

Soft tissue profile changes after Functional Mandibular Advancer or Herbst appliance treatment in class II patients

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Abstract

Objective The objective of the present study is to compare the effects on soft tissue profile in class II patients after treatment with either “Functional Mandibular Advancer” (FMA) or Herbst appliance.

Materials and methods The study included $n = 42$ patients treated with either FMA ($n = 21$) or Herbst appliance ($n = 21$) by the same experienced orthodontist. The treatment followed a single-step advancement protocol. Lateral cephalograms were analyzed through a set of customized measurements. The actual therapeutic effect was calculated using data from a growth survey. After testing for normal distribution and homogeneity of variance, data were analyzed by one-sample Student’s t tests and independent Student’s t tests. Statistical significance was set at $p < 0.05$.

Results For both FFAs, significant upper lip retrusion, increase in lower lip’s thickness, and length of the lower face occurred. Additionally, significant lower lip retrusion and straightening of the profile were found in FMA and Herbst appliance patients. All remaining variables revealed no significant differences.

Conclusions Treatment-related changes on the facial soft tissue profile could be regarded similar in class II patients treated with FMA or Herbst appliance. No treatment-related changes that were specific for FMA or Herbst appliance could be

identified. Only moderate changes were noted comparing pre- and posttreatment soft tissue profiles.

Clinical relevance Despite proven differences in skeletal and dental treatment effects, the facial profile has not to be taken into consideration when choosing between FMA and Herbst appliance for class II treatment.

Keywords Class II · Fixed functional appliance · Functional Mandibular Advancer · Herbst appliance · Soft tissue profile

Introduction

Angle class II malocclusions are frequently diagnosed in orthodontic patients [1]. Class II malocclusions with a mandibular deficiency have been treated with different functional appliances (FAs) [2] for more than a century. Apart from removable functional appliances (RFAs) [3], fixed functional appliances (FFAs) can be used for class II correction without patient’s cooperation [2]. Apart from skeletal and dental changes during treatment [4], facial soft tissue profile [5] and esthetics also ought to be improved during class II correction [2, 6].

FFAs, like Herbst appliance [7] or “Functional Mandibular Advancer” (FMA) [8], exert an anteriorly directed force to the mandible through rigid mechanisms.

Emil Herbst introduced his “Retentions-Scharnier,” later commonly called Herbst appliance, in 1909 at an international dental congress in Berlin/Germany. The Herbst appliance has become the most frequently used FFA for class II correction [9]. In 1934, he summarized his 25 years’ experience with the appliance in a series of three articles [10–12]. After that, the appliance literally disappeared for more than four decades until 1979, when Pancherz [7] reintroduced and continued the development of the Herbst appliance [9, 13]. The Herbst

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appliance rigidly connects the first upper molar with the mandibular first bicuspid on both sides through a telescopic (rod and tube) mechanism [9] for permanent advancement of the mandible into a protruded position.

In 2002, Kinzinger et al. [8] introduced the FMA pursuing a novel biomechanical concept in FFAs. Other than the Herbst appliance, the FMA exerts a rigid intergnathic force from upper to lower first molars for mandibular advancement. Adopting an established concept from functional jaw orthopedics, the FMA uses inclined planes at 60° to horizontal for this purpose [14].

Apart from feasible dentoskeletal effects [15–18], treatment-related changes of the patient's soft tissue profile have been described for different FFAs [5, 19, 20]. However, availability of data is limited [20]. While some studies assessing soft tissue changes are available for the Herbst appliance [5, 21–23], corresponding data for the FMA are unavailable. It can be hypothesized that treatment effects might vary because of the diverse design of FMA and Herbst appliance. This has not been investigated to date.

Therefore, this retrospective investigation compares effects on the soft tissue profile in patients with a skeletal class II, who were treated successfully with either FMA or Herbst appliance. The study analyzes lateral cephalograms which were routinely obtained during orthodontic treatment.

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 recent study [4], 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 (± 2.0 mm/ $\pm 2.0^\circ$). Patients were recruited throughout a 3-year period. The power analysis showed that at least 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 showed the need for

mandibular advancement because of a class II malocclusion. The allocation to either FMA or Herbst appliance was random. Cephalometric measurements prior to treatment (T1) ensured that no significant differences between FMA and Herbst appliance patients existed. Treatment was always performed by the same experienced orthodontist. In all patients, a single-step advancement protocol was employed. The mandible was always initially protruded into an edge-to-edge position.

