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The Denture Frame Analysis: an additional diagnostic tool

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SUMMARY The purpose of this study was to evaluate the Denture Frame Analysis. This adjunctive cephalometric analysis of the lateral headfilm was introduced in Japan, but no data exist for the Caucasian population at present. One-hundred-and-six Caucasians were randomly selected and assigned to one of four groups, according to their malocclusion: Angle Classes I, II, and III, and anterior open bite. Statistical testing showed significant differences among the four groups for most of the measurements investigated. The Denture Frame Analysis distinguished the different types of malocclusion, and evaluated skeletal and dental relationships. The occlusal plane aids in the determination of the objectives and limits of orthodontic therapy.

Introduction

Lateral cephalometric headfilms are used to determine the facial skeletal and soft-tissue relationships, and to perform facial skeletal and soft-tissue growth estimations. They are also used to illustrate the major orthodontic treatment planning decisions in the sagittal plane, particularly with reference to the effect of incisor positioning on lip protrusion. While the validity of using the lateral cephalogram for making clinically-related treatment decisions can be questioned (McDowell, 1970; Baumrind, 1991), most orthodontists incorporate cephalometric data into therapeutic decisions.

Sato (1987) introduced the Denture Frame Analysis (DFA) based on cephalometric data of 61 Japanese subjects. The Denture Frame is a triangle formed by the palatal plane (PP), the A–B plane (AB), and the mandibular plane (MP), and assesses the position of teeth in terms of a maxillary occlusal plane related to this triangle. At first sight, the triangular Denture Frame seems to equal Tweed's triangle (Tweed, 1962, 1963). A careful exploration, however, reveals noteworthy differences in the geometry and clinical consequences since the occlusal plane is related to the triangle. Sato and Suzuki (1988), Sato *et al.* (1988a,b), and Sato (1991) assessed patients with severe dental and skeletal malocclusions for planning orthodontic treatment using the DFA as an adjunctive cephalometric evaluation, as it is not intended for total facial analysis (e.g. lips, profile). These patients underwent successful orthodontic therapy, although their skeletal discrepancies showed a significant open bite or a reverse incisal relationship. This type and extent of skeletal misproportion may have been treated by orthognathic surgery in Europe.

Until now the DFA has been used only in the Japanese population. The distribution of malocclusions was found to be different in a Japanese population from that in a Caucasian population. The Asiatics have a greater tendency toward skeletal open bites (Sassouni, 1969). Open bites were found in 5.4 per cent of Japanese school children (Susami *et al.*, 1971), while Class III malocclusions exist in approximately 13 per cent of the whole population (Ishii *et al.*, 1987). The general facial appearance of this population appears to be prognathic (Uesato *et al.*, 1978; Engel and Spolter, 1981).

The aim of the present study was to apply the DFA to a randomized Austrian sample and to determine if the DFA is able to describe malocclusions. Some commonly used standard cephalometric measurements were applied as a reference for comparison and interpretation of the measurements.

Subjects and methods

The sample

The data for this study were gathered from two private orthodontic offices and five public dental centres in Vienna, Austria, over a period of 10 months. The offices were selected according to demographic data in order to randomize the population of the study. The data were collected on first-time patients as they presented for treatment. Informed consent was given. From all patients examined, 120 individuals were randomly selected. Fourteen subjects had an anterior open bite caused by habits and were excluded from the study, since anterior open bite has a multifactorial aetiology (Kim, 1987). During the mixed dentition period, open bite malocclusions can show normal vertical relations of the maxillae without subsequent development of a skeletal open bite in the permanent dentition. Open bites have been found to close spontaneously in approximately half of a Caucasian sample (Finlay and Richardson, 1995). During the mixed dentition period open bites caused by thumb sucking should not be classified as skeletal open bite. Therefore, the open bite sample of this study also included individuals of a higher age without pernicious habits and without spontaneous correction of the open bite malocclusion. This study evaluated 106 Caucasian patients (36 males, 70 females) aged from 5 to 41 years (Table 1).

