DOI: https://doi.org/10.17921/2447-8938.2021v23n4p287-293

Effects of Herbst Appliance Treatment on the Mandibular Incisor Segment: a Three-Dimensionally Analysis

Efeitos do Tratamento com Aparelho Herbst no Segmento Incisivo Inferior: uma Análise Tridimesional

João Paulo Schwartz*[ab]; Taisa Boamorte Ravelli[a]; Dirceu Barnabé Ravelli[a]; Sabine Ruf[b]

[a]Universidade Estadual de São Paulo, Department of Orthodontics. SP Brazil.
[b]University of Giessen, Department of Orthodontics. Germany.
*E-mail: joaoschwartz@hotmail.com

Abstract

Three-dimensionally evaluation of the treatment changes of a Herbst appliance using a lower anchorage unit not touching the lingual surface of the lower incisors. The sample consisted of 23 Class II:1 patients (12 males, 11 females) with a mean age of 15.7±1.7 years treated with a Flip-Lock Herbst® appliance (TP Orthodontics, Inc., La Porte, IN, USA). The lower anchorage unit for the Herbst appliance consisted of two anchor bands connected by a lingual arch with 3mm distance from the incisor's lingual surface. Treatment changes in mandibular incisor inclination, overjet and overbite were evaluated by means of cone beam computed tomography images (i-CAT® Classic unit, Imaging Sciences International, Hatfield, PA, USA) obtained before and after treatment with the Herbst appliance. On average, there was a statistically significant increase in mandibular incisor inclination (2.6±1.8°) and a reduction in overjet (3.2±2.2mm) and overbite (1.3±0.9mm). Genders did not differ significantly. Incisor proclination was however only seen in 74% of the patients. The changes in mandibular incisor inclination were associated with the changes in overjet (/r/ = 0.1 to 0.5) and overbite (/r/ = 0.3 to 0.7). A Herbst appliance with a mandibular anchorage unit distant from the incisor's lingual surface results in smaller amounts of mandibular incisor proclination compared to literature. However, as it induces canine anchorage loss, the decreased amount of proclination may not prevail after multibracket treatment.

Keywords: Cone-Beam Computed Tomography. Mandibular Advancement. Tooth Movement Techniques.

Resumo

Avaliação tridimensional das alterações induzidas pelo aparelho Herbst utilizando a unidade de ancoragem inferior afastada da superfície lingual dos incisivos. A amostra incluiu 23 pacientes Classe II:1 (12 masculino, 11 feminino), média de idade 15,7 ± 1,7, tratados com aparelho Herbst Flip-Lock® (TP Orthodontics, Inc., La Porte, IN, EUA). A unidade de ancoragem inferior do aparelho Herbst consistiu-se de duas bandas conectadas por um arco lingual afastado 3mm da superfície lingual do incisivo. As alterações induzidas pelo tratamento na inclinação dos incisivos inferiores, trespasse horizontal e trespasse vertical foram avaliadas por meio de imagens de tomografias computadorizadas de feixe cônico (i-CAT® Classic unit, Imaging Sciences International, Hatfield, PA, USA) obtidas antes e após o tratamento com aparelho Herbst. Na média, houve diferença significativa com aumento da inclinação dos incisivos inferiores (2,6±1,8°) e diminuição do trespasse horizontal (3,2±2,2mm) e do trespasse vertical (1,3±0,9mm). Não houve diferença estatística entre os sexos. No entanto, a vestibularização do incisivo ocorreu em apenas 74% dos pacientes. As alterações na inclinação dos incisivos inferiores apresentam correlação estatisticamente significativa com as alterações no trepasse horizontal (/r/ = 0,1 a 0,5) e no trespasse vertical (/r/ = 0,3 a 0,7). O aparelho Herbst com uma unidade de ancoragem inferior afastada da superfície lingual dos incisivos resulta em menor quantidade de vestibularização do incisivo inferior em comparação com a literatura. Entretanto, como isto induz perda de ancoragem do canino, a diminuição da vestibularização pode não prevalecer ao final tratamento ortodôntico com braquetes.

Palavras-chave: *Tomografia Computadorizada de Feixe Cônico. Avanço Mandibular. Técnicas de Movimentação Dentária.*

1 Introduction

Lower incisor proclination is an undesired side effect of Herbst treatment. Although, so far, no investigation could prove a clinically significant negative impact of incisor proclination on periodontal health, neither short- nor long-term[1-5], a proclination may hinder the achievement of a Class I occlusal relationship by increasing lower dental arch length and is said to be more prone to relapse. Up to now, regardless of the type of anchorage unit used, not even with additional skeletal anchorage, could the position of the mandibular incisor be satisfactorily controlled during Herbst treatment[6-9]. To what extent, a lower arch anchorage unit not touching the lingual surface of the lower incisor could prevent or reduce the amount of proclination has not been studied yet.