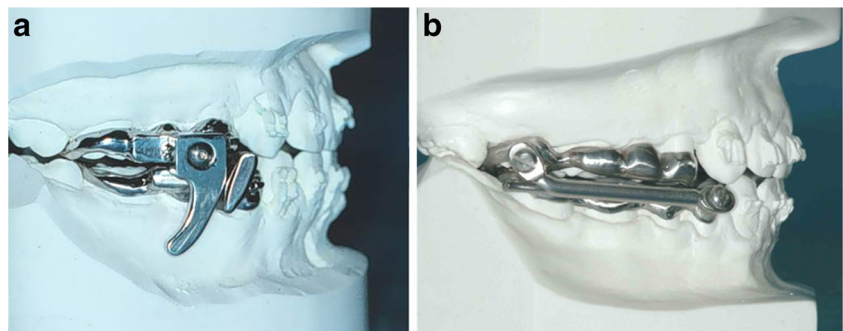
Inclusion criteria were as follows: fully dentate patients in permanent dentition (except for third molars), and no teeth were lost during treatment, no history of previous orthodontic treatment, pretreatment ANB angle $\geq 4^\circ$, and distal molar relationship of at least one-half cusp width. Exclusion criteria included craniofacial anomalies, loss or congenital agenesis of permanent teeth (except for third molars), or planned extraction protocol.

The patients were divided into two groups and received treatment with FMA (group 1) [8] (Functional Mandibular Advancer®, Forestadent, Pforzheim, Germany) or cast splint Herbst appliance (group 2) [9, 13] (Herbst®, Dentaaurum, Ispringen, Germany) based on their choice after being shown images from each appliance (Fig. 1).

A total of five patients dropped out. Three Herbst appliance patients and one FMA patient moved away, and another FMA patient discontinued due to medical reasons. Thus, the FMA group consisted of 21 patients (11 males, 10 females). Pretreatment age (T1) was mean 16 years and 2 months for males and 15 years and 9 months for females. The Herbst appliance group also included 21 patients (11 males, 10 females). Pretreatment age (T1) was mean 12 years and 1 month for males and 13 years and 2 months for females. Similar to other Herbst [24] and FMA studies [25], a control group was set up on the basis of data published by Bhatia and Leighton [26] in 1993. Their longitudinal facial growth data were retrieved from Caucasian subjects who were approached at King's College School of Medicine and Dentistry in London/UK.

According to an earlier investigation [17], the chronological age of the subjects was recorded rather than the skeletal maturation stage. The corresponding values for the control

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



group were then matched to ages recorded at T1 and T2. The difference between T1 and T2 in study and control groups was then assumed to represent growth effects. This difference was then subtracted from the measurements between T1 and T2 in both groups. This result represented the treatment effect, referred to as ‘Net’ effect.

Cephalometric headfilms

Conventional cephalometric headfilms were available pre-treatment (T1) and immediately after appliance removal (T2) for all patients. All headfilms were taken using an analogue X-ray cephalograph (Orthophos®, Sirona, Bensheim, Germany). The focus film distance was 1.5 m. Head posture and maximal intercuspation were standardized: the X-ray device fixated the head through ear olive holders and a nose rest. A line is projected on the patient’s head, allowing to adjust the

head posture according to the Frankfort horizontal. The patients were previously instructed to apply maximal intercuspation. A scale was projected into each image. The radiation data were matched to the patient and varied between 73 kV/15 mA and 77 kV/14 mA with an exposure time of 9 s. The lateral cephalograms were then digitalized using an Epson Expression 1680 scanner (Epson Deutschland GmbH, Meerbusch, Germany) and analyzed using “fr-win®, version 7.0” software (Computer Konkret, Falkenstein, Germany). The image viewing system was officially certified for radiographic diagnostics. This dedicated tracing software can measure 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 (as low as reasonably achievable) [27] principle, hand-wrist X-rays were not taken. The control group data [26] were

Table 1 Definition of the cephalometric landmarks and measurements

Measurement	
I. Soft tissue	
Horizontal (mm)	
Pog’-Sn on FH	Linear distance between the soft tissue pogonion (Pog’) and subnasale (Sn) as projected onto the Frankfort horizontal (FH)
Ls-E-Line	Linear distance between the most anterior point of the upper lip (Ls) and Esthetic line (E-Line)
Ls-Sn on FH	Linear distance between the most anterior point of the upper lip (Ls) and subnasale (Sn) as projected onto the Frankfort horizontal (FH)
Li-E-Line	Linear distance between the most anterior point of the lower lip (Li) and Esthetic line (E-Line)
Li-Sn on FH	Linear distance between the most anterior point of the lower lip (Li) and subnasale (Sn) as projected onto the Frankfort horizontal (FH)
A-A’ on PP	Linear distance between the deepest concavity of the maxilla’s anterior contour (A) and the deepest concavity at the junction of subnasale and upper lip (A’) as projected onto the palatal plane (PP)
B-B’ on MP	Linear distance between the deepest concavity of the mandible’s anterior contour (B) and deepest concavity at contact between the lower lip and soft tissue pogonion (B’) as projected onto the mandibular plane (MP)
Pog-Pog’ on MP	Linear distance between the most anterior point of the bony chin (Pog) and most anterior point of the soft tissue chin (Pog’) as projected onto the mandibular plane (MP)
Vertical (mm)	
Me’-FH	Vertical distance between soft tissue menton (Me’) and Frankfort horizontal (FH)
Sn-FH	Vertical distance between subnasale (Sn) and Frankfort horizontal (FH)
Ls-FH	Vertical distance between upper lip (Ls) and Frankfort horizontal (FH)
Li-FH	Vertical distance between lower lip (Li) and Frankfort horizontal (FH)
Ls-MP	Vertical distance between upper lip (Ls) and mandibular plane (MP) (line parallel to Frankfort horizontal (FH) through soft tissue menton (Me’)
Li-MP	Vertical distance between lower lip (Li) and mandibular plane (MP)
Sn-MP	Vertical distance between subnasale (Sn) and mandibular plane (MP)
Angular (°)	
N’-Pn-Pog’	Angle formed by soft tissue nasion (N’), nose tip (Pn), and soft tissue pogonion (Pog’)
N’-Sn-Pog’	Angle formed by soft tissue nasion (N’), subnasale (Sn), and soft tissue pogonion (Pog’)
Cm-Sn-Ls	Angle (nasolabial angle) formed by columella (Cm), subnasale (Sn), and labrale superius (Ls)
II. Dentoalveolar	
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)