Table 1 Distribution of sex and age in the Classes I, II, III and open bite.

	n	Male	Female	Age (years) (mean ± SD)	Median
Class I	32	12	20	11.6 ± 4.3	11.0
Class II	40	14	26	13.3 ± 6.3	12.0
Class III	16	6	10	11.4 ± 4	11.0
Open bite	18	4	14	19.4 ± 11.8	15.5

Each patient examined had the following records: a clinical record of the malocclusion, a lateral cephalometric headfilm, and mounted dental casts. The patients were assigned to groups according to the Angle classification as identified on the mounted casts by eye. Open bites were the fourth group evolving as zero or negative vertical incisal relationship and precluding oral habits.

The four investigators who conducted the clinical examination, the cast analyses, and the cephalometric tracings, were not involved with any patient treatment. The following standard cephalometric measurements were made:

- The angles S–N–A, S–N–B, and A–N–B in degrees.
- The Björk sum.
- The inclination of the maxillary incisor to the sella–nasion plane (S–N) and the inclination of the mandibular incisor to the mandibular plane in degrees.
- The protrusion of the maxillary and mandibular incisor to the facial plane (N–Pg) in mm.
- The upper and lower lip to the aesthetic plane according to Ricketts (UL–EP, LL–EP) in mm.
- The denture–base relationship (Wits appraisal) in mm.
- The overjet referenced to the Frankfort Horizontal in mm.
- The overbite referenced to the perpendicular to the Frankfort Horizontal in mm.
- The facial height ratio: Posterior facial height (distance sella–gonion in mm) divided by the anterior facial height (nasion–menton in mm), and expressed as a percentage.

Measurements used in the Denture Frame Analysis (Figure 1)

- The angle between the Frankfort Horizontal plane and the mandibular plane (FH–MP) in degrees.
- The angle between the palatal plane and the mandibular plane (PP–MP) in degrees.

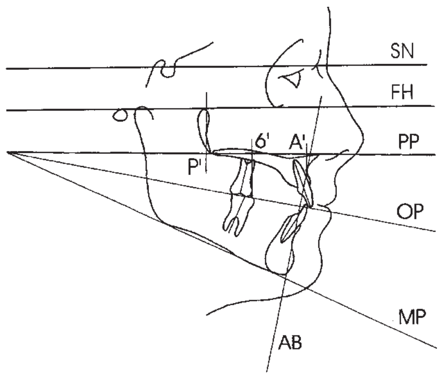

Figure 1 Tracing with the measurements of the Denture Frame Analysis.

- The angle between the sella–nasion plane and the mandibular plane (SN–MP) in degrees.
- The angle between the sella–nasion plane and the palatal plane (SN-PP) in degrees.
- The angle between the occlusal plane and the mandibular plane (OP–MP) in degrees; the occlusal plane is defined as a line drawn from the upper central incisal edge to the midpoint between the mesial and distal cusp of the upper first molar.
- The ratio of the angles formed by the planes OP–MP and PP–MP (OP–MP/PP–MP).
- The angle between the A–B plane and the mandibular plane (AB–MP) in degrees.
- The distance between the perpendicular extensions of points A and P on the palatal plane (A′P′) in mm; point A′ is the perpendicular projection of point A to the palatal plane and point P′ is the perpendicular projection of the posterior-most point of the maxillary tuberosity to the palatal plane (Figure 1).
- The distance between points A′ and 6′ (A′6′) in mm; the anterior maxillary base length is defined by the measurement between A′ and 6′. Point 6′ is the perpendicular projection of the anterior-most point on the proximal surface of the maxillary first molar to the palatal plane (Figure 1).
- The ratio of the anterior maxillary base length A′6′ to the maxillary base length A′P′ (A′6′/A′P′).
- The inclination of the maxillary and mandibular incisor to the A–B plane in degrees.
- The protrusion of the maxillary and mandibular incisor to the A–B plane in mm.
- The intermolar angle, i.e. the angle between the long axes of the upper and lower first permanent molars in degrees.

