European Journal of Orthodontics 18 (1996) 111–118

Morphological associations between the Angle classes

J. M. H. Dibbets
Department of Orthodontics, Philipps University, Marburg, Germany

SUMMARY The association between the Angle classification and craniofacial form has been analysed with the aid of multiple linear regression analysis in a sample of 170 children, before orthodontic treatment had started. It was found that part of the differences between Class II, Class I, and Class III was accounted for by systematical variation in a coherent set of midface and cranial base dimensions. These variations were in harmony with each other: the cranial base angle Ba–S–N closed and the legs S–N and S–Ba shortened systematically from Class II, over Class I, to Class III. The juvenile mandible notably was not systematically different. Because the cranial base provides the framework for the maxilla to be built upon, it is concluded that in juveniles the midface above anything else creates the characteristic difference between the three Angle classes, not the mandible. The Angle classification of malocclusion, therefore, represents three arbitrary markers on a morphological continuum.

Introduction

'In beginning the consideration of malocclusion let us remember that it is but the perversion of the normal in growth and development ...' thus wrote Angle in the first line of his chapter on 'Malocclusion' (1907, p. 28). In the text it becomes obvious that the Angle classification of malocclusion is primarily based on skeletal relationships and not so much on occlusion *per se*. However, the unsolved question is, are the Angle classes three discrete groups characterized by discrepancies in size and position of the maxilla and, notably, the mandible or, do they represent three arbitrary markers on a scale of systematic variation in anatomy between Class II at the one end to Class III at the other end? The fact that Angle positioned Class I before, not between, the two opposite Classes II and III, suggests that he himself considered them as being unrelated.

The association of factors such as lymphoid tissue or head posture with facial morphology has been explored, yet an explicit association with the Angle classes has not been investigated (Björk, 1951; Solow and Tallgren, 1976; Linder-Aronson, 1979; Vig *et al.*, 1981; Solow and Siersbæk-Nielsen, 1986; Hellsing *et al.*, 1987; Woodside *et al.*, 1991). Cole (1988) contends that natural head position affects the cranial base orientation and this alone is capable of producing a Class II or III effect. Textbooks depict the Angle classes as discrepancies in size and position of the maxilla and mandible, without speculation on a special role for any structure (Nanda, 1983; Moyers, 1988; Enlow, 1990; Houston *et al.*, 1992; Proffit and Fields, 1993). Järvinen (1980) reports that a marked part of the variation in the SNA angle is explained by variation in the saddle angle NSAr. Only two publications were found in which morphological variation between Class II and Class III malocclusion systematically is reduced into one single structure (Hopkin *et al.* 1968, Kerr and Adams, 1988). These two studies both assign a central role to the cranial base and conclude that the amount of mandibular prognathism can be explained by, or results from the cranial base configuration which positions the temporomandibular (TM) joint, and thus the mandible, forward into Class III and backward into Class II.

The opinion, however, that the Angle classes represent discrepancies in size and/or position of the maxilla and mandible, explicitly or implicitly dominates the literature. Most studies compare Class II or Class III samples with a Class I reference, and not with each other. Relative to Class I, the Class II mandible is reported to be shorter (Sicher and Krasa, 1920; Sicher, 1947; Craig, 1951; Harris, 1965; Hunter, 1967; Wells, 1970), or almost normal (Nelson and Highley, 1948), while the cranial base angle is reported to be larger (Harris, 1975; Anderson and Popovich, 1983; Bacon *et al.*, 1992), or normal (Wells, 1970). The TM joint in Class II is positioned posteriorly (Sicher and Krasa, 1920; Fisk *et al.*, 1953; Maj *et al.*, 1960; Hunter, 1967; Bacon *et al.*, 1992). Relative to Class I the Class III mandible is reported to be longer (Sicher and Krasa, 1920; Raynes, 1956; Maj *et al.*, 1960; Joffe, 1965; Jacobson *et al.*, 1974; Baer, 1975; Fischer-Brandies *et al.*, 1985; Guyer *et al.*, 1986; Chang *et al.*, 1992; Battagel, 1993), while the maxilla is reported to be shorter (Timmons, 1958; Gebeck, 1969; Guyer *et al.*, 1986; Battagel, 1993), or normal (Stapf, 1940; Joffe, 1965). The cranial base angle is reported to be smaller in Class III (Timmons, 1958; Horowitz *et al.*, 1969; Anderson and Popovich, 1983; Bacon *et al.*, 1992; Battagel, 1993), the linear cranial base dimensions to be smaller (Horowitz *et al.*, 1969; Jacobson *et al.*, 1974) or the basicranial configuration to be different (Martone *et al.*, 1992). The TM joint in Class III is positioned anteriorly (Sicher and Krasa, 1920; Furlong, 1954; Maj *et al.*, 1965; Jacobson *et al.*, 1974; Battagel, 1993) as is the hyoid bone (Adamidis and Spyropoulos, 1992).