All aforementioned mentioned studies have used two-dimensional radiographs for the analysis of Herbst appliance treatment effects, which hinder a tooth specific evaluation of changes. In contrast, cone beam computed tomography (CBCT) images allow to assess a single tooth three-dimensionally (3D) and to study tooth inclination changes induced by different orthodontic appliances[10,11] as well as their impact on alveolar bone support[5].

The aim of the present study was to evaluate individually for each incisor by means of CBCT the mandibular incisor inclination changes as well as overjet and overbite changes induced by a Herbst appliance with a lower anchorage unit not touching the lingual surface of the lower incisors.

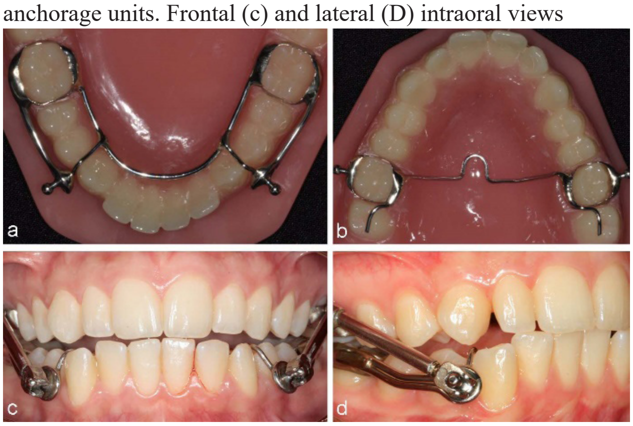
2 Material and Methods

This retrospective study was reviewed and approved by the Ethics Committee of X, project n° 62/2010. A total of 30 patients meeting the inclusion criteria were invited to participate in the study. Five patients refused to participate. Two patients were excluded because of appliance breakage. The final sample consisted of 23 consecutively treated (12 male, 11 female; mean age 15.7 ± 1.7 years) patients with Class II division 1 malocclusion. Hand wrist radiographs were used to assess the skeletal maturity according to Hägg and Taranger[12]. The percentage of cases within the different skeletal maturity groups before treatment were: MP3-G (4%), MP3-H (4%), R-I (17%), R-IJ (27%), R-J (48%).

The inclusion criteria were bilateral Class II canine and molar relationship ≥½ cusp, overjet >5mm, complete permanent dentition (except third molars), convex profile, straight nasolabial angle and short mentocervical line. Exclusion criteria were syndromic patients, increased vertical facial height, previous orthodontic treatment and need for maxillary expansion.

All patients were treated with a Herbst appliance (Figure 1). The anchorage unit for the Herbst appliance consisted of upper first molar bands connected by a transpalatal arch (1.2mm steel wire) with 2mm distance from the palate as well as two occlusal extensions to reduce first molar intrusion and prevent second molar overeruption. In the lower arch two anchor bands were connected by a lingual arch (1.2mm stainless steel wire) with 3mm distance from the incisor's lingual surface to prevent incisor proclination. The labial cantilever was connected to the lingual arch at the level of the interproximal area between the canine and first premolar on both sides. The telescopic mechanism used was a Flip-Lock Herbst® (TP Orthodontics, Inc., La Porte, IN, USA). No additional appliances were used. The average treatment duration with the Herbst appliance was 8.5 ± 0.7 months.

Figure 1- Herbst appliance. Mandibular (a) and maxillary (b) anchorage units. Frontal (c) and lateral (D) intraoral views

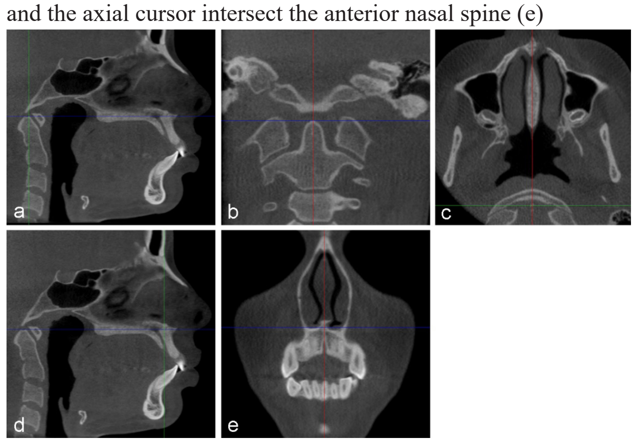


Source: The authors.

CBCT images were obtained before (T0) and after (T1) treatment. Patients were scanned in an upright position with maximum intercuspation using a tomographic i-CAT® Classic unit (Imaging Sciences International, Hatfield, PA, USA) with a 17 x 13.3cm of FOV, 120 kV tube voltage, 18.4 mA tube corrent and 0.4mm isometric voxel size. CBCT images were examined by means of multiplanar reconstruction (axial, sagittal and coronal). The Dolphin® Imaging software (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA) was used to evaluate the mandibular incisor inclination and the RadiAnt™ DICOM Viewer software (Medixant, Poznan, POL) was used for the measurement of overjet and overbite.

