Relationship between dental arch width and vertical facial morphology in untreated adults

C. Matthew Forster*, Elaine Sunga** and Chun-Hsi Chung***

*Private Practice, Newport, Rhode Island, **Private Practice, San Diego, California and ***Department of Orthodontics, School of Dental Medicine, University of Pennsylvania, Philadelphia, USA

SUMMARY The objectives of this study were to investigate if a relationship exists between dental arch width and the vertical facial pattern determined by the steepness of the mandibular plane, and to examine the differences in dental arch widths between male and female untreated adults. Lateral cephalograms and dental casts were obtained from 185 untreated Caucasians (92 males, 93 females) between 18 and 68 years of age with no crossbite, minimal crowding, and spacing. The angle of the mandibular plane (MP) to the anterior cranial base (SN) was measured on cephalograms of each patient. Dental casts were used to obtain comprehensive dental measurements including maxillary and mandibular intercanine, interpremolar, and intermolar widths, as well as the amount of crowding or spacing. The arch widths of males and females were analysed and the differences between them were tested for significance using a Student's *t*-test. Regression analysis was used to determine the statistical significance of the relationships between MP–SN angle and dental arch width and crowding or spacing.

The results showed that male arch widths were significantly larger than those of females ($P < 0.05$). For both males and females, there was a trend that as MP–SN angle increased, arch width decreased. It was concluded that dental arch width is associated with gender and facial vertical morphology. Thus, using individualized archwires according to each patient's pre-treatment arch form and width is suggested during orthodontic treatment.

Introduction

It is generally accepted among orthodontists that a relationship exists between vertical facial morphology and the cant of the mandibular plane. Schudy (1964, 1965) advocated the use of the anterior cranial base (SN) as the reference line to determine the steepness of the mandibular plane (MP). A subject with a high MP–SN angle (steep MP) tends to have a longer face, and one with a low MP–SN angle (flat MP) often has a shorter face (Ricketts *et al.*, 1982; Enlow and Hans, 1996).

A long-face individual usually has narrower transverse dimensions (dolichofacial) and a short-face individual wider transverse dimensions (brachyfacial), according to Ricketts *et al.* (1982), Enlow and Hans (1996), and Wagner and Chung (2005). A question therefore arises as to the relationship between vertical facial morphology and dental arch width. Also, is there any difference in arch widths between male and female subjects? Several studies have addressed these questions, but their results were inconclusive. For example, Howes (1957) found that steep MP individuals generally had larger teeth and narrower and shorter arches than flat mandibular plane individuals when measured from the buccal cusp tips of the maxillary first premolars. Isaacson *et al.* (1971) reported that subjects with longer faces presented with a decrease in maxillary intermolar width. However, they did not distinguish between males and females. Nasby *et al.* (1972) noted that the mean maxillary and mandibular arch

circumference and mandibular intermolar width were greater in subjects with low MP–SN angles when compared with those with high MP–SN angles. In their study, the subjects were adolescents without discussion of gender and ethnicity. Using postero-anterior (PA) cephalograms, Christie (1977) found that adult brachyfacial males, when compared with 'standard' males, had greater maxillary and mandibular widths. No difference, however, was found in the arch widths of brachyfacial versus standard females.

In terms of the difference in arch width between males and females, Wei (1970) evaluated PA cephalograms of Chinese adults and noted gender differences in maxillary and mandibular intercanine widths. Eroz *et al.* (2000) reported that in children, males had significantly larger intermolar widths when compared with females.

Clinically, preformed archwires are routinely used by many orthodontists regardless of the facial type and gender of the patients. The purpose of the present study was to investigate if dental arch widths are correlated with vertical facial types (MP–SN angle) and if there are any differences in arch widths between untreated male and female adults.