The reproducibility of the measurements in terms of intra-operator reliability of the cephalometric tracings was tested for the four investigators using Dahlberg's equation

$$s = \sqrt{\frac{\sum d^2}{2n}}$$

where d is the difference of two measurements and n the number of tested radiographs. From the sample, 10 lateral cephalograms were selected at random and each radiograph was traced by each investigator twice. The time span between the two tracings was 6 months. Twenty-two parameters from the above standard and DFA measurements were subjected for testing (SNA, SNB, Björk sum, FH–MP, PP–MP, SN–MP, SN–PP, OP–MP, AB–MP, A′P′, A′6′, inclination of the upper incisor to S–N and to A–B, protrusion of the upper incisor to N–Pg and to A–B, inclination of the lower incisor to MP and to A–B, protrusion of the lower incisor to N–Pg and to A–B, Wits appraisal, overjet, overbite). For the angular measurements, s ranged from 0.5 to 1.8 degrees (mean: 1 degree) and for linear measurements, 0.3–1.3 mm (mean: 0.7 mm).

Results

Using SAS Statistical Package® (SAS Institute Inc., Cary, NC, USA), descriptive statistics were calculated for each variable. Depending on the distribution of the data either the one-way analysis of variance or the non-parametric Kruskal–Wallis test were used for group comparison. The statistical significance was determined as $P < 0.05$.

In the standard measurements (Table 2), significant intergroup differences existed for the angle ANB, the Björk sum, the inclination of the lower incisor to the mandibular plane, the

Table 2 Results of standard linear and angular cephalometric measurements in a Caucasian sample.

	Class I mean ± SD	Class II mean ± SD	Class III mean ± SD	Open bite mean ± SD	Kruskal–Wallis test ($P < 0.05$)
SNA°	82.7 ± 4.7	82.6 ± 4.2	80.6 ± 6.1	82.7 ± 7.6	NS
SNB°	79.9 ± 3.9	77.9 ± 3.7	80.8 ± 5.3	78.4 ± 4.4	NS
ANB°	2.9 ± 2.5	4.7 ± 2.6	-0.1 ± 2.8	4.5 ± 6.1	0.0001
Björk sum°	392.4 ± 7.3	390.8 ± 6.7	396.5 ± 6.7	398.1 ± 7	0.002
U1 inclination to SN°	102.4 ± 5.9	103.4 ± 12.6	101.1 ± 9.9	103.7 ± 10.4	NS
L1 inclination to MP°	91 ± 6.5	95.3 ± 6.5	83.1 ± 8.4	88.4 ± 7.7	0.0001
Protrusion U1 to N–Pg mm	5.4 ± 3.6	8.3 ± 3.4	2.5 ± 3.1	8.1 ± 4.4	0.0001
Protrusion L1 to N–Pg mm	2.5 ± 3.4	2.3 ± 2.9	1.8 ± 3	3.1 ± 3.6	NS
UL–EP mm	–3.5 ± 3.2	–1.2 ± 3.4	–3.7 ± 2.2	–3.7 ± 3.9	0.006
LL–EP mm	–1.8 ± 2.9	–0.4 ± 3	–0.9 ± 2.1	–1.6 ± 3.4	NS
Denture-Base (Wits, mm)	–2.5 ± 2	1.8 ± 2.6	–5.8 ± 2.7	0.9 ± 5.7	0.0001
Overjet mm	2.7 ± 1.4	5.2 ± 2.9	0.6 ± 1.6	3.5 ± 3	0.0001
Overbite mm	2.8 ± 1.7	3.2 ± 2	0.8 ± 1.9	-2.5 ± 2	0.0001
Facial height ratio (%)	64.9 ± 5.7	66.2 ± 5.3	63.2 ± 4.3	63.2 ± 5.9	NS
FH–PP°	–1.5 ± 2.4	–2.2 ± 6.4	–2.2 ± 3.5	–1.8 ± 5.3	NS

NS, not significant.