The CBCT images were analyzed metrically. In the first step, the reference plans were defined. The plane that includes the superior tip of the odontoid process of the axis, the tip of the anterior nasal spine and the nasion point is defined as the midsagittal plane (MSP) and the sagittal plane was oriented to coincided with the MSP[10,11] (Figure 2). In the coronal and axial view, the cursors are set to intersect in the center of the mandibular incisor of interest[10,11] (Figure 3).

Figure 2 - Definition of midsagittal plane as a reference plane for measurements. In the sagittal view, the coronal and axial cursors intersect the superior tip of the odontoid process of the axis and axial cursor, as well, intersect the tip of the anterior nasal spine (a). In the coronal view, the sagittal and axial cursors intersect the superior tip of the odontoid process of the axis (b). In the axial view, the coronal and sagittal cursors intersect the superior tip of the odontoid process of the axis and sagittal cursor, as well, intersect the tip of the anterior nasal spine (c). In the sagittal view, the coronal cursor is moved until intersect with nasion point (d). In the coronal view, the sagittal cursor intersect the nasion point and the axial cursor intersect the anterior nasal spine (e)



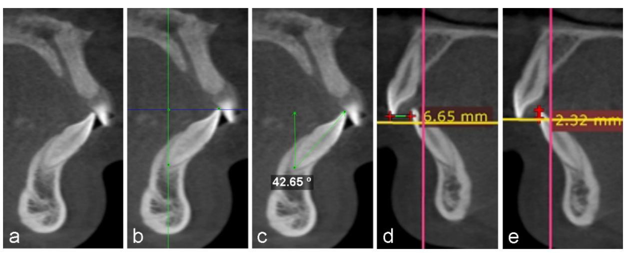
Source: The authors.

Figure 3 - Techniques used to assess mandibular incisor inclination, overjet and overbite. Coronal (a), axial (b) and sagittal (c) views

Source: The authors.

The following measurements were performed in sagittal multiplanar reconstruction: mandibular incisor inclination, overjet and overbite. The mandibular incisor inclination measurement was angular between three points, the first at the incisal edge, the second at the root apex and the third at the intersections of the axial and coronal cursors, positioned at the incisal edge and root apex, respectively (Figure 4). Overjet measurement was linear, parallel to the axial cursor, between two points, one at the incisal edge of maxillary incisor and the other one at the buccal surface of mandibular incisor (Figure 4). Overbite measurement was linear, parallel to the coronal cursor, between two points, one at the incisal edge of mandibular incisor and other at the intersections of the axial and coronal cursors, positioned at the incisal edge of maxillary incisor and incisal edge of mandibular incisor, respectively (Figure 4).

Figure 4 - Measurements used to evaluate mandibular incisor inclination, overjet and overbite. Sagittal view (a). Reference points for mandibular incisor inclination measurement (b). Mandibular incisor inclination (c), overjet (d) and overbite (e) measurements



Source: The authors.

2.1 Statistical analysis

All measurements were performed twice by a single examiner with a minimum interval of at least two weeks between the measurements. The error of the method was evaluated by Intraclass Correlation Coefficient (ICC) and indicated excellent reliability for mandibular incisor inclination (ICC=0.965), overjet (ICC=0.970) and overbite (ICC=0.958).

After the data had been tested for normality with the Shapiro-Wilk Test, Student's t-Test and Wilcoxon t-Test were used to compare dependent samples in parametric and non-parametric cases, respectively. Student's independent t-Tests was used for gender comparison and Pearson's and Spearman's rank correlation analyses were performed to determine the relationship of changes in mandibular incisor inclination, overjet and overbite.

A distinction was made between the following correlations: strong (/r/ ≥0.8), moderate (/r/ 0.4-0.8) and weak (/r/ <0.4). If there was a weak insignificant correlation, it was denoted as no correlation. Statistical analysis was performed using SPSS® (SPSS Inc, Chicago, IL, USA) and GraphPad Prism® (GraphPad Prism Inc, San Diego, CA, USA) and the results were considered at a significance level of 5%.