Subjects and methods

Sample

One hundred and eighty-five untreated Caucasian adults (92 males, 93 females) aged from 18 to 68 years, whose initial

orthodontic records were taken at the University of Pennsylvania Orthodontic Clinic ($n = 35$) and six local private practice offices (n = 11, 21, 22, 26, 34, 36, respectively) were included in this study. Inclusion criteria included a full dentition except third molars, pre-treatment lateral cephalogram, and maxillary and mandibular dental casts available. Exclusion criteria included previous orthodontic treatment, edentulous spaces, history of trauma, significant cuspal wear, extensive restorations or prosthetics, anterior and posterior crossbites, and severe crowding (>9 mm) or spacing (>9 mm).

The sample was randomly selected, and then, for descriptive purposes, the subjects were classified into three different groups according MP–SN angle: low <27 degrees, average 27–37 degrees, and high >37 degrees. These values represent 1 standard deviation (SD) from the average MP–SN angle reported by Riedel (1952).

Measurements

For each subject, MP–SN angle was measured. The mandibular plane was drawn from menton (Me) to the inferior border of the angular area of the mandible (Schudy, 1965; Figure 1).

Dental cast measurements were performed using a digital calliper accurate to 0.01 mm. The following maxillary and mandibular dimensions were measured (Figure 2):

1. intercanine width (buccal cusp tip and widest labial aspect),
2. first and second interpremolar widths (buccal cusp tip and widest labial aspect),
3. first intermolar widths (mesiobuccal cusp, central fossa, widest buccal, and narrowest lingual aspect),
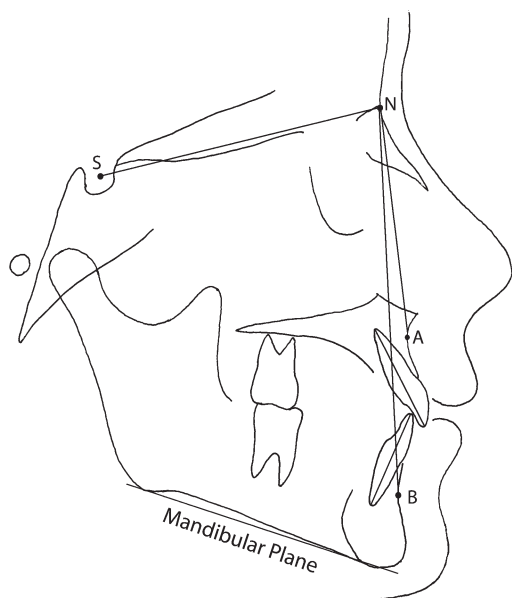4. tooth size—arch length discrepancy.

Tooth size—arch length discrepancy was calculated by first determining the arch length available (Figure 3). The arch length required was then subtracted from this value. Arch length required was equal to the sum of the mesiodistal widths of each individual tooth from second premolar to second premolar, measured from the contact points (Proffit, 2000).

The description of the male and female sample in terms of age, MP–SN angle, ANB angle (point A—nasion—point B, Figure 1), and amount of crowding or spacing are shown in Table 1.

Statistical analysis

Descriptive statistics, including the mean and SD, were calculated for all measurements. A Student's two-tailed
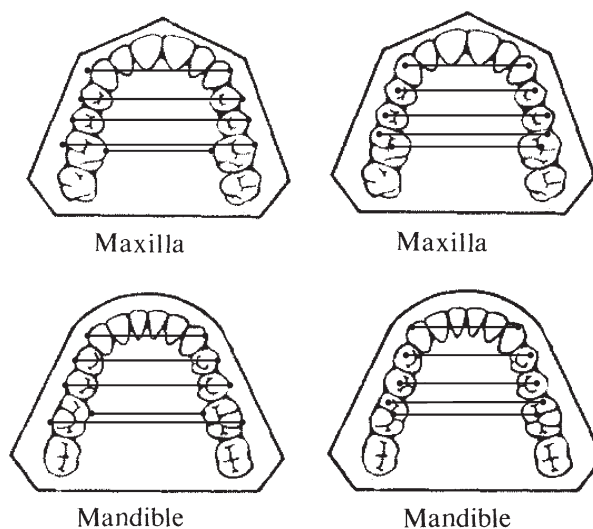