gathered using chronological age instead of skeletal maturation stages. The lateral cephalograms were analyzed according to the method described by Kinzinger et al. [19] by a single blinded examiner. The analysis included a set of linear (horizontal and vertical) and angular soft tissue and selected angular dentoalveolar measurements (Table 1). Figure 2 shows a graphical representation of the measurements.

Statistical analysis

The same examiner retraced and remeasured selected headfilms of both groups after an interval of 1 month. The method error (ME) was then calculated using the Dahlberg-formula ($ME = \sqrt{(\sum d^2/2n)}$) [28]. ME was 0.78 mm for linear

and 0.57° for angular measurements. The ME was <1 for all measurements. Data were recorded using spreadsheet software (Excel®, Microsoft Corporation, Redmond, Washington, USA). The Kolmogorov-Smirnov test confirmed normal distribution of the data. Homogeneity of variance was tested using Levene's method. Treatment-related changes were analyzed with 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*) are recorded for each variable. Additionally, 95% confidence intervals (95% CI) were calculated. All statistical analyses were performed using SAS® for Windows® 9.1 (SAS Institute Inc., Cary, NC, USA). Statistical significance was set at $p < 0.05$.

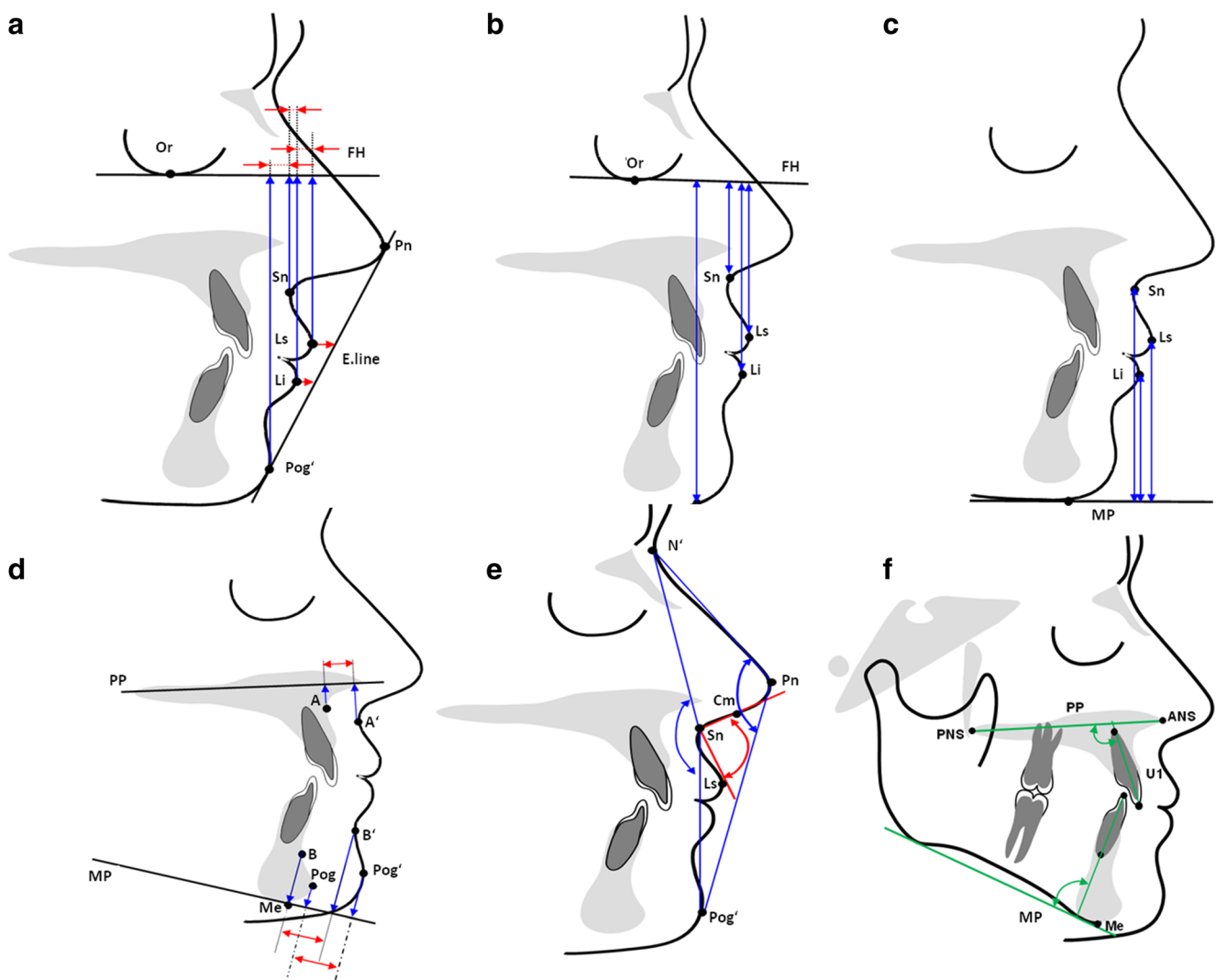


Fig. 2 Cephalometric measurements. **a** Linear measurements in relation to Frankfort horizontal (FH) and Ricketts' Esthetic line (E-Line): Pog'-Sn on FH, Li-Sn on FH, Ls-Sn on FH, Li-E-Line, and Ls-E-Line. **b** Linear measurements in relation to Frankfort Horizontal (FH): Me'-FH, Sn-FH, Li-FH, and Ls-FH. **c** Linear measurements in relation to mandibular plane

(MP): Sn-MP, Li-MP, and Ls-MP. **d** Linear measurements in relation to palatal plane (PP) and mandibular plane (MP): A-A' on PP, B-B' on MP, and Pog'-Pog' on MP. **e** Soft tissue profile angular measurements: N'-Pn-Pog', N'-Sn-Pog', and Cm-Sn-Ls. **f** Inclination of upper and lower central incisors: U1/PP and L1/MP

Results

Prior to treatment (T1), cephalometric measurements revealed no statistically significant ($p > 0.05$) differences between FMA and Herbst appliance patients.

Total treatment time was in FMA patients, mean 1.32 ± 0.71 years, and mean 1.46 ± 0.38 years in Herbst appliance patients. These treatment periods included the necessary leveling and aligning with a comprehensive fixed appliance after FFA removal. The average application of the

Table 2 Means and standard deviations in cephalometric changes at T1 and T2 in FMA patients

