

# A retrospective cephalometric investigation of two fixed functional orthodontic appliances in class II treatment: Functional Mandibular Advancer vs. Herbst appliance

Gero Stefan Michael Kinzinger<sup>1</sup> · Jörg Alexander Lisson<sup>1</sup> · Linda Frye<sup>2</sup> · Ulrich Gross<sup>3</sup> · Jan Hourfar<sup>1</sup>

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## Abstract

**Objective** The objective of the study is to compare skeletal and dental changes in class II patients treated with fixed functional appliances (FFA) that pursue different biomechanical concepts: (1) FMA (Functional Mandibular Advancer) from first maxillary molar to first mandibular molar through inclined planes and (2) Herbst appliance from first maxillary molar to lower first bicuspid through a rod-and-tube mechanism.

**Materials and methods** Forty-two equally distributed patients were treated with FMA (21) and Herbst appliance (21), following a single-step advancement protocol. Lateral cephalograms were available before treatment and immediately after removal of the FFA. The lateral cephalograms were analyzed with customized linear measurements. The actual therapeutic effect was then calculated through comparison with data from a growth survey. Additionally, the ratio of skeletal and dental contributions to molar and overjet correction for both FFA was calculated. Data was analyzed by means of one-sample Student's *t* tests and independent Student's *t* tests. Statistical significance was set at  $p < 0.05$ .

**Results** Although differences between FMA and Herbst appliance were found, intergroup comparisons showed no

statistically significant differences. Almost all measurements resulted in comparable changes for both appliances. Statistically significant dental changes occurred with both appliances. Dentoalveolar contribution to the treatment effect was  $\geq 70\%$ , thus always resulting in  $\leq 30\%$  for skeletal alterations.

**Conclusion** FMA and Herbst appliance usage results in comparable skeletal and dental treatment effects despite different biomechanical approaches.

**Clinical relevance** Treatment leads to overjet and molar relationship correction that is mainly caused by significant dentoalveolar changes.

**Keywords** FMA · Herbst appliance · Cephalometrics · Treatment effects · Biomechanics

## Introduction

Class II malocclusion describes, among other factors, a distal relationship between mandible and maxilla. It is the most frequent skeletal sagittal disharmony in Caucasian populations [1]. For class II treatment, fixed functional appliances (FFA) can be used. In contrast to removable functional appliances (RFA), the FFA can be employed without need for patient compliance with an ensured 24 h per day application [2, 3].

The Herbst appliance has become the most popular FFA [4] for class II correction. This appliance and its specific concept were introduced by Emil Herbst in 1909 at an international dental congress in Berlin, Germany. In 1934, he presented his experiences with his appliance in a series of three articles [5–7] before it literally disappeared for decades [3]. Pancherz reintroduced and continued development of the

✉ Jörg Alexander Lisson  
joerg.lisson@uniklinikum-saarland.de

<sup>1</sup> Department of Orthodontics, Saarland University, Homburg/Saar, Germany

<sup>2</sup> Essen, Germany

<sup>3</sup> Wuppertal, Germany

Herbst appliance [8] in 1979. The Herbst appliance rigidly connects the first maxillary molar with the lower first bicuspid on both sides through a telescopic (rod and tube) mechanism, thus permanently pushing the mandible into a protruded position [3]. From a biomechanical point of view, this results in an oblique intergnathic force vector and a longer lever arm [9].

In 2002, Kinzinger et al. [10] introduced a novel biomechanical concept in fixed functional appliances. Other than the Herbst appliance, the Functional Mandibular Advancer (FMA) exerts a rigid intergnathic force from maxillary to mandibular first molars for mandibular forward movement. For this purpose, the FMA uses inclined planes at 60° to horizontal which adopts an established concept from functional jaw orthopedics [11]. Judged from biomechanical considerations, this results in a far more vertical intergnathic force vector and a remarkably shorter lever arm compared to the Herbst appliance [10].

Treatment-related skeletal effects have been documented for both Herbst appliance [12, 13] and FMA [14, 15]. However, data on the FMA is scarce. Following advancement of the mandible to the therapeutic position, bite jumping was explained by remodeling of the mandibular bone, temporomandibular joints [16–18] and anterior shifting of the glenoid fossa [19]. However, besides feasible dentoskeletal effects, a number of side effects have been described for both FFAs [20–22]. Generally, the magnitude of treatment effects depends on the rigidity of the used FFA and on the extent of mandibular retroposition or rather the amount of therapeutic mandibular protraction [11, 23].

Aras et al. [24] recently complained that in some studies patients undergoing either FMA or Herbst appliance treatment were pooled instead of separate evaluation [15, 25]. Moreover, none of those studies included clear information regarding appliance activations [15, 25, 26]. Determined by the differences in design and biomechanical concepts of FMA and Herbst appliance, it could be hypothesized that treatment effects are different as well. This has not been investigated to date. Therefore, the aim of this retrospective investigation was to compare (1) linear skeletal and dental changes and (2) dentoskeletal side effects on occlusal plane, gonial angle, and lower incisor inclination in patients treated either with FMA or Herbst appliance. The study was performed by analyzing lateral cephalograms that were routinely obtained during orthodontic therapy.

## Material and methods

### Patients

Ethical approval for this retrospective study was granted (Ethics Commission of University of Aachen, Germany, No. 171/08). In agreement with a similar study [27], the sample size was calculated based on a significance level of 0.05 and a

power of 80% to detect a clinically meaningful difference of 2.0 ( $\pm 2.0$  mm and degrees, respectively). The power analysis showed that 17 patients per group were required. However, more patients were included in the sample to compensate for possible dropouts during the study period.

All patients included in this study were treated for class II malocclusion using fixed functional appliances by one experienced orthodontist. All patients received a single-step advancement protocol to protrude the mandible to an edge-to-edge position.