Figure 2 Arch width measurements of the cusp, fossa, most labial, and most lingual on the dental casts.
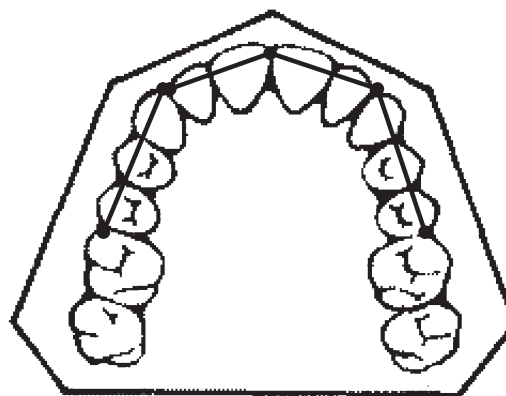

Figure 3 Measurements for arch length available by summing the distances from the mesial contact point of the left first molar to the distal contact point of the left lateral incisor, the distal contact point of the left lateral incisor to the mesial contact point of the left central incisor, the mesial contact point of the left central incisor to the distal contact point of the right lateral incisor, and the distal contact point of the right lateral incisor to the mesial contact point of the right first molar.

Figure 1 Lateral cephalometric landmarks used in the study.

t-test was used to determine if the differences in measurements between the male and female groups were significant. Moreover, regression analyses were carried out to determine the degree to which MP–SN variation was predicted by dental arch width and dental crowding in males and females separately.

In order to evaluate intra-examiner error, lateral cephalograms and models of 13 males and 10 females were remeasured after 4 weeks, and their mean differences were used to determine paired *t*-test significance and Pearson's correlation coefficients. Significance for all statistical tests was predetermined at $P < 0.05$.

Results

Intra-examiner measurement error showed a high correlation with Pearson's correlation coefficient values (r) of 0.90–0.99 for all angular and linear measurements. When using the paired *t*-test to compare the means between the duplicate

measurements, only one measurement (maxillary second premolar width) exhibited a statistically significant difference ($P < 0.05$). For this, the mean difference was 0.47 mm and Pearson's correlation coefficient 0.988, indicating a very high degree of consistency between the two trials.

Table 2 shows the dental arch width measurements of male and female subjects. It was clearly demonstrated that males had significantly larger dental arch widths than females ($P < 0.05$).

The arch width measurements of low, average, and high MP–SN angle groups of males and females, respectively, are shown in Tables 3 and 4. The low-angle group had larger arch widths than the high-angle group for most measurements. Table 5 shows the regression analysis of MP–SN angle versus maxillary and mandibular arch widths of males and females. Regression analyses of males showed statistically significant correlations between MP–SN angle and the following arch width measurements: maxillary canine cusp tip, maxillary canine most buccal aspect, maxillary first premolar cusp tip, maxillary second premolar cusp tip, maxillary first molar central fossa, maxillary first molar most buccal aspect, mandibular canine cusp tip, mandibular first premolar cusp tip, and mandibular first premolar most buccal aspect (Table 5). It should be noted that their R square values were small. In terms of females, a significant correlation was found between MP–SN angle and arch width measurements of maxillary first premolar width (buccal cusp tip) and second premolar width (buccal cusp tip and most buccal) (Table 5). Similarly, their R square values were small. All other dental measurements, for males and females, including maxillary and mandibular crowding, were not statistically significant.

Table 1 Description of the sample.

	Male ($n = 92$)		Female ($n = 93$)	
	Mean	SD	Mean	SD
Age (years)	34.8	11.5	36	10.5
MP–SN (degrees)	29.6	7.6	32.2	7.2
ANB (degrees)	3.1	2.4	3.2	1.6
Crowding (−) or spacing (+)				
Maxilla (mm)	−0.2	2.6	−2.6	3
Mandible (mm)	−2.1	2.7	−4.1	3.3

Table 2 Maxillary and mandibular arch width measurements (millimetres).