	Functional Mandibular Advancer (FMA)			Control ($M \pm SD$) 95% CI (LB, UB)	Net ($M \pm SD$) ^a 95% CI (LB, UB)	<i>p</i> value Net (intra)
	T1 ($M \pm SD$) 95% CI (LB, UB)	T2 ($M \pm SD$) 95% CI (LB, UB)	$\Delta T2-T1$ ($M \pm SD$) ^a 95% CI (LB, UB)			
Horizontal (mm)						
Pog'-Sn on FH	13.25 ± 6.00 10.52, 15.98	11.99 ± 5.85 9.33, 14.66	-1.25 ± 2.79 -2.52, 0.01	-0.06 ± 0.64 -0.36, 0.23	-1.19 ± 2.80 -2.46, 0.08	0.066 NS
Ls-E-Line	2.69 ± 2.72 1.45, 3.93	3.95 ± 3.04 2.57, 5.34	1.26 ± 2.35 0.19, 2.33	+2.40 ± 0.45 0.13, 2.54	-1.14 ± 2.08 -1.19, 2.08	0.021*
Ls-Sn on FH	-0.02 ± 1.82 -0.85, 0.80	-0.37 ± 1.84 -1.21, 0.46	-0.35 ± 1.57 -1.07, 0.36	0.00 ± 0.11 -0.05, 0.05	-0.35 ± 1.57 -1.07, 0.36	0.319 NS
Li-E-Line	1.25 ± 3.61 -0.40, 2.89	1.52 ± 3.57 -0.11, 3.14	0.27 ± 1.95 -0.62, 1.16	-0.13 ± 0.27 -0.16, 0.25	-0.14 ± 1.93 -0.73, 1.02	0.737 NS
Li-Sn on FH	6.10 ± 2.63 4.91, 7.30	4.75 ± 2.41 3.66, 5.85	-1.35 ± 1.97 -2.25, -0.45	+0.05 ± 0.34 -0.11, 0.20	-1.40 ± 2.03 -2.32, -0.47	0.005**
A-A' on PP	14.61 ± 2.36 13.54, 15.68	15.04 ± 2.20 14.04, 16.04	0.43 ± 1.55 -0.28, 1.14	+0.26 ± 0.56 0.01, 0.52	+0.17 ± 1.38 -0.46, 0.79	0.586 NS
B-B' on MP	10.10 ± 1.39 9.47, 10.74	11.04 ± 1.24 10.47, 11.60	0.93 ± 1.14 0.41, 1.45	+0.21 ± 0.22 0.11, 0.31	+0.72 ± 1.10 0.22, 1.22	0.007**
Pog-Pog' on MP	10.45 ± 2.20 9.45, 11.45	11.02 ± 1.57 10.30, 11.77	0.57 ± 1.36 -0.05, 1.19	+0.17 ± 0.29 0.04, 0.30	+0.40 ± 1.32 -0.20, 1.00	0.182 NS
Vertical (mm)						
Me'-FH	91.61 ± 7.87 88.03, 95.19	94.95 ± 6.96 91.78, 98.12	3.34 ± 3.38 1.80, 4.88	+1.34 ± 1.62 0.61, 2.08	+2.00 ± 2.80 0.73, 3.27	0.004**
Sn-FH	26.52 ± 4.01 24.69, 28.34	27.21 ± 3.79 25.48, 28.93	0.69 ± 2.68 -0.53, 1.91	+0.35 ± 0.55 0.30, 0.80	+0.34 ± 2.27 -0.69, 1.37	0.499 NS
Ls-FH	40.22 ± 4.06 38.38, 42.07	41.34 ± 3.78 39.62, 43.06	1.12 ± 2.39 0.03, 2.21	+0.74 ± 0.91 0.33, 1.16	+0.38 ± 2.20 -0.63, 1.38	0.442 NS
Li-FH	58.49 ± 5.49 55.99, 60.99	60.02 ± 4.64 57.91, 62.13	1.53 ± 3.01 0.16, 2.90	+0.69 ± 0.83 0.31, 1.07	+0.84 ± 2.81 -0.44, 2.12	0.185 NS
Ls-MP	51.81 ± 5.83 49.16, 54.47	53.34 ± 5.06 51.04, 55.65	1.53 ± 2.60 0.35, 2.71	+0.73 ± 1.07 0.25, 1.22	+0.80 ± 2.22 -0.22, 1.81	0.116 NS