Inclusion criteria were fully dentate patients in permanent dentition—except for third molars—and no teeth were lost during treatment, no history of previous orthodontic treatment, pretreatment ANB angle  $\geq 4^\circ$ , and distal molar relationship of at least ½ cusp width. Exclusion criteria were patients with craniofacial anomalies, loss or congenital agenesis of permanent teeth—except for third molars—or planned extraction protocol. After achieving informed consent, the patients chose between treatment with either FMA (Functional Mandibular Advancer, Forestadent, Pforzheim, Germany) or cast splint Herbst appliance [4] (Herbst, Dentaaurum, Ispringen, Germany) (Fig. 1), and were assigned to two groups: (1) FMA group and (2) Herbst appliance group.

The FMA group comprised 21 patients (11 males, 10 females). Pretreatment age (T1) was mean 16 years and 2 months for male patients and 15 years and 9 for female patients. The Herbst appliance group comprised 21 patients (11 males, 10 females). Pretreatment age (T1) was mean 12 years and 1 month for male patients and 13 years and 2 months for female patients. Similar to other Herbst appliance [28] and FMA studies [26], a control group was set up on the basis of the growth manual published by Bhatia and Leighton [29] in 1993. This longitudinal survey of facial growth includes data from Caucasian subjects collected at King's College School of Medicine and Dentistry in London/UK. It is referred to as the “London Study” [26] in the text. In an earlier investigation [15], the chronological age of the subjects instead of the skeletal maturation stage was recorded. The corresponding values for the control group were then matched to ages recorded at T1 and T2. The difference between T1 and T2 in the control group was assumed to represent the growth effects. This difference was then subtracted from the measurements between T1 and T2 in both groups. The result represented the treatment effect, referred to as the “Net” effect.

### Lateral cephalograms

Complete patient records were available for both groups, including lateral cephalometric headfilms pretreatment (T1) and immediately after appliance removal (T2). All headfilms were taken with an analogue cephalometric X-ray machine (Orthophos®, Sirona, Bensheim, Germany) under standardized conditions regarding head posture and maximal

**Fig. 1** Functional Mandibular Advancer (FMA) and Herbst appliance



intercuspatation. A scale was projected into each image to allow a digital tracing procedure with dedicated software. The radiation data varied, depending on patient height and weight, between 73 kV/15 mA and 77 kV/14 mA; exposure time was always 9 s. The lateral cephalograms were digitalized using an Epson Expression 1680<sup>®</sup> scanner (Epson Deutschland GmbH, Meerbusch, Germany) and analyzed using “fr-win<sup>®</sup>, version 7.0” software (Computer Konkret, Falkenstein, Germany) including an officially certified image viewing system for radiographic diagnostics.

This dedicated tracing software is capable of measuring two decimals if the magnification factor of the X-ray is known. The latter has been ensured by projection of a scale into each image.

To minimize the patient’s radiation burden according to the ALARA [30] principle, hand-wrist X-rays were not routinely taken. The control group data [29] was also recorded using chronological age rather than stages of skeletal maturity. The lateral cephalograms were analyzed according to Kinzinger et al. [25, 26] by a single blinded examiner. Measurements comprised a set of linear skeletal and dental values as shown in Table 1 and Fig. 2. The measurements analyzed sagittal and vertical positional changes of the maxilla and mandible and included sagittal dental positional changes. Additionally, the ratio of skeletal and dental contributions to molar and overjet correction was calculated for both appliances.

### Statistical analysis

Cephalometric headfilms of both groups were re-traced and re-measured after 1 month by the same examiner. The method error (ME) was calculated using the Dahlberg-formula ( $ME = \sqrt{(\sum d^2/2n)}$ ) [31]. ME was 0.78 mm and 0.57° for linear and

angular measurements, respectively. The ME was <1 for all measurements. Data was tabulated using a spreadsheet software (Excel<sup>®</sup>, Microsoft Corporation, Redmond, WA, USA). The Kolmogorov-Smirnov test confirmed normal distribution of the data. Homogeneity of variance was tested using Levene’s method. Treatment related changes were subject to statistical analysis applying one-sample Student’s *t* tests for intragroup comparisons and independent Student’s *t* tests for intergroup comparisons. Descriptive statistics mean (M) and standard deviation (SD) is presented for each variable. All statistical analyses were undertaken using SAS<sup>®</sup> for Windows<sup>®</sup> 9.1 (SAS Institute Inc., Cary, NC, USA). Statistical significance was set at  $p < 0.05$ .

### Results

At pretreatment (T1), dental and skeletal measurements revealed no statistically significant ( $p > 0.05$ ) differences between FMA and Herbst appliance patients. In FMA patients, treatment time was mean  $1.32 \pm 0.71$  and  $1.46 \pm 0.38$  years in Herbst appliance patients. No significant difference was found ( $p = 0.6223$ ).

The treatment-related results of the different cephalometric measurements are shown in Tables 2 and 3.