	Male ($n = 92$)		Female ($n = 93$)		Significance (P)
	Mean	SD	Mean	SD	
Maxilla					
Intercanine width (cusp tip)	33.47	2.52	32.15	2.57	<0.001
Intercanine width (most buccal)	38.49	2.62	37.08	2.24	<0.001
First premolar width (buccal cusp tip)	39.87	3.27	38.68	2.89	0.01
First premolar width (most buccal)	44.36	2.93	42.79	2.58	<0.001
Second premolar width (buccal cusp tip)	45.39	3.38	43.46	3.39	<0.001
Second premolar width (most buccal)	49.34	3.29	47.17	3	<0.001
Intermolar width (mesiobuccal cusp tip)	50.12	3.97	49.03	3.22	0.042
Intermolar width (central fossa)	45.91	3.27	44.16	2.97	<0.001
Intermolar width (most buccal)	56.08	3.49	54.11	3.07	<0.001
Intermolar width (most lingual)	33.23	3.13	31.71	2.74	<0.001
Mandible					
Intercanine width (cusp tip)	24.87	2.16	24.11	2.19	0.02
Intercanine width (most buccal)	30.48	1.84	29.78	1.86	0.01
First premolar width (buccal cusp tip)	32.77	2.73	31.95	2.51	0.03
First premolar width (most buccal)	38.95	2.87	38.01	2.2	0.01
Second premolar width (buccal cusp tip)	37.98	3.17	37.05	3.31	0.05
Second premolar (most buccal)	44.6	2.61	43.46	2.59	0.003
Intermolar width (mesiobuccal cusp tip)	43.81	3.34	42.52	3.1	0.007
Intermolar width (central fossa)	41.02	3.04	39.22	3.14	<0.001
Intermolar width (most buccal)	53.53	3.15	52.16	2.76	0.002
Intermolar width (most lingual)	31.87	2.76	30.22	2.59	<0.001

Table 3 Arch width measurements in millimetres for low, average, and high MP–SN angle males.

	Low MP–SN angle (<27°), n = 29		Average MP–SN angle (27–37°), n = 48		High MP–SN angle (>37°), n = 15	
	Mean	SD	Mean	SD	Mean	SD
Maxilla						
Intercanine width (cusp tip)	34.29	2.82	33.52	2.14	31.74	2.33
Intercanine width (most buccal)	39.20	2.52	38.49	2.59	37.14	2.56
First premolar width (buccal cusp tip)	40.52	3.62	39.98	2.77	38.25	3.75
First premolar width (most buccal)	45.11	2.99	44.39	2.56	42.82	3.48
Second premolar width (buccal cusp tip)	46.08	3.65	45.37	2.88	44.12	4.16
Second premolar width (most buccal)	50.06	3.01	49.41	2.67	47.70	4.92
Intermolar width (mesiobuccal cusp tip)	51.27	3.57	49.71	3.99	49.19	4.37
Intermolar width (central fossa)	46.76	3.38	45.82	2.58	44.54	4.57
Intermolar width (most buccal)	56.97	3.15	55.84	3.09	55.14	4.93
Intermolar width (most palatal)	33.79	3.17	33.25	2.51	32.08	4.50
Mandible						
Intercanine width (cusp tip)	25.68	2.00	24.39	2.07	24.85	2.40
Intercanine width (most buccal)	31.10	1.75	30.08	1.57	30.55	2.48
First premolar width (buccal cusp tip)	33.21	3.22	32.91	2.17	31.48	3.14
First premolar width (most buccal)	39.63	2.39	39.29	1.76	36.56	4.93
Second premolar width (buccal cusp)	38.44	4.04	38.01	2.70	37.03	2.59
Second premolar width (most buccal)	45.30	3.11	44.39	2.06	43.89	2.99
Intermolar width (mesiobuccal cusp tip)	44.72	4.27	43.45	2.40	43.22	3.74
Intermolar width (central fossa)	41.68	3.25	40.61	2.26	41.05	4.48
Intermolar width (most buccal)	54.39	3.21	53.03	2.68	53.46	4.18
Intermolar width (most palatal)	32.66	3.03	31.55	2.18	31.37	3.65

Table 4 Arch width measurements in millimetres for low, average, and high MP–SN angle females.