Table 3 Results of angular and linear measurements of the Denture Frame Analysis in Caucasians.

	Class I mean ± SD	Class II mean ± SD	Class III mean ± SD	Open bite mean ± SD	Kruskal–Wallis test ($P < 0.05$)
FH–MP°	25.3 ± 5.4	22.9 ± 6.4	25.1 ± 9.3	30.2 ± 5.9	0.0009
PP–MP°	26.3 ± 5.9	25.9 ± 5.7	29 ± 3.8	31.5 ± 6.7	0.004
SN–MP°	32.8 ± 6.9	31.1 ± 6.4	35.5 ± 5.6	36.9 ± 6.6	0.01
SN–PP°	6.8 ± 3.7	5.8 ± 3.2	7.5 ± 7.3	6 ± 5.2	NS
OP–MP°	14.9 ± 5.3	15.7 ± 4.8	17.9 ± 3.6	22.2 ± 5	0.0001
OP–MP to PP–MP ratio	0.56 ± 0.16	0.62 ± 0.2	0.62 ± 0.12	0.71 ± 0.1	0.002
AB–MP°	71.8 ± 4.9	78 ± 5.6	63.4 ± 5.2	67.9 ± 6.3	0.0001
A′P′ (mm)	48.6 ± 3.3	50.2 ± 3.6	46.7 ± 3.7	49.9 ± 4.1	0.01
A′6′ (mm)	26.2 ± 3.1	26.9 ± 3.1	23.4 ± 4	25.5 ± 5.3	0.03
A′6′/A′P’ ratio	0.54 ± 0.06	0.54 ± 0.07	0.53 ± 0.09	0.52 ± 0.1	NS
U1 inclination to AB°	26.7 ± 5.5	34 ± 8.6	25.4 ± 13.4	32.4 ± 8	0.0001
L1 inclination to AB°	19.2 ± 6.3	17.6 ± 5.9	19.4 ± 7.1	19.2 ± 7	NS
U1 protrusion to AB (mm)	5.4 ± 2.3	7.8 ± 3	3.6 ± 2.1	7.4 ± 2.7	0.0001
L1 protrusion to AB (mm)	2 ± 2	1.6 ± 2.3	2.9 ± 2	2.6 ± 2.9	NS
Intermolar angle°	169.5 ± 5.5	162.5 ± 28.8	170.4 ± 6.4	164.7 ± 13.6	NS

NS, not significant.

protrusion of the upper incisor to the facial plane, the distance of the upper lip to the aesthetic plane, the denture-base relationship (Wits appraisal), the overjet, and the overbite. The angles SNA, SNB, the inclination of the upper incisor to the S–N plane, and the protrusion of the lower incisor to the facial plane were not significantly different between the four groups.

The same statistics were calculated on the DFA measurements (Table 3). Significant differences between the four groups were found for the measurements SN–MP, FH–MP, PP–MP, AB–MP, OP–MP, the ratio OP–MP/PP–MP, A′P′, A′6′, and the inclination and protrusion of the upper incisor to the A–B plane. No statistical difference between the groups was found in the angle