### Skeletal and dental effects

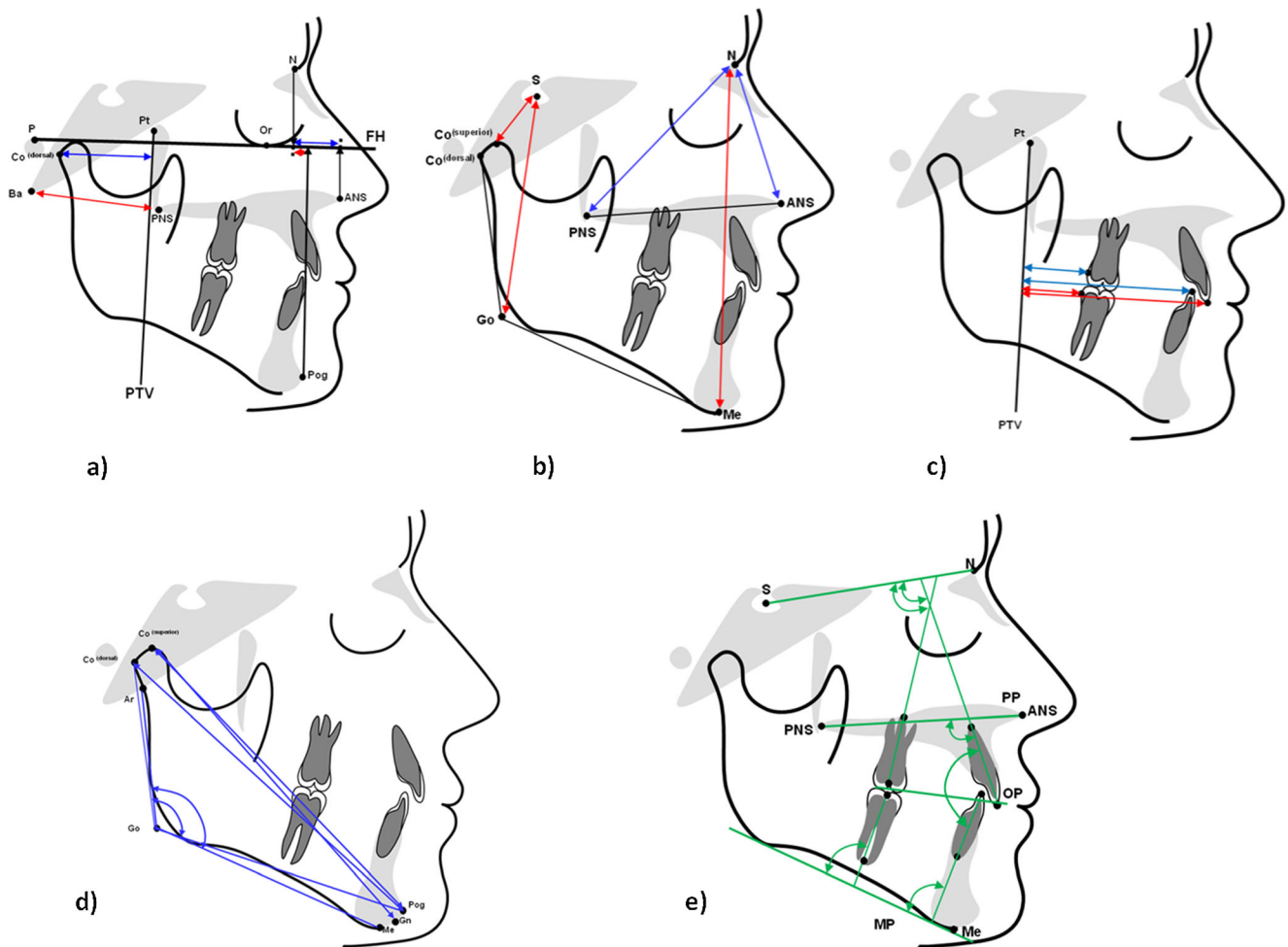
Although differences between FMA and Herbst appliance existed, intergroup comparisons did not reach statistical significance. The measurements either showed increase or decrease for certain values with both appliances, except for the distance between dorsal condyle margin and pterygoid vertical

**Table 1** Definition of the cephalometric landmarks and measurements

Measurement	
<b>I. Skeletal and dental effects</b>	
Maxilla sagittal (mm)	
N-ANS on FH	Anterior position of the maxillary base: linear distance between the junction of the frontal bone and nasal bone at the nasofrontal suture (Nasion (N)) and the most anterior point of the bony floor of the nose at the tip of the anterior nasal spine (ANS) projected onto the Francfort Horizontal (FH)
Ba-PNS	Posterior position of the maxillary base: linear distance between the anterior margin of the foramen magnum (Basion (Ba)) and most posterior point of the bony floor of the nose at the tip of the posterior nasal spine (PNS)
Maxilla vertical (mm)	
N-ANS	Linear distance between landmarks nasion (N) and anterior nasal spine (ANS)
N-PNS	Linear distance between landmarks nasion (N) and posterior nasal spine (PNS)
Mandible sagittal (mm)	
N-Pog on FH	Anterior position of the mandibular base: linear distance between landmark Nasion (N) and most anterior point of the bony chin (Pog) projected onto the Frankfort horizontal (FH)
Co <sup>(dorsal)</sup> -PTV	Position of the dorsal condyle margin: linear distance between the most posterior point of the mandibular condyle (Co <sup>(dorsal)</sup> ) and pterygoid vertical (PTV)
Mandible vertical (mm)	
S-Co <sup>(superior)</sup>	Linear distance between the sella turcica's midpoint (Sella, (S)) and condyle's superior margin (Co <sup>(superior)</sup> )
S-Go	Linear distance between landmark Sella (S) and intersection of the ramus tangent and corpus tangent (Go)
N-Me	Linear distance between landmark nasion (N) and most inferior point of the bony chin (Me)
Dental horizontal (mm)	
U1 <sup>(incisal)</sup> -PTV	Linear distance between the incisal tip of the upper central incisor (U1 <sup>(incisal)</sup> ) and PTV <sup>a</sup>
L1 <sup>(incisal)</sup> -PTV	Linear distance between the incisal tip of the lower central incisor (L1 <sup>(incisal)</sup> ) and PTV <sup>a</sup>
U6 <sup>(dorsal)</sup> -PTV	Linear distance between the most distal point of upper first molar's tooth crown (U6 <sup>(dorsal)</sup> ) and PTV <sup>a</sup>
L6 <sup>(dorsal)</sup> -PTV	Linear distance between the most distal point of lower first molar's tooth crown (L6 <sup>(dorsal)</sup> ) and PTV <sup>a</sup>
Overjet	Distance between the incisal tips of the lower (L1 <sup>(incisal)</sup> ) and upper central incisors (U1 <sup>(incisal)</sup> ) measured along the occlusal plane (OP)
Overbite	Distance between the tips of the lower (L1 <sup>(incisal)</sup> ) and upper central incisors (U1 <sup>(incisal)</sup> ) measured perpendicular to the occlusal plane (OP)
<b>II. Side effects on occlusal plane, gonial angle, and lower incisor inclination</b>	
Mandible diagonal (mm)	
Co <sup>(dorsal)</sup> -Pog	Linear distance between landmarks Co <sup>(dorsal)</sup> and Pog
Co <sup>(superior)</sup> -Gn	Linear distance between the most superior point of the mandibular condyle (Co <sup>(superior)</sup> ) and most anterior, inferior point on the mandibular symphysis (Gnathion, (Gn))
Mandible angular (°)	
Ar-Go-Me	Gonial angle: angle between intersection of the posterior border of the neck of the condyle with the cranial base (Ar) and landmarks Gonion (Go), and Menton (Me)
Co <sup>(dorsal)</sup> -Go-Pog	Modified gonial angle: angle between the landmarks posterior condylar margin (Co <sup>(dorsal)</sup> ), Gonion (Go), and Pogonion (Pog) landmarks
Cant of occlusal plane (°)	
SN/OP	Angle between the anterior cranial base (SN) and the occlusal plane (OP)
Dental angular (°)	
U1 / SN	Angle between the longitudinal axis of the upper central incisor (U1) and anterior cranial base (SN)
U1 / PP	Angle between the longitudinal axis of the upper central incisor (U1) and palatal plane (PP)
L1 / MP	Angle between the longitudinal axis of the lower central incisor (L1) and mandibular plane (MP)
U1/ L1	Interincisal angle: angle formed by the intersection of the longitudinal axis of the upper central incisor (U1) with the longitudinal axis of the lower central incisor (L1)
U6 / SN	Angle between the longitudinal axis of the upper first molar (U6) and anterior cranial base (SN)
L6 / MP	Angle between the longitudinal axis of the lower first molar (L6) and mandibular plane (MP)