	Low MP–SN angle (<27°), n = 24		Average MP–SN angle (27–37°), n = 43		High MP–SN angle (>37°), n = 26	
	Mean	SD	Mean	SD	Mean	SD
Maxilla						
Intercanine width (cusp tip)	32.47	2.65	32.13	2.67	31.90	2.36
Intercanine width (most buccal)	37.56	2.21	37.11	2.33	36.59	2.08
First premolar width (buccal cusp tip)	39.20	2.89	38.75	2.98	38.11	2.75
First premolar width (most buccal)	43.21	2.55	42.84	2.61	42.32	2.58
Second premolar width (buccal cusp tip)	44.16	3.16	43.65	3.53	42.51	3.27
Second premolar (most buccal)	47.60	2.88	47.38	3.12	46.41	2.87
Intermolar width (mesiobuccal cusp tip)	49.69	2.58	48.97	3.69	48.52	2.89
Intermolar width (central fossa)	44.73	2.49	44.05	3.33	43.82	2.75
Intermolar width (most buccal)	54.52	2.74	53.92	3.35	54.06	2.95
Intermolar width (most palatal)	32.57	2.25	31.47	3.03	31.33	2.57
Mandible						
Intercanine width (cusp tip)	24.29	2.48	24.23	2.11	23.75	2.07
Intercanine width (most buccal)	29.95	1.76	29.96	1.91	29.32	1.86
Second premolar width (buccal cusp tip)	31.96	2.68	32.14	2.48	31.61	2.49
First premolar width (most buccal)	37.75	2.08	38.29	2.27	37.79	2.21
Second premolar width (buccal cusp tip)	37.04	2.91	37.02	3.71	37.10	3.05
Second premolar width (most buccal)	43.05	2.45	43.75	2.83	43.38	2.34
Intermolar width (mesiobuccal cusp tip)	42.69	3.65	42.33	3.02	42.68	2.76
Intermolar width (central fossa)	38.80	3.57	39.24	3.24	39.56	2.56
Intermolar width (most buccal)	51.82	2.65	52.24	2.99	52.36	2.51
Intermolar width (most palatal)	30.08	2.61	30.20	2.89	30.38	2.09

Discussion

The results of this study were analysed with regression line fit plots. The sample was drawn randomly from a group of untreated subjects, allowing the use of this analysis. Because the independent variable (MP–SN) and all of the predictor measurements were continuous variables, it was more appropriate to analyse the data with regression analysis rather than ANOVA. However, as the untreated subjects were not recruited from a population sample but from a university clinic and six local private practice offices, some inherent bias might be possible.

Table 5　Regression analysis of MP–SN versus hypothetical predictors.