3 Results and Discussion

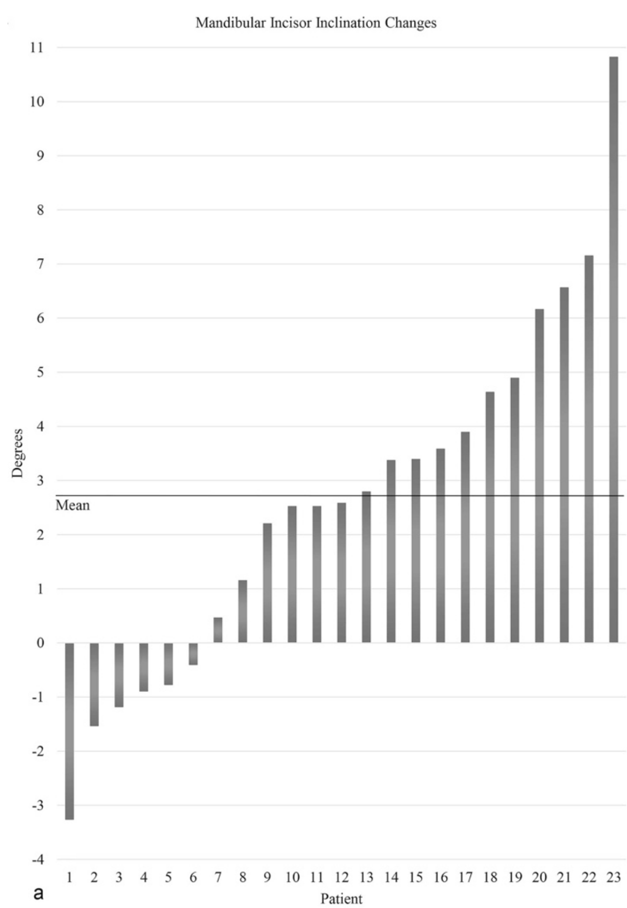
Comparisons of mandibular incisor inclination, overjet and overbite between genders did not show any statistical differences (Table 1), therefore the data were pooled for further evaluation. The individual mean changes for each patient are shown in Figure 5.

Table 1 - Difference by gender of mandibular incisor inclination, overjet, overbite before (T0) and after (T1) treatment. Mean ($\bar{x}$), standard deviation (SD) and level of significance (*P*)

Variable	Period	Male $\bar{x}$ ± SD	Female $\bar{x}$ ± SD	*P* Value
Incisor Inclination (°)	T0	32.7 ± 4.8	32.4 ± 9.2	0.860
	T1	34.3 ± 5.7	36.1 ± 8.5	0.249
	T1-T0	1.6 ± 1.1	3.6 ± 2.6	0.142
Overjet (mm)	T0	6.9 ± 2.0	6.8 ± 1.5	0.813
	T1	3.4 ± 1.3	3.9 ± 1.5	0.109
	T1-T0	-3.5 ± 2.4	-2.9 ± 2.0	0.377
Overbite (mm)	T0	4.0 ± 2.0	4.2 ± 1.6	0.701
	T1	2.7 ± 1.6	2.8 ± 1.0	0.708
	T1-T0	-1.3 ± 0.9	-1.3 ± 0.9	0.940

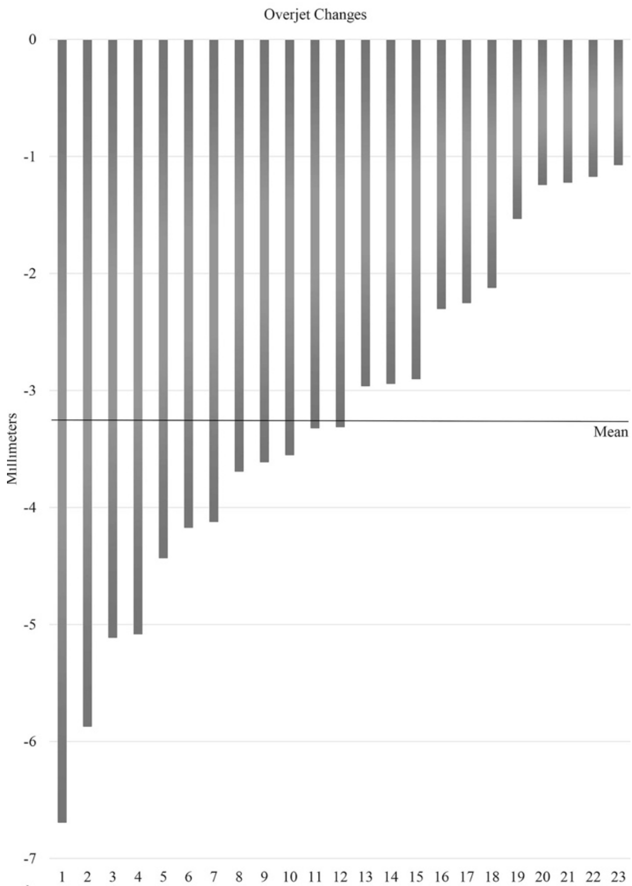
Source: Research data.