Class III generally is considered to be inherited (Kantorowicz, 1915; Schwarz, 1931; Stein *et al.*, 1956; Emrich *et al.*, 1965; Nakasima *et al.*, 1982). A polygenic model has been postulated (Litton *et al.*, 1970; Bookman *et al.*, 1974; Harris *et al.*, 1975). Remarkable is the finding of Bookman *et al.* (1974) that non-Class III family members exhibited a definite trend towards the statistics generated for the Class III patients in their study, rather than to a normal population. Harris (1975) made the same observation in Class II, division I patients who were found to be much more similar to their own immediate family than to a randomly selected set of unrelated Class II individuals. Yet, Harris *et al.* (1975) are of the opinion that the Class II and III malocclusions cannot be considered as occupying opposite ends of the statistical distribution of any single variable. Also interesting is the finding of structural differences in the cranio-vertebral junction in Class III individuals (von Treuenfels, 1981; Hirschfelder and Hirschfelder, 1982a,b; Huggare, 1991). These latter reports suggest that at least Class III is a structural entity separated from the other classes.

It is the intention of the present report to explore if anatomical structures can be identified which vary systematically from Class II via Class I to Class III. If so, the Angle classes are only arbitrary markers in a morphological continuum. If not, the option remains that the classification must be considered as three morphologically discrete groups.

Subjects and methods

A total of 170 children were documented before orthodontic treatment had started. They represent a more or less consecutively referred orthodontic sample, although effort has been made to include some extra Class III individuals. Their mean age was 12.5 years; 45 per cent were boys, 55 per cent were girls. Standardized lateral cephalograms were taken, traced, digitized and checked for errors. The 20 linear and nine angular dimensions studied are listed in Table 1. All linear dimensions have been corrected for enlargement.

Angle classification

An initial Angle classification of one kind or other was necessary in order to allow further statistical analysis. To that purpose the Angle classification has been determined on plaster models only. Deep impressions allowed the inspection of the alveolar process and the apical area. Assessments of sagittal molar and canine relation on the left and right side, with due respect to mesial migration, were combined to estimate the upper to lower basal relationship. It reflects clinical view since there is no consensus on a gold standard for the Angle classification (Rinchuse and Rinchuse, 1989; Katz, 1992a,b; Kerr *et al.*, 1994; Lowe *et al.*, 1994).

Regression analysis

The association between the Angle classification and craniofacial form was analysed with the aid of multiple linear regression analysis, which assesses a linear relationship between independent variables (e.g. age) and a dependent variable (e.g. size). Size in this example is considered to be dependent on age, older children typically being associated with larger size. A strong point of the regression model is the capability of handling multiple independent variables simultaneously, disclosing the influence of subtle independent variables. Another strong point is weighting the influence of independent

Table 1 The 20 linear and nine angular dimensions studied.