	Male (n = 92)		Female (n = 93)	
	R square	Significance (P)	R square	Significance (P)
Maxillary predictors (mm)				
Intercanine width (cusp tip)	0.102	0.002	0.001	0.755
Intercanine width (most buccal)	0.073	0.009	0.023	0.144
First premolar width (buccal cusp tip)	0.057	0.022	0.046	0.039
First premolar width (most buccal)	0.061	0.017	0.036	0.07
Second premolar width (buccal cusp tip)	0.04	0.055	0.045	0.042
Second premolar (most buccal)	0.039	0.061	0.041	0.05
Intermolar width (mesiobuccal cusp tip)	0.034	0.076	0.017	0.212
Intermolar width (central fossa)	0.059	0.019	0.011	0.307
Intermolar width (most buccal)	0.052	0.029	0.004	0.541
Intermolar width (most lingual)	0.036	0.071	0.023	0.15
Crowding	0.017	0.22	0.005	0.511
Mandibular predictors (mm)				
Intercanine width (cusp tip)	0.046	0.041	0.006	0.455
Intercanine width (most buccal)	0.03	0.096	0.017	0.216
First premolar width (buccal cusp tip)	0.06	0.019	0.017	0.214
First premolar width (most buccal)	0.129	0	0.009	0.363
Second premolar width (buccal cusp tip)	0.016	0.23	0	0.87
Second premolar width (most buccal)	0.026	0.125	0	0.976
Intermolar width (mesiobuccal cusp tip)	0.023	0.152	0	0.932
Intermolar width (central fossa)	0.009	0.356	0.013	0.278
Intermolar width (most buccal)	0.018	0.204	0.005	0.493
Intermolar width (most lingual)	0.019	0.195	0.003	0.632
Crowding	0.012	0.292	0	0.978

The MP–SN angle was used as the measurement of vertical facial morphology in the present study. However, due to natural cranial variation, there may be variation in the anterior cranial base (SN), which may tip up or down. The ratio of posterior face height (PFH, S–Go) to anterior face height (AFH, Na–Me) is another measurement for vertical facial morphology not based on the mandibular plane (Björk, 1969). Further research is required to determine if there is a correlation between PFH/AFH ratio and dental arch width.

Only skeletal Class I (as determined by ANB angle) subjects were examined because more dental compensation is expected in skeletal Class II or III subjects, which might obscure the relationship between vertical facial morphology and transverse dental arch widths.

The present study investigated untreated adult males and females separately. It has previously been demonstrated that males and females exhibit different skeletal facial dimensions (Wei, 1970; Ingerslev and Solow, 1975; Chung and Wong, 2002; Chung and Mongiovi, 2003), as well as differences in maxillary and mandibular arch widths (Moyers et al., 1976; Christie, 1977). Unfortunately, many of the earlier studies that examined arch width and mandibular plane angle combined the genders (Howes, 1957; Isaacson et al., 1971; Nasby et al., 1972; Schulhof et al., 1978). In addition, the present sample was limited to non-growing, adult individuals, unlike many of the previous investigations that included only growing children (Isaacson et al., 1971; Nasby et al., 1972; Eroz et al., 2000).

Ideally, this type of study should be conducted using patients with ideal dentitions without any crowding or spacing. However, due to difficulties in finding ideal untreated subjects and subsequent limitations in sample size, those with crowding and spacing up to 9 mm were included. The relationship between crowding (spacing) and arch width was also examined. Interestingly, the data suggested that the cant of mandibular plane was not related to maxillary or mandibular crowding for males and females. This is in direct opposition to the findings of Nasby et al. (1972) and Christie (1977).

For the maxillary arch, there was a statistically significant inverse relationship between the mandibular plane angle and dental arch width between the maxillary canines, first premolars, second premolars, first molars in males, and between the second premolar widths (cusp tip and most buccal measurements) in females. However, statistical analysis showed that the R square value was small, which suggests that the correlation was not very strong.

For the mandibular arch, it was found that males had a statistically significant correlation between the mandibular plane angle and mandibular intercanine and first interpremolar widths. Similar to the maxillary arch, the R square value was small, suggesting the correlation was not strong. No significant correlation was found for females.

In contrast to Nasby et al. (1972), who demonstrated narrower mandibular intermolar widths in high-angle children, the present data did not support such a relationship between mandibular intermolar width and mandibular plane

angle. Wagner and Chung (2005) found that while the growth of the maxilla plateaus at about 14 years of age, the skeletal width of the mandible continues to grow, at least in low- and average-angle groups. It is conceivable that as the mandible continues to increase in width, the mandibular molars compensate by inclining lingually and thereby maintaining the intermolar width. In fact, a number of authors have suggested that individuals with increased vertical dimensions have posterior teeth that tend to be more buccally inclined, whereas those with decreased vertical dimensions have posterior teeth that tend toward more lingual inclination (Isaacson *et al.*, 1971; Schudy, 1971; Schendel *et al.*, 1976; Guilherme *et al.*, 2004).