Li-MP	33.51 ± 4.36 31.53, 35.50	34.82 ± 4.55 32.75, 36.90	1.31 ± 2.61 0.12, 2.50	+0.61 ± 0.94 0.18, 1.04	+0.70 ± 2.21 -0.30, 1.70	0.162 NS
Sn-MP	65.67 ± 6.71 62.62, 68.73	67.52 ± 6.19 64.70, 70.34	1.85 ± 2.42 0.75, 2.94	+1.97 ± 2.21 0.54, 2.55	-0.12 ± 1.89 -1.39, 1.99	0.769 NS
Angular (°)						
N'-Pn-Pog'	123.73 ± 4.37 121.74, 125.72	123.99 ± 4.69 121.85, 126.12	0.26 ± 4.04 -1.58, 2.10	-0.32 ± 1.22 -0.88, 0.22	+0.58 ± 3.97 -1.23, 2.38	0.514 NS
N'-Sn-Pog'	153.94 ± 7.31 149.19, 154.61	158.22 ± 6.43 151.32, 158.71	2.61 ± 4.55 0.54, 4.69	-0.11 ± 1.18 -0.63, 0.44	+2.72 ± 4.69 0.59, 4.85	0.015*
Cm-Sn-Ls	114.22 ± 11.11 113.97, 122.54	114.78 ± 11.77 114.27, 123.01	0.39 ± 6.70 -2.66, 3.44	-0.19 ± 0.77 -0.56, 0.14	+0.58 ± 6.61 -2.43, 3.58	0.694 NS
U1/PP	113.34 ± 8.22 109.60, 117.08	109.77 ± 7.28 106.45, 113.08	-3.57 ± 5.76 -6.19, -0.95	+0.27 ± 0.88 -0.17, 0.63	-3.84 ± 5.51 -6.35, -1.34	0.005**
L1/MP	98.70 ± 6.10 95.92, 101.48	104.70 ± 7.63 90.59, 109.28	6.00 ± 5.71 3.40, 8.60	+0.20 ± 0.40 -0.36, 0.25	+5.80 ± 5.68 3.21, 8.39	<0.001***

Significance of therapeutic effect intragroup

Net net outcome/therapeutic effect, CI confidence interval, LB lower bound, UB upper bound, NS not significant

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

^a Calculation of $\Delta T2-T1$: positive value = increase and negative value = decrease

fixed functionals within this period was 7.2 months in the FMA and 7.3 months in the Herbst appliance group. No significant difference was found ($p = 0.6223$ and $p = 0.7285$).

The results of the cephalometric measurements are shown in Tables 2, 3, and 4. No significant intergroup differences were found. In both appliances, significant ($p < 0.05$)

intragroup changes were found for Ls-E-Line, B-B' on MP, and Me'-FH. In our study sample, significant lower lip protrusion (Li-Sn on FH) ($p < 0.01$) and straightening of the profile (N'-Sn-Pog', soft tissue profile excluding nose) ($p < 0.05$) were found in FMA patients only. In Herbst appliance patients, significant ($p < 0.01$) lower lip retrusion (Li-E-

Table 3 Means and standard deviations in cephalometric changes at T1 and T2 in Herbst appliance patients