Figure 5 - Individual changes (n=23) of average (teeth 32-42) mandibular incisor inclination (a), overjet (b) and overbite (c) induced by treatment (T1-T0)

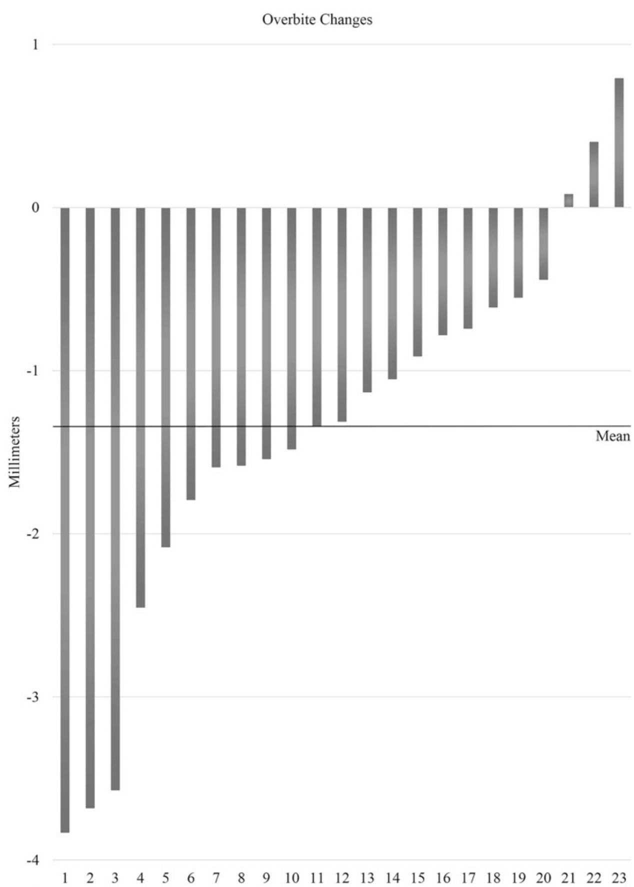


To be continued...

...continued



b



c

Source: The authors.

Mandibular incisor inclination increased in 17 (74%) and decreased in 6 (26%) patients, with a range of changes from +0.4° to +10.8° and -0.4° to -3.2°, respectively. Table 2 shows the means and standard deviations of the changes in mandibular incisor inclination. Treatment resulted in statistically significant changes, showing an increase of all means from T0 to T1.

Table 2 - Mean (x̄), standard deviation (SD) and level of significance (*P*) of mandibular incisor inclination before (T0) and after (T1) treatment

Inclination (°)	**n**	**T0** x̄ ± SD	**T1** x̄ ± SD	**T1-T0** x̄ ± SD	***P* Value**
32	23	32.2 ± 7.0	35.2 ± 8.8	3.0 ± 2.1	0.005**
31	23	33.4 ± 7.7	35.5 ± 6.3	2.1 ± 1.5	0.004**
41	23	32.8 ± 8.2	35.5 ± 7.4	2.7 ± 1.9	0.020*
42	23	31.7 ± 6.2	34.4 ± 6.4	2.6 ± 1.9	0.006**
Total	92	32.5 ± 7.2	35.2 ± 7.2	2.6 ± 1.8	0.000***
Male	48	32.7 ± 4.8	34.3 ± 5.7	1.6 ± 1.1	0.000***
Female	44	32.4 ± 9.2	36.1 ± 8.5	3.6 ± 2.6	0.000***

* *P* <0.05; ** *P* <0.01; *** *P* <0.001.

Source: Research data.

Overjet decreased in all 23 (100%) patients with a range of changes from -1.0mm to -6.6mm. Overbite increased in 3 (13%) and decreased in 20 (87%) patients, with a range of changes from +0.08mm to +0.7mm and -0.4mm to -3.8mm, respectively. Table 3 and 4 show the means and standard deviations of the changes in overjet and overbite. Treatment resulted in statistically significant average reductions for overjet and overbite.

Table 3 - Mean (x̄), standard deviation (SD) and level of significance (*P*) of overjet before (T0) and after (T1) treatment

Overjet (mm)	**n**	**T0** x̄ ± SD	**T1** x̄ ± SD	**T1-T0** x̄ ± SD	***P* Value**
32	23	6.8 ± 1.9	3.6 ± 1.5	-3.2 ± 2.2	0.000***
31	23	6.5 ± 1.6	3.6 ± 1.3	-2.8 ± 2.0	0.000***
41	23	6.9 ± 1.5	3.6 ± 1.7	-3.2 ± 2.3	0.000***
42	23	7.4 ± 1.9	3.8 ± 1.4	-3.6 ± 2.5	0.000***
Total	92	6.9 ± 1.7	3.6 ± 1.4	-3.2 ± 2.2	0.000***
Male	48	6.9 ± 2.0	3.4 ± 1.3	-3.5 ± 2.4	0.000***
Female	44	6.8 ± 1.5	3.9 ± 1.5	-2.9 ± 2.0	0.000***

*** *P* <0.001.

Source: Research data.

Table 4 - Mean (x̄), standard deviation (SD) and level of significance (*P*) of overbite before (T0) and after (T1) treatment.