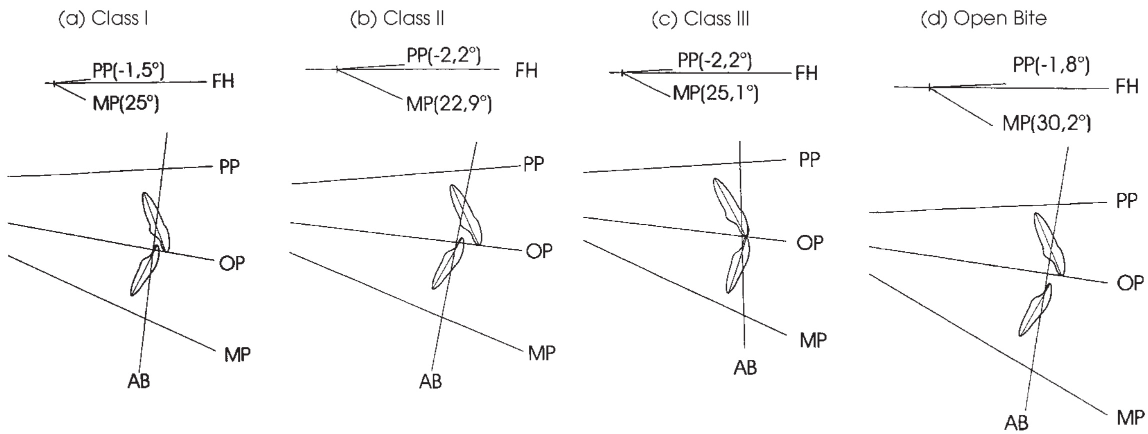

Figure 2 The average Denture Frames of the groups of this study illustrating average measurements. The upper graph shows the inclinations of the palatal and mandibular planes to the Frankfort Horizontal. (a) Class I; (b) Class II; (c) Class III; (d) open bite.

SN–PP, the ratio A′6′/A′P′, the inclination and protrusion of the lower incisor to the A–B plane, and the intermolar angle.

Class II individuals showed a higher length of the maxilla in an anteroposterior direction than the other groups. Class III cases showed the smallest maxillary length. The average Denture Frames of each group are illustrated in Figure 2.

Discussion

The Denture Frame triangle and standard cephalometrics

Regarding the sagittal intermaxillary relationship, the angle AB–MP showed a statistical difference, whereas the angles SNA and SNB did not reveal any statistically significant differences between the groups. The insignificance of SNA and SNB agrees with the findings of Jacobson (1975). In contrast to that finding, the angle ANB showed significant intergroup differences in the present study. The ANB measurement is based on the variability of factors other than jaw relationship itself (Järvinen, 1986, 1988). While other authors use the angle ANB (Viazis, 1992), its geometrical dependence on the position of nasion remains a general shortcoming (Taylor, 1969) even if individualized (Kirchner and Williams, 1993). The perpendicular projections of points A and B to the occlusal plane as they are used for assessment of the denture base relationship in the sagittal plane (Wits appraisal) showed statistically significant intergroup differences in the present study.

Within the AB–MP measurement the A–B plane represents the denture base and is independent of the structure, size, and position of the hard-tissue chin as represented by pogonion. Measurements of the anteroposterior position of the mandible which use pogonion do not consider the alveolar bone and teeth. Pogonion appears to be important only in determining the facial profile (Schudy, 1992a; Nanda and Merrill, 1994) and is highly variable as is the chin structure (Schudy, 1992b; Enlow and Hans, 1996). The AB–MP measurement also depends on the inclination of the mandibular plane. Referenced to the Frankfort Horizontal and to the S–N plane, the inclination of MP was significantly different in all groups. Therefore, the angle AB–MP also indicates the *vertical* sagittal relationship. Kim (1974) used the angle AB–MP plus/minus the angle FH–PP to assess the tendency towards open bite with the overbite depth indicator. Vertical dysplasias influence the anteroposterior position of the denture bases (Sassouni and Nanda, 1964). While the angle AB–MP was

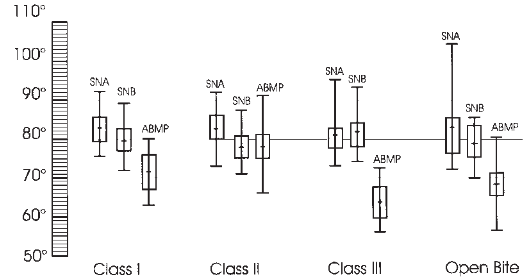

Figure 3 Box plots with maximum, minimum, mean, Q1, and Q3 of the sagittal measurements SNA, SNB, AB–MP for each group illustrating the superiority of the AB–MP measurement.

significantly different between the investigated groups (Figure 3), the measurement AB–MP itself cannot provide sufficient information on the intermaxillary relationship. Geometrical reasons necessitate further measurements.