Linear cranial base and maxilla	
S–N	Sella–Nasion
S–Ba	Sella–Basion
Ba–PTM	Basion–PTM
PTM–A	PTM–point A
Ar–A	Articulare–point A
PNS–A	Posterior Nasal Spine–point A
Ba–Or	Basion–Orbitale
Or–prPP	Orbitale–perpendicular on Palatal Plane
N–ANS	Nasion–Anterior Nasal Spine (upper face height)
ANS–UIE	Anterior Nasal Spine–Upper Incisor Edge
S–PNS	Sella–Posterior Nasal Spine
Linear mandible	
S–Gn	Sella–Gnathion
Ar–Pg	Articulare–Pogonion
Pg–Go	Pogonion–Gonion
S–Go	Sella–Gonion
S–Ar	Sella–Articulare
Ar–Go	Articulare–Gonion
N–Me	Nasion–Menton (total face height)
ANS–Me	Anterior Nasal Spine–Menton (lower face height)
LIE–Me	Lower Incisor Edge–Menton
Angular	
Ba–S–N	Basion–Sella–Nasion
Op–Ba–S	Opistion–Basion–Sella
S–N–A	Sella–Nasion–point A
S–N–B	Sella–Nasion–point B
N–S–Ar	Nasion–Sella–Articulare
Gonial Angle	Gonial Angle
SN/PP	Sella–Nasion/Palatal Plane
SN/OP	Sella–Nasion/Occlusal Plane
SN/MP	Sella–Nasion/Mandibular Plane

Table 2 Average value and SD for the linear and angular dimensions, corrected for cephalometric enlargement. Note that the averages do not take into account differences in the distribution of other parameters such as age, gender or the Angle classification.

Dimension	Average value	SD
Cranial base and maxilla linear		
S–N	69.3	3.8
S–Ba	43.3	3.1
Ba–PTM	42.2	3.3
PTM–A	48.6	3.5
Ar–A	79.5	5.5
PNS–A	45.0	3.4
Ba–Or	76.9	4.9
Or–prPP	20.8	2.4
N–ANS	47.6	3.3
ANS–UIE	26.1	3.2
S–PNS	42.6	3.3
Mandible linear		
S–Gn	110.1	7.1
Ar–Pg	94.7	6.5
Pg–Go	67.6	5.0
S–Go	66.4	5.8
S–Ar	31.7	3.4
Ar–Go	38.7	4.2
N–Me	107.1	7.3
ANS–Me	61.5	6.0
LIE–Me	38.6	3.5
Angular		
Ba–S–N	132.0	5.0
Op–Ba–S	128.3	5.1
S–N–A	80.6	3.6
S–N–B	75.7	4.0
N–S–Ar	125.1	4.9
Gonial Angle	126.4	6.3
SN/PP	8.4	3.2
SN/OP	15.5	4.9
SN/MP	34.7	3.3

variables, instead of splitting up the sample into even smaller sub-groups, thus avoiding substantial sample attrition and arbitrary cut-off points. This latter point made regression especially attractive since age in the three Angle classes was far from being identical. The formulation of an adequate model represents a problem. In case of a linear model, linearity is not always met, as for example, size does not develop linearly with age. Yet, it can be shown by practical examples that power outranks weakness. As a sort of *post hoc* test, the results have been verified, and found to be realistic, by comparing the outcome for age and gender against public domain data (Dibbets, 1977). This approach does not replace testing of the statistical assumptions underlying the model. However, the comparison with data gathered for a different purpose provides a valid verification.

One regression analysis was carried out for each of the 29 cephalometric dimensions as the dependent variable, along with age, gender, and the Angle classification (coded II I III, see discussion), among others, as the independent variables. Age, gender, and a few other independent variables, although not discussed in detail, were a necessary part of the procedure since each of them possibly could explain a specific amount of variance in the cephalometric data. For all analyses, the significance level was set at $\alpha = 0.05$.