	Herbst appliance			Control ($M \pm SD$) 95% CI (LB, UB)	Net ($M \pm SD$) ^a 95% CI (LB, UB)	<i>p</i> value Net (intra)
	T1 ($M \pm SD$) 95% CI (LB, UB)	T2 ($M \pm SD$) 95% CI (LB, UB)	$\Delta T2-T1$ ($M \pm SD$) ^a 95% CI (LB, UB)			
Horizontal (mm)						
Pog'-Sn on FH	12.42 ± 3.60 10.78, 14.06	11.70 ± 4.95 9.45, 13.96	-0.72 ± 3.46 -2.30, 0.85	-0.55 ± 0.82 -0.56, 0.22	-0.17 ± 3.10 -1.58, 1.24	0.805 NS
Ls-E-Line	1.36 ± 2.06 0.42, 2.30	3.18 ± 2.22 2.17, 4.19	1.81 ± 1.44 1.16, 2.47	+3.03 ± 0.66 0.21, 0.82	-1.22 ± 1.36 0.61, 1.84	<0.001***
Ls-Sn on FH	0.59 ± 1.99 -0.32, 1.49	0.01 ± 2.54 -1.14, 1.16	-0.58 ± 1.82 -1.41, 0.25	0.02 ± 0.49 -0.29, 0.15	-0.60 ± 1.64 -1.35, 0.14	0.108 NS
Li-E-Line	1.35 ± 2.38 0.26, 2.43	0.49 ± 2.47 -0.63, 1.62	-0.85 ± 1.35 -1.47, -0.24	+0.31 ± 0.51 0.11, 0.57	-1.16 ± 1.57 -1.87, -0.44	0.003**
Li-Sn on FH	5.94 ± 2.16 4.95, 6.92	4.63 ± 3.44 3.06, 6.19	-1.31 ± 2.33 -2.37, -0.25	-0.29 ± 0.35 -0.36, 0.16	-1.02 ± 2.52 -2.16, 0.13	0.078 NS
A-A' on PP	13.55 ± 1.70 12.77, 14.32	14.54 ± 1.58 13.82, 15.26	0.99 ± 1.59 0.27, 1.72	+0.90 ± 0.74 0.49, 1.16	+0.09 ± 1.64 -0.66, 0.83	0.808 NS
B-B' on MP	9.63 ± 1.08 9.14, 10.12	10.60 ± 1.46 9.93, 11.27	0.97 ± 1.20 0.42, 1.52	+0.46 ± 0.30 0.36, 0.63	+0.51 ± 1.15 -0.01, 1.03	0.056*
Pog-Pog' on MP	10.38 ± 1.50 9.69, 11.06	10.92 ± 2.04 9.99, 11.85	0.54 ± 1.43 -0.11, 1.19	+0.32 ± 0.75 -0.16, 0.53	+0.22 ± 1.68 -0.54, 0.99	0.549 NS
Vertical (mm)						
Me'-FH	89.63 ± 8.29 85.85, 93.40	94.84 ± 7.14 91.59, 98.09	5.21 ± 4.30 3.26, 7.17	+3.38 ± 2.12 2.88, 4.81	+1.83 ± 3.53 0.23, 3.44	0.027*
Sn-FH	26.40 ± 3.76 24.68, 28.11	27.51 ± 4.06 25.66, 29.36	1.11 ± 3.01 -0.26, 2.48	+1.21 ± 2.12 1.02, 1.88	-0.10 ± 2.83 -1.39, 1.19	0.871 NS
Ls-FH	39.85 ± 4.40 37.85, 41.85	41.19 ± 4.93 38.94, 43.43	1.34 ± 3.33 -0.18, 2.85	+1.77 ± 1.27 1.53, 2.68	-0.43 ± 3.21 -1.89, 1.03	0.543 NS
Li-FH	56.46 ± 5.30 54.05, 58.87	60.06 ± 5.69 57.47, 62.65	3.60 ± 3.21 2.14, 5.06	+1.45 ± 1.01 1.29, 2.21	+2.15 ± 2.58 0.97, 3.32	<0.001***
Ls-MP	49.83 ± 5.73 47.22, 52.44	53.82 ± 4.72 51.67, 55.97	3.99 ± 3.19 2.54, 5.44	+2.23 ± 1.44 1.72, 3.03	+1.76 ± 2.56 0.59, 2.92	0.005**
Li-MP	33.34 ± 5.04 31.04, 35.64	35.02 ± 4.25 33.09, 36.96	1.68 ± 2.57 0.51, 2.85	+1.85 ± 1.35 1.47, 2.70	-0.17 ± 2.63 -1.37, 1.03	0.771 NS
Sn-MP	63.50 ± 6.64 60.48, 66.52	67.63 ± 5.59 65.09, 70.18	4.14 ± 3.44 2.57, 5.70	+1.85 ± 1.97 1.23, 3.03	+2.29 ± 3.74 0.59, 3.99	0.921 NS
Angular (°)						
N'-Pn-Pog'	125.21 ± 4.60 123.12, 127.30	125.55 ± 5.37 123.11, 128.00	0.34 ± 4.21 -1.57, 2.26	-1.58 ± 1.04 -2.05, -1.11	+1.92 ± 4.35 -0.06, 3.90	0.056*
N'-Sn-Pog'	151.90 ± 5.95 153.05, 157.80	154.51 ± 7.02 152.90, 156.98	-0.48 ± 4.24 -2.41, 1.45	-0.52 ± 1.13 -1.04, -0.01	+0.04 ± 3.91 -1.74, 1.82	0.960 NS
Cm-Sn-Ls	118.25 ± 9.42 109.60, 118.83	118.64 ± 9.60 111.96, 122.99	3.26 ± 8.72 -0.71, 7.23	+0.05 ± 0.80 -0.31, 0.41	+3.21 ± 8.49 -0.65, 7.08	0.098 NS
U1/PP	114.04 ± 6.84 110.93, 117.15	111.23 ± 6.72 108.18, 114.29	-2.81 ± 7.75 -6.34, 0.72	-0.08 ± 0.77 -0.38, 0.32	-2.73 ± 7.59 -6.19, 0.72	0.114 NS
L1/MP	99.75 ± 7.06 96.53, 102.96	103.65 ± 9.03 99.54, 107.76	3.90 ± 5.47 1.41, 6.39	+0.27 ± 0.86 -0.12, 0.66	+3.63 ± 5.93 0.93, 6.33	0.011*