Vertical relationships between maxilla, mandible, and dentition are represented by the angular measurements PP–MP, OP–MP, and their ratio OP–MP/PP–MP, too. The angle PP–MP was significantly different between the four groups of this study. The Class I and Class II groups showed similar means, whereas the Class III and open bite groups showed higher values for this angle (Figure 3). Similar values of the angle PP–MP were published by Battagel (1994) and Tollaro *et al.* (1996). The angular orientation of the palatal plane was found to be stable during growth despite significant vertical displacement (Nanda, 1990). In open bites the total maxillary height was greater, at both the incisor and molar levels (Sassouni and Nanda, 1964), and the posterior half of the palate was found to tip downward carrying the molar further downward (Sassouni, 1969). This gives rise to a large palatomandibular plane angle (PP–MP). In open bite subjects the palatal plane was inclined posteriorly resulting in the maxillary molars being located in an inferior position (Sassouni and Nanda, 1964; Trouten, 1983; Lopez-Gavito *et al.*, 1985). The molars may act as a fulcrum with the mandibular teeth, resulting in a posterior rotation of the mandible (Björk and Skieller, 1983; Nanda, 1990; Tollaro *et al.*, 1996). In the present study there were no significant differences between the groups in the SN–PP, FH–PP, and intermolar angle measurements.

The Björk sum demonstrated significant intergroup differences showing the highest values in skeletal open bites. No significant difference was found in this investigation when testing the facial height ratio. These findings agree with those of Nanda (1988) who found that the posterior face height and ramal height did not differ significantly between open and deep bite patients.

The occlusal plane and its orientation in the Denture Frame

In the present study the open bite group showed the steepest occlusal plane which is agreement with Sassouni and Nanda (1964), and Ellis and McNamara (1984). The angles OP–MP and PP–MP, as well as their ratio were significantly different between the groups ($P < 0.01$). The occlusal plane is a measure of how teeth are adjusted vertically (Schudy, 1992a,b). The DFA uses a maxillary occlusal plane. A line bisecting the incisor overbite or referenced to the mandibular teeth only is incapable of defining the required treatment objective to which teeth should be aligned orthodontically (Marcotte, 1990).

Within the measurement PP–MP, the angle OP–MP forms two compartments whose relative size can be expressed by the ratio OP–MP to PP–MP. This ratio was 0.56 in the Class I group of this study while it averaged 0.7 in the open bite group. For a normal occlusion sample, Sato (1987) described a value of 0.54 which was found stable during growth (Sato *et al.*, 1988a). They also suggested that PP, MP, and OP should ideally intersect at one point (Sato *et al.*, 1988b).

Further measurements

The angular relationship between the cranial base and the maxilla (SN–PP) was not significantly different between the groups. This differs from the findings of Kerr and Hirst (1987), but is in agreement with Bacon *et al.* (1992) whose cranial base measurements could not account for the Class II relationship.

The maxillary base lengths of the Denture Frame triangle (A′P′, A′6′) showed the highest values in the Class II and the open bite groups. The Class III group had the shortest maxillary base length similar to the findings of Andersen (1986), Williams (1986), and Battagel (1993). The lengths of the maxillae in an Asian Class II sample showed smaller values than the Class II group of the present study, and the maxillary lengths were smaller in the Class II group than in the Class I group (Fushima *et al.*, 1996).

In the maxilla, the axial inclination and anteroposterior position of the incisor were significantly different in the DFA (referenced to the A–B plane), while the inclination referenced to the S–N plane showed no significant difference. Referenced to the A–B plane, the axial inclination of the upper incisor indicated two trends: smaller values in Classes I and III than in Class II and open bite. This finding agrees with Battagel (1993) who showed that the proclined upper incisors of the Class III malocclusions were as far forward within the face as in the Class I controls.