Overbite (mm)	**n**	**T0** x̄ ± SD	**T1** x̄ ± SD	**T1-T0** x̄ ± SD	***P* Value**
32	23	4.0 ± 1.9	2.6 ± 1.4	-1.3 ± 0.9	0.000***
31	23	4.2 ± 1.8	2.9 ± 1.3	-1.2 ± 0.9	0.000***
41	23	4.2 ± 1.8	2.9 ± 1.5	-1.2 ± 0.9	0.001**
42	23	4.0 ± 1.7	2.5 ± 1.3	-1.4 ± 1.0	0.000***
Total	92	4.1 ± 1.8	2.7 ± 1.3	-1.3 ± 0.9	0.000***
Male	48	4.0 ± 2.0	2.7 ± 1.6	-1.3 ± 0.9	0.000***
Female	44	4.2 ± 1.6	2.8 ± 1.0	-1.3 ± 0.9	0.000***

** *P* <0.01; *** *P* <0.001.

Source: Research data.

There was a statistically significant moderate correlation between mandibular incisor inclination changes and overjet changes for the mandibular left lateral incisor and mandibular right central incisor (Table 5). There was statistically significant moderate correlation between mandibular incisor inclination changes and overbite changes for the mandibular left lateral incisor, mandibular right central incisor, mandibular right lateral incisor and total (Table 6).

Table 5 - Pearson's and Spearman's rank correlation analysis between mandibular incisor inclination changes and overjet changes

Variable	n	Pearson's Correlation		Spearman's Correlation	
		Coefficient	*P* Value	Coefficient	*P* Value
32	23	-0.54	0.007**	-0.28	0.195
31	23	-0.32	0.129	-0.39	0.064
41	23	-0.47	0.022*	-0.55	0.006**
42	23	-0.23	0.280	-0.17	0.411
Total	92	-0.30	0.151	-0.22	0.294

* $P<0.05$; ** $P<0.01$.

Source: Research data.

Table 6 - Pearson's and Spearman's rank correlation analysis between mandibular incisor inclination changes and overbite changes

Variable	n	Pearson's Correlation		Spearman's Correlation	
		Coefficient	*P* Value	Coefficient	*P* Value
32	23	-0.71	0.000***	-0.51	0.012*
31	23	-0.35	0.094	-0.30	0.154
41	23	-0.55	0.005**	-0.51	0.011*
42	23	-0.46	0.024*	-0.38	0.067
Total	92	-0.49	0.016*	-0.38	0.071

* $P<0.05$; ** $P<0.01$; *** $P<0.001$.

Source: Research data.

This CBCT study evaluated three-dimensionally the mandibular incisor inclination changes as well as overjet and overbite changes induced by a Herbst appliance with a lower anchorage unit not touching the lingual surface of the lower incisors.

Three-dimensionally CBCT images allow an assessment of the buccolingual inclination of individual teeth with good accuracy in any given plane[13,14]. Regarding the acquisition of tomographic images, the accuracy of CBCT with different voxel resolutions (0.2 and 0.4mm) to linear measurement was evaluated and there was no significant statistical difference between these voxel protocols[15,16].

Up to now, regardless of the type of anchorage unit used, not even with additional skeletal anchorage, could the position of the mandibular incisor during Herbst treatment be satisfactorily controlled nor be predicted on an individual level[4,6-8,17-21]. It is however known, that the length of the anchorage unit[19,20,22], the severity of the malocclusion[8], the incremental mandibular advancement[23,24], the skeletal anchorage[6,7] and the skeletal maturity[25-27] of the patients influence the amount of incisor proclination to a certain extent. Thus, comparisons with literature are difficult and very anchorage sensitive and the corresponding conclusions have to be drawn with care.

In interpreting the results, it must be kept in mind that the changes induced by the Herbst appliance are a summation effect of treatment and dentofacial growth. The skeletal maturity evaluation of the present sample showed that 92% of the patients were in the post-pubertal period, a developmental stage during which more dentoalveolar than skeletal changes are seen during a Class II treatment with a Herbst appliance[27]. The mandibular incisors of patients treated after the pubertal growth peak have been shown to procline more than those of patients treated pre-peak[25,26].

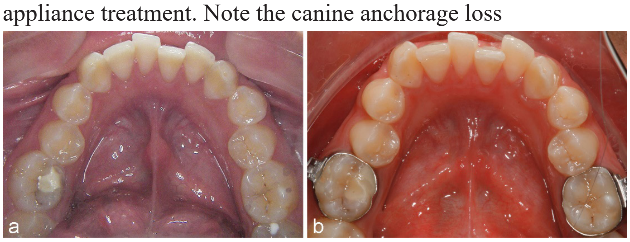
There were no statistical differences in mandibular incisor inclination, overjet and overbite between genders neither before nor after treatment, which is in concordance with previous cephalometric studies[8,28].

The mean increase of mandibular incisor inclination from T0 to T1 (2.6°) was smaller when compared to previous studies using different types of Herbst appliance anchorage such as a cast splint appliances (6.7° to 12°)[8], and even skeletal anchorage (4.8°)[6,7]. One reason for this smaller amount of proclination could be the design of the lingual arch with 3mm distance from the incisor's lingual surface upon insertion, thus reducing the anchorage load on the incisors. According Pancherz and Hansen[19], a reduced anchorage load on the incisors by means of a lingual acrylic pelotte reduces the amount of incisor proclination.