<sup>a</sup> Measurement perpendicularly onto PTV





**Fig. 2** Skeletal and dental cephalometric measurements. **a** Horizontal linear:  $Co^{(dorsal)}$ -PTV; Ba-PNS; N-ANS on FH; and N-Pog on FH. **b** Vertical linear: S- $Co^{(superior)}$ ; S-Go; N-Me; N-ANS; and N-PNS. **c** Dentoalveolar linear:  $U1^{(incisal)}$ -PTV;  $L1^{(incisal)}$ -PTV;  $U6^{(dorsal)}$ -PTV; and

$L6^{(dorsal)}$ -PTV. **d** Mandibular angular and linear:  $Co^{(dorsal)}$ -Pog;  $Co^{(superior)}$ -Gn; Ar-Go-Me;  $Co^{(dorsal)}$ -Go-Pog (“modified gonial angle”); **e** Dentoalveolar angular: SN/OP; U1/SN; U1/PP; L1/MP; U1/L1 (interincisal angle); U6/SN; and L6/MP

( $Co^{(dorsal)}$ -PTV) which decreased in FMA patients and increased in Herbst appliance patients. Overjet and overbite decreased statistically significant with both appliances. The ratio of skeletal and dental contributions to molar and overjet correction are shown in Fig. 3 for both groups. Dental contribution was always greater than at least 70%, therefore the skeletal contribution to the treatment effect did not exceed 30%.

**Side effects on occlusal plane, gonial angle, and lower incisor inclination**

The increase of the gonial angle (Ar-Go-Me) was markedly greater in FMA patients than in Herbst appliance patients. Only intragroup comparisons for dental measurements reached the level of statistical significance. Compared to Herbst appliance patients, FMA patients exhibited greater antero-caudal cant of the occlusal plane, greater proclination of lower incisors,

and greater retroclination of upper incisors. Upper first molars showed average mesial tipping in FMA patients; distal tipping was found in Herbst appliance patients. In lower first molars, mesial tipping was found in both FMA and Herbst patients.

**Discussion**

**Skeletal and dental effects**

In our investigation, we compared patients treated either with the “Functional Mandibular Advancer” (FMA) [10] or the Herbst appliance [8]. Unlike with the Herbst appliance, available data on treatment-related dental and skeletal effects with the FMA is limited [10, 15, 26]. Hence, our study adds new data to the literature. In our investigation, fixed functional treatment resulted to an average increase of total posterior face