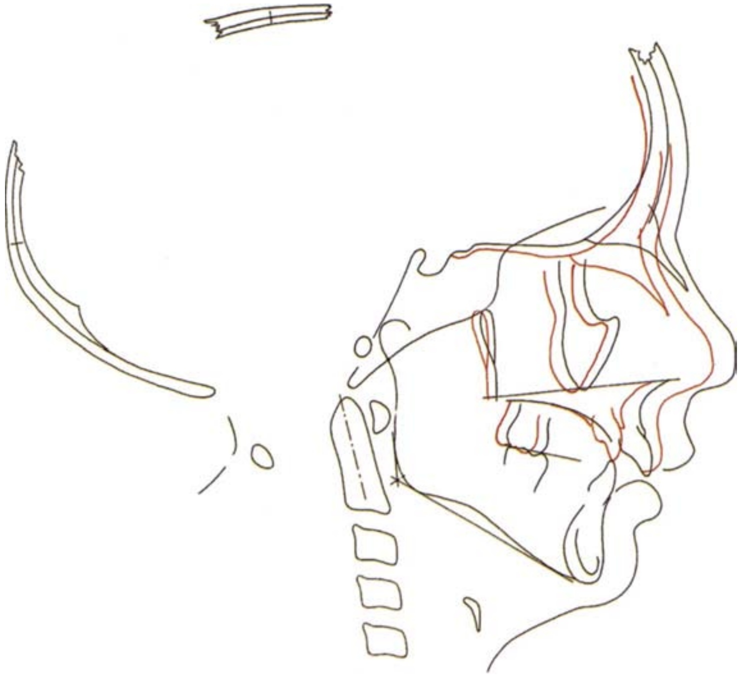

Figure 1 Significant regression coefficients were incorporated as a quantitative (yet artistic) illustration of craniofacial differences between Class II (black) and Class III (red). The soft tissue outline and skeletal contours are estimates since only hard tissue landmarks were digitized. The structure central to these differences apparently is formed by the cranial base, when angle Ba–S–N closes and legs S–N and S–Ba shorten from Class II over Class I to Class III. Note that the mandible was not systematically different.

Results

Angle classification and age

The distribution of the Angle classification was 14 per cent Class I; 69 per cent Class II; and 17 per cent Class III. The average age was 14.2 years in Class I, 12.8 years in Class II, and 10.0 years in Class III.

The average age of the sample was 12.5 years, SD 3.0 years. With exception of the skewed distribution for Class III, (see Subjects and methods), these figures reflect the referring pattern from the regional dental practitioners.

Regression analysis

The results are presented in Tables 2 and 3 and in Fig. 1. Table 2 depicts the average value and SD of the cephalometric dimensions without taking into account age, gender or Angle classification. Table 3 depicts the results from the regression analysis. The regression coefficient may be interpreted as estimated mm or degrees difference between Class II and Class I or Class I and Class III. The difference between Class II and Class III, however, equals two steps or double the regression coefficient, because Class I has been positioned between the two. For example, a regression coefficient of -1.7 for Sella–Nasion may be interpreted such that the Sella–Nasion dimension in Class I is 1.7 mm shorter than in Class II and that the Class III dimension is 1.7 mm shorter than in Class I (from Class II to Class I and from Class I to Class III it 'shortens' each time by 1.7 mm). In other words, Sella–Nasion is 3.4 mm shorter in Class III compared with Class II, or, conversely, Sella–Nasion in Class II is 3.4 mm longer than in Class III. The significant findings have been incorporated in Figure 1.

Discussion

The Angle classification has been determined on plaster models in an attempt to capture the clinical situation and because the method is free from cephalometric bias (Järvinen, 1988). The justification to enter the Angle classification as an independent variable in a regression model

Table 3 Significant regression coefficients* for Angle classification and cephalometric dimensions. The coefficient may be interpreted as estimated difference in millimeters or degrees between the Classes II and I or the Classes I and III. The sign represents direction of the difference.