Musculature has been considered as a possible link in this close relationship between the transverse dimension and vertical facial morphology. In fact, a number of studies have illustrated the influence of masticatory muscles on craniofacial growth. The general consensus is that individuals with strong or thick mandibular elevator muscles tend to exhibit wider transverse head dimensions (Ringqvist, 1973; Ingervall and Helkimo, 1978; Weijs and Hillen, 1984; Hannam and Wood, 1989; Kiliaridis and Kalebo, 1991; Van Spronsen *et al.*, 1991; Bakke *et al.*, 1992; Kiliaridis, 1995). Strong masticatory musculature is often associated with a brachyfacial pattern (short face). This muscular hyperfunction causes an increased mechanical loading of the jaws. This, in turn, may cause an induction of sutural growth and bone apposition which then results in increased transverse growth of the jaws and bone bases for the dental arches. Several studies investigating masseter thickness have also illustrated an effect on the inclination of posterior teeth such that subjects with short faces generally exhibit increased masseter muscle mass, which may result in posterior teeth that are more lingually inclined (Weijs and Hillen, 1984; Kiliaridis and Kalebo, 1991; Van Spronsen *et al.*, 1991; Bakke *et al.*, 1992; Tsunori *et al.*, 1998).

Dental arch width is certainly a multifactorial phenomenon (Schulhof *et al.*, 1978). Although the data from the present study showed an inverse trend between MP–SN angle and dental arch widths, the correlation was not very strong. It seems the MP–SN angle might be only one of the contributing factors. Moreover, in agreement with Eroz *et al.* (2000), the results demonstrated that the male arch widths were significantly greater than female arch widths. This highlights the importance of using individualized archwires according to pre-treatment arch form and width for each patient during orthodontic treatment.

Conclusions

The following conclusions can be made from this study:

1. The dental arch widths in males were significantly greater than those in females.

2. In both males and females, as MP–SN angle increased, arch width tended to decrease.

3. Since dental arch width is associated with gender and facial vertical morphology, using individualized archwires according to each patient's pre-treatment arch form and widths is suggested during orthodontic treatment.

Address for correspondence

Dr Chun-Hsi Chung
Department of Orthodontics
School of Dental Medicine
University of Pennsylvania
240 South 40th Street
PA 19104-6003
USA
E-mail: chunc@pobox.upenn.edu

References

Bakke M, Tuxen A, Vilmann P, Jensen B R, Vilamann A, Toft M 1992 Ultrasound image of human masseter muscle related to bite force, electromyography, facial morphology, and occlusal factors. Scandinavian Journal of Dental Research 100: 164–171

Björk A 1969 Prediction of mandibular growth rotation. Angle Orthodontist 55: 585–599

Christie T E 1977 Cephalometric patterns of adults with normal occlusion. Angle Orthodontist 47: 128–135

Chung C-H, Mongiovi V D 2003 Craniofacial growth in untreated skeletal Class I subjects with low, average, and high MP-SN angles: a longitudinal study. American Journal of Orthodontics and Dentofacial Orthopedics 124: 670–678

Chung C-H, Wong W W 2002 Craniofacial growth in untreated in Class II subjects: a longitudinal study. American Journal of Orthodontics and Dentofacial Orthopedics 122: 619–626

Enlow D, Hans M G 1996 Essentials of facial growth. W.B. Saunders Company, Philadelphia

Eroz U B, Ceylan I, Aydemir S 2000 An investigation of mandibular morphology in subjects with different vertical facial growth patterns. Australian Orthodontic Journal 16: 16–22