**Table 2** Skeletal and dental effects

Measurement	FMA group T1 T2 (M ± SD)	Herbst group T1 T2 (M ± SD)	FMA group Net (M ± SD) <sup>a</sup>	Herbst group Net (M ± SD) <sup>a</sup>	p value Net (intra)	p value Net (inter)
<b>Maxilla sagittal (mm)</b>						
N-ANS on FH	3.88 ± 2.96	4.94 ± 2.53	-0.38 ± 2.63	-0.22 ± 2.73	(1): 0.5170 <sup>NS</sup>	0.8457 <sup>NS</sup>
	3.77 ± 3.58	5.23 ± 3.06			(2): 0.7196 <sup>NS</sup>	
Ba-PNS	44.82 ± 2.68	44.80 ± 3.98	+0.19 ± 2.04	+0.65 ± 2.87	(1): 0.6674 <sup>NS</sup>	0.5647 <sup>NS</sup>
	45.29 ± 2.74	46.32 ± 3.06			(2): 0.3190 <sup>NS</sup>	
<b>Maxilla vertical (mm)</b>						
N-ANS	51.36 ± 4.45	49.27 ± 4.16	+0.48 ± 2.26	+1.34 ± 2.39	(1): 0.3424 <sup>NS</sup>	0.2369 <sup>NS</sup>
	52.39 ± 3.99	52.51 ± 3.90			(2): 0.0182 *	
N-PNS	71.79 ± 5.23	68.06 ± 4.95	+0.14 ± 2.49	+1.40 ± 2.94	(1): 0.7983 <sup>NS</sup>	0.1429 <sup>NS</sup>
	72.47 ± 4.97	71.65 ± 4.44			(2): 0.0414 *	
<b>Mandible sagittal (mm)</b>						
N-Pog on FH	-6.21 ± 6.69	-7.18 ± 3.77	+0.58 ± 4.42	+0.23 ± 5.17	(1): 0.5534 <sup>NS</sup>	0.1171 <sup>NS</sup>
	-5.25 ± 6.52	-5.03 ± 4.41			(2): 0.8424 <sup>NS</sup>	
Co <sup>(dorsal)</sup> -PTV	34.85 ± 2.44	34.33 ± 2.98	-0.66 ± 1.98	+0.52 ± 4.62	(1): 0.1451 <sup>NS</sup>	0.2919 <sup>NS</sup>
	34.44 ± 2.98	35.90 ± 4.73			(2): 0.6149 <sup>NS</sup>	
<b>Mandible vertical (mm)</b>						
S-Co <sup>(superior)</sup>	20.80 ± 2.70	20.29 ± 3.93	+0.23 ± 1.81	+0.63 ± 2.72	(1): 0.5584 <sup>NS</sup>	0.5824 <sup>NS</sup>
	21.30 ± 2.90	22.01 ± 3.99			(2): 0.3016 <sup>NS</sup>	
S-Go	73.85 ± 7.19	71.88 ± 7.03	+1.74 ± 1.88	+1.73 ± 2.63	(1): 0.0004 **	0.9814 <sup>NS</sup>
	76.89 ± 7.32	77.28 ± 6.77			(2): 0.0070 **	
N-Me	113.73 ± 9.47	110.67 ± 9.26	+1.51 ± 2.93	+1.73 ± 4.93	(1): 0.0287 *	0.8586 <sup>NS</sup>
	116.68 ± 8.63	116.27 ± 8.10			(2): 0.1237 <sup>NS</sup>	
<b>Dental horizontal (mm)</b>						
U1 <sup>(incisal)</sup> -PTV	57.55 ± 4.27	53.97 ± 3.81	-1.79 ± 2.58	-0.20 ± 3.76	(1): <0.0001 ****	0.2207 <sup>NS</sup>
	55.74 ± 4.24	55.70 ± 3.48			(2): 0.8092 <sup>NS</sup>	
L1 <sup>(incisal)</sup> -PTV	49.70 ± 4.10	47.02 ± 3.04	+2.42 ± 2.69	+3.03 ± 3.16	(1): 0.0005 ****	0.5060 <sup>NS</sup>
	53.14 ± 4.49	52.10 ± 3.75			(2): 0.0003 ****	
U6 <sup>(dorsal)</sup> -PTV	14.80 ± 4.50	12.51 ± 2.74	-2.24 ± 3.47	-0.27 ± 3.36	(1): 0.0078 **	0.0690 <sup>NS</sup>
	16.88 ± 3.74	14.27 ± 2.36			(2): 0.7182 <sup>NS</sup>	
L6 <sup>(dorsal)</sup> -PTV	14.80 ± 4.50	10.76 ± 3.35	+1.62 ± 3.20	+2.08 ± 2.97	(1): 0.0459 *	0.4924 <sup>NS</sup>
	17.24 ± 4.11	14.87 ± 3.09			(2): 0.0044 **	
Overjet	7.40 ± 2.87	6.95 ± 1.65	-5.06 ± 2.30	-3.82 ± 1.78	(1): <0.0001 ****	0.0586 <sup>NS</sup>
	2.26 ± 1.18	2.81 ± 1.10			(2): <0.0001 ****	
Overbite	2.49 ± 1.70	6.95 ± 1.65	-1.10 ± 1.55	-1.10 ± 1.89	(1): 0.0039 **	0.9942 <sup>NS</sup>
	1.43 ± 1.05	2.51 ± 1.15			(2): 0.0144 *	

Means (M) and standard deviations (SD) in cephalometric measurements at T1 and T2; Net: net outcome/therapeutic effect; significance of therapeutic effect intra- and intergroup

NS not significant

\* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; \*\*\*\* $p < 0.0001$

<sup>a</sup> Calculation of  $\Delta T2-T1$ , positive value = increase, negative value = decrease; (1) = FMA group, (2) = Herbst appliance group

height (S-Go) and total anterior face height (N-Me) in both FMA and Herbst appliance patients. Therapeutic increase in vertical dimensions for the posterior (1.4 to 2.5 mm) and anterior facial heights (1.2 to 3 mm) has been reported [32]. Our results were within the range of those values but were smaller than those reported by de Almeida et al. [33] for S-Go. The

same occurs for the linear distance between the center of the Sella turcica and the superior margin (S-Co<sup>(superior)</sup>) of the condyle, which exhibited only small average changes below 1 mm in FMA and Herbst appliance patients. This is again in agreement with values described in the literature [25]. The results of our investigation showed that maxillary sagittal