Dimension	Regression coefficient	Estimated difference between Class II and Class III[a]
Cranial base and maxilla linear		
S–N	−1.7	−3.4
S–Ba	−1.2	−2.4
Ba–PTM	−1.7	−3.4
PTM–A	−1.9	−3.8
Ar–A	−3.3	−6.6
PNS–A	−2.0	−4.0
Ba–Or	−2.7	−5.4
Or–prPP	−0.5	−1.0
N–ANS	−0.7	−1.4
ANS–UIE	−1.2	−2.4
S–PNS	−0.7	−1.4
Mandible linear		
S–Gn	NS	
Ar–Pg	NS	
Pg–Go	NS	
S–Go	−0.9	−1.8
S–Ar	−1.3	−2.6
Ar–Go	NS	
N–Me	−1.6	−3.2
ANS–Me	−1.6	−3.2
LIE–Me	−1.1	−2.2
Angular		
Ba–S–N	−1.5	−3.0
Op–Ba–S	NS	
S–N–A	−0.8	−1.6
S–N–B	+2.7	+5.4
N–S–Ar	−1.1	−2.2
Gonial Angle	NS	
SN/PP	NS	
SN/OP	NS	
SN/MP	−1.0	−2.0

*$P<0.05$; NS = not significant.
[a] Estimated difference between Class II and Class III = double the regression coefficient.

has been the assumption that cephalometric dimensions varied systematically from Class II via Class I to Class III. To that goal the Angle classification had to be recoded into an ordinal scale in which Class II came before Class I and Class I before Class III. Thus, a significant regression coefficient witnesses a systematic, gradual variation in a cephalometric dimension from Class II via Class I to Class III and *vice versa*. Lack of a significant finding on the other hand, does not signify no difference; it merely indicates no systematic variation between the three classes for that dimension.

From Table 3 it can be seen that a systematic and gradual variation existed for several mid-face and cranial base dimensions from Class II via Class I to Class III. They were in harmony with each other and agreed to some extent with the reports for Class II or Class III relative to Class I mentioned in the introduction. However, the mandibular dimensions Articulare–Gonion, Articulare–Pogonion, Pogonion–Gonion, and Gonial Angle in this study did not vary systematically between the Angle classes. The apparent contradiction between the literature reporting a smaller mandible in Class II and a larger one in Class III, when compared with Class I mandibles, and the present finding of no systematic difference has three possible explanations. One is that a variety of operational definitions for the Angle classification are applied, be it the A–N–B angle, the 'Wits' (Jacobson, 1975;

Järvinen, 1988; Lowe *et al.*, 1994) or the determination on plaster models. Another explanation could be age differences between the reported studies. From the presented literature it seems that differences in mandibular size between Class I and Class II or Class I and Class III emerge later during development and therefore these differences are more likely to be found in adult samples (Jacobson *et al.*, 1974). A third explanation finds its origin in data handling and will be elucidated with one publication, in which cephalometric dimensions in children with a Class I were compared to a Class II sample (Harris, 1965). Initially a larger mean Sella–Nasion dimension in the Class II individuals was found, but no differences were noticed between the means of the mandibular parameters, as becomes evident from a table. Because the cranial base probably was considered to be independent from the Angle classification, the author must have been puzzled by the unexpected discrepancy in anterior base length and decided to compensate for the assumed head size differences of the two samples. A covariance analysis with regression on Sella–Nasion was performed, producing identical Sella–Nasion means and smaller Articulare–Pogonion means in Class II relative to Class I as a result. Thus, a smaller mandible in the Class II sample relative to Class I was reported in the discussion and summary. Apparently, comparison of the outcome of different studies calls for great care and a mere replication of numbers leads to erroneous conclusions.