The mean reduction of overjet (-3.2mm) was rather small in comparison to the above mentioned Herbst studies, thus resulting in a reduced risk for anchorage loss[8,19,29]. However, Martin and Pancherz[8] evaluated mandibular incisor proclination during Herbst treatment with cast splint anchorage including a lingual arch touching the lower incisors and found an average lower incisor proclination of 6.7°, which is twice as much as in the present study.

Another important point regarding the mandibular anchorage unit used in the present study is the connection of the labial cantilever with the lingual arch at the level of the interproximal area between the canine and first premolar on both sides. This contact with the distal surface of the canines favors a canine anchorage loss which induces a crowding in the lower incisor/canine area (Figure 6). As in the modern Herbst therapy, the orthopedic phase is followed by a multibracket appliance (MB) phase, the crowding will result in secondary incisor proclination. Thus, whether the amount of proclination using an anchorage unit not touching the lingual surface of the lower incisors is really smaller after the end of active orthodontic treatment (Herbst plus subsequent multibracket) cannot be answered yet.

Figure 6 - Mandibular dental arch before (a) and after (b) Herbst appliance treatment. Note the canine anchorage loss



Source: The authors.

There was a marked interindividual variation in treatment effects in the present study with respect to the amounts of mandibular incisor proclination, overjet and overbite reduction. This large variation has also been described in previous studies and the reasons for it remain largely unknown[4,6,19,30]. A retroclination of the lower incisors in certain patients has also been reported in previous Herbst publications[6,8,21].

Overall, there were some limitations due the study design which should be considered when interpreting the results. These limitations include the small sample size, absence of a control group, length of observation period (only Herbst phase) and tomography images acquisitions protocols (voxel size and field of vision). These weaknesses will be considered in a future research project.

4 Conclusion

The three-dimensionally evaluation of the mandibular incisor segment by means of CBCT scans revealed that Herbst appliance treatment with a mandibular anchorage unit distant from the incisor's lingual surface results in smaller amounts of mandibular incisor proclination compared to literature. However, as it induces canine anchorage loss, the decreased amount of proclination may not prevail after multibracket treatment. Future studies analyzing the total orthodontic treatment period (Herbst plus multibracket) are needed.