**Table 3** Side effects on occlusal plane, gonial angle and lower incisor inclination

Measurement	FMA group T1 T2 (M ± SD)	Herbst group T1 T2 (M ± SD)	FMA group Net (M ± SD) <sup>a</sup>	Herbst group Net (M ± SD) <sup>a</sup>	p value Net (intra)	p value Net (inter)
<b>Mandible diagonal (mm)</b>						
Co <sup>(dorsal)</sup> -Pog	106.98 ± 7.42 109.33 ± 7.36	102.11 ± 7.19 107.75 ± 6.42	+0.69 ± 3.50	+1.17 ± 3.35	(1): 0.3757 <sup>NS</sup> (2): 0.1256 <sup>NS</sup>	0.6552 <sup>NS</sup>
Co <sup>(superior)</sup> -Gn	110.20 ± 7.77 112.62 ± 7.42	104.68 ± 7.76 111.41 ± 7.22	+0.66 ± 2.81	+2.86 ± 2.75	(1): 0.2960 <sup>NS</sup> (2): 0.5540 <sup>NS</sup>	0.4670 <sup>NS</sup>
<b>Mandible angular (°)</b>						
Ar-Go-Me	124.60 ± 8.70 125.80 ± 7.75	123.81 ± 6.22 123.26 ± 7.29	+1.55 ± 3.47	+0.16 ± 4.59	(1): 0.0544 <sup>NS</sup> (2): 0.8755 <sup>NS</sup>	0.2758 <sup>NS</sup>
Co <sup>(dorsal)</sup> -Go-Pog	118.79 ± 8.14 119.63 ± 7.67	118.16 ± 5.74 117.82 ± 6.99	+1.19 ± 3.26	+0.38 ± 3.73	(1): 0.1115 <sup>NS</sup> (2): 0.6473 <sup>NS</sup>	0.4597 <sup>NS</sup>
<b>Cant of occlusal plane (°)</b>						
SN/OP	18.82 ± 4.50 18.56 ± 5.76	18.68 ± 4.36 18.63 ± 3.28	+0.64 ± 2.71	+1.13 ± 3.02	(1): 0.2888 <sup>NS</sup> (2): 0.1003 <sup>NS</sup>	0.5816 <sup>NS</sup>
<b>Dental angular (°)</b>						
U1 / SN	104.58 ± 8.43 100.71 ± 7.34	104.97 ± 7.02 103.77 ± 7.33	-4.06 ± 5.58	-0.99 ± 8.47	(1): 0.0033 <sup>**</sup> (2): 0.5965 <sup>NS</sup>	0.1741 <sup>NS</sup>
U1 / PP	113.34 ± 8.22 109.77 ± 7.28	114.04 ± 6.84 111.23 ± 6.72	-3.84 ± 5.51	-2.73 ± 7.59	(1): 0.0045 <sup>**</sup> (2): 0.1143 <sup>NS</sup>	0.5908 <sup>NS</sup>
L1 / MP	98.70 ± 6.10 99.94 ± 2.53	99.75 ± 7.06 103.65 ± 9.03	+5.80 ± 5.68	+3.63 ± 5.93	(1): 0.0001 <sup>****</sup> (2): 0.0109 <sup>**</sup>	0.2342 <sup>NS</sup>
U1 / L1 (interincisal angle)	122.90 ± 9.26 121.30 ± 8.79	122.15 ± 11.60 120.89 ± 8.68	-1.97 ± 5.49	-2.13 ± 9.98	(1): 0.1156 <sup>NS</sup> (2): 0.3400 <sup>NS</sup>	0.9504 <sup>NS</sup>
U6 / SN	70.00 ± 6.07 70.71 ± 7.58	66.88 ± 5.65 66.55 ± 6.29	+0.52 ± 4.49	-0.12 ± 5.62	(1): 0.5989 <sup>NS</sup> (2): 0.9209 <sup>NS</sup>	0.6825 <sup>NS</sup>
L6 / MP	93.66 ± 6.65 96.18 ± 6.65	93.35 ± 6.62 94.74 ± 7.00	+2.37 ± 4.47	+1.13 ± 6.91	(1): 0.0248 <sup>*</sup> (2): 0.4627 <sup>NS</sup>	0.0585 <sup>NS</sup>

Means (M) and standard deviations (SD) in cephalometric measurements at T1 and T2; Net: net outcome/therapeutic effect; significance of therapeutic effect intra- and intergroup