The findings in this study quantitatively match those of Hopkin *et al.* (1968) and Kerr and Adams (1988) and also agree that the structure pivotal to the differences between the Angle classes is the cranial base. Both studies cited, however, interpret their findings from a perspective of an immutable anterior cranial base. The cranial base angle in that view affects the position of the spheno-occipital part of the base and, consequently, results in a relocation of the TM joint forward or backward. However, sagittal relocation of the spheno-occipital bone necessarily includes relocation of the cervical spine. In addition from being impractical, this view ignores the impact of size and shape of the cranial base on the maxilla (Koski, 1960; Birch, 1968; Knowles, 1963; Baer and Nanda, 1976; Enlow, 1990). The deepness of the pharynx and the horizontal and vertical maxillary dimensions are entirely accounted for by the size and shape of the cranial base. Therefore it is concluded that the size and configuration of the cranial base, and therefore the size and position of the midface, created the characteristic difference between the Angle classes as established on plaster models. The juvenile mandible was not systematically different. Thus, the Angle classification of malocclusion represents three arbitrary markers in a morphological continuum.

Address for correspondence

Prof. Dr J. M. H. Dibbets
MZ ZMK Department of Orthodontics
Georg-Voigt-Strasse 3
D-35033 Marburg Germany

Acknowledgements

Dr C. Sessler, University of Marburg, Germany, and Priv. Doz. Dr A. Jäger, University of Göttingen, Germany, discussed the manuscript. L. Th van der Weele, University of Groningen, Netherlands, provided indispensable statistical counselling.

References

Adamidis I P, Spyropoulos M N 1992 Hyoid bone position and orientation in Class I and Class III malocclusions. American Journal of Orthodontics and Dentofacial Orthopedics 101: 308–312

Anderson D, Popovich F 1983 Relation of cranial base flexure to cranial form and mandibular position. American Journal of Physical Anthropology 61: 181–187

Angle E H 1907 Treatment of malocclusion of the teeth. Angle's system. 7th edition. S.S. White, Philadelphia

Bacon W, Eiller V, Hildwein M, Dubois G 1992 The cranial base in subjects with dental and skeletal Class II. European Journal of Orthodontics 14: 224–228

Baer L D 1975 A cephalometric study of patients with the Wiedemann–Beckwith syndrome and subjects with Class III malocclusion. Master's Thesis, University of Washington, Seattle

Baer M J, Nanda S K 1976 A commentary on the growth and form of the cranial base. In: Bosma J F (ed.) Development of the basicranium. U.S. Department of Education, Health and Welfare Publication No. (NIH) 76–989, Bethesda, pp.515–536

Battagel J M 1993 The aetiological factors in Class III malocclusion. European Journal of Orthodontics 15: 347–370

Birch R H 1968 Foetal retrognathia and the cranial base. Angle Orthodontist 38: 231–235

Björk A 1951 Some biological aspects of prognathism and occlusion of the teeth. Angle Orthodontist 21: 3–27

Bookman D J *et al.* 1974 Inheritance of the craniofacial complex in Class III malocclusion. Master's Thesis, University Michigan, Ann Arbor

Chang H-P, Kinoshita Z, Kawamoto T 1992 Craniofacial pattern of Class III deciduous dentition. Angle Orthodontist 62: 139–144

Cole S C 1988 Natural head position, posture, and prognathism. British Journal of Orthodontics 15: 227–239

Craig C E 1951 The skeletal patterns characteristic of Class I and Class II, Division 1 malocclusions in *norma lateralis*. Angle Orthodontist 21: 44–56

Dibbets J M H 1977 Juvenile temporomandibular joint dysfunction and craniofacial growth. A statistical analysis. Stafleu and Tholen, Leiden

Emrich R E, Brodie A G, Blanley J R 1965 Die Verbreitung von Anomalien der Klassen I, II und III bei einer stadtischen Population. Deutsche Zahnarztliche Zeitschrift 20: 87–94

Enlow D H 1990 Facial growth, 3rd edition. W B Saunders, Philadelphia

Fischer-Brandies H, Fischer-Brandies E, Dielert E 1985 Über die Gesamtlänge und den Achsenwinkel des Unterkiefers. Eine Analyse seitlicher Fernröntgenbilder. Fortschritte der Kieferorthopädie 46: 241–246

Fisk G V, Culbert M R, Grainger R M, Hemrend B, Moyers R E 1953 The morphology and physiology of distocclusion. A summary of our present knowledge. American Journal of Orthodontics 39: 3–12