References

1. Bock NC, Ruf S, Wiechmann D, Jilek T. Herbst plus Lingual versus Herbst plus Labial: a comparison of occlusal outcome and gingival health. Eur J Orthod 2016;38(5):478-84. doi: 10.1093/ejo/cjw034
2. Bock NC, Saffar M, Hudel H, Evalahti M, Heikinheimo K, Rice DPC, et al. Long-term effects of Class II orthodontic treatment on oral health. J Orofac Orthop 2018;79(2):96-108. doi: 10.1007/s00056-018-0125-5
3. Joss-Vassalli I, Grebenstein C, Topouzelis N, Sculean A, Katsaros C. Orthodontic therapy and gingival recession: a systematic review. Orthod Craniofac Res 2010;13(3):127-41. doi: 10.1111/j.1601-6343.2010.01491.x
4. Ruf S, Hansen K, Pancherz H. Does orthodontic proclination of lower incisors in children and adolescents cause gingival recession? Am J Orthod Dentofacial Orthop 1998;114(1):100-6. doi: 10.1016/s0889-5406(98)70244-6
5. Schwartz JP, Raveli TB, Schwartz-Filho HO, Raveli DB. Changes in alveolar bone support induced by the Herbst appliance: a tomographic evaluation. Dental Press J Orthod 2016;21(2):95-101. doi: 10.1590/2177-6709.21.2.095-101.oar
6. Bremen J, Ludwig B, Ruf S. Anchorage loss due to Herbst mechanics-preventable through miniscrews? Eur J Orthod 2015;37(5):462-6. doi: 10.1093/ejo/cju058
7. Elkordy SA, Aboelnaga AA, Fayed MM, AboulFotouh MH, Abouelezz AM. Can the use of skeletal anchors in conjunction with fixed functional appliances promote skeletal changes? A systematic review and meta-analysis. Eur J Orthod 2016;38(5):532-45. doi: 10.1093/ejo/cjv081
8. Martin J, Pancherz H. Mandibular incisor position changes in relation to amount of bite jumping during Herbst/multibracket appliance treatment: a radiographic-cephalometric study. Am J Orthod Dentofacial Orthop 2009;136(1):44-51. doi: 10.1016/j.ajodo.2007.07.027
9. Pancherz H, Ruf S. The Herbst appliance. Research-based clinical management. London: Quintessence; 2008.
10. Grunheid T, Gaalaas S, Hamdan H, Larson BE. Effect of clear aligner therapy on the buccolingual inclination of mandibular canines and the intercanine distance. Angle Orthod 2016;86(1):10-6. doi: 10.2319/012615-59.1
11. Hamdan HA, Grunheid T, Larson BE. Effect of orthodontic treatment with preadjusted edgewise appliances on the buccolingual inclination of mandibular canines: a CBCT study. Orthod Craniofac Res 2015;18(3):156-64. doi: 10.1111/ocr.12092
12. Hagg U, Taranger J. Skeletal stages of the hand and wrist as indicators of the pubertal growth spurt. Acta Odontol Scand 1980;38(3):187-200. doi: 10.3109/00016358009004719
13. Gribel BF, Gribel MN, Frazao DC, McNamara JA, Jr., Manzi FR. Accuracy and reliability of craniometric measurements on lateral cephalometry and 3D measurements on CBCT scans. Angle Orthod 2011;81(1):26-35. doi: 10.2319/032210-166.1
14. Shewinvanakitkul W, Hans MG, Narendran S, Martin Palomo J. Measuring buccolingual inclination of mandibular canines and first molars using CBCT. Orthod Craniofac Res 2011;14(3):168-74. doi: 10.1111/j.1601-6343.2011.01518.x
15. Patcas R, Muller L, Ullrich O, Peltomaki T. Accuracy of cone-beam computed tomography at different resolutions assessed on the bony covering of the mandibular anterior teeth. Am J Orthod Dentofacial Orthop 2012;141(1):41-50. doi: 10.1016/j.ajodo.2011.06.034
16. Ponder SN, Benavides E, Kapila S, Hatch NE. Quantification of external root resorption by low- vs high-resolution cone-beam computed tomography and periapical radiography: A volumetric and linear analysis. Am J Orthod Dentofacial Orthop 2013;143(1):77-91. doi: 10.1016/j.ajodo.2012.08.023
17. Bock NC, Ruf S, Wiechmann D, Jilek T. Dentoskeletal effects during Herbst-Multibracket appliance treatment: a comparison of lingual and labial approaches. Eur J Orthod 2016;38(5):470-7. doi: 10.1093/ejo/cjw034
18. Pancherz H, Hansen K. Occlusal changes during and after Herbst treatment: a cephalometric investigation. Eur J Orthod 1986;8(4):215-28. doi: 10.1093/ejo/8.4.215
19. Pancherz H, Hansen K. Mandibular anchorage in Herbst treatment. Eur J Orthod 1988;10(2):149-64. doi: 10.1093/ejo/10.2.149
20. Weschler D, Pancherz H. Efficiency of three mandibular anchorage forms in Herbst treatment: a cephalometric investigation. Angle Orthod 2005;75(1):23-7. doi: 10.1043/0003-3219(2005)075<0023:EOTMAF>2.0.CO;2
21. Wiechmann D, Schwestka-Polly R, Pancherz H, Hohoff A. Control of mandibular incisors with the combined Herbst and completely customized lingual appliance--a pilot study. Head Face Med 2010;6:3. doi: 10.1186/1746-160X-6-3
22. El-Fateh T, Ruf S. Herbst treatment with mandibular cast splints--revisited. Angle Orthod 2011;81(5):820-7. doi: 10.2319/101010-591.1
23. Banks P, Wright J, O'Brien K. Incremental versus maximum bite advancement during twin-block therapy: a randomized controlled clinical trial. Am J Orthod Dentofacial Orthop

2004;126(5):583-8. doi: 10.1016/j.ajodo.2004.03.024

24. Du X, Hagg U, Rabie AB. Effects of headgear Herbst and mandibular step-by-step advancement versus conventional Herbst appliance and maximal jumping of the mandible. Eur J Orthod 2002;24(2):167-74. doi: 10.1093/ejo/24.2.167

25. Konik M, Pancherz H, Hansen K. The mechanism of Class II correction in late Herbst treatment. Am J Orthod Dentofacial Orthop 1997;112(1):87-91. doi: 10.1016/s0889-5406(97)70278-6

26. Pancherz H, Hagg U. Dentofacial orthopedics in relation to somatic maturation. An analysis of 70 consecutive cases treated with the Herbst appliance. Am J Orthod 1985;88(4):273-87. doi: 10.1016/0002-9416(85)90126-5

27. Ruf S, Pancherz H. When is the ideal period for Herbst therapy - early or late? Semin Orthod 2003;9(1):47-56. doi: 10.1053/sodo.2003.34024

28. Hansen K, Iemamnueisuk P, Pancherz H. Long-term effects of the Herbst appliance on the dental arches and arch relationships: a biometric study. Br J Orthod 1995;22(2):123-34. doi: 10.1179/bjo.22.2.123

29. Pancherz H. The mechanism of Class II correction in Herbst appliance treatment. A cephalometric investigation. Am J Orthod 1982;82(2):104-13. doi: 10.1016/0002-9416(82)90489-4

30. Bock NC, Ruf S. Dentoskeletal changes in adult Class II division 1 Herbst treatment--how much is left after the retention period? Eur J Orthod 2012;34(6):747-53. doi: 10.1093/ejo/cjr087.