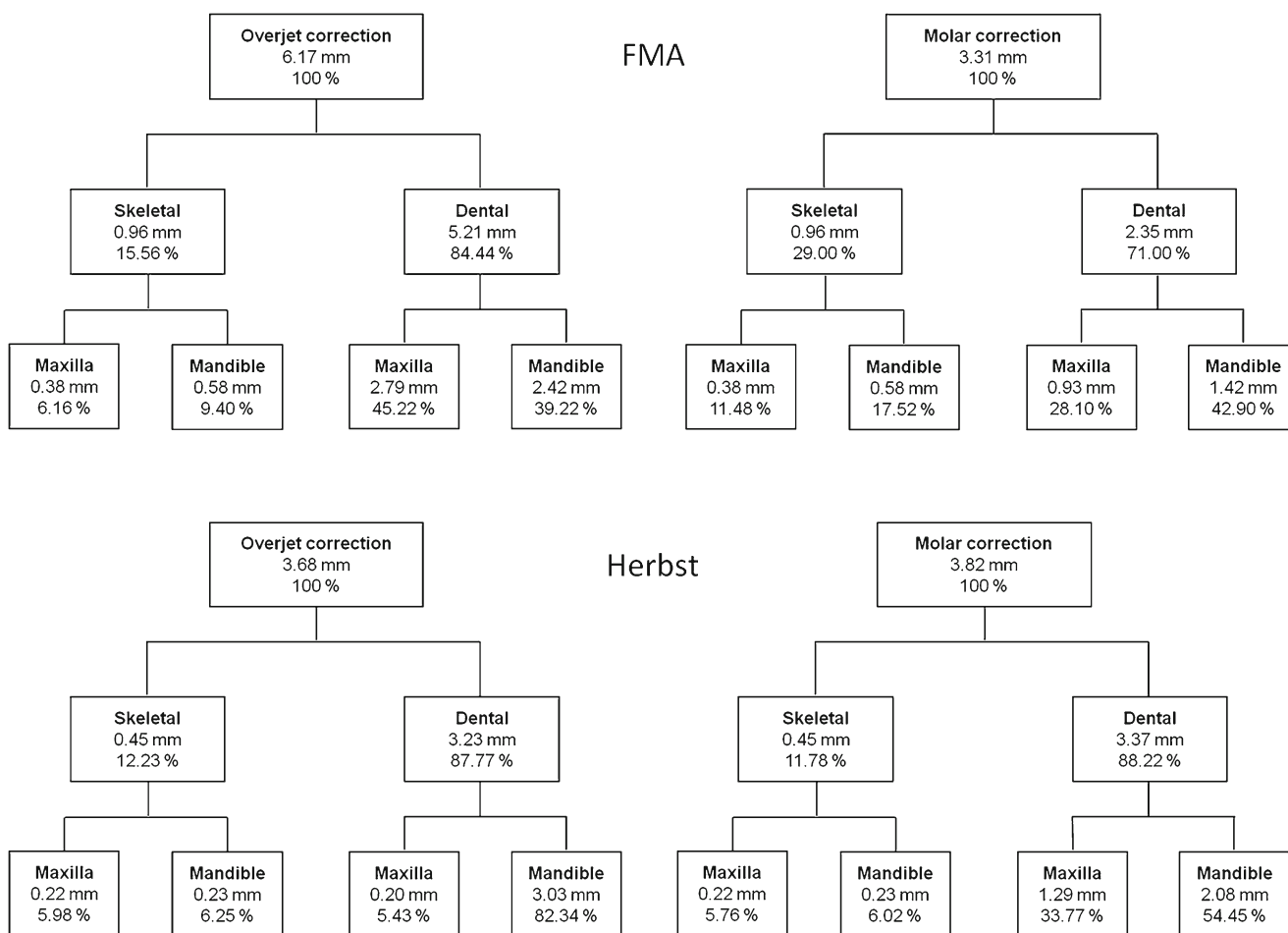
NS not significant

\*p < 0.05; \*\*p < 0.01; \*\*\*p < 0.001

<sup>a</sup> Calculation of ΔT2–T1, positive value = increase, negative value = decrease; (1) = FMA group, (2) = Herbst appliance group

measurements (N-ANS on FH, Ba-PNS), marking the anterior and posterior position of maxillary base, were subject to only very small alterations that are unlikely to be clinically significant. Hence, our investigation revealed neither a growth-inhibiting effect, nor a treatment-related change in maxillary length. Those findings were also confirmed by Kinzinger and Diedrich [26], who found no treatment effect upon the maxilla, and the position of the maxillary base remained stable in patients treated with the FMA. Similar findings were reported for the Herbst appliance [34]. Maxillary vertical measurements (N-ANS, N-PNS) always increased. Other than in FMA patients, changes in Herbst appliance patients were statistically significant. In agreement with Kinzinger et al. [25], changes were very small, i.e., below 0.5 mm in FMA patients and below 1.5 mm in Herbst appliance patients and therefore

likely to be clinically negligible [25, 26]. Due to fixed functional treatment, the anterior position of the mandibular base (N-Pog on FH) and the position of the dorsal condyle margin (Co<sup>(dorsal)</sup>-PTV) were only subject to minor changes in our patients that were statistically not significant. Those findings were also confirmed in a previous study [25]. It is well known that dentoalveolar compensation contributes to class II correction [26] when using fixed functional appliances. Therefore, most of the dental measurements recorded presented statistically significant changes. Overjet was corrected in conjunction with a decrease of the linear distance between the upper central incisor and pterygoid vertical (U1<sup>(incisal)</sup>-PTV) and increase of the distance between lower incisor and pterygoid vertical (L1<sup>(incisal)</sup>-PTV). The distance between upper first molars and pterygoid vertical (PTV) decreased while the distance



**Fig. 3** Skeletal and dental contribution to overjet and molar correction in FMA and Herbst appliance

between lower first molars and PTV increased. These results indicate that the maxillary dentition was distalized, while the mandibular dentition was mesialized. This has been described for both the FMA and the Herbst appliance [15, 26, 35]. Contradictory to our results and other FMA studies [15, 26], a recent study by Aras et al. [24] found no distal movement of the maxillary molars. However, in contrast to the FMA design used in our study, these authors attached a palatal arch to the stainless steel crowns on the molars. In agreement with our investigation and similar FMA studies [15, 26], Aras et al. [24] also found mesial movement of the lower molars. Still, direct comparison with our results is not possible, because these authors did not consider natural growth, investigated during comprehensive treatment, and used a different posterior reference plane.

The findings of our study demonstrate a significant dentoalveolar contribution to overjet and molar correction; its ratio ranged from 71.00 to 88.22% in our study sample (Fig. 3) which is in agreement with literature [35]. Hence, in both FMA and Herbst appliance patient’s molar relationship and overjet correction were rather due to positional changes of the dentition than to skeletal effects. This was confirmed in a

recent systematic review and meta-analysis by Zymperdikas et al. [36]. The authors concluded that, compared with more pronounced dentoalveolar changes, skeletal effects of fixed functionals in class II patients with malocclusion excluding the effects of normal growth were small and probably of minor clinical importance [36].

**Side effects on occlusal plane, gonial angle, and lower incisor inclination**

Other than with the Herbst appliance, data on therapeutic effects of the FMA for comparison with our results is limited [10, 15, 26]. In our FMA patients, mandibular length (Co<sup>(dorsal)</sup>-Pog; Co<sup>(superior)</sup>-Gn) showed an average increase of approximately +0.7 mm which was smaller compared to results of a FMA study by Kinzinger and Diedrich [26]. Mandibular lengthening during Herbst appliance treatment was confirmed by numerous studies [8, 37–42]. Compared to our FMA patients, increase of mandibular length was more pronounced in patients treated with a Herbst appliance. Similar to FMA patients, mandibular length also showed an increase in Herbst appliance patients. The Co<sup>(dorsal)</sup>-Pog



distance in our sample increased by an average of +1.17 mm which was smaller than the previously reported values ranging from 3.0 to 7.5 mm [8, 37, 42, 43].

In Herbst appliance patients, the Co<sup>(superior)</sup>-Gn distance showed an average increase of +2.86 mm which was smaller than the reported values ranging from 3.4 to 6.6 mm [38–41]. The difference between our findings for mandibular lengthening and values reported in the literature [8, 37–42] might be due to variation in pretreatment severity of class II malocclusion of investigated Herbst appliance patients.

In our FMA patients gonial angle (Ar-Go-Me) and “modified” gonial angle (Co<sup>(dorsal)</sup>-Go-Pog) increased by mean +1.55° and +1.19°. These values were greater compared to an FMA investigation which described average values below 1° [26].