Guilherme J, Bombonatti R, Cruz K S, Hassaunuma C Y, Del Santo Jr M 2004 Buccolingual inclinations of posterior teeth in subjects with different facial patterns. American Journal of Orthodontics and Dentofacial Orthopedics 125: 316–322

Hannam A G, Wood W W 1989 Relationships between the size and spatial morphology of masseter and medial pterygoid muscles, the craniofacial skeleton, and jaw biomechanics. Amerian Journal of Physical Anthropology 80: 429–445

Howes A 1957 Arch width in the premolar region—still the major problem in orthodontics. American Journal of Orthodontics 43: 5–31

Ingerslev C H, Solow C H 1975 Sex differences in craniofacial morphology. Acta Odontologica Scandinavica 33: 85–94

Ingervall B, Helkimo E 1978 Masticatory muscle force and facial morphology in man. Archives of Oral Biology 23: 203–206

Isaacson J R, Isaacson R J, Speidel T M, Worms F W 1971 Extreme variation in vertical facial growth and associated variation in skeletal and dental variations. Angle Orthodontist 41: 219–230

Kiliaridis S 1995 Masticatory muscle influence on craniofacial growth. Acta Odontologica Scandinavica 53: 196–202

Kiliaridis S, Kalebo P 1991 Masseter muscle thickness measured by ultrasonography and its relation to facial morphology. Journal of Dental Research 70: 1262–1265

Moyers R E, Van der Linden F P G M, Riolo M C, McNamara Jr J A 1976 Standards of human occlusal development. Monograph No. 5. Craniofacial Growth Series, Center for Human Growth and Development, University of Michigan, Ann Arbor

Nasby J A, Isaacson R J, Worms F W, Speidel T M 1972 Orthodontic extractions and facial skeletal pattern. Angle Orthodontist 42: 116–122

Proffit W R 2000 Contemporary orthodontics. Mosby, St. Louis

Ricketts R M, Roth R H, Chaconas S J, Schulhof R J, Engel G A 1982 Orthodontic diagnosis and planning. Rocky Mountain Data Systems, Denver

Riedel R A 1952 The relation of maxillary structures to cranium in malocclusion and normal occlusion. Angle Orthodontist 22: 142–145

Ringqvist M 1973 Isometric bite force and its relation to dimensions of the facial skeleton. Acta Odontologica Scandinvica 31: 35–42

Schendel S, Einsfeld J, Bell W 1976 The long face syndrome: vertical maxillary excess. American Journal of Orthodontics 70: 398–408

Schudy F F 1964 Vertical growth versus anteroposterior growth as related to function and treatment. Angle Orthodontist 34: 75–93

Schudy F F 1965 The rotation of the mandible resulting from growth: its implications in orthodontic treatment. Angle Orthodontist 35: 36–50

Schudy F F 1971 Cant of the occlusal plane and axial inclinations of the teeth. Angle Orthodontist 41: 219–229

Schulhof R J, Lestrel P E, Walters R, Schuler R 1978 The mandibular dental arch: part III. Buccal expansion. Angle Orthodontist 48: 303–310

Tsunori M, Mashita M, Kasai K 1998 Relationship between facial types and tooth and bone characteristics of the mandible obtained by CT scanning. Angle Orthodontist 68: 557–562

Van Spronsen P H, Weijs W A, Prahl-Andersen B, Valk J, Van Finkel F 1991 Relationships between jaw muscle cross-sections and normal craniofacial morphology, studied with magnetic resonance imaging. European Journal of Orthodontics 13: 351–361

Wagner D C, Chung C-H 2005 Transverse growth of the maxilla and mandible in untreated girls with low, average, and high MP-SN angles: a longitudinal study. American Journal of Orthodontics and Dentofacial Orthopedics 128: 716–723

Wei S H 1970 Craniofacial width dimensions. Angle Orthodontist 40: 141–147

Weijs W A, Hillen B 1984 Relationships between muscle cross-section and skull shape. Journal of Dental Research 63: 1154–1157