Lower incisor protrusion showed no significant differences between the groups both in the standard and DFA measurements, but their inclination was significantly different in the standard measurement, whereas it was insignificant in the DFA. The former finding is in agreement with the results published by Ricketts (1992), Platou and Zachrisson (1983), and Zachrisson (1986), and questions a strict prescription of the position of lower incisors, while the measurement referenced to the mandibular plane suggests reasonable differences between the groups.

How does the DFA serve as a diagnostic tool in treatment planning?

The archial analysis of Sassouni (1962, 1969) and Sassouni and Nanda (1964) classified four basic skeletal facial types: open bite, deep bite, Class II, and Class III. As in the DFA, they did not employ established norms but rather defined relationships within the individual pattern. The same holds true for the quadrilateral analysis for a skeletal assessment and determination of the position of the occlusal plane (Di Paolo *et al.*, 1983; Di Paolo, 1987). In the counterpart analysis (Enlow *et al.*, 1988; Enlow and Hans, 1996), the mandibular dental arch, corpus, and ramus are considered as functional entities each with their own counterpart, i.e. the maxillary arch, maxillary prognathism, and pharynx. Parts and counterparts function in terms of fit and misfit. In paraphrase, the measurements of the DFA indicate an aggregated misfit of maxillary bone and its dentoalveolar part, as well as the mandibular bone and dentoalveolar apparatus in both a vertical and anteroposterior direction. Different from the meticulous counterpart analysis, this approach describes existing skeletal and dental relationships without searching for the aetiological and causative factors of developing malocclusion and intrinsic controls.

The Denture Frame and the occlusal plane have an impact on the clinician's decision or how to move the teeth in the sagittal and vertical planes according to the individual pattern. The dentition of a patient should be aligned within the existing skeletal framework of that patient and not to a statistical mean of a population (Kim, 1974) nor 'any set of magic numbers' (Baumrind *et al.*, 1976). The Denture Frame establishes the borders in which the teeth can be moved for the correction of a malocclusion with anticipation of the resulting effect on the cant of the occlusal plane, i.e. changing the ratio OP–MP/PP–MP. The risk for developing an open bite is estimated by the ratio OP–MP/PP–MP during correction of a Class I malocclusion. The higher the ratio, the more severe the open bite. The treatment objective for open bite patients with a ratio 0.7 aims at a decrease of this ratio and closing the bite.

The ratio A′6′/A′P′ indicates the space occupied by the maxillary teeth anterior to the first molar in relation to the entire maxilla. A high ratio may be caused by posterior crowding, precluding distalization of upper molars and providing clinical implications for extraction or non-extraction of molars or premolars.

In anteroposterior correction of the dentition the vertical component of this movement must be considered (Williams and Melsen, 1982). This aspect is respected by the DFA in controlling the orientation of the OP either with use of elastics or extra-oral traction or intra-oral anchorage. The variability of the position of the lower incisors allows incisor alignment following the individual Denture Frame.

Conclusions

In the present study the Denture Frame Analysis distinguished between different malocclusions in Caucasians using the Angle classification and open bite malocclusion.

The protrusion of the lower incisor was variable. Significant differences of the lower incisor inclination between the investigated groups were found in relation to the mandibular plane only.

The Denture Frame Analysis stresses that the triangle mandibular plane, A–B plane, and palatal plane define the space of orthodontic treatment. This area is divided by the occlusal plane as expressed by the ratio OP–MP/PP–MP. This ratio was significantly different between the groups, showing the smallest values in the Class I group and the highest in the open bite group. The position of the occlusal plane aids in the determination of the objectives and limitations of orthodontic therapy. The DFA exemplifies the correction of the malocclusion by individual alignment of the occlusal plane. As an adjunct to evaluation, the assessment of the position of the lips requires further measurements for judging aesthetic aspects.

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