Significance of therapeutic effect intragroup

Net net outcome/therapeutic effect, CI confidence interval, LB lower bound, UB upper bound, NS not significant

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

^a Calculation of $\Delta T2-T1$: positive value = increase and negative value = decrease

Table 4 Intergroup comparison (FMA versus Herbst appliance) of the Net effect

FMA vs Herbst appliance			
	ΔNet^b ($M \pm \text{SD}$)	95% CI (LB, UB)	p value Net (inter)
Horizontal (mm)			
Pog'-Sn on FH	-1.02 ± 3.57	-2.64, 0.60	0.270 NS
Ls-E-Line	-0.09 ± 2.36	-1.16, 0.98	0.871 NS
Ls-Sn on FH	0.25 ± 2.28	-0.78, 1.29	0.616 NS
Li-E-Line	1.30 ± 2.63	0.10, 2.50	0.219 NS
Li-Sn on FH	-0.38 ± 3.29	-1.88, 1.22	0.594 NS
A-A' on PP	0.08 ± 1.84	-0.76, 0.91	0.868 NS
B-B' on MP	0.21 ± 1.97	-0.68, 1.11	0.541 NS
Pog-Pog' on MP	0.18 ± 2.53	-0.98, 1.33	0.708 NS
Vertical (mm)			
Me'-FH	0.16 ± 4.24	-1.77, 2.09	0.869 NS
Sn-FH	0.44 ± 3.90	-1.34, 2.22	0.579 NS
Ls-FH	0.81 ± 4.08	-1.05, 2.66	0.346 NS
Li-FH	-1.31 ± 3.95	-3.10, 0.49	0.125 NS
Ls-MP	-0.96 ± 2.89	-2.28, 0.36	0.152 NS
Li-MP	0.87 ± 3.11	-0.55, 2.29	0.253 NS
Sn-MP	-1.99 ± 4.91	-4.22, 0.24	0.602 NS
Angular (°)			
N'-Pn-Pog'	-1.35 ± 5.79	-3.98, 1.29	0.300 NS
N'-Sn-Pog'	2.68 ± 5.81	0.03, 5.32	0.677 NS
Cm-Sn-Ls	-2.64 ± 11.93	-8.07, 2.79	0.268 NS
U1/PP	-1.11 ± 10.88	-6.06, 3.84	0.591 NS
L1/MP	2.17 ± 8.49	-1.70, 6.03	0.234 NS

Significance of therapeutic effect intergroup

Net net outcome/therapeutic effect; CI confidence interval, LB lower bound, UB upper bound, NS not significant

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

^a Calculation of $\Delta T2-T1$: positive value = increase and negative value = decrease

^b Calculation of $\Delta\text{Net} = \text{Net (FMA)} - \text{Net (Herbst appliance)}$

Line) and a straightening of the profile (N'-Pn'-Pog', soft tissue profile including nose) ($p < 0.05$) occurred. Moreover, vertical linear measurements Li-FH ($p < 0.001$) and Ls-MP ($p < 0.01$) increased corresponding with the increased length of the lower face. All remaining variables revealed no significant differences.

Discussion

Treatment-related changes of the soft tissue profile between patients treated either with FMA or Herbst appliance by analyzing lateral cephalograms have not been studied to date. Hence, our investigation adds new data to the literature.

As expected, some studies assessing soft tissue changes are available for the Herbst appliance [5, 21–23] but none specifically for the FMA. Due to methodological differences between these investigations, direct comparison with our values is partially impossible.

Similarly, in both groups, the upper lip was retruded (Ls-E-Line), but the lower lip's thickness (B-B' on MP) and the length of the lower face (Me'-FH) increased statistically significant. The results of these linear measurements were quite similar. Differences between the mean values were approximately 0.2 mm, which is in agreement with data from the literature [5]. Obviously, the mean changes of these variables were clinically insignificant.

Although no statistically significant differences between both FFAs existed, the nasolabial angle (Cm-Sn-Ls) showed more pronounced Net changes in our Herbst appliance patients. Surprisingly, posttreatment (T2) nasolabial angles were mean 114.78° for FMA and 118.64° for Herbst appliance and hence greater than the proposed “normal” values—ranging from 85° to 105° [29, 30]—and also greater than an “ideal” nasolabial angle [31]. However, race and gender differences have to be considered [30, 31].

