multiple regression analysis to predict facial growth in 21 severe Class III subjects. The outcome was accurately predicted in 86 per cent of the cases. Another multivariate statistical technique which is not widely used in orthodontics is discriminant analysis (Kerr and Ford, 1986). Battagel (1993) attempted to predict relapse post-treatment in subjects with a corrected Class III malocclusion using stepwise discriminant analysis. One hundred per cent prediction of the outcome was produced based on four variables. In the present study, an acceptable discrimination percentage (80 per cent) was obtained when all subjects were pooled. However, when the sample was subdivided into three distinguishable groups using cluster analysis, complete discrimination was obtained in cluster III based on eight variables and good discrimination was obtained in cluster I (92 per cent) based on four variables and cluster II (85 per cent) based on three variables. The predictive variables produced from the discriminant analysis were of clinical relevance; for the whole sample these were the intermaxillary horizontal discrepancy, mandibular length, lower incisor position and inclination, vertical position of PNS and articulare, nasolabial angle and the patient's profile. The predictive factors in each of the three clusters produced were mandibular length, saddle angle, posterior cranial base length and vertical position of PNS in cluster I, lower incisor inclination, saddle angle and mandibular length in cluster II and lower incisor position and inclination, vertical distance between gonion and point A, overbite, angle of convexity (SAB), saddle angle, soft tissue maxillary prominence and vertical position of nasion in cluster III. Although additional factors were included in the predictive equation of cluster III, the accuracy of prediction was improved.

In clinical use, the overall discriminant function giving 80 per cent discrimination might be seen as useful, but for clinicians seeking the higher discrimination of 92 per cent in cluster I, 85 per cent in cluster II and 100 per cent in cluster III, patients need to be allocated to the appropriate cluster. One method of doing this is to use the squared Euclidean distance which is the sum of the squared distances of the variables from the cluster centroid. The individual is allocated to the cluster from which the squared Euclidean distance is the least.

In order to be able to test the discriminant equations for each cluster, the new cases should be allocated to the appropriate cluster. First the data for each case should be standardized using the formula $Z = (x - \bar{x})/S$ where Z is the standardized variable, x is the original variable, $\bar{x}$ is the mean of the whole sample and S is the standard deviation of the whole sample used to derive the clusters. The squared Euclidean distance is given by $\sum_{i=1}^{m}(Z_i - \bar{Z}_{ci})^2$ where there are m variables (induced by i), Z_i is the value of the ith variable after standardization and Z_{ci} is the ith variable centroid (Table 6). The case is considered to belong to the cluster with the least sum of the squared Euclidean distances.

Conclusions

1. Discriminant analysis on the initial radiographs of 115 untreated subjects who subsequently grew favourably or unfavourably produced correct outcome prediction in 80 per cent of subjects.
2. Cluster analysis of these subjects produced three clusters broadly corresponding to severe horizontal discrepancy cases, an intermediate group and long face types.
3. Individual discriminant analysis of the clusters produced 92 per cent discrimination in cluster I, 85 per cent in cluster II and 100 per cent in cluster III.
4. The validity of these discriminations should be tested on a further sample.

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