Furlong F J 1954 A radiographic investigation of the temporomandibular joint in Class III malocclusion. Master's Thesis, Northwestern University of Chicago

Gebeck T R 1969 A cephalometric study of moderate Class III malocclusion. Master's Thesis, University of Michigan, Ann Arbor

Guyer E C, Ellis E E, McNamara J A, Behrents R G 1986 Components of Class III malocclusion in juveniles and adolescents. Angle Orthodontist 56: 7–30

Harris J E 1965 Cranio-facial growth and malocclusion. Transactions of the European Orthodontic Society, pp. 103–119

Harris J E 1975 Genetic factors in the growth of the head. Inheritance of the craniofacial complex and malocclusion. Dental Clinics of North America 19: 151–160

Harris J E, Kowalski C J, Walker S J 1975 Dentofacial differences between 'normal' sibs of Class II and Class III parents. Angle Orthodontist 45: 103–107

Hellsing E, McWilliam J, Reigo T, Spangfort E 1987 The relationship between craniofacial morphology, head posture and spinal curvature in 8, 11 and 15-year old children. European Journal of Orthodontics 9: 254–264

Hirschfelder H, Hirschfelder U 1982a Die Halswirbelsäule im seitlichen Fernröntgenbild aus orthopädischer Sicht. Fortschritte der Kieferorthopädie 43: 52–56

Hirschfelder U, Hirschfelder H 1982b Veranderungen der oberen Halswirbelsaule bei Patienten des progenen Formenkreises. Deutsche Zahnarztliche Zeitschrift 37: 691–698

Hopkin G B, Houston W J B, James G A 1968 The cranial base as an aetiological factor in malocclusion. Angle Orthodontist 38: 250–255

Horowitz S L, Converse J M, Gerstman L J 1969 Craniofacial relationships in mandibular prognathism. Archives of Oral Biology 14: 121–131

Houston W B J, Stephens C D, Tulley W J 1992 A textbook of orthodontics. 2nd edition. Wright, Oxford

Huggare J 1991 Association between morphology of the first cervical vertebra, head posture, and craniofacial structures. European Journal of Orthodontics 13: 435–440

Hunter W S 1967 The vertical dimensions of the face and skeletodental retrognathism. American Journal of Orthodontics 53: 586–595

Jacobson A 1975 The 'Wits' appraisal of jaw disharmony. American Journal of Orthodontics 67: 125–138

Jacobson A, Evans W G, Preston C B, Sadowsky P L 1974 Mandibular prognathism. American Journal of Orthodontics 66: 140–171

Järvinen S 1980 Relation of the SNA angle to the saddle angle. American Journal of Orthodontics 78: 670–673

Järvinen S 1988 Relation of the Wits appraisal to the ANB angle: a statistical appraisal. American Journal of Orthodontics and Dentofacial Orthopedics 94: 432–436

Joffe B M 1965 Cephalometric analysis of mandibular prognathism II. Journal of the Dental Association of South Africa 20: 173–180

Kantorowicz A 1915 Die Progenie und ihre Vererbung. Deutsches Monatsschrift für Zahnheilkunde 33: 105–128

Katz MI 1992a Angle classification revisited. 1: is current use reliable? American Journal of Orthodontics and Dentofacial Orthopedics 102: 173–179

Katz MI 1992b Angle classification revisited. 2: a modified Angle classification. American Journal of Orthodontics and Dentofacial Orthopedics 102: 277–284

Kerr W J, Adams C P 1988 Cranial base and jaw relationship. American Journal of Physical Anthropology 77: 213–220

Kerr W J S, Miller S, Ayme B, Wilhelm N 1994 Mandibular form and position in 10-year old boys. American Journal of Orthodontics and Dentofacial Orthopedics 106: 115–120

Knowles C C 1963 The influence of cranial base structure on the orientation of the middle third of the face. Dental Practitioner 13: 531–542

Koski K 1960 Some aspects of the growth of the cranial base and the upper face. Odontologisk Tidskrift 68: 344–358