One aim of class II correction is the reduction in profile convexity [5]. In both studied FFAs, a straightening of the soft tissue profile occurred: N'-Sn-Pog' (soft tissue profile, excluding nose) and N'-Pn'-Pog' (soft tissue profile, including nose) showed a mean increase, ranging from +0.04 to 2.72 mm, which was smaller than reported in the literature [5, 21].

A recent systematic review and meta-analysis by Zymperdikas et al. [20] found that FFAs had statistically significant influence on patients' soft tissue profiles. The authors found that the N'-Sn-Pog' angle (soft tissue profile, excluding nose) increased on average by 2.01° per year, thus also confirming straightening of the soft tissue profile. Interestingly, only one [22] of the four [22, 32–34] included studies investigated a cast splint Herbst appliance type, whereas the remaining three studies [32–34] focused on nonrigid Herbst appliance hybrids. Based on the results of their review, Zymperdikas et al. [20] stated that soft tissues were significantly affected in favor of profile improvement by FFAs.

Meyer-Marcotty et al. [35] investigated treatment-related alterations of the facial soft tissues in Herbst appliance patients using three-dimensional face scans based on a stereophotogrammetric method. The authors also found favorable effects on the facial soft tissue profile, particularly in patients with a convex profile and a retrusive lower lip. There is considerable variation in how attractive raters judge a face to be [36–39]. Although there is no accepted standard as to what constitutes an attractive soft tissue profile, a general preference for relatively straight profiles has been reported [40, 41]. At least Caucasians prefer a straight profile [2, 6], and this was achieved in our sample with both FFAs, since the soft tissue profile was always straightened.

In our study sample, the upper lip (Ls-E-Line) retruded similarly in FMA and Herbst appliance patients. However, contradictory results have been published regarding the positional changes of the upper lip [2]. Whereas one study [5] reported a retrusion, another showed protrusion of the upper lip [42]. In agreement with the literature [5, 42, 43], the lower lip (Li-E-Line) showed marginal retrusion in our patients. This seemed contradictory because significant proclination occurred in our sample after treatment with both FFA types. Similar to other investigators [5, 43], we used the Esthetic line (E-Line) as reference to record positional changes of the upper and lower lips. However, this is not without controversy. Flores-Mir et al. [2] stated that E-Line is not a good reference to quantify changes in the lips because simultaneous changes in the soft tissue pogonion (Pog') or pronasale (Pn) could create the impression of lip changes that are really nonexistent. We accounted for growth-related changes by calculating the treatment effect, referred to as the Net effect.

Bhatia and Leighton's [26] longitudinal survey of facial growth was used as control and basis for the calculation of the Net effect. Individuals with and without malocclusion included in their survey were between 4 and 20 years of age and age-matched to our study sample. However, an ideal control group would comprise untreated class II subjects followed up on a regular basis, which is not available. Thus, limitations are inevitable when employing data from growth studies [44].

Typical dental changes as described in the literature [45, 46] occurred in both groups. All patients experienced proclination of mandibular incisors and retroclination of maxillary incisors. The FMA patients showed greater proclination of mandibular incisors than the Herbst appliance patients, but the differences were not statistically significant. Besides the size of the nasolabial angle or the sagittal position of the lips, the thickness of the upper lip might also be altered by changes in upper incisor inclination [47–50]. In our sample, the average upper lip thickness (A-A' on PP) remained nearly unchanged in both groups despite the retraction of maxillary incisors. Contradictory to our results, some authors [47, 48] reported increases in upper lip thickness whereas other investigators [49, 50] described decreases. However, different methodologies should be considered when judging the results of those studies. The extent and predictability of changes in incisor's axial inclination on soft tissue profile remain a matter to debate [2].

Our study analyzed lateral cephalograms which were routinely obtained during orthodontic treatment. Cephalometric measurements were found suitable to describe changes of the soft tissue profile due to FFA treatment [5, 21–23]. Still, lateral cephalometry is a two-dimensional imaging modality which is not able to detect three-dimensional (3D) alterations of the facial soft tissues. To overcome these drawbacks, different 3D approaches have been described in the literature [51]. Data on functional appliance treatment are rather scarce

[35]. However, reliable superimposition of soft tissue structures is difficult, and many unsolved questions have to be addressed in future research [51, 52]. These studies also state that none of the modalities is superior to the other.

In our study sample, treatment-related changes of the patients' soft tissue profiles were similar between the examined FFAs, and hence, no significant intergroup differences were found. Therefore, our results suggest that none of the two appliances was superior in altering the facial profile. Still, it is possible to improve the patients' soft tissue profiles using FFAs [20]. However, treatment-related soft tissue changes are difficult to predict [35] and may differ from patient to patient.

Conclusions

- Treatment-related changes on the facial soft tissue profile were similar in patients treated with FMA or the Herbst appliance.
- Results suggest that none of the measurements exhibited treatment-related changes that were specific for FMA or Herbst appliance.
- Only moderate changes of the soft tissue profile were noted.

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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