On average, in our Herbst appliance patients, the gonial angle remained nearly unchanged during treatment which is in agreement with two previous investigations [8, 44]. Other investigators observed an increase of the gonial angle ranging from 2.0° to 5.0° but showed complete relapse during the posttreatment period [45, 46]. Studies investigating long term changes after Herbst appliance treatment found further decreasing gonial angles by 1.0° [47] to 7.7° [45, 48].

Although not statistically significant, our FMA patients exhibited average increase of the gonial angle greater than 1° while in Herbst appliance patients, almost no change was found. Finite element model (FEM)-simulations [49] might help to explain the treatment-related increase of the gonial angle and the difference between the investigated FFA. Stress, displacement, and deformation of the mandible under different loads have been evaluated using FEM simulations [50–54]. Due to the elastic properties of the human mandible [55, 56], mandibular deformation in different spatial directions was found [50–53]. It seems reasonable that rigid FFA-like Herbst appliance and FMA might cause an increase of the gonial angle through mandibular bending throughout treatment [50]. Interestingly, only two FEM analyses [9, 57] have been conducted to study treatment related effects of FFAs. However, none of the latter simulations investigated possible changes of the gonial angle during simulated mandibular protraction. Although a FEM analysis is helpful to explain therapeutic effects, it is still a computerized in vitro study model in which clinical condition may not be completely replicated. Hence, the results may only be acknowledged qualitatively [49].

In our study, both appliances were cast splint variants rigidly splinting teeth in both arches. It is known from prosthetic literature that inhibition of mandibular spatial deformation increases as more teeth are splinted and more rigid attachments are used [58, 59]. Different changes in gonial angle between FMA and the Herbst appliance might hence be attributed to the number of splinted mandibular teeth (3 vs. 4) and to different concepts of intergnathic force application (“molar to molar” vs. “molar to first premolar”).

In our Herbst appliance patients, the gonial angle nearly remained unchanged which might be attributed to the used cast splint Herbst appliance variant that rigidly splints lower posterior teeth thus counteracting mandibular deformation. Our findings were in contrast to other investigators who observed an increase of the gonial angle in Herbst appliance patients ranging from 2.0° to 5.0° [45, 46]. Interestingly, patients of these studies were treated with a Herbst appliance variant in which a telescope mechanism on either side of the jaw is attached to orthodontic bands only [45]. Compared to cast splint Herbst appliance, the banded variant is less rigid [4] and hence might not counteract to mandibular deformation to the same extent. Although three different mandibular anchorage forms in Herbst appliance treatment (banded premolar anchorage, banded premolar-molar anchorage, cast splint anchorage) were compared, the gonial angle was not measured by these authors [60]. Therefore, no data is available; neither to confirm nor to refute our assumptions.

For geometrical reasons, mandibular lengthening has always to be assessed related to alterations in the gonial angle area. Any increase of the gonial angle (mandibular bending) leads to displacement of cephalometric reference points Pogonion (Pog) and Gnathion (Gn) caudally and dorsally. Hence, treatment-related mandibular lengthening might be underrated in linear sagittal measurements and overrated in linear oblique measurements.

The results of our study suggest that mandibular lengthening in Herbst appliance patients was, if ever, affected only minimally by increase of the gonial angle. In contrast, treatment-related increase of the gonial angle (i.e., mandibular flexure) was on average 10 times greater in FMA patients than in Herbst appliance patients. The latter suggests that linear cephalometric measurements of the mandible were affected particularly in FMA patients.

Not unexpectedly, pronounced dental changes occurred. In both groups proclination of lower incisors and retroclination of upper incisors was found. Very similar to +5.82° found by Aras et al. [24], average proclination was +5.8° in our FMA patients. Interestingly, our FMA patients showed greater proclination than Herbst appliance patients, but without statistical significance. The mesially directed force that both appliances exert on the mandibular dentition causes the lower incisors to procline. In case of potential periodontal problems, this may lead to limited indications for this therapy [25].

To counteract proclination or to treat patients with existing lower incisor proclination, orthodontic miniplates [27, 61–63] or orthodontic miniimplants (OMIs) can be used. In one investigation, the lower splints of an acrylic splint Herbst were connected to OMIs via different types of ligation; still, some flaring of the lower incisors could not be prevented [64]. Other authors [27, 61–63] connected the FFA they used to orthodontic miniplates that were attached to the bony chin, and were successful in class II correction due to pronounced skeletal

effects without protruding the mandibular incisors. Even retrusion of the lower incisors was observed [27, 61]. It was deemed possible that the pressure of the upper incisors and lower lip caused this change [27]. Besides significant advantages of this approach, the surgical procedure to place orthodontic miniplates on the mandibular symphysis, and the necessity of a second operation for their removal at the end of the treatment are disadvantages of this treatment [61].

In our investigation, the antero-caudal canting of the occlusal plane was greater in Herbst appliance patients than in FMA patients. Still, changes were minimal and statistically insignificant.

The “Net” effect was calculated as control using the data of a longitudinal survey of facial growth [29]. This data was obtained from a mixed sample of individuals of Caucasian origin with and without malocclusion. Included individuals were between 4 and 20 years old and age-matched to our study sample. However, an ideal control group would comprise untreated class II subjects followed up on a regular basis. The latter is not available though. Therefore, some limitations have to be acknowledged when employing data from growth studies [65].

## Conclusions

- Linear skeletal and dental effects were comparable between FMA and Herbst appliance. In both appliances, changes in overjet and molar relationship were mainly caused by statistically significant dentoalveolar changes.
- Side effects on occlusal plane, gonial angle, and lower incisor inclination are comparable when using FMA or Herbst appliance, and occur despite different protrusive elements, i.e., telescopes or inclined planes.
- Effects upon occlusal plane and gonial angle are negligible.
- The pronounced lower incisor proclination may represent a relative contraindication for the use of FFA.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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**Ethical approval** This article does not contain any studies with human participants or animals performed by any of the authors. Ethical approval for this retrospective study was granted by the Ethics Commission of University of Aachen, Germany, No. 171/08.

**Informed consent** For this type of study, formal consent is not required.

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