Linder-Aronson S 1979 Naso-respiratory function and craniofacial growth. In: McNamara J A (ed.) Nasorespiratory function and craniofacial growth. Monograph No 9, Craniofacial Growth Series, Center for Human Growth and Development, University of Michigan, Ann Arbor, pp. 121–147

Litton S F, Ackermann L V, Isaacson R J, Shapiro B L 1970 A genetic study of Class III malocclusion. American Journal of Orthodontics 58: 565–577

Lowe B F, Phillips C, Lestrel P E, Fields H W 1994 Skeletal jaw relationships: a quantitative assessment using elliptical Fourier functions. Angle Orthodontist 64: 299–310

Maj G, Luzi C, Lucchese P 1960 A cephalometric appraisal of Class II and Class III malocclusions. Angle Orthodontist 30: 26–34

Martone V D, Enlow D H, Hans M G, Broadbent B H, Oyen O 1992 Class I and Class III malocclusion subgroupings related to headform type. Angle Orthodontist 62: 35–44

Moyers R E 1988 Handbook of orthodontics. 4th edition. Year Book Medical Publishers, Chicago

Nakasima A, Ichinose M, Nakata S, Takahama Y 1982 Hereditary factors in the craniofacial morphology of Angle's Class II and Class III malocclusion. American Journal of Orthodontics 82: 150–156

Nanda S K 1983 The developmental basis of occlusion and malocclusion. Quintessence, Chicago

Nelson W E, Highley B 1948 The length of mandibular basal bone in normal occlusion and Class I malocclusion compared to Class II, division I malocclusion. American Journal of Orthodontics 34: 610–617

Proffit W R, Fields H W 1993 Contemporary orthodontics. 2nd edition. Mosby Year Book, St. Louis

Raynes J G 1956 A study of facial patterns of individuals with class III malocclusions. Master's Thesis, University of Washington, Seattle

Rinchuse D J, Rinchuse D J 1989 Ambiguities of Angle's classification. Angle Orthodontist 59: 295–297

Schwarz A M 1931 Die Ontogenese des menschlichen Gebisses in ihren Beziehungen zur Orthodontik. Fortschritte der Orthodontie 1: 8–21

Sicher H 1947 The growth of the mandible. American Journal of Orthodontics and Oral Surgery 33: 30–35

Sicher H, Krasa F C 1920 Anatomische Untersuchungen an Schadeln mit Stellungsanomalien der Zahne. Osterreichische Zeischrift für Stomatolgie 18: 375–403

Solow B, Siersbæk-Nielsen S 1986 Growth changes in head posture related to craniofacial development. American Journal of Orthodontics 89: 132–140

Solow B, Tallgren A 1976 Head posture and craniofacial morphology. American Journal of Physical Anthropology 44: 417–436

Stapf W C 1940 A roentgenographic appraisal of the facial pattern in Class III malocclusion (Angle). Master's Thesis, University of Illinois, Chicago

Stein K F, Kelley T J, Wood E 1956 Influence of heredity in the etiology of malocclusion. American Journal of Orthodontics 42: 125–141

Timmons L S 1958 Integration of certain variants as a determinant of facial morphology in Class III malocclusion (Angle). Master's Thesis, University Illinois, Chicago

Treuenfels von H 1981 Die Relation der Atlasposition bei prognather und progener Kieferanomalie. Fortschritte der Kierferorthopädie 42: 482–491

Vig P S, Sarver D M, Hall D J, Warren D W 1981 Quantitative evaluation of nasal airflow in relation to facial morphology. American Journal of Orthodontics 79: 263–272

Wells D L 1970 A multivariate cephalometric study of Class II, division 2 malocclusion. Master's Thesis, University of Michigan, Ann Arbor

Woodside D G, Linder-Aronson S, Lundstrtm A, McWilliam J 1991 Mandibular and maxillary growth after changed mode of breathing. American Journal of Orthodontics and Dentofacial Orthopedics 100: 1–18